ProSpects

Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems

Deliverable No. 2
Evaluation Tools

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Preface

PROSPECTS (Procedures for Recommending Sustainable Planning of European City Transport Systems) is a project funded under the European Commission’s 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 PROSPECTS consortium is led by Institute for Transport Studies (ITS), University of Leeds (Great Britain) and includes the partners TUW (Austria), TØI (Norway), KTH (Sweden), UPM (Spain) and VTT (Finland).

This document is the report on Work Package 20 of PROSPECTS, for which TØI has had the responsibility. It is the second formal deliverable of the project. The evaluation, presentation and optimisation issues treated in this deliverable will be applied and tested in Work Package 30 before being included in the Methodological Guidebook, one of the three main outputs from PROSPECTS.

The report was edited by TØI, Work Package 20 leader. The partners responsible for separate tasks of the work package have written the parts of their concern: Part II by TØI, Part III by VTT, and Part IV by ITS. The co-ordinator and the work package leader have been responsible for the common parts of the report. All PROSPECTS partners have contributed to the work of the work package.

With respect to user benefit calculation in integrated land use/transport models, we have been able to use results recently developed by Simmonds (2001) in a project prepared for the UK Government Office for the North-West. We are thankful for this. We also wish to express our gratitude to representatives of planning authorities, politicians and organisations in the six core cities of Edinburgh, Vienna, Oslo, Stockholm, Madrid and Helsinki MA for their contribution during a series of interviews. The views expressed by the interviewees have however been personal and do not necessarily reflect the standpoints of the cities.

Oslo, November 2001

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Summary

In Deliverable 1 of PROSPECTS, we reviewed the planning requirements of European cities that want to develop long-term strategies to achieve sustainable land use and transport systems. We defined what we mean by a sustainable urban land use and transport system. We developed a hierarchy of objectives for urban planning of land use and transport with respect to sustainability and developed indicators for each of the sub-objectives in this hierarchy. Finally, we identified the possible policy instruments that might be applied in a strategy, and developed ideas on how to conceptualise the more or less given conditions in which urban land use and transport strategies are to be implemented (scenarios and barriers).

The current report builds on this planning framework and applies it to evaluation, presentation and optimisation.

Evaluation

The framework and the choice of performance indicators to be included in the framework are the most critical steps of all in seeking good evaluation practice. To assess each project/-strategy explicitly against identical performance indicators for each alternative is the single most important contribution to sound evaluation.

Our approach to evaluation has been to establish a set of high-level objectives to guide the direction of a city’s transport and land-use developments and beneath this set of objectives to set out a hierarchy of indicators of achievement to evaluate the success of alternative policies. Given these, it is possible to provide information for decision-makers, or for public participation, in a disaggregate fashion, simply in terms of the indicators, or in some aggregate way which involves weighting the indicators to give a multi-criteria appraisal (MCA), or valuing them to give a cost benefit assessment (CBA). The aggregate “indicator of indicators”, whether MCA or CBA, is termed an objective function. In addition to the objective function, there will also be a need to set targets for some of the indicators.

We propose to make the economic efficiency objective the basic element in the objective function, which means to perform an ordinary cost benefit analysis of each strategy. Then we propose to modify this to take account of sustainability: (a) we do not use ordinary discounting, but attach more weight to the last of the modelled years, and (b) we add terms to reflect the other objectives and targets with respect to the environment. Both the short term/long term trade-off and the weight attached to the added terms can be changed.

In this report, the indicators have been defined more precisely. Care has been taken to ensure that they can be computed from the output of models and other available data. Our indicators will not measure progress from year to year at present, but changes from strategy to strategy in some future situation. Thus the data need to be derived from models, assumptions about the scenario etc. Such data will not be very detailed and perhaps not very accurate. However, data at a very detailed level is not always needed for our strategic planning purposes.

The level of achievement with respect to some of the softer objectives will inevitably be more difficult to measure than others. The objective of “liveable streets and neighbourhoods” is a case in point. Indicators of economic growth objectives are inherently difficult for other, more theoretical reasons. With respect to air pollution objectives, a main problem in designing indicators is to choose the right level of spatial detail. Detailed dispersion modelling is beyond reach for our kind of strategic planning.
With respect to indicators of equity and social inclusion objectives, we have set out a range of possibilities, covering most of the issues. However, if they can be applied to a particular distributional or equity problem depends on whether the available models are able to produce data that throws a light on this problem. Income inequality, for instance, can only be measured in a model with different income groups.

Building on previous work by partners in the consortium, especially Dave Simmonds Consultancy, we believe to have found working solutions to the measurement of user benefits in integrated land use/transport models. Our proposal for the measurement of accident costs and the benefits to pedestrians and cyclists will hopefully constitute an improvement from the current state of the art.

Strategic planning for urban sustainability considers a wide range of possible strategies and policy options and aims at broadly identifying the most promising ones, taking into account the whole range of city objectives. It will have to provide information that is useful for all interested parties, that throws a light on the practical implications of different opinions with respect to the relative importance of objectives, and that can promote public involvement in the important long term policy choices. To achieve this in practice, some of its indicators and other policy assessment tools will inevitably be less detailed. We believe that we have found at least workable solutions to all the measurement problems involved in such a wide-ranging and forward-looking undertaking. But there is of course a need for more detailed modelling and assessment of the most promising options before decisions are made.

Besides single indicators and an objective function composed of such indicators, a city will also want to use planning by targets – whether strict or only reflecting aspiration levels. The evaluation framework we propose leads naturally to the problem of maximising a measure of the combined short term and long term welfare subject to long term environmental targets. Equity, financial and other objectives can also be cast as targets. This problem captures the essence of sustainability, which is a concern about the welfare of future generations and about the conservation of the environment and cultural heritage. Solving this optimisation problem is a way of identifying the most promising strategies, which can then be subjected to more detailed analysis. Solving it under different scenarios and assumptions with respect to values and costs will provide information on the robustness of strategies and the implications of differing political priorities.

There is an increasing emphasis on public participation in land use and transport planning. For instance, in the UK, public participation has become a requirement of the Local Transport Plan development process. The PROSPECTS evaluation framework should be flexible enough to tailor the evaluation process and the output to the need for public participation. A general overview of what should be considered when designing a public participation exercise and what methods are available to carry out public participation has been included in this report.

In a series of interviews with representatives of our Core Cities, our general evaluation framework won approval, although there may be a need to explain our approach to discounting and sustainability more thoroughly. It was found that in all cities, there is a need both for targets and objective functions. The objective function should be kept simple and transparent, and at the same time, all indicators should be reported separately. The framework should make use of both CBA and MCA. To be useful, the evaluation framework must be consistent with frameworks and criteria at the national and EU level. Financial, environmental, social and safety issues must be addressed. Particularly, distributional issues were seen as important, and it is necessary to be able to identify winners and losers and to discuss compensating measures. The framework should be above all flexible and capable of adapting to a wide range of needs.
Presentation

We want to make goal achievement with respect to the objectives and trade-offs between objectives the central elements in presentation, in contrast to the usual indicators like mode split, mean speed, mean trip distances etc. We suggest and present means and tools for presentation of both model and evaluation results. The main task has been to find the best presentation method for all relevant information that could help decision makers and promote public participation as well as the right level of accuracy and aggregation for different purposes.

Even though the same results of a plan should be presented to all groups involved officially or unofficially and with same presentation tools, it is essential to interpret the results, in order to not to block the interaction with overwhelming amounts of data and to not to undermine credibility with lacking pieces of information. Different individuals process information in different ways, so main findings should be available as text, numbers and maps or figures.

Typical presentation methods are maps, visualisations, installations, animations, reports, leaflets, www-sites, tables, charts, GIS, thematic maps or 3-D presentations etc. The suitability of each tool is analysed and suggestions produced. In particular, we give a broad overview of visual forms of presentation. Finally, we survey the Core Cities with respect to the formal requirements on presentation, and try to identify best practice.

Optimisation

The last part of the report discusses the approach required for formal optimisation within PROSPECTS. Formal optimisation of strategies consisting of a whole range of policies is a relatively new concept in transport planning. In Work Package 30 of PROSPECTS, this concept will be applied for the first time to integrated land use/transport models. The formal optimisation procedures will play a part in the overall evaluation framework but will not always be applicable to every decision made about transport and land use policy.

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 time dimension of the problem, the challenges posed by the range of policy instruments and the treatment of constraints and barriers are covered, and algorithms are discussed. The optimisation methods will be applied to a wide range of models available to us. The particular technical solutions in each case are briefly discussed.

Conclusions and implications for subsequent PROSPECTS work

The main objective of PROSPECTS is to produce a set of guidebooks in integrated urban land use and transport planning for sustainability. The topics covered in the present report are vital, especially for the Methodological Guidebook. In all three topics, innovative approaches have been set out. If they are to be confidently included in the Methodological Guidebook, it will be necessary to test them in practice in the following work package, Work Package 30. For instance, this includes our proposals for calculating the “liveable streets and neighbourhood”, accidents and equity indicators, setting targets for the equity indicators and incorporating them as constraints in optimisation, and implementing our suggested solution to user benefit calculation in land use models. For presentation, it will be a challenge to apply the suggested
visual forms of presentation in the context of strategic modelling, since some of the indicators are not developed at a very detailed spatial level. It is important that the focus is on the objectives according to their importance and not according to whether they are amenable to visualisation or not. The challenges to optimisation will arise from the increased complexity brought about by integrating land use and transport, combining evaluation by an objective function with planning by targets, and incorporating the wide range of policy instruments. Only practice will show if our algorithms will be able to cope equally well with all these aspects.

At the same time, the basics of our objective-led evaluation framework will be applicable to all strategic planning exercises, even if no models at all are used. It will be flexible enough to adapt to differing requirements stemming from EU policy guidance, national laws and rules and the particular preferences of each city authority. Above all, it incorporates concerns about sustainability in a new and consistent way.
PART I

Introduction

1. The objective of Work Package 20 and its role in PROSPECTS

This report is the second deliverable of PROSPECTS: Procedures for Recommending Sustainable Planning of European City Transport Systems. PROSPECTS is funded under the European Commission’s Environment and Sustainable Development Programme. Its principal objective is 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 sub-objectives are:

- To identify the decision making needs of cities
- To assess and enhance evaluation tools to aid decision making
- To assess and enhance forecasting and analysis tools for the land use/transport system
- To publish a Decision-Makers’ Guidebook and supporting Methodological and Policy Guidebooks
- To disseminate the results and exploit the three Guidebooks and the enhanced tools.

Each Work Package in the project seeks to meet one of these sub-objectives. Thus the first deliverable (May et al 2001) reported the results of Work Package 10, which identified the decision-making needs of cities. The current report provides the results of work in Work Package 20 to assess and enhance evaluation tools. WP 20 consists of three tasks, each with their own objective.

The objectives of WP20 are to

- produce enhanced procedures for evaluating transport and land use policies which address all of the indicators from Task 11 in the format needed for the decision-making processes of Task 14 (Task 21);
- review and produce optimisation methods capable of addressing the indicators from Task 11 and of application to the models in WP30 (Task 22);
- design formats for presentation of the output of strategy analysis suitable for politicians and lay users using GIS presentation tools (Task 23).

Bearing in mind that the end product of PROSPECTS will be a set of guidebooks that we hope will be useful to cities throughout Europe, we have tried throughout to develop methods of evaluation, presentation and optimisation that can be applied to all forms of strategic planning of urban land use and transport systems, provided they share our overriding objective of urban sustainability and broadly agree with the objective-led approach to planning that was set out in May et al (2001). A key concern has been that the methods we suggest should be transparent and simple to use. Another key concern is that they should promote public participation.

As indicated in figure 1.1 below, there is however also a need to develop methods that will be used immediately in the next stage of the PROSPECTS project, the modelling tests of Work
PROSPECTS

Package 30. The range of models available to us in Work Package 30 will inevitably not cover all possibilities, and so our evaluation framework must be adapted to the particular models that we have. Furthermore, the Work Package 30 modelling work will be special in the sense that its purpose is not to develop particular strategic plans, but rather to pass judgement on the usefulness of the different kinds of model and planning approaches. It will be more technical in nature than the average planning exercise because of its focus on optimisation. Thus we are faced with the task to choose from the wider range of options that we outline the particular indicators, targets, presentation tools and optimisation methods that suit our purposes and available resources in Work Package 30. It will be indicated clearly whenever we pass over from our general evaluation framework to the specific methods to be adopted in Work Package 30.

The modelling tests will in fact also be a test of the particular methods of evaluation, presentation and optimisation that we specify for use in Work Package 30. The results of this will be reflected in the Methodological Guidebook, one of the main outputs from the project.

Figure 1.1 shows how Work Package 20 fits into the PROSPECTS project as a whole. As already indicated, WP 20 takes input from WP 10 and provides results to be used in WP 30 and 40. To be more specific, the objectives and indicators set out in Deliverable 1 are the essential elements on which the evaluation framework is built. All main elements of the present report – the evaluation framework, the presentation tools and the optimisation procedures – are to be used in the case studies of WP 30. This provides a test of the practicability of the proposals of the present report. But in fact, it will also be a test of the forecasting and analysis tools of WP30 with respect to their ability to fulfil the requirements set out in this report. Finally, the tested evaluation, presentation and optimisation methods are to be included as parts of the Methodological Guidebook.
Figure 1.1 Flowchart for PROSPECTS technical work packages and main deliverables

**WP10**
Cities’ decision making requirements
(Deliverable 1)

**WP20**
Evaluation tools
(Deliverable 2)

**WP30**
Forecasting and analysis tools
(Deliverables 3, 8)

**WP40**
Guidance
(Deliverables 4, 13-15)

**WP50**
Dissemination
(Deliverables 5, 12)

- indicators, objectives, trends/scenarios, policy options, barriers
- evaluation tools, optimisation methods, presentation software
- representing key issues, model developments for policy explorers, sketch planning methods, land use transport interaction, case study results
- Decision Makers’ Guidebook, Policy Guidebook, Methodology Guidebook
- dissemination to user groups, decision makers, governments, and academics.
2. The structure of the report and the methods applied

Figure 2.1 shows the main structure of the present report. The report has five parts, three of which are shown in the figure. Part II is concerned with evaluation, Part III with presentation and part IV with optimisation. Thus Part II, IV and III addresses the first, second and third objective of WP 20, respectively. Part V draws conclusions. The evaluation framework developed in Part II raises issues of presentation that are taken up in Part III and gives rise to the optimisation problem that is addressed in Part IV. The reason why presentation is treated before optimisation is that all planning for a sustainable urban land use and transport system will need some form of systematic evaluation and presentation, while optimisation can only be undertaken if there is a suitable model available.

![Diagram of report structure](image)

*Figure 2.1 The structure of the report*
The evaluation framework is central to the definition of the problems of presentation as well as to the definition of the optimisation problem. The evaluation framework that we propose is open to a multitude of approaches, as shown in Figure 2.2 on the next page. This figure also provides some more detail on how the different tasks in PROSPECTS relate to each other.

Scenarios and policies (covered in tasks 12 and 13 of Work Package 10, respectively, and reported in Deliverable 1) are fed into models (covered in task 31 and reported in Deliverable 3). Outcome from models forms the basis for evaluation. Evaluation starts by specifying the objectives which the policies are intended to achieve and design indicators to measure the level of achievement of the objectives. This was covered in task 11. Targets may be set for some of the indicators. Various forms of barriers and constraints to implementing policies or setting targets may be present, and this was covered in task 15 and reported in Deliverable 1.

Indicator values for a single year or many years might be reported in this “raw” form or be processed by presentational tools. This might form the basis for decision making, or some more elaborate forms of evaluation might be applied. The indicators might be computed and reported at a more or less aggregate level, allowing us to analyse the distribution of impacts in more or less detail. There should also be a check on whether single-year targets are achieved or not (and possibly a feedback to more model runs if they are not).

The more elaborate forms of evaluation are at the core of part II of this report, which mainly sums up task 21. They start by setting targets or weights. Money values are a particular form of weights. Monetary valuation will usually be carried out according to the rules of CBA, which among other things requires us to discount future benefits and costs. However, discounting needs to be modified to take account of the intergenerational equity aspect of sustainability. Non-monetary weights or a combination of monetary and non-monetary weights – with or without discounting – gives rise to MCA methods. Output may be presented for single and multiple years, and as far as MCA is concerned, with or without discounting.

Provided the results are aggregated across the indicators and over the years by way of an objective function, optimisation may be carried out to find the combination of policy instruments that performs best. If targets and constraints stemming from barriers are present, this will be constrained optimisation. Our recommendations with respect to methods of optimisation are set out in part IV of this report, based on work in task 22.

Figure 2.2 shows that output can be had in many different forms, and that it has been the subject of task 23 to indicate what the most useful forms may be and how it might be presented. More and more, concerns about public participation will be a key factor in determining this. Public participation concerns are covered in part II of this report, while part III covers presentational tools.
Figure 2.1. The evaluation process
Obviously, all forms of evaluation that fit into the framework of Figure 2.2 are objective-led. Although our survey of current planning practices in task 14 and 16 (reported in Deliverable 1) did not show this to be the most common form of planning today, the approach that we initiated in Work Package 10 was generally approved by the cities. This is why we continue to build on that approach here.

The methods we have used in Work Package 20 include literature surveys, consultations within the consortium and with outside experts, and a round of interviews with representatives of the Core City Group of the project. With respect to user benefit calculation in integrated land use/transport models, we have been able to use results recently developed by Simmonds (2001) in a project prepared for the UK Government Office for the North-West.

At two points, there was a need to complement the results of Deliverable 1. The indicative table of indicators that was produced at that stage needed to be revised and exact definitions provided. Also, although in task 14 of WP 10 we conducted an extensive survey in European cities to chart their current planning practices, it was felt that we still needed to know more about the normative side of it: How would they ideally want the planning process to go? To complement Deliverable 1 on these two issues, we conducted a series of interviews with representatives of the Core Cities in April 2001. These interviews also sought to get cities’ views on a host of other issues related to our first ideas on evaluation, presentation and optimisation. The results are summarised in chapter 9. The full questionnaires can be found as appendices in each individual Task Summary Report, copies of which can be obtained from the Coordinator.
Part II
Evaluation of urban land use/transport strategies with respect to sustainability

3 The objective and structure of part II

Task 21 in PROSPECTS is concerned with the evaluation of urban land use/transport strategies with respect to sustainability. It builds upon the results of Work Package 10, summed up in Deliverable 1. More specifically, we build on task 11 of that work package, which defined a sustainable urban land use/transport system and specified a set of six sub-objectives to sustainability and their related indicators. We also build on task 14, which outlined the key elements of the decision-making process, including sole and shared responsibilities, consultation requirements and influences. Deliverable 1 also covered scenario building, policy instruments and barriers and contains a survey of the practices and aspirations of 54 cities in 17 countries in the field of land use and transport planning for sustainability. This has been useful background material.

The objective of task 21 is to produce enhanced procedures for evaluating transport and land use policies which address all of the indicators from Task 11 in the format needed for the decision-making processes of Task 14. The evaluation framework should be designed to be transparent and simple to use. It should be flexible enough to allow two methods: sustainability multi-criteria analysis (MCA) and sustainability cost-benefit analysis (CBA). The latter means to modify CBA methods to take account of sustainability issues.

The results of task 21 feed into task 22 on optimisation, reported in part III of the current report, and provide a necessary foundation for evaluating the model tests of Work Package 30. However, task 21 has a wider scope than this. It will set out a comprehensive and consistent framework of evaluation of urban land use/transport strategies that can be useful to all strategic planning for urban sustainability. It will contribute to resolve outstanding questions of evaluation in a wide range of LUTI models and to provide ideas on how to compute indicators of some of the more difficult-to-quantify sub-objectives of sustainability.

We may assume that there will be many cities that find themselves in agreement with the general outline of planning for sustainability set out in Deliverable 1, but which do not have the modelling capabilities of large scale 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, our evaluation framework should be of use to them too.

It is not our intention to supplant the administrative or legislative evaluation framework in use in European cities. Rather, the intention is to enhance the methods used within such frameworks to take account of the specific evaluation issues encountered in integrated urban land use and transport planning for sustainability. Throughout, our evaluation methodologies should accommodate concerns for sustainability, quality of life and social inclusion, they must pay attention to the needs of “low profile” modes such as cycling and walking and to the evaluation of competing land-use strategies, and they must pay particular attention to evaluation over time. The question of the discount rate will be important in this context. Also, the question of the level of spatial disaggregation of the indicators will have to be addressed, not least because we need to find visual forms of presentation of the results to facilitate public participation in the planning process.
To clarify which of the indicators proposed in Deliverable 1 could actually be computed from the models available to us in PROSPECTS, a survey among the modellers was conducted. As a part of the task, evaluation was also discussed with the six Core Cities in a round of interviews. These two surveys resulted in modifications in the definitions of some of the indicators and served as an input to operationalise indicators. Some of the details regarding operationalisation have been omitted from this report and are only covered in the task 21 report.

The structure of Part II is as follows: Built on the structure of objectives and indicators from Deliverable 1, chapter 4 sets out a general and flexible framework for the evaluation of strategic land use/transport plans for sustainability and explores some of the opportunities within that framework. Regardless of the level of formal modelling and the availability of data to compute indicators, this framework and the considerations in this chapter should be of help in evaluation. Chapter 5 on indicators sets out a broad list, provides more precise definitions of the most immediately promising ones, and discusses some key indicators in more detail. It has not been possible to provide exact blueprints for the calculation of all indicators, and this is anyway very dependent on the models available and the preferences of each city. Nevertheless, with some effort we believe all of the indicators in the broad list could be developed to be useful for cities’ planning for sustainability.

Chapter 6 is the centrepiece of part II. In it, we develop our proposal on how to fit the indicators together in an objective function that provides a measure of the sustainability of land use/transport strategies, provided that target values for some of the other indicators, reflecting environmental, equity and financial concerns, are reached. The last part of chapter 6 is more technical than the rest of part II and provides the starting point for part IV.

The purpose of evaluation is to provide the necessary data for the decision makers and the general public to pass judgement on the strategies. Implementation issues are covered in chapter 7, and the question of public participation is taken up in chapter 8. Finally, cities’ comments on the evaluation framework are taken up in chapter 9.
4 The purposes and forms of evaluation

4.1 The evaluation framework

An evaluation framework is typically a matrix, with one row for each impact that is in some way relevant to the evaluation 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 to each other, 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 evaluation 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 evaluation practice. To assess each project-/strategy explicitly against identical performance indicators for each alternative is the single most important contribution to sound evaluation. 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 evaluation 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 alternatives

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, but computer-based presentation now facilitates presentation of selected data in disaggregate form.

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 higher numbers of rows, irrespective of
their intrinsic importance, whether or not formal weighting of impact rows is done. Thus, for example, if impacts are 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 Work Package 10 determines the evaluation framework that we propose for strategic land use and transport planning for sustainability.

4.2 Strategies, scenarios and barriers

Deliverable 1 introduced the following terminology:

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. To take a simple example, an integrated urban transport/land use strategy might consist of a 10 % increase in public transport frequency in peak and off-peak by the year 2015, 40 000 new units of housing built along the public transport corridors by the same year, and road tolls of 2 euros at a toll cordon surrounding the inner city. It is strategies like this (or usually a bit more complex with respect to the number of policy instruments and the time frame) that we want to test and evaluate.

The strategies are the actions that are open to the local or regional authorities. They are embedded in a wider framework, consisting of the given conditions (political, economic, demographic, technological,… ) that apply in the urban area at each 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 at the regional, national or EU level. A set of such conditions, thought to be important for the feasibility or success of strategies, have been identified in Deliverable 1 as barriers.

4.3 The main purpose of evaluation

The main purpose of evaluation 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 evaluation 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. Evaluation, 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.

We have assumed already in Deliverable 1 that for evaluation to perform this role, it should be objective-led. Thus in Deliverable 1 we defined a sustainable urban land use and transport system, and derived from that definition six objectives (or rather classes of objectives) that form legitimate parts of the overriding sustainability objective. The six objectives were economic efficiency, growth, environment, equity and social inclusion issues, accidents and liveable streets and neighbourhoods.

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 six sub-objectives at any point in time. This framework of objectives should contain the most relevant aspects of the choice of urban land use and transport strategies, and it is within this framework of objectives that we expect political differences to occur. Consequently, evaluation 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 evaluation 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 packages vary can be the basis for seeking re-design to accommodate the concerns of stakeholders and perhaps the identification of an agreed alternative package derived by amending one of the original ones. Even where complete consensus cannot be achieved, the fact that an open and participative evaluation has been seen to take place can often have a significant influence on stakeholders’ willingness to accept the finally proposed option.

4.4 Forms of evaluation

The six sub-objectives under the sustainability objective are at a fairly high level of aggregation – in fact, most of them are classes of objectives rather than single objectives. Specifying their different aspects, for each of the six objectives we arrived at sub-objectives that could be measured by single indicators. These indicators were broadly defined in Deliverable 1 and are made operational here in Deliverable 2.

Obviously, the simplest form of evaluation might consist in computing these indicators for each of the tested strategies, and leave 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 in recommended and discarded strategies etc., this form of evaluation might be called informal. However, it is still based on a systematic and comprehensive framework of quantified indicators.

Among the formal forms of evaluations, 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 evaluation that does not produce a complete ordering of strategies. Forming an objective function is the basis for evaluation that does produce a complete ordering.

4.4.1 Targets

Targets are defined as the level of the indicators that is necessary to bring about a sustainable urban land use and transport system.

Note that targets relate to and describe the future state that we want to attain. If, however, the transition can clearly be divided in stages, it may be relevant to set intermediate targets. In that case, a distinction is 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 we know, it does not make much sense to make detailed model predictions and compute indicators beyond 2020 or 2030, say. But by that time we should not expect the urban system to be sustainable in the full sense. So some judgement must be made as to what targets are the most important and what their levels should be to secure that the 2020 state would evolve to
be fully sustainable.

Planning by targets runs the risk that the targets are set so high that they cannot all be met. 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 speak of them 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 exactly reached. 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.

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 evaluate 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 must be interaction between planners and decision makers about what target to optimise to arrive at a complete ranking of the acceptable strategies.

4.4.2 Objective functions

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

There are two main forms of objective functions with a pretention to include all or most indicators, and thus to produce a comprehensive evaluation and a complete ranking of the tested strategies. They are Cost-Benefit Objective Functions and Multi-Criteria Objective Functions. We treat each in turn and consider their pros and cons in the evaluation of urban sustainability.
4.4.3 Cost-Benefit Analysis

A basic principle of CBA is to use the individuals’ own valuation 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 big problem with this point of view is of course 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 has a number of strong attractions as a base for assessing potential public expenditure, notably its link back to the widely understood and readily comparable yardstick of money. It is very 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, Deliverable 9 (Nellthorp et al., 1998) not only thoroughly assesses current appraisal practice and general appraisal issues, but also explores the specifics of evaluation 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 good, 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 evaluating individual types of impact, such as noise, safety, etc. Discussion of how to derive monetary evaluations for such impacts is not included in the present report.

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, the financial markets set the price of getting money now rather than later. However, when we evaluate 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 (inter-generational equity) involved. This may call for other approaches to discounting, and this is one of the important points where CBA in its traditional form may be inadequate and needs to be modified.
Since CBA is based on the possibility to treat efficiency and equity issues separately, and concentrates solely on efficiency, it goes without saying that the distribution of impacts, socially and spatially, is not covered by CBA evaluation. It might be possible to derive the distribution of impacts from a CBA, but distributional aspects are certainly not evaluated by the CBA. Thus in the context of the six sub-objectives to sustainability identified in Deliverable 1, CBA can be used to compute an overall indicator of economic efficiency, but the equity objectives must be tackled by other means.

More generally, society might very well have other objectives beside economic efficiency, including “non-welfarist” objectives that cannot be derived from individual utility functions. Such objectives require something else than CBA to be evaluated.

Finally, 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 et c. pose much greater problems. For the impacts that can be quantified but not valued, we will have to establish separate indicators, and this is also what we do.

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 other objectives. It will also be possible to perform constrained optimisation with a CBA objective function and constraints on the levels of environmental, equity and financial indicators. The objectives that are taken care of by the constraints must be regarded as the objectives with the highest priority, which must be reached regardless of what it means to the level of the objective function. At the same time, they need not be commensurable with the monetary values of the objective function. This provides a way of incorporating environmental and sustainability issues in a CBA setting, or conversely of taking care of economic efficiency issues in an Environmental Impact Analysis setting.

One example of incorporating sustainability in cost benefit analysis is Barbier et al (1990). Here, the possible policies are a set of mutually independent projects. Some of the projects - the "shadow" projects - are specifically designed to improve the environment to the same extent that the ordinary projects worsen it. The welfare function to be maximised includes the (discounted) benefits minus cost in a traditional sense, plus (discounted) environmental benefits minus costs. The maximisation is carried out by selecting projects subject to the constraint that the discounted net benefit to the environment is positive (weak sustainability) or environmental benefits minus costs is positive for each year (strong sustainability).

### 4.4.4 Multi-Criteria Analysis

Monetary-based assessments of public policy alternatives are often a central, necessary part of a search for well-informed decisions. Arguably, however, they are not sufficient to ensure the multi-faceted understanding of policy that is increasingly required. Multi-criteria assessments offer an additional perspective.

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1 Technicalities of that paper have been criticised by Pires (1998).
There are many distinct multi-criteria approaches, responding to a number of different types of potential application in terms of, e.g.:

- 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 organisation involved.

This section concentrates on some 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).

In particular, one style of MCA that is not explored here relates to those models that focus on argumentation, that is, are “constructive” in the sense of consciously seeking to support a process of dialogue with decision-makers that helps establish both suitable alternatives and their evaluation (see Viegas and Macario 2000, Toman et al 1998). Although such methods can be very effective in a small group of local stakeholders, they have the disadvantage of not readily embedding into any wider optimisation and evaluation framework, and are hence less supportive of the formal assessment of alternatives, which is normally required for major transport planning exercises.

To the extent that monetary methods can 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 are 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.

All the above are potentially important inputs to an effective development of public policy and support of decision process.

Implementations of multi-criteria decision support tools are becoming more and more common, as familiarity with the methods grows and as the quality and flexibility of software to support larger implementations has grown. Central to most applications is what may be seen as a performance matrix, or evaluation 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.

It is important to point out that there is no single normative model even of how individuals, let alone groups, should make multi-criteria choices 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 evaluate 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 on major projects where time and expertise are both necessary and available.

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 the present report. 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.
- Identify the objectives and criteria that reflect the value associated with the consequences of each alternative.
- Describe the expected performance of each alternative 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.

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.

4.5 The choice of an approach to evaluation

In the preceding section, we introduced the three core elements in any approach to the evaluation of transport projects, the evaluation framework and aggregation of impacts through CBA and/or MCA. We related them to the specific task of evaluating urban land use/transport strategies for sustainability. The three elements are complementary, not competing. All seek to impose a level of formality on the evaluation process which is strict enough to ensure defensible and genuinely informative evaluation practice, but which is nonetheless sensitive to the realities of evaluation in practice.

Different cities are likely to want to use the three 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. More likely, 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. Within a single evaluation, for example, it may be appropriate to use MCA at early stages, before sufficiently robust data is available to justify the work involved in a CBA.

An alternative approach is the one adopted in EUNET. Here, it was decided to use CBA to assess all those direct and indirect transport project impacts that could be confidently evaluated in money terms. This provided what might be seen as a “conventional” CBA. However, it was also recognised that a number of important impacts were not, at least currently, susceptible to monetisation. To accommodate these and to ensure that they entered the overall evaluation in a consistent and transparent way, a complementary MADA model was set up, in which the aggregated CBA output was one input, alongside a range of other impacts. All were then aggregated through the MADA, using weights to establish their relative contribution to the overall objective.

While at one level it can be argued that this is simply an indirect monetisation of all impacts, another view is that there is less homogeneity. Specifically, the non-monetised impacts often reflect more difficult and contentious judgements about the relative importance of societal objectives, whereas the components of the CBA are firmer in their relative evaluation, precisely because they are all referenced back to the market, no matter how imperfect that may be. Thus the MADA can more readily be used in an exploratory way, with an emphasis on sensitivity testing and robustness and the search for improved alternatives, to an extent that might be harder to achieve through a combination of CBA simply supplemented by discussion of the consequences of impacts omitted through inability to monetise.

An implicit theme throughout is the importance of users’ needs in relation to the role and style of evaluation in transport planning. In the typical environment of modern urban transport planning, there is a multiplicity of stakeholders, or potential users of the evaluation process. Such users need the information provided through evaluation to be:
Right, both in the sense of appropriate accuracy, but more importantly as addressing the questions they are currently seeking to answer

- Timely
- Digestible.

Where there is this multiplicity of users and also the same users making assessments at different stages in the time horizon of a proposal’s life and possibly with different emphases (environmental, cash flow, npv, etc.) flexibility within a formal structure is an important feature. Arguably, the combination of framework, CBA and MCA offers precisely that.

### 4.5.1 Consistency between levels of planning

The strategies we are testing and the impacts that we are considering are inevitably at a level of aggregation and roughness that ranges from the very coarse to the coarse (depending on the models that we use). The purpose of the testing and optimisation is a search to identify a broad strategy type that is “in the right ball-park” in the sense of identifying a broadly defined strategy mix, taking account of sustainability concerns, that is consistent with optimising achievement of the city’s land-use/transport objectives. At this level, some of the impacts are likely to disappear from view to a greater or lesser extent. For instance, concerns for the mobility impaired are not easily accounted for in models where there are no mobility impaired and where the details of transport supply and the construction of transport facilities are not addressed.

Once a general strategy direction is established in this way, however, a second level of evaluation and choice will probably take place, in which a series of discrete alternative packages of measures, all linked in general style and content to the one identified by the optimisation model, are evaluated, amended, re-evaluated and so on, until a preferred package is identified.

It is within this interaction between the functioning of a high-level, abstract, dynamic and strategic optimisation model, probably defined in terms of continuous decision variables, and a more conventional, possibly static evaluation of discrete packages of real potential policy measures, that consistency is needed. Clearly, there is little sense in running the strategic model with an evaluation emphasis implicit in its objective function that is seriously out of kilter with the preferences incorporated in the evaluation method that will then be applied to individual packages.

The framework, with its hierarchy of objectives and with indicators that reflect the sub-objectives at the lowest level in an adequate way, will contribute to consistency between the strategic and the detailed planning level, provided the same objectives are also governing planning at the detailed level. The indicators used may differ between the levels, but in either case they should reflect as truly as data permits the objectives in the same hierarchical structure of objectives. At each of the different stages – optimisation, sketch plan, full evaluation – the same basic evaluation hierarchy should be used, but at a level of detail consistent with the level of application.

It should be remembered that development and evaluation of policy alternatives should not, in any case, be seen as a linear process. More typical, and preferable, is for iteration through the overall modelling and evaluation process to take place. Therefore, one would quite possibly, for example, re-visit the optimisation model with one or two of the more detailed packages that were emerging from subsequent more detailed evaluation, in order to ensure that the developing packages of measures were not departing too much in either form or evaluation,
from the general ball-park strategy initially located by running the optimisation model.

It will be necessary for each group applying the evaluation model to check its own understanding of sustainability against that set out by PROSPECTS, to adjust the set of objectives and indicators accordingly and then to undertake forecasting, assessment 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 set out here.

4.6 Uncertainty

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 evaluating 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 evaluating them with respect to how they perform across the scenarios. Evaluation across scenarios might of course be performed in a number of ways, but regardless of the method chosen, this is the general approach to uncertainty about what given conditions that will prevail in the future.

There will also be other forms of uncertainty, and they might have to be tackled by other means. We might feel uncertain about whether our models and methods capture the key elements and relations of the system we are studying – the urban land use and transport system. Such uncertainty is tackled by continuing theoretical discussion, by comparing the performance of different types of model and approaches, and by subjecting model results to a critical discussion among a wider group of experts and practitioners. 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.

From an evaluation perspective, the initial response to all of these inevitable uncertainties may be sensitivity analysis and a later search for robustness. To test how a strategy performs in different scenarios is just one example of sensitivity analysis. Sensitivity analysis seeks to assess the extent to which the overall attractiveness and hence ranking of alternatives changes as plausible changes are made to key input assumptions, reflecting the degree of uncertainty that might surround them. Such testing may be simple, one input at a time, or more sophisticated, such as 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 alternatives that reflects lack of sensitivity. It is particularly appropriate to long-term strategic planning, where alternatives are often implemented in stages. In such circumstances, robust alternatives are those where the early actions that have to be taken for implementation are consistent with acceptable performance in many different
possible futures. By pursuing robust options, decision-makers seek to avoid costly mistakes, should the anticipated future for which an alternative was designed not in fact arise. Robustness analysis at a strategic level is often pursued through scenario analysis, using a series of plausible, internally consistent visions of the future as “wind tunnels” in which the performance of alternative packages of measures may be tested. For an explanation of how to put this approach into practice in urban transport planning, see Allport et al. (1986, 1987).

There is a further trade off to be explored between overall performance and what Ignizio (1998) terms stability – the ability to demonstrate “graceful degradation” of performance. In real world decision making, what tends to be preferred is a good solution whose performance degrades only slowly in response to changes in input parameters and that exhibits slow performance degradation over as wide a range of parameter changes as possible. This characteristic is more valuable than the alternative of higher performance if all model parameters are correct, but severe degradation if they do not.

Providing means of facilitating sensitivity testing and the search for stable, and robust policy packages is necessary to address the needs of users. Sensitivities to value changes, in response to uncertainty about model accuracy, and in response to changes in the external environment must all be capable of being explored. In large scale modelling, this is however often ignored due to lack of resources.

Obviously, robustness might be a high-level objective on a par with sustainability, or rather forming a part of the concept of sustainability. We have chosen to leave it out from the hierarchy of objectives at the moment, just as we have also left out procedural objectives (a democratic planning process). One reason for that is that in PROSPECTS, resources will probably not allow us to explore the robustness of strategies to any degree. This does not mean that this is not an important aspect of strategic planning which need to be addressed in the guidebooks.

Going beyond sensitivity tests, expected utility theory might be used to define an objective function over many scenarios. The degree of risk aversion of the decision maker might 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 that, this approach would also be very computer time demanding and perhaps difficult to communicate to stakeholders.

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). This approach too requires probabilities of the scenarios and would be very computer time demanding.

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 scenarios, and if uncertainty is about growth rates or economic conditions, this concept will be more useful than the concept of robustness.
4.7 Equity

Concerns about not only spatial, but also social distribution of impacts are likely to be important in planning for urban sustainability. This may provide the reason for needing some more micro-scale modelling, but it also raises the possibility that some distributional inequalities may be assessed and others not. Justification for such judgements needs to be benchmarked against best practice and the concerns of the responsible decision-makers.

From an evaluation perspective, treatment of equity can be handled in one of three ways:

- In principle, it is possible to build into CBA or optimisation objective functions functional forms and parameters that would allow aggregate evaluation to be sensitive to distributional differences, spatial or social. In practice, this is rarely, if ever done, partly for reasons of practical complexity and data demand and partly because of the extreme difficulty (and political sensitivity) of making explicit and general statements about preferences between distributions of impacts.

- Secondly, it would be possible, within an MCA framework of evaluation, for example to include equity as a sub-objective and for alternatives to be assessed, perhaps judgementally, in terms of equity before converting these judgements on to a numerical scale for inclusion in a MADA. This represents a degree of political and theoretical difficulty substantially lower than the previous approach, but still is not without its difficulties and sensitivities.

- Thirdly, a post hoc check of distributional indicators may be used. In other words, each package of measures being seriously evaluated and with real potential for implementation should be checked for adverse distributional consequences, and either abandoned or amended if its performance is unsatisfactory. In many ways, this is not dissimilar to the previous MCA approach, except that the explicit trade-off of distributional changes against other impacts is not directly countenanced.

For either the second or third approaches, an important requirement is to formalise the process of assessing distributional changes sufficiently to ensure that all alternatives assessed against this concern are assessed in broadly comparable ways. The MCA framework formally requires it, but it is equally important if the third, constraint-based approach is adopted. Our battery of inequality and social inclusion indicators has been designed to fulfil these needs in a flexible way and to cover all aspects of inequality and distributional concerns.

4.8 Conclusion

Deliverable 1 offers a specific evaluation framework for urban land use/transport planning for sustainability. This framework is structured around the six sub-objectives to sustainability and their indicators. Economic efficiency is one of the sub-objectives. Thus, the framework can be formalised by using an MCA objective function in which the aggregated CBA output is one of the inputs, alongside a range of other impacts as measured by the other indicators. However, since intergenerational equity is a central aspect of sustainability, we will want to modify the CBA part of the function with respect to discounting.

Even if we use MCA for exploratory purposes, we might feel that in the end, the environmental and equity objectives should not be easily traded off against the efficiency objective. Minimum levels with respect to some of these objectives can be secured by setting targets. It will then be possible to rank all strategies that meet the targets and to carry out constrained optimisation to find the best strategy that meets the targets.
Consequently, our preferred form of evaluation with respect to sustainability will involve an MCA objective function with a strong CBA element, and possibly with targets for some of the indicators. It is a matter of taste whether one would like to call this CBA or MCA-based evaluation. There will be room for flexibility according to circumstances and the preferences of the participants in the decision making process.

Consistency between planning at the strategic and the detailed level is sought by using the same evaluation framework in each. But even if the hierarchical structure of objectives will be the same, indicators will have to be defined on the basis of data available at each stage in the planning process, and objectives and indicators will probably have to be adjusted to fit the particular preferences in each city and the national planning requirements.

Strategic planning requires us to clarify the uncertainty involved, the robustness of the strategies and their degree of irreversibility. The specification of different scenarios and testing the strategies under different scenarios and different assumptions are the keys to such analyses. They can be extended by different methods, most of which are resource demanding and experimental.
5 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 particular of the six sub-objectives identified in Deliverable 1. Furthermore, we will almost be able to combine them into an overall indicator of sustainability. To be more specific, some of the indicators could be combined to form a Sustainability Objective Function, while others will have to be kept separate. By setting targets for a selection of the stand-alone indicators, reflecting the sustainability requirements with respect to each of them, a constrained optimisation problem can be defined. The problem is to find a strategy that makes the Sustainability Objective Function as large as possible, subject to the separate indicators reaching their target values.

Of course, this problem can be approached in more or less formal ways. And even when we think we found a solution to it, it will be absolutely necessary to subject it to discussion and further evaluation in a more comprehensive process as outlined in Chapter 4. The Sustainability Objective Function could be CBA-based or MCA-based. But regardless of the methods applied, we think that, as long as sustainability is the overriding objective, it will be useful to think of the strategic planning problem as some form of constrained optimisation embedded in a more comprehensive democratic decision-making framework.

Whether or not one chooses to form a Sustainability Objective Function, our indicators should readily fit into the framework defined in Chapter 4. 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 evaluation 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 want to use a rather short list of comprehensive indicators.

Deliverable 1 represented the start of PROSPECTS work on indicators. It was pointed out that our indicators are impact indicators, or more specifically that 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 introduced 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 evaluate or weights 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 green areas, a sub-objective regarding green areas may be considered as reached. Such decisions are also used as level 3 indicators.

The structured set of indicators was already broadly outlined in Deliverable 1. This list has been reviewed and revised in the current work. The aim has been to ensure that they can all be operationalised and that they reflect cities' objectives. Therefore, the most important and the most problematic indicator issues have been discussed anew with representatives of the Core Cities.

Below, we first set out a rather long list of indicators at the three levels, and provide short definitions of each of them (section 5.1). 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 evaluation process and avoid double
counting, only one of them should be chosen. It is however thought that because of differences in the availability of data and different preferences with respect to MCA, CBA etc., it might be useful to present indicators of the same sub-objective at different levels.

In section 5.2, we pick from the menu the indicators that we think will be the preferred options in most cases. This is also the list we want to apply in the subsequent PROSPECTS work. 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 in the task report, and proposals for modelling the indicators are set out. A summary of the task report results is given in sections 5.3–5.8. Further implementation issues concerning the modelling work in PROSPECTS is addressed in Work Package 30.

Traditional indicators like mode split and average speed etc. will not be in our lists of indicators. 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 whole issue of evaluation is really how to devise and present relevant pieces of information while not overburdening decision-makers with irrelevant information. We take it that the relevant information is information about the level of goal achievement with respect to clear and distinct objectives!

Section 5.3 treats the economic efficiency indicator. This indicator is of a very composite nature. We briefly discuss its elements and how they relate to each other. The specific problems of user benefit calculation in integrated land use/transport models are addressed in section 5.4. Issues concerning the calculation of indicators of air pollution, equity, accidents and walking and cycling benefits are taken up in the subsequent sections.

5.1 The comprehensive list (The menu)

The indicators are numbered much like work packages and tasks in a project description. So 10, 20, 30, 40, 50 and 60 represents our six sub-objectives, while 11, 12 etc. represents different indicators covering the sub-objective 10. The level of the indicator 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 4-12(1)) are meant to be annual values. Where relevant, these annual values will of course be discounted and added to form present values. This is treated in section 5.3.
10 Economic efficiency

11(1) Economic efficiency  
Annual net benefits as measured by an ordinary CBA, see section 5.3.

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 Liveable streets and neighbourhoods

2.1 Increased freedom of movement for vulnerable road users

21(1) Vulnerable user accidents  
Number of accidents involving pedestrians/cyclists and a car multiplied by average cost. See section 5.5, 5.7 and task 21 report.

22(3) Safety and security score  
As defined by results from a questionnaire

2.2 Positive external effects on social, cultural and recreational activity

23(2) Local activity index  
Attractivity measure –see task report.

24(3) Positive externalities score*  
As defined by results from a questionnaire

30 Protection of the environment

3.1 Energy use and climatic change

31(1) CO₂ cost  
Emissions in tonnes weighted by shadow cost of national CO₂ target. May be presented by source. See section 5.5, 7.1 and task 21 report.

32(2) CO₂ emission  
Emissions in tonnes

3.2 Local and regional pollution

33(1) Air pollution cost  
Pollutants in tonnes weighted by unit costs. May be presented by substance and
34(2) Emissions of air pollutants*
   Pollutants by substance in tonnes. May be presented by sources. See section 5.5 and task 21 report.

35(2) Air quality*
   Requires dispersion model. See task 21 report.

36(3) Local pollution index
   As defined by answers to a questionnaire

3.3 Protection of valuable areas

37(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.

38(2) Green areas etc.
   Types of land as in 37, measured as a percentage of built area.

39(3) Green area index*
   As defined by answers to a questionnaire

3-10(3) Green poster*
   A system of valuing valuable area changes, see Deliverable 1 for reference.

3.4 Urban sprawl

3-11(1) Urban sprawl direct cost
   Area of built sites weighted by opportunity cost of land at the city fringe.

3-12(2) Urban sprawl*
   Area of net new sites in hectares

3-13(2) Main land uses*
   Area of land (a) not used, (b) built and (c) used for transport purposes in percent.

3-13(3) Urban sprawl index
   As defined by results from a questionnaire

3.5 Fragmentation

3-14(3) Fragmentation index*
   As defined by results from a questionnaire

3-15(3) Green poster fragmentation assessment* See Deliverable 1 for reference to Green poster

3.6 Vulnerable areas

3-16(2) Vulnerable areas
   Percentage lost or damaged
3-17(3) Conservation measures*  Percentage subject to special conservation laws or measures.

3-18(3) Green poster vulnerable areas assessment*  See Deliverable 1 for reference to Green poster

3.7 Noise

3-19(1) Noise cost  Unit noise costs per vehicle kilometre in an area multiplied by vehicle kilometres of different classes of vehicle

3-20(2) Noise  Residents exposed to outdoor average noise level 60dbA (Leq or Leu) at home

40 Equity and social inclusion

4.1 Accessibility for those without a car

41(1) Accessibility for those without a car*  A Kolm measure of inequality – see section 5.6. Alternatively, consumer surplus per capita for those without a car as a proportion of overall consumer surplus per capita.

42(2) Public transport performance*  Frequency and geographical coverage of the public transport supply.

43(2) Proximity to services*  Index of mean distances from residential areas to green areas and basic services.

44(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.

4.2 Accessibility for the mobility impaired

45(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

46(3) Level of special services*  Describe special services

47(3) Mobility impaired access index*  As defined by the results of a questionnaire

The indicators 45(3) and 46(3) should preferably be used in conjunction.

4.3 Equity and compensation to losers

48(1) Income inequality index  A Theil $S_0$ measure of the inequality of the distribution of generalised income. Might be decomposed. See section 5.6 and task 21 report.
49(2) Equity impact tables  
*Consumer benefits plus compensation displayed by group (Household income groups, household types, households by location). See section 5.6 and task report.*

4-10(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 section 5.6 and task 21 report.*

4-11(2) Benefits/accessibility by zone  
*A map presentation of spatial distribution of benefits. See section 5.6 and task 21 report.*

An alternative way to specify indicator 4-10(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 5.6.

### 4.4 Economise on taxpayers' money

4-12(1) Taxpayers' money  
*Net present value of finance as a percentage of total net benefits. See section 5.3 and 5.6*

### 50 Reduce traffic accidents

51(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 5.5, 5.7 and task 21 report.*

52(2) Accidents  
*Number of accidents of average severity. May be presented by modes involved and location/type of road.*

53(3) Danger & intimidation  
*As defined by results from a questionnaire*

### 60 Support economic growth

61(1) Growth potential  
*Sum of user benefits, producer surpluses and value of finance as defined in section 5.2. See section 5.3.*

Although care was taken to define indicators that can be quantified from output of the planning process, there are problems of measuring several of the indicators. In some instances, such problems stem from the low level of detail or the high level of aggregation of the available models. Our aim has however not been to operationalise all indicators in this report, but to choose from this list a set of indicators covering all sub-objectives and capable of being operationalised in most models. Subsequent sections and the task report will provide further guidance on quantification and operationalisation of the chosen indicators.
5.2 The indicators most likely to be used

We need to make a choice of indicators for the model tests in PROSPECTS. Probably this shorter list will also 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.

5.2.1 Economic efficiency

There is only one composite indicator under this heading, the economic efficiency indicator. It is treated more fully in the next section, section 5.3.

**Definition:** 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 combine these indicators with data on public expenditure in the strategy. These can be included in MCA.

5.2.2 Liveable streets and neighbourhoods

Two indicators are carried forward 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 MCA purposes.

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

**Definition:** The local activity index is defined for each destination zone as a measure of the attractiveness 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.

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.

5.2.3 Environmental indicators

Five indicators are retained. Air pollution is covered by the two indicators "CO₂ 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 MCA, 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.
**Definition:** CO₂ cost is the annual volume of emitted CO₂ from transport and energy use in the households, multiplied by a value thought to represent the marginal cost to society of reaching a national target of CO₂ reductions. The target will be the Kyoto target for 2010 and a stricter target for 2020. See section 7.1 and the task 21 report.

**Definition:** The air pollution indicator 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 5.5 and the task 21 report.

**Definition:** The noise cost indicator consists of a unit cost per vehicle kilometres 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.

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

**Definition:** The green areas indicator is the square kilometres 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.

**Definition:** The main land uses indicator 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.

### 5.2.4 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 PT wrt the mobility impaired".

**Definition:** Accessibility for those without a car 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. The higher the index, the more disadvantaged are those without cars.

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

**Definition:** The quality of public transport with respect to the mobility impaired 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.

**Definition:** The income inequality index is a Theil $S_0$ 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.

**Definition:** The equity impact tables 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.

**Definition:** The user benefit inequality indicator is a Kolm inequality index applied to household types, residents at different locations or any other differentiation.

**Definition:** The indicator of benefits by zone 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 difference between using a map of the benefits and a map of accessibility is that the first shows the change from the do minimum scenario 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.

**Definition:** The taxpayers' money indicator 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 30 year period and to all government. This is perhaps not always the only relevant definition. Other definitions may be needed as constraints in an optimisation problem, see section 16.2.2.

### 5.2.5 Accidents

Two indicators are retained here, "Accidents cost" and "Accidents". As shown in the task 21 report, 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.

**Definition:** The accident cost indicator 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. See section 5.7 and the task 21 report.

**Definition:** The accident indicator 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).

### 5.2.6 Economic Growth

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 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 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.

**Definition:** *The growth potential* 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.

### 5.2.7 Concluding remark

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 back to section 6.1 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.

### 5.3 Economic efficiency

#### 5.3.1 Discounting

Annual net benefits are really only the raw material for the calculation of economic efficiency. To be comparable and be summed, 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.

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. 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. 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.

The present report is not the place to go deeper into the question of how to set the right discount rate. For some countries, the discount rate to be used in CBA is set by national authorities. For other countries, we recommend to use a discount rate in the range of 6-8%. If strategies are tested in low-growth and high-growth scenarios (section 4.6), 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 is to use a risk-free rent 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%, giving a discount rate of 8%. For strategies that produce the same benefits regardless of the economic conditions, the risk premium is 0.

From now on, when we speak of the economic efficiency indicator and its elements, we mean net present values, which we take to be the sum of the corresponding discounted annual values from year 0 to year 30.

It might very well be that we only have data on costs and benefits for one or two years in the 30 years period. In this case, some form of interpolation must be used to estimate the intermediate years. This issue is taken up in part IV.

We have indicated that the discount rate has to be modified to take account of sustainability. How this is done is the subject of the next chapter.

### 5.3.2 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 entrepreneurs.
3. Value of finance, defined as annual government tax revenue minus expenses 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.
5. Investments:
   - Infrastructure and house building costs
   - Rolling stock costs  (annuity of infinite chain of investments)$^2$

For the calculation and presentation of this 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 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.

Table 5.1. Simplified example of presentation of economic efficiency results by sector

<table>
<thead>
<tr>
<th>Strategy no.:</th>
<th>Euros, present values, year n prices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Households (a)</td>
</tr>
<tr>
<td></td>
<td>Public transp.</td>
</tr>
<tr>
<td>Investment costs</td>
<td></td>
</tr>
<tr>
<td>Transport benefits</td>
<td></td>
</tr>
<tr>
<td>Location benefits</td>
<td></td>
</tr>
<tr>
<td>External costs</td>
<td></td>
</tr>
<tr>
<td><strong>Column totals</strong></td>
<td></td>
</tr>
</tbody>
</table>

Transfers cannot be ignored or too hastily be eliminated in the calculation of economic effici-
cency. The reason is that it is the perceived costs, including transfers to the public transport
companies 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.

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

$^2$ 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 $a = \frac{c \cdot r^a}{1 - (1 + r)^n}$, 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.
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.

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 5.1. 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. We propose not to use a shadow price of public funds in subsequent PROSPECTS work, although this is something that must be considered in the guidebooks.

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.

5.4 Benefit calculation in integrated land use/transport models

In this section, we treat the calculation of user benefits in 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.

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.

To decide on how to calculate user benefits, a series of questions must be answered.

5.4.1 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 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.

5.4.2 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. 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, appropriately specified to reflect the nested logit structure. The indirect utility function of the representative consumer is the potential function (some would say the generator function) of the line integral that goes by the 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) call it, in all travel markets. And as shown by Williams (1976), the rule-of-a-half is a linear 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 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 and attraction 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 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.
5.4.3 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 at the moment. For the remaining classes of model, we are left to use some heuristic approach or to refrain from measuring welfare.

5.4.4 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.

5.4.5 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).

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. Using the appropriate composite costs, linearisation can also be performed at more aggregate levels, as shown in appendix B of Simmonds 2001. 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 underlying assumption in appendix B of Simmonds (2001) is that of a consistent nested logit model – or a corresponding entropy model. In that case, there is an answer to the question of the total user benefits – the logsum formula. The whole purpose of the Simmonds
approach must however be to establish an heuristic rule for benefit calculations in models of a more difficult-to-assess nature. 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.

Our proposal is 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.

### 5.5 Environmental and safety impacts

The principal environmental and safety impacts of transport and land use strategies are:

- Atmospheric pollutants
- Noise
- Danger
- Accidents
- Severance
- Visual impact

Except for visual impacts, indicators of all of these are suggested above in section 5.1, and indicators of the first four are carried forward to the short list of section 5.2.

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\(_x\)); 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\(_2\) 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 NOx and VOCs. The most elevated 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).

Accidents need to be categorised by level of severity and, potentially, by the nature of the victim; however, the process for appraisal is identical. 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.

All the impacts except for the levels of atmospheric pollutants, noise and accidents are difficult to categorise; each is considered as a separate entity below. It should be noted, however, that all present problems of quantification, and hence analysis.

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

5.5.1 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:

1. Flow (on links or as veh-km in a network)
2. Vehicle type, including vehicle age and type, engine size and type
3. Technological factors, for instance the use of catalytic convertors
4. Speed
5. 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 the following table, where ++ indicates a strong relationship, + a weaker one, and ? an uncertain one. In many cases the
latter arise from problems of quantification.

Table 5.2. Strength of causal relationships influencing environmental effects and accidents

<table>
<thead>
<tr>
<th>Cause:</th>
<th>Flow</th>
<th>Veh type</th>
<th>Speed</th>
<th>Accn/decn</th>
<th>Cold Start</th>
<th>Link type</th>
<th>Meteoroology</th>
<th>Chemisty</th>
<th>Built form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air pollution (emissions)</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Air pollution (air quality)</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Noise (emission)</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise at receptor</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Danger</td>
<td>+</td>
<td>?</td>
<td>+</td>
<td>?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidents</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>?</td>
<td></td>
<td>++</td>
<td></td>
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</tr>
<tr>
<td>Severance</td>
<td>+</td>
<td>?</td>
<td>?</td>
<td></td>
<td>+</td>
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<tr>
<td>Visual Impact</td>
<td>?</td>
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</tr>
</tbody>
</table>

5.5.2 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. The table below 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 5.3. Strength of the influence of factors that affect the environment and accidents

<table>
<thead>
<tr>
<th>Factor:</th>
<th>Absolute level</th>
<th>Threshold</th>
<th>Change</th>
<th>Link type</th>
<th>Built form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air pollution</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Noise</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Danger</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Accidents</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severance</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>++</td>
<td>+</td>
</tr>
</tbody>
</table>

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.

5.5.3 Levels 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, 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 complex for appraisal of city-wide strategies.

5.5.4 Proposed approach to CO2 emission

CO\textsubscript{2} 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.

The relevant targets are the Kyoto targets for 2010 and some more ambitious target (closer to a sustainable situation) for a later year. See chapter 7 for a closer discussion of this.

CO\textsubscript{2} 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 in strategic analyses 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 the next section (5.5.5) 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 had, we prefer to include energy consumption (and thereby CO\textsubscript{2} emissions) from housing in the indicator.
5.5.5 Proposed approach to air pollution

We want to establish indicators of the cost of air pollution for the pollutants CO, NO\textsubscript{x}, 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. We should also be able to derive an indicator of SO\textsubscript{2} 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

\begin{equation}
APC = C \cdot EF \cdot A
\end{equation}

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 however 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.
Prospects D2: Evaluation Tools

The other option is to make emission rates a function of average vehicle speed. Since emission of most pollutants increases sharply in highly congested conditions, this option is strongly recommended. 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. This is discussed more in full in the task 21 report.

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 (see section 5.7). 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.

Table 5.4 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>
<thead>
<tr>
<th></th>
<th>SO₂</th>
<th>NOₓ</th>
<th>VOC</th>
<th>PM₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
<td>Rural</td>
<td>Urban</td>
<td>Rural</td>
</tr>
<tr>
<td>Eyre</td>
<td>52</td>
<td>7</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>EUNET</td>
<td>1.7</td>
<td></td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>ECMT</td>
<td></td>
<td>8</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Eriksen</td>
<td>9</td>
<td>2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>SIKA</td>
<td>27</td>
<td>2.3</td>
<td>10</td>
<td>6.8</td>
</tr>
</tbody>
</table>

* PM₂.₅

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 NOₓ 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
The SIKA small town value of PM$_{10}$ applies to Stockholm’s surroundings, but is very similar to the corresponding value for a small to medium sized town.

The task 21 report discusses a number of points not taken up here, including the emissions from housing, life-cycle costs and environmental input-output modelling.

### 5.5.6 Proposed approach to noise costs

Noise is similar to air pollution in that a clear distinction must be made between the level of emission and the final impact, and that to find the final impact, detailed information on the number affected and their location relative to the sources of noise is required. Just as for air pollution, one would like to have the opportunity to switch between the strategic and the detailed level of analysis to verify the assumptions used at the strategic level.

If there is no opportunity to do this, a very crude approach to noise costs must be taken. It consists in using a constant noise cost per vehicle kilometre, differentiating only between the broad classes of vehicle and the broad types of area (urban, rural). This will be our choice for the subsequent PROSPECTS work.

Noise emissions, as well as noise impacts, are measured in decibels, appropriately adjusted to filter out the sounds to which the human ear does not respond (dB(A)). 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.

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.

Unit values can be found in many studies of external costs. For our purposes, we might try to apply the principle of the Leu measure by adjusting these values somewhat up for traffic during the evening (and night, if our models include such traffic).

### 5.6 Equity objectives and indicators

#### 5.6.1 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).

5.6.2 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 still is 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 5.1 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 Lorentz curve. (In actual fact, the depicted Lorentz 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.

![A Lorentz curve](image)

**Figure 5.1: Lorenz curve for the taxpayer population of Norway 1995.**

For our purposes, probably the most useful formulation of the Gini coefficient is:

\[
G = \frac{1}{2n^2 \bar{x}} \sum_{i=1}^{n} \sum_{j=1}^{n} x_j - x_i
\]

(5.2)

Here we have assumed a population of \( n \) individuals with incomes \( \mathbf{x} = (x_1, x_2, ..., x_n) \). The average income is \( \bar{x} \). Suppose however that there are instead \( n \) income groups with incomes \( \mathbf{x}_i = (x_{i1}, x_{i2}, ..., x_{in}) \), \( n_i \) members of group \( i, i = 1, ..., n \) and \( \sum n_i = N \). Then

\[
G = \frac{1}{2N^2 \bar{x}} \sum_{i=1}^{n} \sum_{j=1}^{n} n_i n_j | x_i - x_j |
\]

(5.3)

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:

\[ S_c(x) = \frac{1}{nc(c-1)} \sum_{i=1}^{n} \left( \frac{x_i}{x} \right)^c - 1 \]  

for \( c \neq 0 \) or 1

(5.4)

\[ S_0(x) = \frac{1}{n} \sum_{i=1}^{n} \log \frac{x}{x_i} \]

\[ S_1(x) = \frac{1}{n} \sum_{i=1}^{n} \frac{x_i}{x} \log \frac{x_i}{x} \]

where \( x = (x_1, x_2, ..., x_n) > 0 \) is the distribution of income among the \( n \) members of the population, and \( x \) is the mean income. The constant \( c \) can take all real values. This class of functions \( S_c \) is called the 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.\(^3\,4\)

Decomposition of \( S_0 \) takes the form:

\[ S_0 = B + \sum_g w_g S_0(x_g) = B + \sum_g \frac{n_g}{n} \sum_{i=1}^{n_g} \log \frac{x_g}{x_i} = B + \sum_g \frac{n_g}{n} \sum_{i=1}^{n_g} \log \frac{x_g}{x_i} \]

(5.5)

where

\[ B = \frac{1}{n} \sum_g n_g \log \frac{x}{x_g} \]

Here, the groups are indexed by \( g \), the population in group \( g \) is \( n_g \) and average income in group \( g \) is \( x_g \). \( B \) 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. Since we do not want to impose stricter requirements on equity than is acceptable to most people, we are willing to go along with the scale invariance property and discard translation invariance. However, for purely mathematical reasons we will also have a need for inequality measures displaying translation invariance. Of course, if we are not certain that our inequality measure embody the norms and

\(^3\) The weights on the within-group terms of \( S_1 \) will also sum to 1, but will be functions of between-group inequality. On the other hand, \( S_1 \) (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 \( S_1 \). This allows for a normalisation of the measure and is obviously convenient for expressing targets.

\(^4\) 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).
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

\[ K_a(x) = \frac{1}{a} \log \left( \frac{1}{n} \sum_{i=1}^{n} \exp \left( a(x - x_i) \right) \right) \]

where \( a > 0 \) is a transfer sensitive parameter.

### 5.6.3 Intragenerational equity objectives and indicators

In principle, we might incorporate intragenerational equity in a welfare function along the lines suggested by Atkinson (1970) and others. In order not to make the interpretation of the objective function too difficult, we prefer to have intragenerational equity expressed by a separate indicator. This indicator 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 it in the objective function. Nevertheless, it 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 were 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.

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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 if the inequality is 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 carowners, 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 (Fridstrom 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.

5.6.4 Proposed set of indicators and targets

For the subsequent work in PROSPECTS and for most other practical uses, 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 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.

5.6.5 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.
5.7 Accidents and liveable streets

We need indicators of accidents and liveable streets to help us assess urban land use and transport strategies with respect to their achievement of accident reductions and the difficult-to-quantify objectives of a lively, thriving and safe inner city and safe outdoors conditions for children in residential areas. 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 the difficult-to-quantify objectives. This needs to be verified, but we feel confident enough to use it.

Like the environmental indicators, the accident indicator 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.

To construct the "liveable street" indicator and come to grips with walking and cycling benefits (see next section), we need to distinguish between accidents involving only cars, accidents involving only pedestrians and cyclists, and accidents involving both a car and vulnerable road users. Let us call the first category M-accidents, the second S-accidents and the last X-accidents. We are going to treat all accident costs as external costs. The reason is that accidents are not a part of generalised cost in our models. Therefore, let the total cost of an average accident of each of these three types be $C_M$, $C_S$ and $C_X$, respectively.

Consider a particular part of the transport system. It might 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 is shown in the task 21 report that the total change in accident costs from the base strategy in this part of the transport system is

$$(5.7) \quad dT_C^A = C_M r_M (1 + El_M r_M) dM + C_S r_S dS + C_X R M \left[ (1 + El_M R) \frac{dM}{M} + El_S R \frac{dS}{S} \right].$$

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), Elvik (1994) or Fridstøm (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 measure to reduce risk can easily be modelled as a change in $R$. Finally, $C_M$, $C_S$ and $C_X$ can be taken from manuals like Elvik et al (1997), which incidentally also contains evidence on the risk $r_S$. European costs and risks can also be found in Persson and Ödegaard (1995).

A reasonably informed choice of parameter values can be made by modifying the values from these 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

$$
(5.8) \quad E_{l_M} R + E_{l_S} R = k - 1
$$

where $k$ is a parameter between 1 and 2. As slow modes increase, the risk perceived by motorists should not go down, so $E_{l_S} R$ 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 $E_{l_M} R$ 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 $E_{l_M} R$ closer to 0 will go together with an $E_{l_S} R$ closer to 0 (inner city).

### 5.7.1 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

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5 The total change in accidents for a measure that affects both the risk and the traffic volume would be $d(RM) = RdM + MdR$. 

66
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.

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.

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.

### 5.7.2 Liveable streets indicator

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 however not be modelled adequately in the 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. Our models only recognise walking and cycling as forms of transport.

Nevertheless, there is enough here to suggest that our measure of X-accidents, as given by the last term of the total accident cost formula, 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 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, an indicator like

\[
I = -\frac{1}{M} \left( \frac{dM}{M} + \frac{dS}{S} \right)
\]

would perform very much in the same way, without being bothered by the accident interpretation. Here \( M \) 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.

### 5.7.3 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.

### 5.8 Benefits to pedestrians and cyclists and health impacts

#### 5.8.1 Benefits to pedestrians and cyclists

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 the preceding section. 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 et al (1997) 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.

5.8.2 Health

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. All have been accounted for above, and that is why health is not identified as a separate objective. 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.
6 Measuring sustainability

In chapter 4, we outlined the evaluation framework consisting of objectives and indicators, and the key elements of formal evaluation: an objective function (MCA or CBA) and targets for the indicators not included in the objective function. In chapter 5 the indicators were defined and some of the more difficult issues of measurement considered. We are now ready to put these bits and pieces together in a more specific approach to evaluation with respect to sustainability. We start by looking more closely at the coefficients that are used to sum the impacts/indicators in the objective function.

6.1 Weights

Weights are the coefficients of the (linear) objective function. Weights can be derived from four sources, namely from within a CBA framework, a MCA framework, a mathematical programming framework and from intergenerational equity considerations. We treat each in turn.

6.1.1 Social costs

The core of our sustainability objective function will be an indicator of economic efficiency. The principles of cost-benefit analysis (CBA) are used to compute this indicator. It will however eventually be transformed to reflect intergenerational equity considerations.

In a CBA, the resources used, saved or newly produced within a strategy are valued at their social cost. If the resource is traded in a perfect market, the social cost will be the market price. However, the existence of market imperfections like external effects, taxes, monopoly power etc. makes the market price differ from the social cost and calls for corrections. There will also be important resources that are not traded in markets, like environmental qualities and individuals' own time, health and life.

The opportunity cost of using one more unit of a resource in a strategy is the value this marginal unit would have had in its best alternative use.

This value is the yield or benefit that would accrue to the owner of the resource in the best alternative use. Since a rational agent would be willing to pay any amount for the resource up to the gain he would get from using it, the opportunity cost is also the best price that could be got for it.

In line with this principle, the value of a resource that is not traded in any market is determined by willingness-to-pay (WTP) or by willingness-to-accept (WTA). Willingness-to-pay is the maximum amount any individual would be willing to pay to get a resource that does not by right belong to him. Willingness-to-accept is the minimum amount any individual with a right to the resource would be willing to accept to give it up. In practice, WTA is seldom used, as it would mean giving a veto to anybody who is sufficiently strongly opposed to a strategy. Furthermore, in the strategies we are considering, there will be many individuals that are gaining or loosing time and other resources, traded or not traded. In this case, average willingness-to-pay is used as the opportunity cost of the resource.

The social cost of the use of a resource in a strategy is the sum of opportunity costs inflicted upon all members of society. Unit values, resource costs and accounting prices are other words for the same thing.
The question of how to treat taxes in a CBA is solved by applying the concept of social cost. If there is an inelastic supply of a resource, its use in the strategy must be drawn from other uses, and its social cost is consequently determined by how much consumers or producers would be willing to pay for it. This includes all the taxes included in its price, so the true social cost of the resource is the price including taxes. Assuming the same taxes will have to be paid wherever the resource is used, the government tax revenue is the same with and without the strategy. Labour is the prime example of such resources. Except for situations with high levels of unemployment, the cost of labour as perceived by employers, including social expenses, is the true resource cost.

If on the other hand a resource is in elastic supply, its use in the strategy is not drawn from other uses, but from new production at the same cost of production or from import at a fixed price. In this case, the social cost is the cost of production excluding taxes or the import price excluding tolls. The individuals that consume the resource in the strategy pay a price including taxes and tolls (a "perceived cost" which is higher than the social cost), but on the other hand the government receives a tax and toll revenue which they would not otherwise have got. If we include both the cost to the individuals and the benefit to the government in the CBA, the net result is that the resource is valued at its social cost. Most market goods except labour should be valued in this way.

Monopoly pricing may call for a similar correction of market prices as in the tax example. The unit values of non-market resources will often have been set in each country by government decree based on national studies.

A defining property of CBA is that all weights used in a CBA convert the impacts of a strategy, both market and non-market, into monetary values. European countries differ with respect to what non-market impacts are monetised and included in CBA in this way. We will be including noise costs, accident costs and important air pollution costs in the CBA, which will also include benefits to households or individuals from their transport and location choices, rents to landowners, producer surpluses to transport operators and government revenue. The weights we need will be accident costs, noise costs, pollution costs, values-of-time and the true social costs of the market goods. Our indicators help us with most of these.

6.1.2 MCA weights

Secondly, weights may derive from some process of MCA. To avoid double-counting, MCA-based weights will primarily be used for the indicators not included in the CBA. However, from the point of view of sustainability, there might also be a case for overruling the valuation used in the CBA. This is the case if current individual preferences will have to be changed or overruled if sustainability is going to be achieved and the processes of setting weights in MCA is thought to reflect the necessary direction of such changes.

6.1.3 Shadow prices

Thirdly, weights may be guessed-at or previously derived shadow prices from the solution of a constrained optimisation problem. The objective function is interpreted to be the Lagrangian of this constrained optimisation problem, the constraints of which consist of requirements that indicators at least reach their targets. However, instead of deriving the shadow prices as part of the optimal solution, we regard them initially as constants. If so, there will usually be a need to confirm that the weights are correct by showing that they minimise the objective
function evaluated at the optimal level of the policy variables. (If such a process is carried out in a systematic way, it is called inverse optimisation).

The cost of one tonne of CO$_2$ emission is a special case, since it is derived not from a target set at the urban level, but rather from national models which have been subjected to national CO$_2$ targets. The cost of CO$_2$ emission is the marginal macro-economic cost of measures that makes the national economy meet the target. Consequently there is no way of confirming that it is correct by using the urban modelling system and its objective function.

6.1.4 Discounting and intergenerational equity considerations

Fourthly, effects in different years are weighted differently. This stems partly from discounting. But – fundamental to the use of the objective function to evaluate sustainability – the elements of the objective function that reflect costs, benefits and other impacts in the last of the modelled years is given more weight than discounting at a normal rate would imply. Our last modelled year must be assumed to be sustainable in the long term, at least in some important respects. The added weight to this year reflects the interests of future generations, which are largely ignored in ordinary cost-benefit analysis. This issue is taken up in section 6.3.

The core of the objective function consists of the terms that could not be interpreted as involving shadow prices. Shadow prices are weights on terms in the objective function involving only a single indicator. But to be called shadow prices, they should reflect the marginal increase in the value of the core of the objective function that can be expected if the target level of the corresponding indicator is reduced by one unit.

Our evaluation involves long term targets for the indicators – explicitly for the indicators not included in the objective function, and implicitly for the indicators weighted by the correct shadow prices. It also involves giving more weight to the last of the modelled years than ordinary discounting would imply. These features constitute an evaluation of the success of a particular strategy in bringing about the transition to sustainability. The costs of this transition is however also included, since costs, benefits and other impacts in the first of the modelled years are also included in the objective function. If a strategy achieves sustainability in the end only by imposing substantial losses in the short and middle term, it will perform poorly in the evaluation.

There is considerable scope for subjective judgement and differences of opinion. Such elements enter in the setting of goals and targets, the setting of weights by MCA to give priority to certain aspects and the particular weighting of the last modelled year. These features might not be a weakness but a strength in interactive and participative planning, at least if the rest of the planning system is capable of providing quick results of changes in the assumptions.

6.2 The sustainability objective function

Recall once more the PROSPECTS working 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, 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.

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$_2$-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 a reference to intragenerational equity 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 an ordinary discount rate)
2. Welfare improvements for future generations (which should not be made 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 equity indicators applying at all times.

How to combine the first two elements is exactly the issue at stake in the heated discussions about the appropriate discount rate to be used to evaluate 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 a rather rough way, such a combination would 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 evaluation of policies that affect sustainability (IPCC 2001).\(^6\)

Now we bring in 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 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.\(^7\) This is a very compelling reason for adopting such a function as a measure of sustainability.

Broadly, there are two ways of ensuring that the environmental targets are met. Either we could include them in the Sustainability 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 6.4.

We will not try to include the fourth element, the indicator on intragenerational equity, into the Sustainability Objective Function (SOF). The reason is that as outlined here, the SOF 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.

However, there is only a short step from this to an MCA formulation. If we chose 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 done in the further PROSPECTS work.

A slightly less general version of the Sustainability Objective Function than the one we will be using in PROSPECTS was used in the OPTIMA project. See OPTIMA (1998) and Minken (1999) for details. Our extensions now consist first and foremost in the application to land use/transport planning, the inclusion of more environmental indicators and the fact that we will run the models and compute indicators for more than one "target" year. Also, we will be treating CO\(_2\) emissions differently.

An in-depth treatment of the properties of Chichilnisky's function can be found in Heal (1999).

\(^6\) "...there is still no consensus on appropriate long-term rates, although the literature shows 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).

\(^7\) The discount factor of the EEF needs however not be a constant.
It needs once more to be pointed out that we are not of the opinion that the final word about the sustainability of a strategy has been said once the sustainability function has been calculated. Rather, the most important purpose of such formalisation is to allow us to explore trade-offs and to allow optimisation. The most important purpose of optimisation in turn is not to find "the" solution to the problem of sustainability, but to point the way to promising new policy packages that we might otherwise have overlooked and never tested. Formal planning methods are not the decision-making process itself.

6.2.1 The sustainability objective function and the optimisation problem

Let $y_{int}$ be the level of the indicator $i$ in the strategy $n$ and the year $t$, and let $z_i$ be the current level and $z_i^*$ be the targeted long-term value. Assume a high value of the indicator is better. In a certain year $t$, we would like to have less than the proportion $a_{it}$ of the road between $z_i$ and $z_i^*$ left to go:

$$\frac{z_i^* - y_{int}}{z_i^* - z_i} \leq a_{it}, \text{ or } z_i^* - y_{int} - a_{it}(z_i^* - z_i) \leq 0 \tag{6.1}$$

We know that if we faced the problem to maximise the core part $V$ of the evaluation function subject to such constraints as the above, we would form the Lagrangian

$$L = V - \sum_{it} \mu_{it}(z_i^* - y_{it} - a_{it}(z_i^* - z_i)) \tag{6.2}$$

and maximise it with respect to strategies. (We assume that there is a continuum of strategies and that the indicator level $y_{it}$ is a function of the strategy). The Lagrangian multipliers $\mu_{it}$ are unknown variables that will be determined together with the optimum values of the strategy variables.

If we had guessed correctly the values of the Lagrangian multipliers in this problem, we could substitute the problem to maximise $L$ with these guessed values of $\mu_{it}$ inserted for the constrained maximisation problem, and still get the same solution.

Consequently, when we have indicators with a target value, provided we make wise guesses at the $\mu_{it}$'s, we can express our evaluation function as

$$L = V - \sum_{it} \mu_{it}(z_i^* - y_{it} - a_{it}(z_i^* - z_i)) \tag{6.3}$$

or

$$L = V + \sum_{it} \mu_{it}(y_{it} - z_i^* + a_{it}(z_i^* - z_i)) \tag{6.4}$$

or even simply

$$L = V + \sum_{it} \mu_{it} y_{it} \tag{6.5}$$

It is plain to see that in the last instance, the evaluation function can be interpreted as a multicriteria function, combining some cost benefit analysis terms with some terms reflecting other objectives. We should however remember to check that our $\mu_{it}$’s have been chosen

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8 Furthermore, we could find a good approximation to the correct values of the Lagrangian multipliers by solving the problem to maximise $L$ many times over with different values of the multipliers, and choosing the solution that gives the smallest value of such maximal $L$'s.
wisely, that is, that the original inequality is satisfied with as little difference as possible between the left and right hand side at the optimum.

It can be noted that the way the original constraints (inequalities) are formulated makes it possible to shift the attention from mere improvement upon the present situation \( (a_{it} = 1) \) to reaching the long term goal \( (a_{it} = 0) \), or vice versa. The "Lagrangian multipliers" will be very different in the two polar cases.

We are now able to summarise our discussion in the preceding sections. We propose to adopt an objective function \( OF \) to evaluate the sustainability of strategies and to be optimised and find optimal strategies. The general form of \( OF \) is:

\[
OF = \sum_{i} \alpha_i (b_i - c_i - I_i) + \gamma_i g_i + \sum_{i} \mu_i y_i
\]

where

\[
\alpha_i = \alpha \frac{1}{(1 + r)^t} \quad \text{for all years between 0 and 30 except year } t^*, \text{ the last modelled year}, \ r \text{ is a discount rate and } \alpha, \ \text{the intergenerational equity constant, is a constant between 0 and 1, reflecting the relative importance of welfare at present as opposed to the welfare of future generations},
\]

\[
\alpha_i = \alpha \frac{1}{(1 + r)^t} + (1 - \alpha)
\]

\( b_i \) and \( c_i \) are benefits and costs in year \( t \), including user benefits, producer surpluses, benefits to the government, and external costs. Investment \( I_i \) has been singled out as a special type of cost.

\( \gamma_i \) is the shadow cost of CO\(_2\) emission, reflecting national CO\(_2\) targets for year \( t \),

\( g_i \) is the amount of CO\(_2\) emissions in year \( t \),

\( \mu_i \) is the shadow cost of reaching the year \( t \) target for sub-objective \( i \),

\( y_i \) 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 \( W \) 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\(_2\) term in the middle and the last summed terms).

It is left for part IV of this report to apply this function.

### 6.2.2 The core of the objective function

Recall that the core of the objective function consists of the terms that could not be interpreted as involving shadow prices. Here it includes the "CBA" and the CO\(_2\) cost. The air pollution, noise and accident indicators are included in this. This does not prevent us from setting targets for these indicators. But if instead of setting targets we want to include CO\(_2\), air pollution, noise and accident indicators in the objective function, we will have to take account of the fact that they are already included in the core part of the objective function. 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 are already elements of the "CBA", and this should be acknowledged when setting separate weights for the additional terms.

6.2.3 Keep the same objective function throughout evaluation

As pointed out in chapter 4, a basic requirement of evaluation is to use the same evaluation criteria to evaluate 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.

6.2.4 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.

6.2.5 The optimisation problem

In very general terms, the constrained optimisation problem to be considered in part IV is to optimise the core of the objective function plus any additional terms where weights have been preset, subject to the remaining indicators reaching their goals for each year. As already stated, to the extent that weights in the function \( OF \) are derived from previous constrained optimisation, the \( OF \) can be viewed as the Lagrangian of such a problem. But the optimisation of \( OF \) will normally take place subject to constraints, which means that a new, “second” Lagrangian could be formed, consisting of \( OF \) plus terms weighted by the implied marginal cost of imposing these constraints (the shadow price or Lagrangian multiplier). If the constraint concerns an indicator already included in the \( OF \), the shadow price at the optimum only reflects the *additional* cost per unit of imposing the constraint, over and above the cost already set in the \( OF \).

If each year of the optimisation problem could be optimised separately, there would be no need to consider the long term effects of a strategy, and consequently no need to include the
intergenerational parameter $\alpha$ in the formulation (6.6). But the policies adopted at one point in time have consequences in later years. This is obviously the case in reality, and is also obvious in the so-called “time-marching” models, which take elements of the situation of the previous year as input to the modelling of the current year. If static equilibrium models are used, one needs to think about how the policies of past years affect the current situation and to reflect this in the input to the model. Past investments will have caused permanent or long term changes in the transport network and the housing supply. Land once used for building and construction will never be brought back to its natural state, and could only with difficulty be used for new purposes. Such effects must be included in the model. Other effects must be brought in via the constraints (this goes for all kinds of model). This is the financial constraint to balance the budget over the entire 30 years period, as well as any cumulative effects on the environment. The existence of irreversible, cumulative and other long term effects are at the essence of the whole strategic planning problem and must be reflected in both the objective function, the constraints and the practical approach to the optimisation problem.
7 Implementation issues

In this chapter, we discuss briefly how to apply the objective function/target framework of section 6.2 and the associated constrained optimisation programme. Although some of the issues discussed are of wider interest, the focus is on the immediate implication of the framework in Work Package 30 of PROSPECTS. The issues are what weights should be used in the objective function, which of the indicators to use as targets, and what targets to set.

7.1 Global warming – the CO$_2$ cost

7.1.1 Deriving the CO$_2$ cost

We need a simple assumption to be able to derive the marginal cost of CO$_2$ emissions. The problem that we pose is: What would be the level of a national CO$_2$ tax, set to assure that a national political target of CO$_2$ 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$_2$ in the atmosphere at particular levels (450, 550, 650 and 750 ppmv). The latter are long term targets that can be reached quicker or slower, 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$_2$ tax is used together with other instruments with an influence on CO$_2$ 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. It seems that on this assumption, a tax rate in 2010 of 50 euros per tonne of CO$_2$ is broadly in line with the bulk of the model studies.$^9$ 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$_2$ 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 $0.74 \times 3.15 \times 0.05 = 0.12$ euro per litre on petrol and $0.84 \times 3.15 \times 0.05 =$

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$^9$ 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.
0.15 euro per litre on diesel.\textsuperscript{10} These values could be applied to all years up until 2010, 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\textsubscript{2} emissions do not appear.

This tax can be interpreted as being equal to the marginal cost to society of reaching the CO\textsubscript{2} 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\textsubscript{2} emissions will stay the same under such alternative assumptions.

\subsection{7.1.2 Applying the CO\textsubscript{2} 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\textsubscript{2} tax to be understood? Is it an addition to other fuel taxes (whether or not they are also called CO\textsubscript{2} 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\textsubscript{2} tax should appear in \textit{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\textsubscript{2} 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.\textsuperscript{11}

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\textsubscript{2} 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\textsubscript{2} use, is however the same as in the first case and must be added to the objective function.

\subsection{7.1.3 The longer term CO\textsubscript{2} costs}

The optimal path to stabilise CO\textsubscript{2} in the atmosphere at a certain level is a much more involved problem that 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 (2001) are not useful for deriving

\textsuperscript{10} 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.

\textsuperscript{11} This is a particular instance of the recommended approach from section 5.3 and chapter 6.
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\textsubscript{2} 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\textsubscript{2} emissions than the Kyoto target will be needed. Also, there will probably still be a need in 2020 to apply a high CO\textsubscript{2} 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\textsubscript{2}, 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 100 and 200. But the long term CO\textsubscript{2} tax level will obviously be a clear candidate for extensive sensitivity testing.

### 7.1.4 City targets and city fuel taxes

If a national CO\textsubscript{2} 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\textsubscript{2}. 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\textsubscript{2} (the Lagrangian multiplier) as close as possible to the marginal social cost of CO\textsubscript{2} found from national studies.\(^\text{12}\) This is because if the marginal costs differ between cities and sectors, the CO\textsubscript{2} 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\textsubscript{2} element, but we cannot compare the constrained case with no CO\textsubscript{2} in the objective function with the unconstrained case with CO\textsubscript{2} included in the objective function.

The case for a target instead of simply valuing CO\textsubscript{2} by the marginal cost is much 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\textsubscript{2} in the atmosphere such a target would

\(^{12}\) To be specific, the Lagrangian multiplier should be zero if the marginal costs of CO\textsubscript{2} are already included in the objective function, and equal to the marginal cost if they are not.
represent, though. There is nothing to suggest that the target should be the same in physical terms for all cities.

Finally, if we want to model a case where political resistance hinders the national CO₂ 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.

### 7.2 The intergenerational weight \( \alpha \)

For a similar formulation of the objective function in OPTIMA, a value of \( \alpha = 0.1 \) was used and seemed to produce a suitable “greening” of the optimal strategy. We propose to use the same value in WP 30 work, in part to facilitate comparisons with OPTIMA results. Each choice of \( \alpha \) will be translatable into an equivalent constant discount rate over the 30 year period that we consider. Given a functional form for a discount rate that diminishes over time, it will also be translatable into a path for such a falling rate. These relationships should be explored to get an opportunity to relate our choice of \( \alpha \) to a wider literature on discounting, and to choose other values of \( \alpha \) for sensitivity testing.

### 7.3 Other weights

In a CBA setting, some guidance on setting other weights is included in the Task 21 Report. We do not consider it necessary to say much more about this, which will anyway often be governed by official guidance at the national level.

### 7.4 Which indicators to use as targets

#### 7.4.1 Finance

Invariably, targets must be set for financial indicators – or rather, they are *preset* through the political process that allocates money to transport purposes and new development and the institutional framework governing funding and use of funds. The targets will simply be that accounts must at least be balanced, in the short or long term. If the institutional framework is complex, there might be a need to have many separate financial targets, although in previous chapters we have assumed that they can all broadly be covered by a target on the one single indicator of the net present value of public budgets (the “value of finance”).

This means that strategies that do not meet the preset financial constraints are discarded or ranked very low. It also means that in the constrained optimisation problem, there will be at least one financial constraint. It might be transformed to a penalty term in the objective function, but at least conceptually, it stems from a target on the financial indicator.

If the financial constraint is not binding, it means that our strategy produces a budget surplus. A key question is then how this surplus is used. It might be used inside or outside the urban land use/transport system. If outside, it might nevertheless be used inside the urban area (for instance on schools and hospitals), or it might go back into national government coffers. In all

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13 What we have termed financial barriers are simply barriers on the inflow of funds from outside the urban land use/transport system, barriers to funding by taxes on the activities inside this system, and institutional arrangements that makes it necessary to balance several accounts instead of the single net present value of public budgets.
three cases, it might be used to improve efficiency or equity. Assumptions on the use of the surplus are essential to the specification of the objective function and the equity indicators.

Some of the possibilities are:

1. The surplus is used at the national level to cut back distortionary taxation. In this case, a positive shadow price of public funds might be used to value the surplus. (See OPTIMA, FATIMA and AFFORD reports. In AFFORD, values of 0.00 and 0.25 were used).

2. The surplus is used at the local level to compensate losers. Such compensation is one of our policy instruments – hitherto unspecified. To keep things simple, assume that compensation can take one of three forms: Equal amounts paid to all individuals, amounts proportional to income, and public transport subsidies. In the first two cases, our inequality indicators are affected, and this must be taken account of when the objective function and the indicators are programmed. For the proportional repayment, there is once more a case of using a positive shadow price of public funds to value the surplus. Assuming that at optimum, public transport runs a deficit, the third case is simply taken care of by including public transport in the budget constraint.

Our approach in WP 30 will be to specify the compensatory scheme and to apply it regardless of whether the public budget runs a surplus or not. We will also specify if the local government is supposed to finance public transport deficits or not. The compensatory scheme and the public responsibility for public transport financing should be decided based on local political objectives and institutional frameworks. Once these two decisions are made, there is a high probability that the financial constraint will in fact be binding. Consequently, there is less use for the shadow price of public funds, which will be set to zero. Finally, the implications for the calculation of equity indicators must be addressed by some programming.

7.4.2 Equity
For WP 30, one of the inequality indicators might be included as a constraint in the constrained optimisation problem. It must be recognised that this is experimental. There will be no experience with setting the target in a feasible way, and it might be challenging to find optimal solutions. But we need to try it out if we are to cover it in the guidebooks. The other option, of course, is to compute the inequality measures and present them to decision makers as additional information on the strategies.

7.4.3 Local air pollution, accidents and green areas
Often, the city will in fact have targets with respect to air pollution and/or accidents. Say that an objective is to reduce accidents by 50%. To use this in our evaluation, we first have to ask if this is a minimum requirement (a target in our terminology) or an ideal which we can only hope to achieve partially (a goal in our terminology). Once we have found out what the target is, next we need to assess how much of it can be reached by policies that we do not model (safer cars, roundabouts, traffic signalling, information campaigns, etc.). Say we end up with a target of 20% reduction, which we include as a constraint in our constrained optimisation problem.

If we will always use a city target of accident reductions as a constraint, we might want to remove accident costs from the objective function. If we can have the Lagrangian multiplier of this constraint, and if the objective function is obviously denominated in money, we may
compare the cost per accidents from such an optimisation and the “official” cost per accidents to see if the target implies a higher valuation.

A similar approach is applied to air pollution, only in this case, it is more probable that there will be targets in our sense (maximum values that cannot be exceeded).

In some models, the green areas are not influenced by a strategy but are set in the scenario. More housing in a zone in such models could be interpreted as building on “brownfields” or “whitefields” (derelict land or under-utilised land). We have no objective or indicator with respect to such areas, although if the city wants it, it would be easy to include a maximum value for such property development among the targets and perform constrained optimisation with this constraint. The same goes for green areas if building in the model infringes on them.

7.4.4 Liveable streets

If accidents between cars and non-motorised travellers are used as a “liveable streets” indicator, we should set a target value and include this target among the constraints. The method will be similar to accidents, also with respect to taking such accidents out from the objective function. Due to our imperfect modelling of accidents, it is very probable that if both the accidents and the liveable streets targets are included as constraints, only one of them will be binding. However, this needs to be studied in practice. It might also be that accidents and air pollution will move together, so that only one of them will be binding. Experience will show which one is the most essential to include for different levels of the targets.
8 The public participation process

8.1 Introduction

There is a wide body of literature which has been developed over the last few decades on the process of public participation in various fields. In the UK, public participation in the transport field has become a requirement of the Local Transport Plan development process. However, proper public participation is a complex process, which can take place at a number of different levels and in a wide range of different ways.

This section is intended to provide a general overview of the public participation process for the purposes of the PROSPECTS project. In that sense this section does not come out with any firm answers about public participation, but does make it clear what should be considered when designing a public participation exercise and what methods are available to carry out public participation.

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.

8.2 A framework for public participation

Over 30 years ago Arnstein (1969) characterised public participation as “a little like eating spinach: no one is against it in principle because it is good for you”, and this view permeates much of the prevailing attitudes towards the process. Arnstein goes on to suggest a “ladder of citizen participation”, which goes from non-participation at the bottom to real citizen power at the top. As observed by Booth and Richardson (2001), this does represent a very rigid structure and fails to recognise that different levels of participation are appropriate for different situations. However, the ladder does provide a useful shorthand for the different levels used. Traditionally, participation in transport planning has taken place at the lower levels of the ladder and has involved informing and consultation rather than a significant degree of delegated power.

Wilcox (1994) suggests, as an alternative to the ladder, five “stances”:

- Information
- Consultation
- Deciding together
- Acting together
- Supporting independent community interests

No one stance is intrinsically “better” and different stances are appropriate for different situations. In this framework, only the latter three stances involve substantial participation. Wilcox also suggests that there are two further dimensions to the public participation process, the phase at which participation takes place and who should be involved.

The phase concerns the timing of the participation process and this is characterised by four successive stages:

- Initiation – the stage at which public participation is first considered
- Preparation – first contacts and the agreement of an approach
• Participation – the actual carrying out of participation
• Continuation – how the participation is to be continued

These provide a link between the development of a project and the public participation process, but when exactly these stages take place might be affected by what stance is to be adopted for public participation.

The third dimension is the stakeholders – who should be involved. These could be:
• Professionals
• Decision makers
• Activists
• Residents
• Businesses

In addition, at least as far as transport related decision making is concerned, there is also the consideration of the level of scheme, plan, policy or programme being considered. These might be:
• Strategies
• Policies
• Plans
• Programmes
• Projects

These are in order from higher-level general themes for the development of transport in an urban area as a whole, through to specific proposals for projects perhaps at the very local level.

8.3 Considerations for public participation

There are a number of important considerations that need to be taken into account in the public participation process. Most of these refer to the questions implicit in the framework described above; some are taken from the issues raised by Booth and Richardson (2001), others from Wilcox (1994). The answers to all these questions are clearly interdependent and all are important when initiating a public participation process.

8.3.1 Why involve the public?

This is a rather fundamental question but important from the point of view of policy makers – it involves considering what is to be gained from involving the public. Policy makers should ask themselves whether they really want to take part in an honest attempt to delegate decision-making or just to attempt to win support for a decision which has already been made. It is perfectly legitimate for decisions to be taken by elected representatives if that is felt appropriate; indeed, it may be fairer to do this, rather than attempt a public participation exercise which might exclude certain elements within society.
8.3.2 What is negotiable?
It is important for those organising the public participation exercise to decide on 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. It is sensible for the policy maker to state clearly at the outset of public participation the extent of the decisions, which can be affected by the process.

8.3.3 What is the appropriate stance?
Clearly, the appropriate stance or position in the ladder of citizen participation will be affected by the answers to the two previous questions. An “information” stance might be appropriate for a decision which has already been made. As noted above, this stance does not suggest substantial participation.

8.3.4 At what stage should public participation take place?
When during the development process should public participation be initiated, prepared and actually take place? What continuation processes might be appropriate?

8.3.5 Who should be involved?
The appropriate stakeholders might be people or organisations who:

- are affected by the development
- help or hinder the public participation process
- have skills or other resources they might be able to devote to the development or the public participation process
- decide on the development

Stakeholder analysis may be a useful procedure for thinking through the role of stakeholders as well as deciding on what should be presented, and by what means.

8.3.6 What level of scheme/plan/policy/programme is involved?
An important consideration is the level of the development on which consultation is sought. In the well-documented process of Environmental Impact Assessment (see, for example, Glasson et al., 1999) the typical scope is that of a project which has already been fairly well developed. On the other hand, the process of Strategic Environmental Appraisal (see, for example, Therivel and Partidario, 1996) considers much wider plans, policies and programmes where the overall strategic direction is still capable of being influenced. This level will not cover the detailed impacts in the same way and will want to avoid detailed discussion of specific impacts to avoid diverting attention from the consideration of a strategic direction.

One obvious example of how techniques might vary involves the level of detail of the information to be provided. At a strategic level less detail is appropriate, both because the effects have not necessarily been worked out at a fine level of detail and to avoid diverting attention away from the strategic issues to be discussed into less useful consideration of misleading detail.
8.4 Methods for public participation

Methods used will depend on the different answers to the questions posed above. This is a list of some examples of techniques which are particularly suited to the different stances. The detailed use and delivery will depend on the other considerations.

- **Information**
  - posters leaflets and information sheets
  - telephone hotline
  - website
  - media coverage
  - unstaffed exhibition

- **Consultation**
  - public meeting
  - staffed exhibition
  - mailback leaflet or surveys
  - focus groups
  - website
  - public inquiry

- **Deciding together**
  - Planning for Real®
  - Citizen’s forums

- **Acting together**
  - the development of partnership bodies

- **Supporting independent community interests**
  - citizen’s planning
  - advice
  - support
  - funding
9 Tailoring to city requirements

Deliverable 1 confirmed that in most cities, no single and clear-cut format of strategic planning for sustainability exists. The most common approach amongst the survey cities was some mix of plan-led and consensus-led decision-making. Frequently, both other political bodies and interest groups demanded their say in the planning process. Models were frequently used, but results were never uncritically accepted as providing the final answer to the plan.

To find out more about how cities would like the evaluation process to be (as opposed to how it was done at present), we approached our Core Cities in a round of interviews. We should point out that the views expressed in the interviews were personal, and should not be taken as the cities’ official views. It was exactly such informal views and impressions that we were seeking. Here are some of the questions we asked:

1. **Is our approach of focusing on achievement of objectives, and thus output indicators rather than process ones, acceptable within this city’s working practices?**

   All the cities were satisfied with our approach, or saw it as a move in the right direction. However, Stockholm and Helsinki pointed out that not only goals, but also the process of moving towards the goals needed close attention. Oslo pointed to the fact that decision makers and the general public have individual needs and tastes with regard to what information they want. There will always be a need to provide many forms of information, and not exclusively information on the achievement of the objectives.

   Cities are dependent on money from the outside (national or EU) to achieve their transport targets. Thus they need planning tools that conform to the requirements of these bodies and are capable of interacting with their plans, for instance producing and evaluating proposals for the national transport plans. At the same time, they need to keep an integrated perspective on the city's development.

   In Oslo, the current strategic plan is a combination of a long-term land use plan and a medium term plan for the municipal budget. Any method to make it an integrated land use and transport plan, and to include effects for the regional economy as a whole, would be most welcome. In devising new forms of plans, citywide planning with respect to air quality would be a priority.

2. **Within our list of criteria and indicators, which are the ones where we should focus (either because the impacts are currently not well measured, or because the impacts are important)?**

   Madrid highlighted the difficulty of measuring some of the “liveable streets” and environmental indicators. Helsinki pointed out that the financial, environmental and social issues surrounding land use/transport strategies are becoming ever more important, and so more effort need to be put into the design of clear criteria and reliable indicators in these fields. Equity and safety issues were also mentioned. Evidently, there is a need to improve the evaluation of all aspects that are traditionally treated in a more qualitative way, if at all.

3. **Do you currently work with targets concerning, for example, sustainability goals? If so, are these rigid targets that must be met, or are they more like aspiration levels?**

   Both rigid targets and aspiration levels (“goals” in the terminology of chapter 6) were frequently used. It seems the rigid targets are often set at national and EU level, except for specific issues such as nature conservation areas. The cities take a more flexible approach to their own targets at the strategic level.
4. In advising decision makers, do you need an aggregate or a disaggregate assessment, or both? If both, where is each needed? If aggregate, should this be CBA or MCA? If MCA, where should the weights come from?

By aggregate assessment in this question, we meant the use of an objective function. The cities that expressed themselves clearly on this issue, stressed the need for both aggregate and disaggregate assessment. So in addition to the overall assessment through CBA or MCA, the single indicators should also be presented. Stockholm pointed out that aggregate assessment needs to be transparent. The weights should not be hidden inside a very complex aggregate function. Politicians and the public want to see details and want to know what lies behind the results. Obviously, existing national evaluation frameworks, like the YHTALI framework of Finland, also state the need for both overall and detailed assessment. Edinburgh stressed the need for information to the public to be simple and non-technical. CBA and MCA results are too technical in this context.

Generally, it was felt that both CBA and MCA were needed. Madrid would prefer MCA at the strategic level, while Oslo had no experience with formal MCA. Experts were relied on to provide the weights for MCA.

5. For either, is our suggested approach to discounting and sustainability acceptable?

Since our approach had not yet been described in detail, the cities were not prepared to commit themselves on this issue.

6. How important are distributional impacts, and how are they best dealt with?

Unanimously, the cities saw distributional impacts as very important. Both social and spatial distribution should be addressed, and the winners and losers identified. Oslo pointed out that distributional impacts should not only be passively recorded, but forms of compensation to losers must be devised along with the rest of the strategy. As interesting forms of compensation they mentioned tax relief to firms and use of the revenue to improve outdoor environment in residential areas.

7. How do you/should we treat uncertainty?

Testing strategies across different scenarios and sensitivity tests of key uncertain parameters were mentioned – but there was a feeling that this subject is perhaps not as high on the agenda as it deserves.

8. When providing information for public participation, in what ways do the requirements differ from those which you have indicated in answer to questions 5-10?

As mentioned earlier, Edinburgh was very clear on the need to keep things simple and non-technical.

In conclusion,

- Our general evaluation framework won approval, but there may be a need to explain our approach to discounting and sustainability more thoroughly.
- There is a need both for targets and objective functions. Both rigid targets and softer aspiration levels should be accommodated within the evaluation framework. The objective function should be kept simple and transparent, and at the same time, all indicators should be reported separately. The framework should make use of both CBA and MCA.
- To be useful, the evaluation framework must be consistent with frameworks and criteria at the national and EU level.
• Financial, environmental, social and safety issues must be addressed. Particularly, distributional issues were seen as important, and it is necessary to be able to identify winners and losers and to discuss compensating measures.

• The framework should be above all flexible and capable of adapting to a wide range of needs.
Part III

Presentation tools

10 Objective and methods of part III

10.1 Objectives

Part III reports the work of task 23 on presentation tools. Task 23 was also occupied with public participation – this work was reported in chapter 8 of Part II.

The overall aim of Task 23 “Output presentation” is to give guidelines on what and how to present, and to whom. We suggest and present means and tools for presentation of both model and evaluation results. The main task is to find the best presentation method for all relevant information that could help decision makers and promote public participation as well as the right level of accuracy and aggregation for different purposes. New output tools may be introduced and developed where necessary.

In addition to the conventional output of nearly all existing transport and/or land use models, the importance of additional output to be presented here will depend on other tasks of the project: indicators and objectives, important trends and scenarios, policy options modelled, optimisation process, and key issues of evaluation etc.

Typical presentation methods are maps, visualisations, installations, animations, reports, leaflets, www-sites, tables, charts, GIS, thematic maps or 3-D presentations etc. The suitability of each tool will be analysed and suggestions produced.

Even though the same results of a plan should be presented to all groups involved officially or unofficially and with same presentation tools, it is essential to interpret the results, in order not to block the interaction with overwhelming amounts of data and not to undermine credibility with lacking pieces of information. Different individuals process information in different ways, so main findings should be available as text, numbers and maps or figures.

10.2 Overview of methods, interviews and surveys

The preparatory work done in Task 23 was based on a literature survey as well as partners’ expertise and practical experience.

Personal interviews in the six Core Cities (Edinburgh, Oslo, Stockholm, Helsinki MA, Vienna and Madrid) played a key role in evaluation of methods for output presentation of indicators, plans and scenarios. Interviews were mainly addressed to city authorities responsible for transport and land use planning.

The intention was not only to reveal the current practice in the cities but also have expert suggestions for novel presentation methods as well as opinions of the use of current methods. However, the long interviews for the other tasks detracted from the response to questions related to this task. With more practical experience in Work Package 30 we hope to clarify some of the issues and incorporate these in the Task Report as well as in the Guidebooks. The full list of subjects and questions raised in the interviews are available in appendices in the Task 23 Summary Report.
10.3 Overview of presentation

In PROSPECTS we consider three separate stakeholder groups: decision makers, public and professionals. These are groups involved in the planning process and for whom the output presentations should be designed. Regarding the presentation techniques, since in most cases decision makers and the public share common interests, they may be considered as a single group.

The material for presentation may be categorised under three groups as:

1. Data related to the scenario such as demographic data, land use data, socio-economic data, etc.
2. Models and methods used such as LUTI models, CBA, MCA, etc.
3. Results

Our viewpoint in this report has very much been from the perspective of presenting results to the public. Presentations of models and methods to professionals and to decision makers will be more closely defined during the modelling work in Work Package 30 and will be incorporated into the Task Report as well as to the Guidebooks.
11 Presentation of PROSPECTS indicators

The purpose of this section is to make a proposal for presentation of strategies with respect to urban sustainability (including spatial and temporal forms of presentation and presentation of options and trade-offs e.g. response surfaces). In practice this section contains an assessment of presentation of PROSPECTS indicators, indicator by indicator, with links to model outputs.

It should be pointed out that with respect to transport and/or land use models there is always a choice between a high level of detail and a high number of model runs – the first referring to tactical models and the latter to more strategic ones. Given the strategic approach and methods used in this project it should be understood that the results are coarse and the output presentation should correspond accordingly. However, as mentioned in chapter 4, strategic analyses may need to be complemented by more detailed analyses of the chosen strategic options, not least to get a firmer grasp on sustainability issues that are lost sight of at the coarse strategic level. Therefore, some aspects concerning more tactical models and plans in general are covered, and some more general advice given in this chapter and the next.

The indicators we cover are those listed in section 5.2.

11.1 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 outlined in section 5.3 (table 5.1). These 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. Table 5.1 and similar tables used in OPTIMA, FATIMA and AFFORD will be adapted in Work Package 30 to suit the needs of each particular case. One of the purposes of these tables is to show broadly who wins and who looses by the strategy. However, there will also be a need for tables that summarises the main indicators for all of the tested strategies.

We propose to present economic efficiency for each strategy by a refined version of table 5.1 in section 5.3, and to present aggregated information on the economic efficiency of all strategies in another table. These tables provide the data for bar charts where necessary.

It has to be remembered that several issues covered in the economic calculus are also part of other impact descriptions (mobility, environment, even land-use). 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.
11.2 Liveable streets and neighbourhoods

Indicators of liveable streets and neighbourhoods are mainly a subgroup of the accidents indicator, namely accidents involving pedestrians and cyclists. Consequently the same presentation methods as for the accident indicators (see 11.5) 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.

11.3 Protection of the environment

As stated in previous chapters 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 \( \text{NO}_X \)) and some global (like \( \text{CO}_2 \) and \( \text{N}_2\text{O} \)). Also, their temporal frames are different, like immediate noise, or cumulative 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.

This variation makes it also impossible to sum up different impacts together – only if a (sometimes debatable) monetary valuation of the external costs is used will it be possible to present the combined impacts. Therefore 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 might want to opt for monetarisation of the impacts after all.

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 the 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 presentations are needed to cover the various aspects, and careful consideration must be used in selecting representative items for different presentation purposes. The meaning is not to flood decision-makers or public under details, but to show the importance and relevance of the impacts. Our proposal is to present the monetised impacts in a table that is a specification of the external costs of the economic efficiency table, and to use these data to produce bar charts. The spatial distribution of noise, local air pollution and land use effects will be presented by maps.

11.4 Equity and social inclusion

Equity and social inclusion indicators address accessibility for different groups such as those without a car or 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.

Security or even better the feeling of security has a substantial impact on choices made by people when they decide where, how and when to go. Objective indicators may be difficult to define, and social and cultural differences make comparisons between areas, cities or countries vague. Police statistics about criminality and disturbance could be presented in a similar way with accidents. The impact of the feeling of security on trip making may be even greater than that of traffic accidents.

11.5 Accidents

For the visual presentation of accidents our first impression 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 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, when appropriate 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 is starting to be accepted in many countries and allows for aggregation of accident of different degrees of severity, presenting accident costs is clearly an alternative to presenting accidents by number.

*Our proposal is to present accident costs as specifications of the external costs of the economic efficiency table, and to supplement this with maps showing relative change when possible.*

11.6 Economic growth

The economic growth indicator proposed in chapter 5 is a global indicator and is derived from economic efficiency indicators. Thus similar methods of presentation can be adopted.

11.7 All

*The level of all major indicators in all tested strategies should be presented in a table.* This can provide the data for comparison of selected strategies through bar charts. Clearly, it could also in principle be used as a basis for ranking strategies in the manner of the European Song Contest (the so-called Borda rule) and other ranking principles. We do not propose to use such rules.
12 Visualisation with reference to transport/land use plans and models

This section will give an overall description of possible presentation methods concentrating especially on visualisation of the output of transport/land use plans and LUTI-models. The section is mainly based on a literature review on the subject and on examples of good as well as bad practices with respect to presentation of overall strategies, scenarios, model results and evaluation results.

12.1 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).

12.1.1 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).

12.1.2 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, and
- 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).

12.1.3 Choropleth maps

Choropleth maps portray geographic patterns for regions composed of areal 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).

12.1.4 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. 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).

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).

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).

### 12.1.5 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).

### 12.1.6 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).

### 12.1.7 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 easy mislead and cheat public. The same applies to the scaling effect of graphs and diagrams as well.
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.
10. Enchant with elegance.
11. When all else fails, try bribery.

12.2 Basics and potential of GIS (Geographic Information System)

12.2.1 Definition of GIS

Although the term GIS can not 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 geographic information system (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 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. Mapping and geographic analysis are not new, but a GIS can perform these tasks better and faster than conventional methods.

GIS's are closely related to several other types of information systems, but it is the ability to manipulate and analyse geographic data 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 (see the task 23 report).

Geographical Information Systems (GIS) 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 provides 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.

12.2.2 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 ZIP 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 needs 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 to combine according to the users needs.
The overlay analysis is the most important and best known in GIS analysis for gaining new information. The 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.

### 12.2.3 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. You 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 in 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 esthetical and artistic requirements of cartography into consideration we often do not regard a GIS map 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 isochromes, 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.

12.2.4 Evolution of GIS in land use and transportation planning

(Hensher and Button 2000)

For many years the interaction of transportation and land use has been well recognised, but the computational power to model the interactions was not well developed. The models used were greatly simplified, as illustrated in Figure 12.1. Land use was forecast and planned, and transportation demand was forecast to serve that plan, without a feedback loop. From this forecast came a plan for transportation facilities to serve the land use. Figure 12.2 illustrates the process with the appropriate feedback loops to provide for land use/transport interaction, or to achieve equilibrium between land use and transportation. Figure 12.3 illustrates the minimal application of GIS to land use and transportation planning. It is used merely to prepare data for input to the land use and transportation models, and to display the results. Figure 12.4 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 be appropriately interfaced to preserve the computational emphasis of modelling and the data-processing emphasis of GIS.
Figure 12.1. Sequential urban transportation planning process

Figure 12.2. Iterative process to achieve equilibrium between land use and transportation

Figure 12.3. GIS used for inputs and outputs
Figure 12.4. 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 achieve consensus on results. Whether improvements in the rational planning model will lead to improved decision-making is another matter.

Dutton and Kraemer (1985) studied the politics of fiscal impact analysis systems. They found that the process of modelling – the “modelling effort” – was more important than the model itself, because the participants reached agreement on assumptions, methods, data, and alternatives in advance, thereby securing commitment to the model outputs, which facilitates negotiation, consensus building, and conflict resolution.

De Neufville (1987) looks at the same example – fiscal impact modelling – to make the point that planning methods need to mesh with the understandings of non-users, by means of strategies and processes, to integrate knowledge of non-technicians, clients, and the public with expert knowledge. This means less emphasis on model outputs and more on designing the analysis.

12.2.5 Examples of the use of GIS in land use and transport planning

Governmental institutions have to deal with very widespread areas of responsibility. Especially regarding public decisions and the production of aid for decision-makers GIS 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 12.5, Figure 12.6)
- Accessibility studies
- Network planning and capacity analysis (Figure 12.7)
- Traffic flow analysis
- Population and work place densities (Figure 12.5, Figure 12.6)
- Route maps (Figure 12.8).
Figure 12.5: Thematic Map on Work Places Classified into Two Groups

Figure 12.6: Work Place Intensity by Focal Method
A stronger integration of GIS and transport planning can be realised by different ways of integration:

- Construction of certain of traffic planning functionality into existing GIS 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 including special topics or data.

The amount 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 hardly is 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 12.9).

12.2.6 The use of GIS in PROSPECTS

None of the models available to us in Work Package 30 will be GIS-based. Thus in the main, the situation will remain the one depicted in Figure 12.3. Some of our environmental and equity indicators, like noise, could benefit from being computed at a detailed level using GIS, but this can probably only be done in a very limited number of cases in the context of Work Package 30. One reason is that frequent interchange of data between GIS and the LUTI models will slow down the optimisation process (see Part IV). On the other hand, the rich output from the model runs and the subsequent computation of the indicators (see Part II) will provide material for innovative forms of GIS presentations, going well beyond the examples shown in Figure 12.2.5-8. It is to this task that our use of GIS in PROSPECTS will be geared. The exact forms of such presentations will have to take account of the conclusions reached in chapter 11, the theory on effective visual communication of results from section 12.1, and the legislative framework and preferences of the cities as outlined in the next chapter.
13 Spatial visualisation in the Core Cities

In section 13.1, we first provide background information about relevant legislation in the Core Cities and their countries. On this background, we go on to present current practices in output presentation in these cities with respect to PROSPECTS’ indicators and presentation of scenarios, model results and evaluation results. Parts of this material were collected through a series of interviews with representatives of the Core Cities in April 2000. The specific questions regarding legislation and current practice were:

- What must cities present, according to the legislation?
- To whom must they present it?
- Are there guidelines on presentation of these indicators? What are the main points within the context of PROSPECTS?

The spatial visualisation and output presentation capabilities of the models available to us in Work Package 30 are reviewed in section 13.2. However, between them, the Core Cities have experience with output presentation from strategic modelling that goes well beyond this. Consequently, in the interviews, we aimed to bring forward the current best practice in the cities. The specific questions regarding output presentation were:

- What method works best and for which target group?
- Should indicators be presented alone or together (e.g. pollution against land use, accidents)?
- What to actually present for each indicator (absolute value, absolute change from present or base scenario, relative value, relative change etc.)?

At the time, the sustainability objectives of the project were somewhat unfamiliar and new in the form they have been presented and consequently the responses from the cities were somewhat insufficient. Thus this part will be complemented and presented in more detail in the specific task report.

Section 13.3 concludes.

13.1 Legislation and current practice

13.1.1 What must cities present?

The UK

This section covers the relevant UK guidance on current practice in the development of local transport plans and strategies. The situation in Scotland is described in most detail, though a brief overview of the situation in England and Wales, which differs slightly from that in Scotland, is also provided.

England and Wales

The Government has recently introduced Local Transport Plans (LTPs) for English local authorities outside London. LTPs describe the local authorities transport strategy for the next 5 years, they are partly a public statement of the strategy and plans and partly a bidding document to central government. The first full LTPs were submitted in July 2000. The process of developing an LTP is described in “Guidance on Full Local Transport Plans” (DETR, 2000a) and “A Good practice guide for the development of Local Transport Plans” (DETR, 2000b). Officially, these documents do not apply to Wales, but the process is, in practice, similar.
Scotland

In Scotland local authorities are encouraged, though not legally required at present, to prepare Local Transport Strategies for submission to the Scottish Executive (Scotland’s devolved government). They are linked to funding, in that bids to the ‘public transport fund’ will place high importance on how they contribute to achievement of the strategy, and provide useful context for the national road traffic reduction targets. The first round of full strategies were submitted in October 2000. Guidance on the preparation of local transport strategies is provided by the Scottish Executive (2000).

Local transport strategies should address diversity, policy linkages and should “be comprehensive in their coverage and describe and explain how integrated transport is to be delivered across the full range of local authority activities” (Scottish Executive Development Department, 2000). They should: specify clear objectives, consistent with Scotland’s integrated transport policy; provide an analysis of relevant problems and opportunities; test the full range of potential solutions; outline a long term strategy for overcoming problems and achieving objectives based on the best combination of potential solutions; set out a costed and realistic implementation programme; and provide a set of performance indicators, targets and other outcomes for use in on-going monitoring.

Strategy objectives should be consistent with the overall UK integrated transport policy and its 5 key objectives of Accessibility, Economy, Environment, Safety and Integration. Furthermore, strategies should comprise a mix of higher level, aspirational objectives and lower level, more specific targets, and a mix of short term – 3 years - and longer term – 10-20 years - objectives.

Analyses of problems and opportunities should include an analysis of the current situation and set of transport and transport-related issues, as well as forecasts of future problems and opportunities. Care should be taken to account for any differences in the types and intensity of problems and opportunities across an authority’s area.

Strategies should set out how their component measures inter-relate and contribute towards addressing objectives, problems and opportunities in an integrated way. The range of potential solutions should be tested (though it may not be possible to work up all solutions in the same level of detail). The priorities amongst the different elements of the strategy should be indicated and, where there are subsidiary components of the strategy, their linkages with the overall strategy should be demonstrated.

Effective appraisal will be key in delivering a strategy which is achievable, which provides value for money and which represents the most effective way of addressing identified objectives, problems and opportunities. The appraisal framework to be used should be based on the ‘New Approach to Appraisal’, adapted to incorporate multi-modal impacts wherever appropriate (DETR 2000c). The new approach takes account of 5 criteria: environmental impact – protecting the built and natural environment; safety – to improve safety for motorists, bus passengers, cyclists and pedestrians; economy – supporting sustainable economic activity in appropriate locations and getting good value for money; accessibility – improving access to every-day facilities for those without a car and reducing community severance; and integration – ensuring that all decisions are taken in the context of the Executive’s integrated transport policy. The strategy should include all proposed expenditure (capital and revenue) on transport and should identify significant items separately.

The precise package of performance indicators, targets and planned outcomes specified in strategies is a decision for each local authority based on their local circumstances. However, targets should be unambiguous and, wherever possible, quantitative. In particular, quantitative
targets should be set so as to show local contribution to the achievement of national targets, eg for air quality, CO2, road casualty reductions, increased cycle use and road traffic reduction. Local authorities should put in place arrangements for monitoring performance against the specified targets and it is expected that they will prepare annual monitoring reports to assess performance.

Oslo/Norway
Cities are required to keep updated strategic land use and economic plans. At the project level, integrated impact analyses are required for projects that will have significant influence on environment, natural resources and society. A description of the project and relevant alternatives are required, as well as of impacts on environment, natural resources and society and possible measures to compensate for adverse impacts.

The relevant legislation is the Planning and Building Act and the Municipality Act. Within this framework the municipalities are free to choose the design they find appropriate with respect to their planning/strategic documents.

The project impact analysis includes cost-benefit analyses and analyses of non-monetised consequences. Signals from the national government imply that CBA is of increasing importance.

CBA in the transport sector is based on transport modelling or simpler traffic analysis and includes changes in benefits to travellers, benefits to operators (costs and revenues), changes in environmental costs and accident costs, as well as investments and changes in operation and maintenance of the infrastructure. It also includes changes in revenues from taxes, and a shadow price which reflects the costs of the need for public financing (i.e., efficiency loss and administration costs due to taxes).

Analyses of non-monetised impacts include the non-monetised environmental impacts and mobility impacts, and impacts on the local area such as physical barriers or esthetical deterioration. If the method in the National Public Road Administration’s Handbook is used, the non-monetised impacts have two dimensions: Their extent and their value. These dimensions are combined and the impact is assigned a value from the following scale:

- **very large positive consequence**
- **large positive consequence**
- **medium positive consequence**
- **small positive consequence**
- **insignificant consequence**
- **small negative consequence**
- **medium negative consequence**
- **large negative consequence**
- **very large negative consequence**

Regarding current practice and PROSPECTS indicators the consistency is in general good. In CBA calculations and analyses of non-monetised impacts one will find most of the PROSPECTS indicators. However, PROSPECTS cover social inclusion and equity better than current practice usually does.
Stockholm/Sweden

Regarding the Stockholm region it has to be remembered that the strategic level of planning we are discussing in PROSPECTS considers all 26 municipalities in Stockholm County. Most legislative requirements are on the municipality level and their detailed plans.

The county plans are more in line with PROSPECTS’ objectives, as they are focused on a more strategic level, handling issues like

- national roads;
- other roads;
- county railroads;
- regional public transport;
- accessibility to public transport for mobility impaired;
- policy instruments regarding environment and traffic safety on roads and railroads;
- municipality airports; and
- ports.

There are some requirements from the national government:

- The planning objects should be ranked with respect to their economic efficiency. The overall evaluation of efficiency should, however, include qualitative aspects as well.
- Plans should reflect how well targets are met regarding carrying capacity for national roads, and noise levels for roads as well as railroads. The noise target is that areas with over 65dB daytime road noise, or 55 dB night time noise from rail, are to be remedied by 2003. The carrying capacity of national roads should comply with the highest classification, BK1 (a Swedish classification).
- Each plan should include a regional program for environmental policies with instruments to take care of water run-off and protect areas vital for the fresh water supply.
- Possibilities of shared financing with other organisations should be investigated in each case.

The first two requirements are directly related to our PROSPECTS indicators, while the other two are of a more qualitative nature.

The Swedish Institute for Transport and Communications Analysis, SIKA, has evaluated the current planning process and some suggestions for the future are made (SIKA 1999:1). For PROSPECTS the interesting parts are how assumptions, policy packages and their impacts are presented.

The county plans are intended as a tool for following up national objectives in the transport sector as well as being the main information to the public, media and politicians at other administrative levels, e.g. municipalities. SIKA reports that there are shortcomings in the current plans with respect to the latter. As an example only the chosen alternatives and their priorities were presented. It would of course be more informational if other alternatives were presented together with the reasons why they were not chosen.
Helsinki/Finland

In Finland both the Land Use and Building Act and the Environmental Impact Statement Act give some instructions regarding the master plans:

- The Land Use and Building Act states that the land use plans must be presented on a map with an appropriate scale. For the map symbols there are detailed regulations. It also states that master plans must be public and a public hearing about the plan must be arranged.

- The Environmental Impact Statement Act states that in the EIA programme, the following information must be presented:
  - information about the project, about its realisation alternatives and about plans and permissions required;
  - a proposal for the definition of the affected area; and
  - a plan for the arrangement of (public) participation and a plan for the project schedule.

According to the environmental impact statement in the (final) report of the plan or project the following information must be presented:

- thorough information about the project;
- a statement of the relations of the project to the land use plans and environmental protection plans;
- detailed technical information of the project;
- information about the environmental impacts and suggestions for how to prevent adverse effects; and
- a proposal for the monitoring programme.

In Helsinki Metropolitan Area the Helsinki Metropolitan Area Council (YTV) has since its foundation in 1970 enhanced regional co-operation. The objective is to regionally co-ordinate land use on the master plan level and to promote various policy measures to secure balanced development in the region. For this purpose YTV has prepared the so-called co-operation plans (YTO) approximately at five-year intervals. The most recent work, Helsinki Metropolitan Area Vision 2020 (PKS 2020), is a continuation of this work, though putting more emphasis on the application of future studies, participatory planning and co-operation with transportation planning. The final report presents four scenarios, a vision for the future based on the scenarios, as well as estimates of population and job growth and of required housing and work place construction. The programming and initial study phases of the new planning round (PKS 2025) is in progress.

The first specific transport plan for the Helsinki region was approved in 1994 and was called the Helsinki Metropolitan Area Transport System 2020 (PLJ 1994). According to the decision made then by the Council, the plan was to be reviewed at four-year intervals. The first review was carried out in 1998 (PLJ 1998). The aim of the review was to re-examine the planned transport system, firstly to ensure that it corresponds to the prevailing situation, secondly to assure the progress towards the objectives set out for public transport and the environment, and thirdly to ensure that it reflects a consensus between the various parties involved regarding priorities of the planned projects. Among others, the effect of the transport system on air quality, the interaction between the transport system and land use, the capital city’s external connections, as well as the economic and other effects of the largest transport projects were studied in the review. In the beginning of the project, an overall strategic environmental impact assessment was made.
In addition each city in the MA prepares their own plans and makes them public for their decision makers, residents and other interested groups as well for their own authorities for more detailed development work.

**Madrid/Spain**

In Spain the current legislation is the Refunded Text of the Land and Arrangement Urban Act (1992), which states the setting up of different Plans: National Arrangement Plan (at national level), General Plan of Urban Arrangement (at municipality level), Partial Arrangement Plan, etc.

Madrid, as a municipality, has a General Plan of Urban Arrangement (P.G.O.U. – 1997) and it must contain: major and complementary studies, urban land arrangement plans, urban principles, action program and financial as well as economic studies.

According to the Environmental Impact Statement Act (2000, last modification of 1986 Act), some information must be presented:

- technical information of the project;
- definition of the affected area by the project;
- environmental impacts produced by the project;
- definition of measures to minimise, or remove, negative impacts; and
- proposal for the monitoring programme.

The main environmental aspects to be mapped in a project’s Environmental Impact Assessment are the following: air, water and soil quality, noise levels, landscape, Flora and Fauna.

**Vienna/Austria**

In Vienna there are no direct legislation concerning long time planning but more for separate projects. However, the Environmental Information Act (Umweltinformationsgesetz), Environmental Impact Assessment Act (Umweltverträglichkeitsprüfungsgesetz) and Building regulations Vienna (Bauordnung) give some instructions which can be applied to plans as well:

- The Environmental Information Act states that environmental data (§2/2 especially mentions emissions) on an aggregated level; for disaggregated data secrecy interests have to be considered and weighted against public interests.

- The Annex 1 of the Environmental Impact Assessment Act defines a list of project types for which an environmental impact assessment has to be made. E.g.: Road and rail infrastructure projects. If an application for an environmental impact assessment is made, the developer has to produce an "Environmental Impact Statement" (Umweltverträglichkeits-erklärung §6). This has to include a description of the project, alternatives taken into account, reasons for choosing the specific alternative, environmental impacts and mitigation measures.

- For other projects the Viennese building regulations are relevant. If the rights of neighbourhood are affected by building projects (§134a), a hearing has to be made (§70).
13.1.2 Target groups for presentation

UK
The LTP and LTS documents which are part of the local transport planning process in England and Scotland respectively, are bid documents to the relevant National Departments which allocate local transport funding (the Department of Transport, Local Government and the Regions in the case of England and the Scottish Executive in the case of Scotland). In this respect the target groups include these Government Departments. These documents are also public plans and therefore “the public” in the widest sense are also a target group. In practice, local authorities will follow the Guidance given by DETR (2000b) and by the Scottish Executive (2000) and consult with a wide range of groups and organisations as well as the general public if this can be done cost effectively. Particular groups mentioned in the guidance are:

- transport operators and providers eg bus operators, Railtrack, train operating companies, freight companies, the Highways Agency, airport and port owners
- local community and interest groups eg disability groups, user groups such as local pedestrian and cycling groups etc.
- local business
- the general public

Major local transport schemes, that is those costing more than £5 million have to be identified separately in the Local Transport Plan. These schemes, together with major trunk road schemes and other large scale transport infrastructure have to go through a process of public consultation which involves a public inquiry at which affected members of the public or statutory bodies can make objections to the scheme.

Oslo/Norway
A plan must be presented to affected individuals or groups, authorities, organisations and to the public in general, and of course to the decision-makers. A strategic city plan should be a plan for the municipality as an organisation and for the municipality as a society.

According to the Planning and Building Act, planning authorities must inform the public from an early stage in the process. Affected individuals and groups must have the opportunity to be involved in the planning process.

The integrated impact analysis is sent to affected authorities and organisations for comments. At the same time it is made available for the public in the municipality/-ies and there is a public meeting. A meeting is not required in all cases.

The responsible authority should see to that the requirements for the impact analysis are full-filled.

Stockholm/Sweden
The county plans are intended to be the main information to the public, media and politicians.

The Stockholm City municipality uses GIS to produce a variety of information for different purposes, some available over the Internet, with e.g. geological information or planned housing projects. Maps with different geocoded information can be ordered.
PROSPECTS

Helsinki/Finland

A preliminary land use plan must be made public and a public presentation must be called. Residents and other interested parties have the right to complain about the plan. In some cases a comment and/or approval must be sought from special authorities concerned e.g. the Regional Environment Centre.

The EIA programme and the EIA report must be presented publicly. The interested parties (especially the municipalities involved) have the right to complain about the programme and the report.

The plans must, of course, be presented and approved by the decision makers concerned.

Madrid/Spain

All the parties involved are entitled to review a plan: authorities, decision-makers, planners and to the public in general. The parties involved may vary according to the type of project. Affected individuals and groups must have the right to complain about the plan.

Land use and urban development projects must be approved by local authorities, but they can be elaborated by any private company. Regional Governments co-ordinate different urban plans afterwards.

Vienna/Austria

In Austria normally everyone has free access to the public documents.

Regarding the Environmental Impact Statement the administrative body has to submit the application to the local authority (§9). Both have to allow the public to look at the document for a minimum of six weeks. The local municipality has to announce the planned project and the date and place of the hearing. According to §9/4 everybody has the right to examine and comment the Environmental Impact Statement. Civic action groups have the right to act as involved parties (§19).

13.1.3 Guidelines for presentation

UK

England and Wales

Presentation of the Local Transport Plan or Local Transport Strategy is covered in "Guidance on Full Local Transport Plans" (DETR, 2000a) and "A Good Practice Guide for the Development of Local Transport Plans" (DETR, 2000b). Officially, these documents do not apply to Wales, but the process is, in practice, similar. The guidance document includes a section on public participation. It suggests that a high priority should be attached to effective public involvement in local transport policy. Without being prescriptive, it suggests:

− a wide range of local stakeholders should be involved;
− the aims and limits of public involvement should be made clear;
− early involvement should be sought;
− interaction and two way dialogue are important;
− effective feedback to participants should be given; and
− maintaining participation is also important;

but leaves the actual mechanisms to be employed up to the local authority.

The good practice guide is more specific and suggests that while traditional methods of public participation can be used (public meetings, exhibitions and leaflets or brochures) more interactive techniques should also be deployed such as discussion groups and workshops. The guide also recommends that use is made of surveys based on representative sampling to make sure that the attitudes and opinions of the wider public are accurately assessed. Other methods that are mentioned include:

− exhibitions and web sites;
− leaflets and mail shots;
− sample surveys and panels;
− targeted interviews;
− focus groups;
− public meetings; and
− workshops.

The guidance also includes a number of examples of good practice.

Scotland

In its Guidance on Local Transport Strategies and Road Traffic Reduction Reports, the Scottish Executive stresses to Scottish local authorities that “the Executive attaches a high priority to effective public involvement in local transport policy and this should be a key factor in the preparation of strategies” (Scottish Executive Development Department, 2000). It is stated that “local authorities will need to actively involve all those who have an interest in the development and implementation of their strategy” (Scottish Executive Development Department, 2000). Whilst the guidance leaves the decision of what methods of public involvement should be used to the local authority involved, it stresses that the aims of the public involvement should be made clear from the outset so as to avoid any confusion.

The guidance sets down 5 criteria for effective public involvement which the Scottish Executive will be looking for from local authorities. Their criteria state that local authority public involvement should:

− promote early involvement;
− be inter-active;
− be inclusive;
− be continuous; and
− be open.

Whilst this is provided as guidance, Local Transport Strategies are bid documents and the means by which most Scottish local authorities secure most of their funding for transport. Therefore, authorities are obliged to follow this guidance quite closely so as to secure satisfactory transport funding.

The relevant details are in paragraphs 2.12-2.18 of Scottish Executive Development Department (2000).
Oslo/Norway
The Ministry of Environment, which is the ministry in charge of municipality plans, has published guidelines on how to work with the various topics of integrated impact analysis. These include presentation with respect to each topic (such as population development, housing development, employment, pollution, landscape, cultural environment, social effects, health effects etc.). The guidelines suggest when to use maps, tables, diagrams, verbal presentations, photography etc.

Maps seem important for presentation of indicators relating to the environment and natural resources. Tables and diagrams are suggested for indicators regarding society. GIS is mentioned for some of the topics regarding society: Development pattern and transport system; social impacts and quality of life; health effects; and recreational areas. Verbal descriptions should be included in all presentations.

Stockholm/Sweden
Although the Swedish government has some requirements for the plans it has no special requirements on how these are presented, so there is a large variation between counties.

The guidelines SIKA formulates in the report (SIKA 1999:1) can be seen as examples of what the government might require in future planning documents.

- The cost of large investments should be specified as costs per year for the whole period. If the costs are clearly specified it is more likely that government can find use of the planning documents when they allocate money, and give the regional planning influence over that process.

- Present value ratios should be presented for all objects. The government requires economic efficiency assessment. SIKA suggests formalising this point for better comparability.

- The ‘runners-up’ should also be presented. SIKA finds that there is need a need for motivation if the most economically efficient projects are rejected in favour of less efficient ones. If projects not chosen are presented as well the whole choice process becomes more transparent.

SIKA also suggests that impacts on e.g. the environment and traffic safety should be presented in map form, to pinpoint the problem locations.

Since there are no requirements on the shape and form of the plan document the Regional Development Plan for the County of Stockholm may serve as an example:

- Last year, the Office of Regional Planning and Urban Transportation has presented basic material used for consultations with the County Council, the 26 municipalities in the county and the public. These documents were made available over the Internet and they are still available though the official consultation period is over.

- Impacts of the plans on the transport sector have been studied with a transport model called T/RIM, and results are presented in a variety of ways. Maps are used to show the intended investments in each scenario, and spatially dependent results, such as accessibility.

- Charts are used for presenting impacts and for comparison between different scenarios as well as for sensitivity analysis.
Helsinki/Finland

There are no official guidelines for or a guidebook on presentation, only common practice each authority has adopted. The authorities have fairly well developed their output presentation according to new tools and methods available, such as GIS and the Internet.

The county Uusimaa makes the county master plan. Since 1996 they have used MEPLAN LUTI-model for the work and evaluation. This has somewhat changed the presentation of the results as well because of the capabilities of the computer software used (e.g. MapInfo).

Madrid/Spain

There are no guidelines to follow for the presentation of the indicators. At present, there are only a few municipal departments using the advantages of GIS: forestry and agriculture departments, but for urban and transport planning this tool has not yet been used.

In Madrid, the Public Transport Authority, CRTM (Consortio Regional de Transportes de Madrid), works with the vector based MapInfo GIS system. This GIS is connected to the EMME/2 program for public transport network.

The Environmental Authority uses the ArcGIS program suite namely ArcInfo and ArcView.

The presentation of the indicators depends on their nature, for instance, some indicators should be presented by charts to show the evolution by the time (population, investments, traffic flow, etc.), but spatial indicators should be presented with GIS (land uses, geographical information, pollution levels, etc.)

The new plans should be presented on a map or using GIS. If this is the case, it’s possible to see more clearly the different changes within a period, or the new actions planned.

Vienna/Austria

There are no guidelines what and how projects or plans should be presented. §9 of the Environmental Information Act says that the administration can publish environmental data in suitable form.

However, the Vienna Municipality has been one of the first municipalities in Europe to see the need for the use of GIS in the planning and administration of a city. In the 1970s it started to collect data for the multiple-use town map, MZK (Mehrzweckkarte) and the spatial reference system Vienna, RBW (Räumliches Bezugsstystem Wien).

The MZK is a detailed vector data set including all fire buildings, pavements, hydrants etc. It has been derived from interpretation of aerial images and terrestrial surveying. The RBW is a true GIS vector data set. Areas (blocks) mainly defined by surrounding streets are stored in a strict hierarchical model. Each block is categorised according to various attributes, the most important one being the block’s actual use. The RBW also shows all streets as lines, including their names and official codes. Both data sets are revised every three years. Today these two data sets form the basis of all other GIS tools and analyses.

At present various municipal departments make use of the capabilities and advantages of GIS. Some have developed their own applications, others have relied on consulting companies. However, the principal provider of most of the GIS solutions, has been the municipal GIS
competence centre. Yet, the generation of high-quality, accurate and up-to-date maps is only one important use of GIS, there are other solutions as well.

The Traffic-Planning and Traffic-Organisation Department uses GIS in many different ways, such as to provide information on one-way streets, pedestrian zones, highways, bicycle paths, traffic censuses, etc. For such information, the RBW and demographic data are combined. GIS tools are used to optimise changes in traffic organisation, new bicycle paths and the like. Furthermore, they have introduced a system for intersection design as well as for traffic and traffic light simulation etc.

GIS is also used as an important tool in the Town Planning and Land Use Department. In 1996 the Vienna Municipality for the first time provided GIS tools in the Internet. As the first service, a digital town map was established and provided a facility to locate a person’s address. Then, systems were introduced to find the best route between two points, be it by bicycle, public transport or foot, or to identify the nearest open pharmacy and the way to get there. All of these services were combined with a digital high-quality map and included the option to zoom in or out.

Today various other interactive applications with up-to-date technology are accessible to the public. Among others you can have a look at the following:

- the development plan of the area you want to buy an apartment in,
- information about buildings including characteristics like age, use, number of floors etc, their history and possible photos,
- road works taking more than one week: What construction is to be done? How long does it last? How will the traffic be diverted?

The Vienna Municipality also uses intranet services for applications processing information for the needs of various departments but this is not public.

13.2 Spatial visualisation of LUTI-models

The aim of this section is to review the spatial visualisation methods and output presentation presently used in the LUTI-models available for the project.

13.2.1 TRAM/DELTA

The output of model suite TRAM/DELTA used in Edinburgh is in the process of being developed to a perfectly visual format. GIS-suite MapInfo is used for all geographic visualisation, such as zone boundaries for thematic maps, all network statistics (flows, speeds, link-based emissions etc), isochrones, accessibility etc; and Excel for basic reporting (graphs, tables etc). Linkage from DELTA via Excel to MapInfo is simple enough for regular use of it to examine interim results, not just for major presentations.

Different outputs are needed for different people involved the decision maker’s needs in the other end and the modeller’s needs for checking the results of the optimisation process in the other).

In general, absolute values are rarely as interesting as changes (or percentage changes) between scenarios— emissions (especially CO2), accidents, speeds or journey times, accessibility, traveller benefits, financial viability of public transport schemes and a pretty graphical view rather than a table of numbers.
The use of MapInfo and Excel now gives a lot of power to produce good-looking graphical presentations of outputs relatively easily – the effort goes more into identifying which sequence of graphics best tells the story of why these inputs produce those outputs.

13.2.2 IMREL

Both in Stockholm and Oslo the city’s own transport model has been combined with IMREL (the Integrated Model of Residential and Employment Location in metropolitan region) into an integrated transportation land use model (SAMPERS/IMREL, RETRO/ IMREL).

The program itself produces exportable and exchangeable data files that are compatible with the main transport program and EMME/2 used together with the former as well as GIS suites, Excel etc.

13.2.3 EMME/2

EMME/2 is an interactive-graphic multimodal urban transportation planning system. It offers the planner a complete and comprehensive set of tools for demand modelling, multimodal network modelling and analysis, and for the implementation of evaluation procedures.

However, in spite of the capabilities of its own, it is often used together with a discrete program suit, as is the case in Stockholm, Oslo, Helsinki and Madrid.

The visualisation of the results is fairly good being a widely used transportation suite but cannot be compared with GIS. There are, however good possibilities for data exchange:

- Data and results can easily be exchanged between EMME/2 and many software packages (spreadsheets, databases, traffic signal setting programs, GIS, etc.), through the use of ASCII files.

- INRO, the developer of EMME/2 offers special utilities, which enable data exchange with ArcInfo GIS data bases. An example is a Data Exchange Protocol between EMME/2 and ArcInfo. An EMME/2 coverage is built in ArcInfo and is based on a one-to-one relationship with the EMME/2 network data. This relationship permits the development of an automatic process that performs the information exchange between the two software packages.

13.2.4 PLUTO

PLUTO is a policy explorer software for Planning Land Use and Transport Options. At the moment the output reporting is extensive, but presented only by tables. For an accustomed user this is satisfactory mainly because of the idealised/symmetrical form of the city represented in PLUTO that makes it simple to interpret the results. For a new or occasional user it would be helpful if some of the output could be represented via maps or graphs. The use of GIS does not give any advantages due to the hypothetical and non-dimensional structure of a city.

13.3 Conclusions and implications for WP30

According to the survey of current legislation concerning presentation of plans and current practice in the core cities it is statutory to prepare strategic land-use/transportation plans, assess their impacts and present them to decision-makers and the public. However, in most
cases they lack normative guidance for the presentation and thus each city follows their own practice. In PROSPECTS we particularly aim to present our objectives and chosen indicators as well as the model performance in the optimisation process. In WP30 the guidelines given in this report will be tested in practice and the good examples of presenting indicators should be highlighted in Task 34.

It is very important to recognise which target group the presentation is aimed at; decision-makers, public or professionals. For a layman the presentation should be kept sufficiently simple but still informative, which makes the task very challenging because of the complexity and extent of the subject. There are many important decisions to be made when designing a presentation:

- what method works best, for which indicator and for which target group; map, thematic map, chart, table, single figure, in writing; or should two or even more methods be used;
- levels of disaggregation or aggregation;
- should indicators be presented alone or grouped, e.g. pollution against land use, accidents against traffic volumes;
- what value is best for each of the indicators: absolute value, absolute change from present or base scenario, relative value, relative change etc.

In the case of land-use/transportation plans it is obvious that visual map presentations preferably using state-of-the-art GIS techniques should be used where adequate, but, on the other hand with nice maps you can easily mislead and cheat the public – and even professionals.
Part IV

Optimisation Methodology

14 Background and objective of part IV

PROSPECTS Deliverable 1 summarised the issues covered in WP10 including indicators and objectives, scenarios, policy instruments, decision making requirements, and barriers to implementation. Task 21 provided a fuller definition of objectives and indicators set in a framework for evaluation based on the principles of sustainability.

The objective of Task 22 in PROSPECTS was to

- review and produce optimisation methods capable of addressing the indicators from Task 11
- specify applications of these methods suitable for use in WP30.

This part of the report discusses the approach required for formal optimisation within PROSPECTS. Formal optimisation is a relatively new concept in the analysis of integrated transport strategies. A number of papers, including Fowkes et al (1998), May et al (2000) and Timms et al (forthcoming), have described a method for finding optimal urban transport policies. At the heart of this policy optimisation process lies the definition of objective functions which encapsulated policy-maker objectives. By use of a suitable transport model, sets of transport policies are found that maximise the value of these objective functions. Within PROSPECTS the formal optimisation procedures will play a part in the overall evaluation framework but will not always be applicable to every decision made about transport and land use policy.

Optimisation requires a quantifiable objective function to be maximised (or minimised). The overall evaluation framework deals with both quantitative and qualitative indicators which feed some form of CBA or MCA. The formal optimisation process will be employed with a fully quantified objective function. The value of the objective function will be derived by running a land-use transport interaction model with different sets of instruments and their associated levels.

The instruments identified in Deliverable 1 covered 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 level which may be varied e.g. a price which can be optimised.

All other instruments are considered as local and relatively inexpensive. The local instruments are to be evaluated within the overall framework against the same set of indicators and this is covered under Task 21 (Part II of this report). 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.

Included in the evaluation framework is the concept of scenario analysis. Various scenarios will be developed for each city within the PROSPECTS case studies. The optimisation process will be used within a given scenario. Robustness of the optimal solution will be
tested against other scenarios via sensitivity tests.

Barriers to implementation of certain instruments were identified in Work Package 10. Barriers can be dealt with in two ways, first the barrier can act as constraint on which instruments may be considered or which levels of a particular instrument may be considered; second the instrument can be considered within the optimisation process and the benefit of removing the barrier to implementation can be presented to the decision maker.

Having set the scene for the use of optimisation within PROSPECTS, this part of the report develops generally applicable optimisation approaches which will be adopted in WP30 for use with either the sketch planning model, LUTI models, and EMME/2. Chapter 15 looks at the general problem from a theoretical viewpoint and considers the practicalities of the time dimension required for the evaluation period. Chapter 16 considers optimisation approaches and constraints, while Chapter 17 considers the treatment of scenarios versus strategies. Chapter 18 considers the practical constraints imposed by the PROSPECTS models. Chapter 19 concludes and raises issues which require further work within PROSPECTS.
15 The general optimisation 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 evaluation period is taken to be 30 years though the sustainability issues relate to an even longer term. Task 21 has defined the overall objective in terms of sustainability and its six sub-objectives:

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

The first sub-objective is dealt with by standard cost-benefit analysis. For the other 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. 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 30 years. 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. It is not assumed that the indicators that goes into the constraints cannot be used in the objective function, neither is it assumed 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 evaluate all strategies against the same objective function, we do require the objective function to be the same throughout a particular study. Thus the general form of the optimisation problem can be written as follows:

\[
\begin{align*}
\max_{x_t} & \quad \sum_{i=0}^{30} \alpha_t (b_t(X_t) - c_t(X_t) - I_t(X_t)) + \sum_{i \in M} \sum_{t=0}^{30} \mu_i y_{it} \\
\text{subject to} & \quad \sum_{i=0}^{30} \omega_i y_{it} \leq C_i \
& \quad y_{it} \leq C_{it}.
\end{align*}
\]

OF is the overall objective function and 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 $t$

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 inter-generational 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, \( \alpha \) 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)
- \( X_t \) is the vector of levels of policy instruments which can be used to maximise the objective function \( OF \).

The formula (15.1) is identical to the formula given for the objective function in chapter 6, except that for generality, the CO\(_2\) costs have now been included in the other \( \mu_{it}y_{it} \) terms.

Note that the constraints and weights for the indicators are taken as inputs from the evaluation 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 (as 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 the year 2010 and that targets for years 2020 and 2030 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.

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\(^{14}\) Although the general form allows for targets in any year \( t \) it is expected that targets will only be set for one possibly two years depending on the model type. (Similarly shadow prices or weights may be independent of time).
These are discussed further in Chapter 16.

It is assumed that the policy instruments can in the most general case be applied at any level in any one year \((t = 0, ..., 30)\). 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 next sections discuss the general problem and simplify the approach where appropriate. The sections are written to be of general use with Chapter 18 picking up some specific problems/approaches related to the use of PROSPECTS packages.

### 15.1 Types of policy instrument

The vector \(X_t\) 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, 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 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 $X_t$ 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 a regression approach.

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 variability of all the instruments over the evaluation period.

For the present study, policy instrument levels will be 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 will be seen the assumptions regarding choice of implementation year and long run year plays a crucial role in developing the modelling approach.

### 15.2 The time dimension

Economic theory suggests that 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 seems 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 for a package of measures some measures will be implemented immediately having immediate effect, others will be implemented but have lagged effects while 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. We have identified two generic model types :-
• Time-marching 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 to ensure consistency.

### 15.3 Time-marching models

The time-marching models include the sketch-planning model (SPM), Policy Explorer PLUTO and DELTA-START (within PROSPECTS). 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 and any specifics regarding the SPM and DELTA/START are left to Chapter 18.

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 (15.1), 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 $X_A$ and levels on instruments in the long-term year are denoted $X_L$. The levels on instruments in intermediate years can be determined by interpolating between the instrument levels in year $t_A$ and $t_L$ while the level is then assumed constant for any year after the long run year as depicted in figure 15.1.

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 evaluation 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 15.1: Instrument profile for the continuous instruments $X_i(t)$.

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 evaluated (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 path feasible defined by only two parameters. If a non-linear path were to be assumed then 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 $t_A +$ 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 which would simplify the optimisation process. This would be advisable where the discrete option had an associated level or price such as the charge for a given toll location as it is expected the optimum price would also vary with 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 (15.1).

15.4 Equilibrium based models

For the time marching model the policy profile determines the instrument levels for every (or every modelled) year, and the model is run for these instrument values. The level on instrument values in years that are previous to a specified year affects the model in all subsequent years. Contrary to this, equilibrium models are not affected by instrument values in previous years. Consequently, different policy profiles may give the same results. This ambiguity emerges if the policy profiles intersect at the time points for which the model is run. Both the solid and the dashed instrument level profiles in figure 15.3 give the same result if they are used in an equilibrium model run at time points \( t_A, t_B, t_S, t_L \) or \( t_H \) (where the profiles intersect at the same level).

When we consider more than one instrument the above choices of modelled years will have to be made such that one time lag satisfies all instruments. Hence we will have to assume common implementation years for all instruments and there will be only one modelled year \( t_S \) and one modelled year \( t_H \) for assessing the effects relative to the base case as the effects in year \( t_S \) cannot be disaggregated by instrument type. When we make assumptions about benefit profiles, we must distinguish between the assumption that the level on the instruments have stayed at these levels since the previous years \( t_A \) and \( t_L \), respectively, or alternatively that instrument values between \( t_A \) and \( t_L \) are gradually changed as represented by linear interpolation between the instrument values in \( t_A \) an \( t_L \). In order not to violate any of the equilibrium assumptions, which would make the model results useless, we would have to make sure the time-lags \( t_S - t_A \) and \( t_H - t_L \) are long enough to take into account the relevant responses or that the slope of the continuous profile is not too steep.

What constitutes ‘long enough’ and ‘not too steep’ is a matter of judgement and can of course vary between instruments, and also between modelled effects. As prices change, it takes time...
before travel demand is again in equilibrium and much more time before household and workplace location are once again in equilibrium. We cannot say how long it will take before the new equilibrium is reached. The time horizon depends on how narrow we set the intervals that are bounded by the upper and lower bounds on shares of residential - and employment location and the size of the areas available for different purposes. In real life it seems reasonable that at least 10 years is needed to capture a significant trend i.e. we must have $t_S - t_A \geq 10$ and $t_H - t_L \geq 10$. If only effects on travel behaviour are considered, however, it is reasonable to assume that there is an immediate or quick response, which means that the time lags could be reduced to zero, one or two years.

Hence for a policy profile where $t_S - t_A$ is small and where $t_H - t_L \geq 10$, we have for the short run year, $t_S$, only short-term effects are required and thus only the transport demand model is run. It is reasonable to allow mode and route choices to change for work and school trips and possibly destination choice, trip frequency, and departure time choice. The interpretation of this is that while it is difficult to change place to live or work immediately, you could very well change your behaviour when it comes to recreation or shopping in a fairly short time in response to policy changes. For the long run year, $t_H$ a full transport and land use model that captures travel behaviour, car ownership and land use changes, can be applied.

The level of a given policy instrument is assumed to remain constant after a certain “long” run year $t_L$.

As explained in section 15.3 time-marching models can produce the costs, benefits and indicator values for various points in time with intermediate values being interpolated. Note that for both time-marching and equilibrium models the capital costs associated with an instrument are external to the model runs (as are the operating costs).

The calculation of benefits and indicator values requires certain assumptions to be made when applying equilibrium models. Consider the horizon year to be defined as $t_H = t_L + \text{time lag}$, where the time-lag is judged to be long enough to take into account all long-term effects and the system is assumed to be in equilibrium. Having determined $t_H$ the benefits are estimated by running the complete land use and transport demand model.

An important difference between time marching and equilibrium models is the ability to distinguish between different rates of introduction of an instrument. Where the time marching

![Figure 15.3](image-url): These two instrument profiles will yield the same result from an equilibrium model run at the year $t_A$, $t_S$, $t_L$ and $t_H$. 

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models calculate the net benefits (denoted $b_t - c_t$) at every, or every other year, the equilibrium models will be limited to two points in time. Both the instrument profile and benefit profile can have an infinite number of valid slopes in-between. The benefits arising in other time periods will then have to be estimated via interpolation with certain assumptions being made about net benefit path/profile.

The total costs and benefits for the period will depend upon the assumed benefit profile between the modelled years, and the benefit profile between the two years will depend upon the instrument profile discussed above. For the equilibrium-based models costs and benefits are modelled for two years only, $t_S$ and $t_L$. If we assume that the instrument profile is horizontal in years subsequent to $t_S$ and $t_L$, then for this type of benefit profile, we can assume $B_{t_L} = B_{t_S}$, interpolate linearly between $B_{t_L}$ and $B_{t_H}$ and set $B_{t_S} = B_{t_H}$. This profile is based on the assumption that all effects of introducing measures at $B_{t_A}$ are visible at $B_{t_S}$, and that the benefits of altering measures at $t_L$ are gradually becoming visible until they are fully visible at $t_H$. The drawback is of course that this does not reflect a gradual change in instrument levels. For gradually changing instruments, we could in the simplest case base costs and benefits in the years between $t_A$ and $t_H$ on a line through the net benefits in $t_S$ and $t_H$ that extrapolates backwards to the net benefit in $t_A$. Alternatively, we may assume linear interpolation between $t_A$ and $t_L$ and a horizontal line from $t_H$ to $t_L$ (Figure 15.4).

Capital costs require special treatment, however, as they are connected to whether discrete instruments are active or not.

Large capital costs in year $t_A$ or $t_L$ are not necessarily followed by large capital costs in subsequent years. To deal with this, the linear interpolation is used before capital costs are added as with the time-marching approach. Pre-calculated capital costs are then added individually for the years, which gives coherence between results from equilibrium based models and time marching models.

For gradual introduction of instruments, then, the objective function would then be the weighted area below the benefit profile between $t_A$ and $t_H$ and can be calculated as follows: -

\[
OF = \frac{1}{2} \cdot B_{t_A} \cdot \sum_{i=t_A}^{t_H} \alpha \cdot \frac{1}{(1+r)^i} + \frac{1}{2} \cdot (B_{t_H} - B_{t_A}) \cdot \sum_{i=t_A+1}^{t_H} \alpha \cdot \frac{1}{(1+r)^i} + B_{t_H} \cdot \frac{1}{(1+r)^H} + B_{t_H} (1 - \alpha)
\]

subject to constraints $C$, where

\[
\begin{align*}
B_{t_S} &= b_{t_S} - c_{t_S}, & \text{is the net benefit in year } t_S. \\
B_{t_L} &= b_{t_L} - c_{t_L}, & \text{is the net benefit in year } t_L. \\
B_{t_H} &= b_{t_H} - c_{t_H}, & \text{is the net benefit in year } t_H.
\end{align*}
\]

Note the value of $B_{t_L}$ depends upon the interpolation assumptions between modelled years as discussed above.
It is desirable, however, to refine the assessment of costs and benefits further by adding more model runs in between. The more points the better from an evaluation point of view. From a modelling point of view this is not the case. For each extra point one extra model run is required for evaluation of the objective function.

In the short run there could also show up some short term effects of land use measures, but that would depend on the actual implementation of each instrument. (For example property taxes would cause (dis)benefits in the short term and people may move in the long term).

Figure 2.4: Suggested benefit profile for equilibrium based models. Linear interpolation (dashed line) between the cost benefit calculations in \( t_S \) and \( t_L \) (except capital costs) can be extended backwards to \( t_A \). Capital costs are subsequently added to give the total costs (solid line).
16 Optimisation approaches

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 most important the objective function must be considered non-linear and black-box in nature.

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

Of the above it is thought that many cases will involve continuous variables only, very 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 then 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.

This chapter gives an overview of various optimisation approaches. A non-linear optimisation algorithm is needed in order to obtain a solution to the maximisation problem :-

$$\max_{x \in R^n} OF(x)$$

Non-linear optimisation algorithms are based on differing principles. An important difference is that some algorithms require the derivative, $d(OF)/dx$, 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.

16.1 Dealing with Constraints

There are two types of constraint which affect the optimisation approach. The first relate to the ranges of the policy instruments and are decided prior to the simulations, the second are related to either the MCA evaluation or targets in general which should reflect the objectives of the decision-makers.

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 or as rates of change in certain indicators towards the end of the evaluation period. We are not concerned within the optimisation process how the indicators are derived (though some may require further model runs which increases computing time). The constraints are taken as given and the indicators 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 the general type of constraint and how to deal with it in terms of constrained optimisation.

16.1.1 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
- Implementing constraints as penalties within the objective function
- Re-parameterisation of the input variables

The first approach was used in the OPTIMA/FATIMA regression approach where each model run was run manually between regression forecasts. Methodological approaches for implementing constraints within the objective function include unconstrained optimisation with penalties and constrained optimisation. Unconstrained optimisation with penalties was used in the SAMI project in conjunction with the AMOEBA optimisation process (see section 16.1.2). Basically a large penalty was incurred if the prediction was out of the allowed range for any instrument. Another method is that of re-parameterisation of the input variables. This method adopted by Vold in conjunction with the AMOEBA routine (Vold, Minken and Fridstrøm, 1999) uses a logarithmic transformation of the input variables which allows the problem to be recast as an unconstrained optimisation (detailed in Appendix A of the Task 22 report).

16.1.2 Dealing with Targets for indicators/MCA approach

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 :-**

Penalty\(^{15} = -\beta(I-I^*)\)

---

\(^{15}\) 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.
where $\beta$ is a positive input coefficient (and could be the shadow price) and the penalty is positive if the output value of the indicator $I$ is less than the target value $I^*$ and negative otherwise. The coefficient $\beta$, could be set at the best available estimate of the shadow price of $I$.

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 $I$ which is not equal to the target value $I^*$. Such a penalty was used to represent the profit requirements of the private sector in FATIMA (required profit was assumed to be 15%). It is more likely that the penalty relates to a threshold value and the hard penalty could be used as follows:

\[
\text{Penalty} = \begin{cases} 
\text{Large Number} & \text{If } I < I^* \\
= 0 & \text{If } I \geq I^* 
\end{cases}
\]

Experience in FATIMA and SAMI showed that if hard penalties are used alone then 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.:

\[
\text{Penalty} = \begin{cases} 
\gamma(I-I^*)^2 & \text{if } I \text{ is within } x\% \text{ of } I^* \\
= \text{large number} & \text{otherwise}
\end{cases}
\]

Obviously the form of the penalty will depend upon the type of indicator and the meaning of the target e.g. 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 be traded with other constraints (so if $I$ is close to $I^*$ 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.

A more advanced approach would be to apply a constrained optimisation algorithm. A constrained optimisation algorithm can solve problems on the form in equation (15.1). The constraints in constrained optimisation can be linear and nonlinear equalities and inequalities with both indicators and instruments as variables (i.e. both model input and model output). The constraints $C_{it}$ in problem (15.1) could for instance consist of $I_1(X_t) - I_1^* \leq 0$ and $\sum I_2(X_t) = I_2^*$, where $I_1^*$ may be the target for $CO_2$ emissions and $I_2^*$ may be the revenue collected in peak and off peak period from a toll cordon. Associated with each constraint is a Lagrange multiplier that can be interpreted as a shadow price. The Lagrange multiplier is calculated automatically by the constrained optimisation algorithm.
16.2 Barriers to strategies

Within PROSPECTS Task 15 the barriers to policy instruments/strategies were defined as legal, financial, political and cultural barriers.

16.2.1 Legal, Political and Cultural barriers

Legal, political and cultural barriers can be dealt with by considering them under different Institutional settings as in the AFFORD project. In the AFFORD project all barriers were combined under the title “Institutions”.

In general a policy package was understood to be a combination of policy instruments under the constraints represented by technology, geography, legislation, and institutional barriers.

These constraints may, of course, be defined in various ways, depending on the temporal and spatial horizon. As a first ordering, AFFORD distinguished between settings:

- **I1**: Strategies/packages under current institutions, and
- **I2**: Strategies/packages after institutional reform.

The first policy package is, by assumption, enforceable given the instruments presently available to the city authorities. The second package, on the other hand, cannot be implemented at the city level without foregoing legislative or institutional changes, as this policy presupposes the use of instruments that are not currently under the jurisdiction of local governments.

Given the way that these two settings have been defined, their «technical content» in terms of available instruments may vary from one city to another. For instance, in Oslo there is already a cordon toll ring in place, and the implementation of higher, lower or time differentiated toll rates is considered to be within the limits of the current institutions. A local fuel tax, on the other hand, would require a special legal provision, since excise taxes cannot presently be levied by any authority other than the central government. In Helsinki, the converse is true: a toll ring would require special legal provisions, and hence belongs in a strategy under I2, while a fuel tax is considered to be within the authorities of the modelled urban region, and can be included in the policy package under I1.

The detailed content of each sub-package under settings (I1 or I2) will, therefore, for this and other reasons, depend on the local conditions. It will – in our modelling exercise – inevitably also reflect the analytic opportunities offered by the various modelling frameworks. As the various models differ in terms of what kind of policy instruments they are able to deal with in a meaningful way.

In essence the label I1 refers to some constrained set of instruments and their levels while I2 refers to a much less constrained set of instruments and their levels in terms of institutional barriers (though the future instruments may still be constrained to some extent too).

One difference between AFFORD and PROSPECTS is the time dimension; AFFORD models were run for a single long run year generally and the switch between current and future institutions was considered to be carried out prior to the modelled year. In PROSPECTS we have to consider timing of implementation carefully and the time it can take to remove certain...
barriers may be an issue. Acceptable input ranges should be defined for both I1 and I2 and over the time horizon if necessary.

16.2.2 Financial barriers

Financial barriers cannot be dealt with via institutional settings this way. 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 (eg 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 PVF over the 30 year period which may vary with instruments considered.

Each of the above types of barrier is discussed below :-

1. Overall limit on capital expenditure.
   We could ask the user to define $C_{\text{max}}$ which is applicable to any year $t$. We then have to add a constraint such as $C_t \leq C_{\text{max}}$ ($C_t$ is the sum of capital costs over all instruments used in year $t$) and have a large penalty for combinations of instruments which exceed this threshold. When using the regression approach we could presumably “screen” combinations of instruments and would not model any combination which exceeds the threshold. Similarly we could “screen” a combination within the automated procedure but this may then upset the algorithm as we would have to find a new point somehow – i.e. run the combination and simply add a large penalty which puts the combination low down the ranking.

2. Total Operating Costs in any year
   This will include subsidies to fares etc and we would need to have some rules for subsidies, deriving from current practice or legislation.

3. Capital costs by instrument.
   We suggest these can be “screened” by the user prior to optimisation.

4. Operating costs per instrument. (see 2 above).

5. Revenue use and hypothecation
Again some feedback rule will be needed otherwise we assume all revenue can be used to fund all modes.

6. **Limit on borrowing**

If borrowing is prohibited, we have already dealt with this through our discussion of the previous points. If borrowing is allowed, it will have the effect of easing one or more of the above constraints, as the case may be. But in that case we should also include the seventh constraint to make sure that it will be possible to repay the loan inside the 30 year time horizon.

7. **PVF over 30 years.**

Either use a hard constraint as in FATIMA but modified to allow for user defined “extra” money.

We require $\text{PVF} \geq \text{PVF}_{\text{min}}$

PVF is the change in present value of finance over 30 years (do-something minus do-min). $\text{PVF}_{\text{min}}$ is the threshold for the change in PVF between the do-something and the do-min case.

Thus if the Do-min is allowed to “lose” x million Euros then the Do-something could also “lose” x million Euros. This would be represented by setting $\text{PVF}_{\text{min}} = 0$.

If we assume there is extra money available e.g. if LRT is an option and we may assume an extra y million euros are invested by Government then $\text{PVF}_{\text{min}} = -y$ would represent the extra money being met by Government and we do not require the money to be paid back. Generally, this would be inconsistent with the principles of Cost-Benefit analysis, which requires us to take the cost of all parties into account.

However, if it seems relevant to choose between strategies from a strictly local perspective, we could introduce an “Extra money from Government” column in the evaluation table and then have a $\text{PVF}_{\text{min}} = 0$ for all cases, reflecting the requirement to pay back all but the extra money. This would have the advantage of showing the “extra” money in the evaluation table.

In summary we would need constraints for points 1 and 7 and have possibilities for “rules” to be used in some of the other points.
17 Optimisation algorithms

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 the efficiency of algorithms that use values of the derivative is often efficient in terms of function evaluations, it is sometimes cumbersome to establish the routine that calculates the values of the derivatives.

Some optimisation algorithms apply one-dimensional maximisation along lines in multidimensional space. Powell’s Method (Press et al, 1988) is of this type. It uses information about the optima obtained from previous line maximisation in the multidimensional space in order to choose new directions for line maximisation. To apply optimisation algorithms that break the problem down into a number of line maximisations it is necessary to set two convergence criteria - one for line maximisation and one for the overall multidimensional function maximisation.

Application of the AMOEBA method that is commonly referred to as the Downhill Simplex algorithm (see Press et al, 1988, Nelder and Mead, 1965) requires the specification of only a single convergence criterion. Evaluation of the derivative of the objective function is not required. Besides this, the method is easily understood and implemented. However, it is not very efficient in terms of the number of function evaluations it requires.

PROSPECTS partners have experience in applying the Downhill Simplex method due to Nelder and Mead, (1965) via the AMOEBA routine (Press et al, 1988) in projects SAMI and AFFORD. It is a robust and easy to use DUD method in multi-dimensions. It can deal with a set of continuous policy variables and has been applied with hard and soft constraints within the objective function. Previous experience shows that the number of iterations required increases quite dramatically with the number of variables considered and the accuracy of the final solution deteriorates with increased dimensions. However if the problem can be broken down into a number of sub-problems, then the algorithm can be applied in a decentralised manner and the solution can be improved with fewer total iterations than if the problem were set up in full. This decentralised approach was also used for regions with competing objectives creating a game situation between different regions. More details about the method can be found in appendix A of the Task 22 report.

Values of the derivative of OF in the land use transport context are not readily available. Moreover, it is not easy to pre-set the convergence criterion. Due to the long computing time for some packages, it is more desirable to monitor the change of function and parameter values and terminate the optimisation algorithm when changes are considered small. Considering the long computing time, this gives a flexible way of compromising between the number of iterative runs and the accuracy of the calculated optimum.

Hence, the Downhill Simplex algorithm seems like a good starting point in the attempt to understand how to optimise the objective function OF. Experience with the Simplex method may be of great value if more sophisticated algorithms are introduced at a later stage. The Simplex method is well suited for optimisation of OF both with and without constraints on independent variables (policy instruments) and on output indicators (target constraints). However, the objective functions must be modified according to the penalty method if constraints on target indicators are introduced.
Another approach to optimisation is based on a regression analysis (Fowkes et al., 1998). This method has been applied in both OPTIMA and FATIMA. 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 can also run into difficulties around hard penalties which introduce discontinuities into the objective function. However it 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 beliefs.

The method may be an option when optimisation of policies involves transport models that are very slow and/or difficult to adapt to the interfaces that are provided in more general optimisation algorithms.

Algorithms for constrained optimisation are capable of solving problems of the very general form (17.1) and are often capable of calculating the optimal Lagrange multipliers that can often be interpreted as shadow prices:

$$
\max_{x} OF(x_i) \\
h_i(x_i) = 0, \quad i = 1, \ldots, m \\
g_j(x_i) \geq 0, \quad j = 1, \ldots, n
$$

Constrained optimisation algorithms are available as part of many software packages, and free Fortran – and C routines are available on the Internet. Prof. Dr Peter Spellucci has developed the constrained optimisation algorithm DONLP2\(^\text{16}\), which is available on the Internet in both C and Fortran code with Users Guide. Luenberger (1984) gives a general introduction to the theoretical basis for constrained optimisation algorithms.

### 17.1 Scenarios and strategies

A scenario is a projection of a likely future image and is defined by setting certain assumptions about various exogenous variables such as economic growth, population growth etc. The performance of a strategy is measured by the objective function $OF$ (as defined in equation 15.1) under a given scenario. This performance will change if the scenario is changed, as will the performance of the reference (or Do-minimum) case.

A strategy is defined by a specified set of land-use and transport instruments and their levels. For some instruments there is a case for considering them as part of a given scenario e.g.

16 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”)….”
some land use planning assumptions may be considered as scenarios in their own right. Other instruments which come under National control such as fuel taxes may also be considered as exogenous inputs to the urban planning scenario. Where there is such a policy instrument, the PROSPECTS approach is to keep assumptions regarding instruments separate from assumptions regarding uncontrolled variables whilst recognising that these assumptions may form part of a larger scenario.

As stated in Chapter 14 the instruments which are to be assessed using formal optimisation techniques are of a strategic nature with local instruments being dealt with post-optimisation. Thus there are two possibilities for defining an “optimal” strategy with regard to scenarios:-

1. the strategy is optimal for a given scenario and there are feasibly as many optimal strategies as there are scenarios considered
2. the strategy is optimal across all considered scenarios i.e. it is the most robust strategy against the future uncertainties included in the considered scenarios.

It is far from clear which of the above problems the decision-maker is interested in solving.

The simplest approach from a modelling point of view is to solve the first problem i.e. find the optimal strategy for each scenario. Indeed the models are usually set up to model one scenario at a time and it makes sense to continue in this way. When planning against one main scenario the choice of the preferred planning scenario will affect the optimal levels of instruments considered. For example if the planning scenario is based upon a high growth - high demand scenario, then the optimal prices will tend to be higher and the overall benefits may appear greater than those obtained under a lower growth scenario. Thus it may be that a conservative scenario should be the preferred planning scenario.

Robustness of the resulting optimal strategy can be tested against other scenarios via sensitivity tests. This will involve running the Do-minimum in each scenario to identify which scenarios cause significant changes in the indicators and objective function, followed by running the optimal strategy plus other related strategies (and options) for the scenarios which are of most interest.

To some extent this meets the second problem of finding an optimal strategy across scenarios. An alternative approach would be to vary the exogenous “scenario” variables during the optimisation process. For example if we have three scenarios A, B and C; population growth is assumed to be 1%, 3% and 5% per annum and economic growth is assumed to be –2%, 2% and 3% respectively. Suppose all scenarios are assumed to occur with equal probability in the future, then we could at each iteration of the optimisation process impose any of the scenarios A-C with equal probability and set the population and economic growth forecasts accordingly. Note we could not use an “average” scenario with population growth of 3% and economic growth of 1% as this combination is not considered to be a feasible future image!

Notwithstanding the problems of changing model input assumptions between iterations this procedure is also not guaranteed to converge so easily as each change of scenario would introduce some noise into the optimisation process. It is also not clear what the reference point should be and whether the change in the objective function will be due to the change in instruments or the change in scenario assumptions. This obviously requires further thought.
18 Options within PROSPECTS

This chapter sets out the optimisation and modelling approaches for the case studies within PROSPECTS. It does not detail which instruments and scenarios are to be investigated, it is only meant to detail the general approach.

18.1 Sketch planning model (Core cities)

Sketch planning models are developed within PROSPECTS for all the core cities. Documentation will be forthcoming.

Common policy tests using a subset of the available instruments will be performed in all six core cities. Initially the instruments considered will be strategic and continuous only (perhaps vary spatially but still continuous), thus allowing the use of the AMOEBA routine as detailed in Appendix A of the Task 22 report. However we then move to city specific tests in which we consider modelling some discrete options and either adapt AMOEBA, or implement a new routine. The team will also look into increasing the efficiency of the AMOEBA routine by investigating the use of the stopping criteria (in particular looking at the accuracy required in defining a policy level).

Initially the SPM model will run for each modelled year in a time-marching fashion. The effects of different policy profiles to implement instruments will be examined. However if initial results show that the model could be run with a greater time step without losing detail then this could save model run times allowing a greater number of iterations to be performed per optimisation. The speed of the SPM will allow a number of optimisations to be performed and for the production of response surfaces (May et al 2001) which will enable a better understanding of the underlying models.

18.2 DELTA-START (Edinburgh)

START-DELTA was developed by MVA and David Simmonds Consultancy. START is a strategic transport model capable of representing all modes of transport. It was designed to evaluate area-wide strategies rather than single road investments. DELTA is a dynamic land use model which covers Development, Employment, Location, Transition and Area Quality at the household level of detail. The Land Use -Transport Interactions have DELTA responding to the transport strategies (as modelled by START) via household responses to changes in accessibility and environmental improvements to specific areas within Edinburgh.

The long run time of the DELTA-START model coupled with the manual input procedures essentially dictate the optimisation method be based upon the regression approach as detailed in Appendix B of the Task 22 report.

DELTA has implicit time lags associated with the land use responses. The longest time-lag is 11 years which limits the choice of the long run year $t_L$. DELTA will run for each modelled year whereas the START transport module is run at five-yearly intervals. In effect this restricts the policy changes to years 0, 5, 10, and 15 (possibly year 20 depending on the interpretation of the largest time-lag and the final horizon year = 30). These variable time steps between DELTA and START imply that some from of interpolation of benefits and indicators will be required.
The optimisation process could be supported by suggestions arising from the sketch-plan model of Edinburgh. These suggestions would fit in with the incremental process of building an optimal strategy which allows the user to specify one-off tests based on judgement.

DELTA-START will be used to perform one possibly two optimisations against one planning scenario. Further model runs will be used in sensitivity tests to assess the robustness of strategies against other scenarios.

18.3 RETRO/IMREL (Oslo)

RETRO is a disaggregate or behavioural travel demand model for the greater Oslo area, consisting of submodels for licence holding, car ownership, trip frequency and a nested logit model of destination and mode choice. It is documented in Vold (1999). IMREL was formulated and applied as a policy analysis tool in the Stockholm region by Anderstig and Mattsson (1991). In the integration of RETRO and IMREL as applied to the Oslo region, households choose residential locations based on rush hour accessibility as given by RETRO, as well as on housing prices and housing density. Employers choose employment location to maximise accessibility to the labour force.

Policy instruments may have short- and long term effects. Increasing fuel taxes, for instance, would affect mode choice, destination choice and trip frequency, whereas the long term effects would include all the short term effects plus altered car ownership and household and employment location changes. Application of an equilibrium model for evaluation of the objective function \( OF \) requires two model runs where the first run is considered short term and the second run is considered long term. The approach will be to use the policy profile as described in section 15.4.

General algorithms for solving the constrained optimisation problem are easily available. Our experience from the AFFORD project (Vold, Minken and Fridstrøm, 1999) is however that at least 50 evaluations are needed if six instruments are optimised. The optimisation approach will be based upon the automated AMOEBA routine and the DONLP2 routine for some small set of strategic instruments applied to one planning scenario. This will be supported by sensitivity tests of the weights used in the objective function.

18.4 SAMPERS/IMREL (Stockholm)

SAMPERS is the newly developed national passenger transport model system for Sweden. IMREL was developed and applied as a policy analysis tool in the Stockholm region by Anderstig and Mattsson (1991). In the integration of SAMPERS and IMREL, households choose residential locations based on accessibility to work as given by SAMPERS, as well as on housing prices and housing density. Employers choose employment location to maximise accessibility to the labour force.

There is little chance of using an automated optimisation with SAMPERS, as it has a user interface where manual input is necessary. This also will put a limit on the number of runs possible and so the optimisation will have to be carried out manually, using the regression approach. At least two model runs are needed to evaluate the objective function \( OF \) as in the Oslo case study. These can consist of a SAMPERS (transport model) run, to capture the short run effects, and a SAMPERS/IMREL (transport and land use) run to capture the long-term effects.

It is very difficult to estimate the time for a run, as the time to reach equilibrium will depend
on the size of the introduced changes. A run including IMREL could take up to 10-12 hours, and a SAMPERS-only model run a third of that. It is envisaged that the Stockholm model will optimise a set of instruments against one planning scenario but then perform many sensitivity tests with different scenario assumptions which are readily available for the Stockholm model.

18.5 EMME/2-SPM (Madrid)

EMME/2 is to be used as a detailed transport model in conjunction with the sketch-plan model being developed in PROSPECTS. The sketch plan model will be calibrated to a combination of real data and EMME/2 model outputs for the base scenario. The SPM will be used to predict the optimal strategy for some area-wide strategic policy instruments. These policies will affect the future demand and land-use patterns around corridor N-III which has a major new metro line. The EMME/2 model of corridor N-III will be used to assess the impact of the area wide strategies in combination with the new metro-line.

The figurative process would be as follows:

1. Run EMME/2 : Do-nothing
2. Run SPM to produce optimal area-wide policy
3. Results from SPM will be the framework inputs for N-III model
4. Run EMME/2 for N-III model to determine land use and transport demand in N-III detailed zones

Regional Model: Pass data from EMME/2 and other statistics sources to SPM and calibrate the models to Do-nothing

Conduct SPM level evaluation

Conduct EMME/2 level evaluation
Part V

Conclusions and implications for WP30 and 40

1. Conclusions

The objectives of WP20 were to

- produce enhanced procedures for evaluating transport and land use policies which address all of the indicators from Task 11 in the format needed for the decision-making processes of Task 14 (Task 21);
- review and produce optimisation methods capable of addressing the indicators from Task 11 and of application to the models in WP30 (Task 22);
- design formats for presentation of the output of strategy analysis suitable for politicians and lay users using GIS presentation tools (Task 23).

Deliverable 2 – the current report – has to be assessed against these objectives.

An evaluation framework building on the hierarchy of objectives and indicators from task 11, and incorporating the results from the other tasks of Work Package 10, has been devised in part II. Specifically, we have enhanced current MCA methods and modified current CBA methods to take account of all aspects of sustainability. It is a matter of taste if this framework is labelled MCA or CBA. It is flexible enough to incorporate both as special cases. Indicator issues have been given a fuller treatment than in Deliverable 1 to secure that all sub-objectives to sustainability should be measurable by an operational indicator. User benefit calculations in land use/transport interaction models have been discussed, and the approach developed by Simmonds (2001) has been adopted as a guide to such calculations. Walking and cycling benefits are incorporated as far as current theory and data permits. Suggestions for improvements with respect to accidents and air pollution have been made, and proposals to include equity concerns more fully in evaluation have been set out. It must be recognised that many of the approaches are experimental and need to be tested in practice. The views of our six Core Cities on the evaluation issues have been sought, and will be continually sought in the practical tests.

The potential uses of GIS in the presentation of results have been discussed in part III. The challenge has been to present the level of achievement of the sustainability objective and its sub-objectives in a form that is readily absorbed and meets the needs of each particular group of users of the planning results. Each of the main categories of indicators has been discussed with this in mind. The discussion showed that guidance on the balance of presenting different indicators and sub-indicators needs to be developed. This also goes for correct map and graph presentations, since these easily become deceptive. At the same time, we have surveyed the legal and other requirements on strategic planning in each of the Core Cities to make sure presentation meets these requirements. There will however still be work to do to specify the details of presentation and try them in actual practice.

In part IV, we have described the general problem of identifying optimal land-use transport policies to be implemented and evaluated over a long-term evaluation period. The evaluation framework of part II lends itself naturally to constrained optimisation by the use of land use/transport models. The optimisation problem was set out. Details on modelling the introduction of policy instruments over time and modelling the constraints were discussed. The practical limitations due to policy presentation, optimisation procedures and modelling restrictions were recognised. This resulted in a simplified approach being specified for both time-marching and equilibrium based models. The approaches were consistent in the
assumptions behind the policy profile over time. Both modelling approaches use two points in
time to optimise the levels of the instruments which are consistent with a short term and a
long term response. It has also restricted the type of instruments considered to be strategic in
nature and to be optimised against one identified planning scenario with a suggested approach
for robustness tests against other scenarios.

Two types of optimisation algorithm have been suggested for the packages within
PROSPECTS. The first is an automated downhill simplex method (AMOEBA) which is to be
used for the faster models, the second is a regression approach based on previous work in
OPTIMA and FATIMA to be used with the slower LUTI models.

The main objective of PROSPECTS is to produce a set of guidebooks in integrated urban land
use and transport planning for sustainability. The topics covered in the present report are vital,
especially for the Methodological Guidebook. In all three topics, innovative approaches have
been set out. If they are to be confidently included in the Methodological Guidebook, it will
be necessary to test them in practice in the following work package, Work Package 30. For
instance, this includes our proposals for calculating the “liveable streets and neighbourhood”,
accidents and equity indicators, setting targets for the equity indicators and incorporating
them as constraints in optimisation, and implementing our suggested solution to user benefit
calculation in land use models. For presentation, it will be a challenge to apply the suggested
visual forms of presentation in the context of strategic modelling, since some of the indicators
are not developed at a very detailed spatial level. It is important that the focus is on the
objectives according to their importance and not according to whether they are amenable to
visualisation or not. The challenges to optimisation will arise from the increased complexity
brought about by integrating land use and transport, combining evaluation by an objective
function with planning by targets, and incorporating the wide range of policy instruments.
Only practice will show if our algorithms will be able to cope equally well with all these
aspects.

At the same time, the basics of our objective-led evaluation framework will be applicable to
all strategic planning exercises, even if no models at all are used. It will be flexible enough to
adapt to differing requirements stemming from EU policy guidance, national laws and rules
and the particular preferences of each city authority. Above all, it incorporates concerns about
sustainability in a new and consistent way.

2. Implications for WP 30 and 40

The challenges facing us when we proceed to Work Package 30 are by no means small.
Among other things, future tasks required within PROSPECTS WP 30 include :-

- Specification of policy instruments to be optimised including capital and operating
costs, implementation year(s) and lower and upper bounds.
- Specification of scenarios, exogenous variables and their ranges, and selection of a
preferred planning scenario.
- Specification of any barriers to any of the policy instruments selected for
optimisation (especially financial).
- Implementation of the evaluation indicators and objective function(s).
- The design of output presentation tables that addresses all indicators, and the
further use of visual tools to illustrate the results.
• Training in the use of the regression based optimisation approach.
• Interfaces with the AMOEBA routine to be implemented for the SPM and RETRO/IMREL.
• Consider the presentation issues surrounding the optimisation procedures.

Strategic planning and strategic models will have to be kept simple. For some of the modelling systems this has meant less spatial detail, and for others it means less differentiation with respect to income groups, household types etc. Obviously, this may cause difficulties with respect to the modelling of noise and local pollution, and with respect to equity analysis. It needs to be assessed what such shortcomings may mean for evaluation of sustainability. With respect to the development of the guidebooks (WP 40), it might be conjured that modelling systems in the future will have to be assessed not only with respect to their ability to predict transport and land use changes, but equally with respect to their capability to predict the ensuing environmental qualities and distributional impacts.

Work Package 40 will have to take on board the whole broad and flexible evaluation framework outlined here. "Hard" and "soft" methods are not competing but complementing each other. With respect to the hard core of our method (the Sustainability Objective Function and the constrained optimisation problem) this is still so new to planners that it needs to be set out in the guidebooks in more detail and with a better pedagogic approach than we have achieved here.

Finally, the guidebooks will have to give rise to a permanent effort to revise and enhance them as knowledge grows, and to improve planning for sustainability as set of in the seventh point.

To be able to achieve this, we need to keep close contact with the Core Cities throughout the process.
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