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Optimisation Of Policies For Transport Integration In Metropolitan Areas

Report on Work Package 10

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CONTENTS

1 THE TASK OF WORK PACKAGE 10

The task of Work Package 10 is to specify the objective functions to be optimised in the project. As set out in the Technical Annex of the project, there are to be two or at most three versions of the objective function. The first one is to reflect economic efficiency objectives. The second one is to reflect concerns about the sustainability of urban transport. A combination of the two may possibly reflect both kinds of objectives and a definite trade-off between them.

There is of course a wide range of objectives of transport policy in urban areas, but most can be grouped under the broad headings of economic efficiency, including economic development, on the one hand, and sustainability, including environment, safety, equity and quality of life, on the other. Therefore, although the objectives of the nine studied cities will inevitably be different, if the objective functions are adequately specified, it should be possible for each of them to find its own transport policy objectives mirrored in either the economic efficiency objective function or the sustainability objective function, or both. To enhance the chances that the optimal policies that we identify in the project will in fact be implemented, an important element of Work Package 10 is to discuss the formulation of the objective functions with the cities, and to secure that the final specification is acceptable to them.

The transport models of the nine cities differ as to what policies can be modelled and what information they produce. These practical limitations will have to be taken into account when formulating the objective functions.

The methods in use to evaluate urban transport policy differ between the cities. For example, cost benefit analyses are not used everywhere, and the effects included in these kinds of analyses and the weights attached to them differ. To take account of that, a disaggregated yet simple form of presentation of the results of applying the objective functions to each particular model run is sought. It will then be possible for each city to relate the results to their usual evaluation methods. Also, each city may use their own values for the discount rate, value of time savings etc. within limits imposed by the needs to compare the results of the different cities.

Summing up, the task of Work Package 10 is to *«specify a standard set of objective functions for both economic efficiency and sustainability, which are acceptable to, and can be applied in, all the cities being studied»* (Technical Annex, p.4).

2 STRUCTURE OF THE REPORT

In section 3, the transport policy objectives of the cities are outlined briefly. In section 4, some features of the transport models of the cities that may put restrictions on the formulation of the objective functions are outlined. Based on that, the choices made are described and discussed in section 5, and some comments from the cities are noted. This section includes a discussion on the concept of sustainability and how to operationalise it in an urban transport context. The definition and operationalisation of sustainability has been the most difficult part of Work Package 10.

Section 6 describes indicators that can be had from the output of the transport models, but are not optimised in the project.

Section 7 give detailed descriptions of the two objective functions to be used in the project. As a point of departure for the description, we show two tables that are to be used in the project to record the outcome of the objective functions for each run of the transport model.

The formulas that go into the calculations are given in an appendix. A software program that performs the calculations based on EXCEL spreadsheets has been worked out, and is used for the calculations in some of the cities.

3 THE OBJECTIVES OF THE CITIES

3.1 Edinburgh

In 1991, Lothian Regional Counsil (shortly to become four separate authorities, one of which will be Edinburgh) commissioned a strategic transport study for the city, JATES. The evaluation in JATES was based on the following objectives:

- efficiency in the use of resources
- accessibility within the city
- environment
- safety
- economic development
- practicability (including financial feasibility)

In 1994, «Moving Forward: a Transport Strategy for Lothian» was published. This non-statutory document was based on the JATES study and sets out in some detail the strategies to be followed to the turn of the century. All policies in the strategy are designed to:

- improve road safety
- achieve a healthier environment
- encourage economic development

Commenting on an initial proposal for the objective functions in the OPTIMA project, Edinburgh indicated that they felt safety to be particularly important, particularly the reduction of pedestrian accidents. An unsafe transport system was felt to be unsustainable, and the results of any optimisation not including accidents would be of limited interest to Edinburgh.

3.2 Merseyside

The Merseyside Integrated Transport Study (MERITS) was commissioned by the five local authorities in the conurbation, together with Mersey Travel and the Merseyside Development Corporation. The evaluation in MERITS was against the following transport objectives:

- to contribute to the economic development of Merseyside
- to preserve and enhance the environment of Merseyside, including townscape and safety issues
- to improve the accessibility of Merseyside internally, regionally, nationally and internationally
- to enhance efficiency in the use of resources
- to ensure practicability, including financial feasibility.

Subsequent to Merits, Merseyside has submitted an annual «package bid» for central government and EU «Objective One» funds for transport. The package bids for 1995/96 and 1996/97 have defined a set of four «core policy themes» which are in some ways akin to objectives, and which flow from the objectives and policies of MERITS.An *abbreviated version* of these core policy themes are given below:

- *Promoting economic regeneration.* ... A primary aim is to promote sustainable economic regeneration in Merseyside. A vital requirement of this aim is a satisfactory level of accessibility, particularly for commmercial and industrial traffic.
- *Attractive public transport.* ... The strategy aims to improve the quality of public transport and improve pedestrian and cycling facilities with the intention of reducing car use. ...
- *Best use of existing roads.* ... In preference to initiating major highway improvement schemes it makes sense first to make use of the existing highway network. This aim recognises that whilst capacity improvements are desirable on some roads, on others the need to reduce speed and capacity is more appropriate. ...
- *Safety and the Environment.* To give a high priority to safety and environment schemes and measures aimed at reducing casualities and improving the quality of life for those working and living in Merseyside. ...

Commenting on an initial proposal for the objective functions in the OPTIMA project, Merseyside made it clear that the overriding objective is that of economic regeneration. This is to be achieved by pursuing the twin and equal objectives of improving public transport and making most efficient use of existing highways.

3.3 Wien

In 1994 the Vienna City published VERKEHRSKONZEPT WIEN, Generelles Massnahmenprogramm. It was then adopted for STEP (STadt EntwicklungsPlan), the City Development Plan, in 1994. The general objectives are listed below:

1. *Land use.* In 1996, a policy to extend the populated area is adopted (as a reaction to the population increase due to the fall of the iron curtain in 1989). The city decides to increase the density to reduce the needs for car traffic and increase public transport ridership, walking and cycling.
2. *Modal split.* It has been decided that the city must change the modal split from 1990
   - car 37%
   - public transport 37%
   - pedestrian 23%
   - cyclist 3% to
   - car 25%
   - public transport 45%
   - pedestrian 24%
   - cyclist 6% by 2010
3. *Public transport.* It is decided to develop public transport as an integrated system by: (a) Increasing frequency and extending the network of commuter rail, (2) extending underground rail by 35 km in 20 years, (c) developing public transport actuated signals and lane separation.

4. *Car traffic.* Improve the situation by wide-area parking management. The whole city road network will be short-term parking zones and resident-only permission. Additional P&R facilities will be developed in the urban periphery. Introducing road pricing (still in discussion)
5. *Pedestrian.* Improve the condition for pedestrians in terms of comfort and safety, e.g. improved sidewalks and crossings.
6. *Commercial traffic.* Improve traffic safety by further reduction in the number of accidents (by using ongoing strategies).
7. *Environmental issues.* Reduce current CO2 emission in 2010 by 50%. Use greenery/plants as street furniture. Encourage more environmentally friendly transport means, from pedestrian to electric vehicles. All buses are to use LPG only (previously diesel and LPG)
8. *Economy.* Strengthen the position of Vienna in competition with other cities.
9. *Implementation.* All measures have to be implemented through public consultation/hearing or inquiries. All plans must be shown to public.
10. *Regulation.* The needs to adopt regulations that meet the future requirements.

3.4 Eisenstadt

The goals of a new traffic plan was decided in 1995.

1. *City structure.* Car-free areas. New structures for commerce and sport to be developed along the rail line.
2. *Pedestrian.* Extend the pedestrian areas/zones. Pedestrian network must be developed in order to maintain safety.
3. *Car traffic.* The paid parking area must be extended and new parking facilities must be organised to improve the accessibility of public transport.
4. *Commercial traffic.* Direct access from motorway to industrial area, no through traffic.
5. *Public transport.* Optimisation of the location of railway station and regional central bus station. Introduce smart card system
6. *Environmental issues.* Reduce transport-related environmental impacts by national and international standards.
7. *Economy.* Strengthen the unique position of Eisenstadt as provincial capital (currently 10.000 residents and 30.000 workplaces). Further development of tourism sector. Discourage through traffic in the city.

3.5 Helsinki

In 1994, the Helsinki Metropolitan Area Council approved the Transportation System Plan for the Helsinki Metropolitan Area. The goal of the development of the transportation system is, by means of traffic measures, to improve the quality of life for residents as well as business opportunities and capital city functions. An abbreviated version of its objectives are set out below:

1. *Land use*. Densify the city structure in order to reduce the need for travelling, and increase the possibilities for public transport as well as for walking and cycling.
2. *Public transport*. Develop public transport so that it is a competitive mode of travel. Enhance the joint use of public transport and other modes.

   During the morning peak public transport should account for at least two thirds of the inbound motorized trips to Inner Helsinki and public transport's share of the regional daily trips should be maintained at least at the present level of 42 %.
3. *Car traffic*. Maintain operating conditions for car traffic outside peak hours and during peak at the present level.
4. *Walking and cycling*. Forcefully develop walking and cycling connections, conditions and safety.
5. *Commercial traffic*. Provide a high level of service for commercial traffic.
6. *Traffic safety*. Guarantee high level of traffic safety in accordance with Nordic standards.
7. *Environmental issues*. Reduce traffic related local environmental impacts and fulfil national and international objectives for reducing carbon dioxide emmissions to 80 % of 1990 levels by 2020. Develop and support pro-environmental travel habits. Reduce the need to travel by car.
8. *Economy*. The Helsinki Metropolitan Area will receive a fair share of state financing in relation to its traffic volumes and national taxes and special traffic fees collected in the area.

   With regard to transport investments, the country directs its economic resources to produce the maximum national economic benefit. In the Helsinki area also projects which are aimed to enhance the area's competitiveness for new employment in the long run will be implemented. These new work places should be located in areas with good accessibility to public transport services.
9. *Implementation*. Carry out the transport system development measures in a coordinated and democratic manner. The tasks of the Transportation Commision of the Helsinki Metropolitan Area will be revised and defined so as to coordinate the implementation of the transportation system plan.

At the political level, a joint regional system for the transportation decision making process is initiated.

3.6 Torino

A Traffic Plan for Torino was approved in 1995. It covers only the near future, but refers also to wider strategic ideas. Its objectives are:

- to improve the efficiency of public transport and increase its share in modal split
- to improve the efficiency of the highway network, with due regard to the different functions of the roads

- to manage the parking spaces
- to decrease pollution and noise
- to improve safety
- to improve the quality of the pedestrian space and increase pedestrian areas
- to increase the cycle lanes.

3.7 Salerno

A Traffic Plan for Salerno is currently at the planning stage. The transport policy objectives of the city can however be summarized in two points:

- to improve the efficiency of the public transport system
- to improve the performance of the highway network, mainly by increasing the number and the capacity of roads.

At the present time, environmental questions are felt to be less important than transport and traffic problems. This is due to the specific problems of the city.

3.8 Oslo

In 1990 the Norwegian Government instigated a programme to establish integrated transport plans for the 10 larger town areas in Norway, including the Oslo/Akershus region. The plans seek to integrate planning of road investments, public transport and land use. Its aims are to develop integrated transport systems capable of securing accessibility for all groups of travellers, traffic safety, health and the environment. In particular, the objectives are:

- Reduced energy consumption to help meet Norways international commitments
- Increase public transport's share of trips and reduce the growth of private car travel
- Increase efficiency
- Major reductions of pollution and noise

These national governmental objectives are relevant, because many instruments of the urban transport policy are controlled at the national level.

As for local authorities, the present transport policy of the city of Oslo was laid down in 1994, when a strategic transport policy document (Oslo Samferdselsplan. Bystyremelding nr.1/94) was approved by the City Counsil. The document advocates a shift in policy towards increased weight on environmental objectives and promotion of public transport. The main objectives can be summarized as:

- to shift the modal split in favour of public transport to improve the environment
- not to increase highway capacity on radials to the centre, and to use more of the available funds originally earmarked for highway construction to improve conditions for public transport
- to improve the conditions for walking and cycling.

Since 1994, a new election has brought changes in the City Government, but to date, no new major change of transport policy has occurrred. However, the political situation is unstable.

3.9 Tromsø

In 1990, the Norwegian Government instigated a programme to establish integrated transport plans for the 10 larger town areas in Norway, including Tromsø. The objectives of this programme and its relevance are described under 3.8 Oslo.

At the county level, the objectives of transport policy include the following: « In the cities of Tromsø and Harstad, an objective is to improve public transport services so that a considerable part of total transport work is shifted from private car to bus.»

At the municipality level, an integrated transport plan was approved by the City Council in 1995. Its overriding objective is that land use and transport policy in Tromsø should contribute to high levels of accessibility to all functions of the city for all inhabitants, high standards of traffic safety and good conditions of health and environment. This is broken down into goals for transport standard and equity, environment and health, natural resources and outdoor life, efficiency and reductions in private car use.

3.10 General

The cities' transport policy objectives cover the whole range of objectives traditionally set out for urban transport policy. The aims of improving the quality of public transport and pedestrian and cycling facilities with the intention of reducing car use seems to be of importance to most of the cities. The Nordic and Austrian cities refer specifically to the need to reduce CO_2 emissions. Three cities (Merseyside, Helsinki and Oslo) aim at making the best use of the existing road network rather than adding to road capacity.

The shift of policy towards priority for public transport and environmental goals is a relatively new tendency, and strategic highway investment plans are still implemented for many years to come in for example Oslo.

All cities include economic efficiency and accessibility objectives. The British cities, especially Merseyside, put stress on economic regeneration.

Edinburgh seems to stand out in putting safety as top priority, while Helsinki and Vienna stands out in the weight attached to a dense city, and Salerno in its low priority of environmental issues.

The impressions that can be had from a review of official transport policy objectives may of course be modified at a later stage in the project, when the actual measures planned and taken are considered.

All the objectives of the cities can be subsumed under the headings of economic effiency and sustainability, broadly defined. But the broadest definitions are rarely the most operational. To formulate the economic efficiency and sustainability objective functions, the definitions of efficiency and sustainability will have to be narrowed down to be operational in the context of the transport models of the cities. This may have to be done at the peril of some of the objectives of the cities, and it is to this problem that we now turn.

4 LIMITATIONS IMPOSED BY THE MODELS

4.1 Limitations imposed by all models

Transport models will be unable to mirror the whole range of changes in the economic and physical conditions of a city and its inhabitants brought about by a transport strategy. They concentrate on changes in *some* aspects of travellers' behaviour, namely trip frequency, destination, mode and route choice. From a prediction of these changes, changes in travellers' benefits and costs as well as the immediate impacts on the number of accidents, pollution levels etc. may be had.

Some of the objectives of the cities do not depend for their fullfillment in a clearcut way on these four aspects of travellers' behaviour. Instead, they depend directly on decisions made by the authorities, or on other changes in behaviour than those assessed by transport models, like decisions to relocate houses and businesses. It makes little sense to include such objectives in the objective functions.

Land use objectives. Our models are not integrated land use-transport models. This means that the impact of an exogenously given land use change on traffic flows, costs and benefits in the transportation sector could be assessed, but the impact of an exogenously given transport strategy on land use cannot. The objectives of preserving townscapes (Merseyside) and landscape and outdoor life (Tromsø) must therefore be taken care of when formulating the land use scenarios and investment strategies, and the degree of fullfillment of them will be immediately apparent from an inspection of these scenarios and strategies. Such objectives need not and cannot be included in the objective functions.

Dense city structure. Regarding the objective of a dense city structure (Helsinki, Vienna), this objective is not entirely an end in itself, but a means to reduce the need for travelling and increase the modal shares of public transport and walking and cycling. For a given dense land use scenario, the effects on travelling and modal split can be had from the transport model. The effects on city structure from a transport strategy that reduces travel and travel by car in particular, can however not be assessed. To the degree that city structure is shaped by market forces, this makes it difficult to judge whether the objective is attained by any given combination of land use and transport policy instruments.

Economic regeneration objectives. The attainment of this objective can not be assessed fully by transport models. These models are static, and unable to mirror the process towards economic regeneration. Income levels are exogenously inputted, and no feedback from transport cost savings to income levels exist. Economic regeneration will depend in part on land use policy, and in turn have strong impacts on land use. None of these interactions are modelled. If, however, a consumer surplus measure is included in the economic efficiency objective function, the change in consumer surplus, especially for freight and business trips, will be a measure of the *possibilities* of economic regeneration brought about by a transport strategy.

National and international accessibility. This objective can not be assessed because of the limited geographical area covered by the models, and so need not be included in the objective functions.

4.2 Limitations imposed by some of the models

Safety objectives. At present, five of the 9 models do not have accidents as an output. Only the Austrian and British models do. This does not, however, preclude the inclusion of accidents in the objective functions of those cities where it can be obtained, and for Edinburgh, it is essential that this is done.

Local emission objectives (other than noise). Three out of nine models do not output any local emission indicators at present, and only CO figures are available from the Merseyside model. This situation may however be remedied, at least for the British cities, which would leave us with Torino and Tromsø with no local emission indicators. For Salerno, figures are available for the private car mode only.

In a cost benefit framework, emission indicators will not suffice if local pollution is to be included in the objective function. Some measure of what impacts these emissions have on people (immission, exposure) must also be obtainable, for example in the form of the number of people seriously inflicted in each zone. The cost to each person seriously inflicted must also be available. If however a multicriteria analysis framework is chosen, the level of emission can be directly included into the objective function, using a subjectively set weight per unit of emission. It may also be possible to weight zonal levels of emission by the population of each zone, to obtain some coarse indicator of the damage done by these emissions.

Noise reduction objectives. Most cities' models will be able to output noise level indicators, but not all. The remarks above on the vital difference between emission and immision, and the need to set a price per seriously inflicted person in a cost benefit framework, and a subjective weight in a multicriteria analysis framework, apply to noise as well as to other local pollution.

5 CHOICES MADE AND THE REASONS WHY

5.1 The exclusion of distributional and financial feasibility objectives from the objective functions

The perspective of the OPTIMA project is that of society as a whole. This means that to the extent possible, all benefits and disbenefits that flow from a given urban transport strategy should be included in the objective function, whether they are monetary or not, and whether or not they accrue to households, firms, government or other agencies inside or outside of the city.

Obviously, the question of who gets the benefits and disbenefits is a matter of concern to the cities. Some (Merseyside, Helsinki) single out benefits to commercial traffic as a special concern. There are concerns, for example in Tromsø, that benefits should be fairly distributed among all inhabitants, regardless of car ownership. Financial feasibility is important, and is specially mentioned by a number of cities. Finally, it is only natural that local authorities are concerned that the benefits should accrue to the city, and not be siphoned off to the region as a whole.

The choice we have made is to disregard these distributional concerns when formulating both of the objective functions.

Regarding the *economic efficiency* objective function, it is only when distributional objectives carry no weight in it that it will be possible to interpret this function as a measure of social efficiency (as this concept is usually understood in welfare economics). Furthermore, if each city's distributional objectives should be taken fully into account, it would have made comparisons between the cities much more difficult.

This choice is a fundamental one, and it is not difficult to see the objections that can be made against it. The concept of social efficiency rests on the possibility of treating efficiency and distributional questions separately. It can legitimately be doubted that this will be possible in our context. Will it be possible, after a socially efficient transport strategy has been found, to compensate the local authorities that would have benefitted more by another transport strategy? Or to compensate commercial traffic or those without access to a car for losses to them?

Although distributional objectives are not included in the objective functions, they will not be lost sight of in the project. Care will be taken to display the results of a transport strategy in a way that permits judgments on distributional effects and financial feasibility (see chapter 7). This may provide inputs to the Work Packages 50 and 60, where the feasibility of implementation of the optimal strategies are to be judged both in terms of technical effectiveness and political and public acceptance, and ways to overcome barriers to implementation may be found.

Regarding the *sustainability* objective function, the concept of sustainability has obvious distributional connotations. To be sustainable, development will have to reduce the gap between rich and poor countries and be able to secure a decent standard of living for everybody. It is felt that these aspects of sustainability go beyond the scope of the distributional objectives of the cities, and so there is no need to include the distributional objectives of the cities in the sustainability objective function either.

Regarding *financial feasibility*, it is to be studied more closely in a proposed follow-up project to the OPTIMA project (FATIMA). In FATIMA, optimisation is carried out subject to restrictions on financial feasibility. This is then also a reason not to include it in the objective function of the present project.

In conclusion, it is possible to assess distributional objectives and financial feasibility from the output of the transport models, and care will be taken to display the results in a way that makes this easy. Distributional objectives and financial feasibility are however not included in the objective functions that are to be optimised in this project. The reasons for this are, besides the need to keep the functions simple to allow for comparisons across cities, that the economic efficiency indicator should be as closely connected to the social efficiency concept of welfare economics as possible, and that the distributional concerns of the cities are only weakly relevant to the distributional aspects of the concept of sustainability.

5.2 The choice of a cost benefit framework

A cost benefit or a multicriteria analysis framework was possible for the objective functions. A cost benefit framework is chosen. One reason for this is again to connect as closely as possible to the concept of social efficiency, as this provides us with a fairly clear interpretation of what is achieved by optimising the economic efficiency objective function. The optimum of a multicriteria objective function with more than a couple of terms is much more difficult to interpret.

Concerns about sustainability obviously will not be reflected in an ordinary cost benefit framework. The discounting procedure may not give the intended weight to the interests of future generations, and the market prices or willingness to pay of individuals may not reflect the true long term costs of resources used. The cost benefit framework will have to be modified on these two points to reach an objective function that truly can be said to reflect sustainability. The way we have done it, and the reasoning behind it, is described in section 5.4 and in chapter 7. Basically, however, the cost benefit framework has been retained for the sustainability objective function, too. This allows for easy comparisons between the results of applying the two objective functions.

5.3 Choices relevant to the economic efficiency objective function

5.3.1 Cost benefit analysis

In a cost benefit framework, to calculate the net present value of a strategy, the changes in costs and benefits relative to a «do nothing» or «do minimum» strategy are calculated for each year of a given period of calculation. These changes are the net benefits that accrue to the different categories of people that are affected by the strategy: the travellers, suppliers and operators, government and third parties. The net benefits of each of these groups are added together and discounted to a common comparison year. The sum of the discounted net benefits for each year and each affected group is the *net present value of the strategy* (supposing investment costs are included in the net benefits).

This framework calls for decisions on (among other) the discount rate, the period of calculation, the comparison year, the supposed first year of operation of the strategy, what values to use to evaluate the travel time savings and external effects, how to evaluate user (travellers') benefits, how to treat taxes, whether or not to include a shadow price of public funds, and how to impute net benefits for the years not actually predicted by the transport model. The key decisions are treated below, while less crucial decisons are treated in chapter 7, where the economic efficiency objective function is described in detail.

5.3.2 User benefits

We consider Neuberger (1971) to be a good theoretical foundation for multimodal cost-benefit analyses of transport. Neuberger discusses three methods of evaluation of user benefits in transport. His *first* method is essentially the minimization of total cost of travel for a given origin-destination (OD) matrix. This is the method of cost-benefit analysis that is used by road authorities in many countries. It is inapplicable in our case, partly because we will wish to consider changes in the OD matrix, and partly because it is *essential* for us to consider changes in modal split. But travellers' mode choices are not based on cost (monetary and time) minimization alone, but also involves comfort etc. This is recognized in the transport model, and so an evaluation procedure that does not recognize it, is at variance with the transport model as well as with the whole purpose of our study.

Neuberger's *second* method is «the rule of a half». Let total user benefits in the whole transport system under consideration be UB. The formula for UB is then:

$$(5.1) \quad UB = \frac{1}{2}\sum_{i,j,k}\left(T^1_{ijk} + T^2_{ijk}\right)\left(G^1_{ijk} - G^2_{ijk}\right)$$

where superscripts 1 and 2 on the T's and G's refer to the original or «do nothing» situation and the situation when a strategy has been implemented, respectively, (i,j) is a pair of origin and destination, and k is a mode. T_{ijk} is the amount of travel from i to j by mode k, and G_{ijk} is generalized cost of travel from i to j by mode k. All of these data are easily obtained from the transport model.

A value of time must be applied to add travel time and travel expences to form a generalized cost G_{ijk}.

The problems with this second method fall broadly under three headings:

It may be a crude approximation to the true benefit. Very strong assumptions are needed for generalized cost to be formed, and additional strong assumptions for UB to be an exact measure of the benefits from the changes in generalized costs. The error is more likely to be substantial if the changes are very great.

It is inapplicable when new modes are introduced. In such cases, G^1 is infinite. However, the analysis could be made at such an aggregate level that the question does not arise.

It is also useless in evaluating land use plans. This is because the generalized costs will be unaffected by the changes in land use, at least if there is not congestion everywhere. To put it differently, the benefit of living in another place, or of moving populations, is not at all measured.

It may be possible, though, to assess the effectiveness of policy measures other than land use plans under different land use scenarios. From this, conclusions on what land use scenario is to be preferred may be reached.

We propose to calculate user benefits by the rule of a half. This is because it is not found feasible to apply Neuberger's *method three* to all of the transport models. This method utilizes the demand functions implicitly contained in the transport model to calculate consumer surpluses. It would have been better suited to the evaluation of land use plans. In other respects, the difference between method three and the rule of a half is usually thought to be minor.

5.3.3 Values of time

To calculate the generalised costs of the user benefit measure (5.1), a set of values of time is needed, differentiating between travel purposes and possibly between modes, and taking account of the mean number of riders per vehicle. On the one hand, the need for comparison between the cities favours that the same values are used in each city. On the other hand, for consistency between evaluation and the prediction of travel behaviour, a different set of values should be used for each city, each set reflecting the implicit values of the behavioural model.

This problem cannot be solved entirely satisfactory. We think that some discretion could be given to the cities on this point. The standard set of values should be those of the EVA manual. Provided the structure of the values are broadly in line with the EVA manual, each city could use values that mirrors more closely the implicit values of their model, or the official values used for cost benefit analyses in their country.

5.3.4 What external effects to include

Chapter 4 tells us that it is not feasible to include both noise, accidents and local pollution in the economic efficiency objective function of every city. For inclusion in a cost benefit framework, noise and local pollution requires additional modelling after the transport model has been run. If some of these effects are included by some cities, but not all, it makes comparisons more difficult.

Accidents may be included for those cities that are able to output this effect. However, if they do, they should also be able to report whether or not the found optimum would be appreciable changed by not including accidents.

Noise and local pollution are not included in the economic efficiency objective function. Along with accidents, they are however reported for they cities where these indicators are available. It may then be possible to pass judgments on whether or not their inclusion would have changed the found optimum.

5.3.5 Taxes

The following choices are made for the economic efficiency objective function:

Investment costs, including costs of land, is generally entered with all taxes included, and there is no change in tax revenue on the government side. If however, the construction company is exempted from some taxes, the loss in tax revenue that results from this is added to investment costs.

The social cost of fuel is net of all taxes. This is accounted for by entering these costs as they are perceived by the users and operators, and then adding the revenue from fuel and car taxes on the government side.

All other resources are valued including taxes, and changes in the use of them inside the transport sector is not thought to influence tax revenue.

The reasons for these rules are firstly, that they are simple, and secondly, that they are theoretically sound

- if the investment packages are of a magnitude that is able to replace other ongoing production and construction activity in the local region. As there exists someone who would be willing to pay up to the after tax price for these resources, the social cost of using them for the investment project instead is their after tax price.
- if most of the labour power used for investment and operating purposes have to be drawn from the ranks of the already employed, and
- if fuel is elastically supplied.

Changes in operating costs (except fuel) and maintenance costs will, we think, not be of major importance in the evaluation of most policy packages, time savings being the most important factor in the effiency evaluation. This is why we propose to treat the cost of materials parts of maintenance and operating cost (except fuel) on a par with labour costs, that is, with taxes included, and without considering changes in tax income. This simplifies the calculations without distorting them very much.

5.3.6 The discount rate

The discount rate should reflect society's trade-off between consumption now and consumption later, and the technical possibilities of transferring consumption between periods. Probably it should be fairly closely tied to the return on a private investment of average risk.

We have agreed to use a discount rate between 6 and 9%. Each country where the government has fixed a rate to use in cost-benefit analyses of transport plans will use its own (UK 8%, Norway 7%).

5.3.7 Shadow price of public funds

In most cases, the transport companies will be subsidized to maintain certain public transport levels, or at least they would be subsidized if they where to run a deficit. The changes in the result are therefore changes in public subsidy. In these cases, we propose to multiply the changes in results by a shadow price of public funds, to take account of the distortionary effects of taxes.

Taxpayers' money may also be saved by surpluses in publicly run toll collection agencies and parking agencies. Tolls and parking fees may be considered transfers, but these transfers cannot altogether be ignored, because it goes into what determinates the behaviour of the travellers, and so it has to be included as a cost for the travellers and a gain for the collection agencies. As it saves taxpayers' money, surpluses for the governmental agencies should be multipied with the shadow price of public funds.

The importance of multiplying with the shadow price of public funds can be seen when toll schemes are a part of the strategy. The cost of running the toll scheme must be included on the goverment side, but the gain from saving taxpayers' money may partly offset this cost, making toll schemes an effective way of raising public funds, in addition to the benefits for traffic.

The shadow price of public funds is set at 1.25.

When making these guidelines operational, it was decided that the shadow price is applied to *increases* in the *total* cost of operators, providers and government, but *not* to decreases. The economic meaning of this is that taxes will have to be increased to finance an increase in total costs of operators, providers and government, that is, that operators and providers can recover their cost increases by increases in public subsidies, whereas any decrease in total cost is kept by those who benefit from it, and will not result in tax changes.

5.3.8 Calculation period, start year (year when measures begin to take effect), interpolation procedure, price level and comparison year

The models are run for one year (the horizon year or test year). As it will be convenient for the different cities to use slightly different horizon year (ranging from 2010 to 2015), the following procedures are adopted to calculate the net present value of a strategy:

The calculations are carried out for a 30 year period. The year when measures begin to take effect, is set at, say, 14 years ahead of the horizon year. The discount rate should be set at between 6 and 9 %, as indicated above. It is assumed that the net benefit of the horizon year is obtained in every year of the 30 year period. This coarse approximation may on one hand overestimate the benefits of the first years, as it takes some time to phase in the measures and for travellers to adapt their behaviour. On the other hand, this overestimation may be offset because the net benefit of the horizon year is obtained at a certain level of exogenous factors like income levels and car ownership levels. In the earlier years of the period, exogenous factors probably would have given a higher net benefit if the measures had been fully operational at that time.

If the undiscounted net benefit of the horizon year is b and the discount rate is r, the formula for the present value of the net benefits of all years (excluding investments) is

$$(5.2) \quad B_1 = \sum_{i=1}^{30} \frac{1}{(1+r)^i} b$$

The formula for the net present value (the economic efficiency objective function) is then

$$(5.3) \quad W = B_1 - I$$

where I is investment costs. Investment costs should include interest in the construction period, using the discount rate as the rate of interest.

All prices should be 1996 prices.

The interpolation rule (5.2) is just a coarse way of transforming the net benefit of the only year that is actually modelled into a present value. It should not be taken to mean that the yearly net benefits evolve in exactly this way.

Observe that W for the cities with 2015 as horizon year is the net present value of year 2001, whereas the W of cities with 2010 as horizon year is a net present value of year 1996. As the difference in 0-years is only a matter of convenience (easier comparison between cities), the W of the former should not be discounted to 1996.

5.4 Choices relevant to the sustainability objective function

5.4.1 An operational concept of sustainability

The treatment of sustainability in this section relies on notes on a series of lectures given by Geoffrey Heal at the University of Oslo in 1995 (Heal 1995). The Chichilnisky criterion is also treated in a the paper by Beltratti, Chichilnisky and Heal (1995).

We propose a sustainability objective function that essentially differs from a cost-benefit measure only in prices of resources and in the discounting procedure. The reasoning is as follows:

Sustainability becomes a concern only when

1. We care about the (very) distant future
2. We care about the flow of services from the stock of resources, not only about consuming these stocks

Ignoring both of these points, a non-renewable resource should be depleted according to the socalled «Hotelling's rule», with consumption falling each year and assymptotically reaching zero.

If we introduce point 2, that stocks provide services by not being consumed, but retain the normal discounting procedure, the solution to the dynamic utility maximization problem typically will be that the resource should be run down to a certain level and be kept there forever. At this level, the marginal utility of the services from the remaining stock equals the marginal utility of consumption of the stock at the point where no consumption takes place. For such a level to exist, the consumption of the stock must be *inessential*. Man must be able to survive without the consumption of this ressource.

If the stock has some regenerative power, of course at this point some consumption will take place, consumption equalling regeneration. But still there will be a period before this point, where consumption is either higher or lower than regeneration, and slowly moving towards the regeneration rate.

Now, this kind of solution will still treat future generations less favourably than present generations. Graciela Chichilnisky has proposed an objective function that is a weighted mean of the usual (cost-benefit, utilitarian, discounted) objective function and the undiscounted sustainable utility level that will obtain when no consumption of the stock is allowed. The first term she calls «a dictatorship of the present» and the second term «a dictatorship of the future». She has shown that any objective function that is neither a dictatorship of the present nor a dictatorship of the future, and that obeys some other axioms like Pareto-efficiency, has this form of a mix of the two terms.

Applying the Chichilnisky criterion, consumption of the resource at all times will be lower than in the case of the benefit-cost criterion where utility is derived both from services of the stock and from consuming the stock, and the moment where consumption stops will arrive sooner. This last criterion will in turn give lower consumption than in the Hotelling case, and furthermore in the Hotelling case the moment when consumption stops never comes.

There may also be a fourth criterion. It may be named «the green golden rule». It tells us to maximize the utility that obtains when time goes to infinity, that is the sustainable utility level. Applying this, the solution is to retain the entire stock of nonrenewable ressources, and to consume renewable ressources at the regeneration rate. This is obviously a «dictatorship of the future». No weight is attached to the consumption of present generations. Consequently, with the green golden rule, today's investments will carry no weight on the cost side. Investments that only have impacts in the short term, will not influence the benefit side either - only the long term benefits will count.

Summing up, the four possible criteria for the depletion of a nonrenewable resource may be characterized this way:

1. *Consumption of the resource only gives utility, services of the stock does not. The net present value is used as a criterion.* This gives a dictatorship of the present, and no sustainable utility level.
2. *Services of the stock gives utility, too. The net present value is used as a criterion.* This gives a dictatorship of the present, but if the resource is inessential in consumption, there is a sustainable utility level.
3. *Chichilnisky criterion* (the same as 2, but a nondiscounted sustainable utility level is added). This treats present and future more symmetrically.
4. *Green golden rule.* This is a dictatorship of the future, because only the sustainable utility level is considered. It may be possible to increase utility for present generations by choosing a path toward this utility level other than the one that introduces the sustainable utility level immediately. Generally, therefore, the green golden rule is not Pareto-efficient.

Clearly, only the last two of these criteria can be a basis for formulating a sustainability objective function, when sustainability has the two distinguishing features of taking care of the interests of future generations, and recognizing the utility derived from stocks.

Along the different optimal paths given by the first three of these criteria, shadow prices of the resources will change with time. For a nonrenewable resource, the shadow price will increase as the resource is depleted.

5.4.2 Application to our case

The resources consumed by urban transport have a value both in consumption and as a stock. The stock of fossile fuels delivers a stream of services consisting of stable atmospheric conditions. The stock of unused land delivers a stream of services consisting of outdoor life, skiing, mushroom gathering, bird song etc. The stock of old urban buildings and the built environment delivers services of a cultural and aestetic nature. The stock of clean air and silence - the only one of these stocks that is easily renewable - delivers services to the mental and physical health of the inhabitants.

This calls for an application of the Chichilnisky criterion. As long as we use only one horizon year (run the models for only one year for each strategy), this can however only be done in a hybrid way. What we do, is

1. define the resources whose depletion may hurt the utility of future generations
2. define the levels of stocks of these resources that must be kept constant forever from a certain point of time
3. define the restrictions on urban transport that must hold if these levels of stocks are to be kept constant
4. assume that the point of time from which the resources are to be kept constant is the horizon year of the transport model
5. assume that the level of the exogenous factors in the transport model for the horizon year, are compatible with constant levels of the defined resources
6. include the restrictions of point 3 into the objective function, weighted by shadow prices that, if applied as market prices, are thought to be able to just bring about the fullfillment of the restrictions for the optimal strategy
7. allow for the fact that the level of the exogenous factors in the transport model for the horizon year may be incompatible with the required constant levels of the defined resources, or that the shadow prices are too low to bring about the fullfillment of the restrictions. In that case, the horizon year must after all only be seen as a step towards the final sustainable situation. To secure that the urban transport system at least moves in the right direction towards sustainability, a weaker restriction with a higher penalty attached should also be included in the objective function
8. use the mathematical expression of the Chichilnisky criterion to derive an expression for the sustainability objective function on the assumption that the horizon year's transport is in fact sustainable and that the chosen shadow prices reflect the true value of the resources in that sustainable situation.

Regarding point 1, we chose to concentrate on the resource of stable global atmospheric conditions. We also considered the resource of urban land, but decided to leave it out from the sustainability function because the required changes in land use in the different strategies were difficult to quantify.

The resources of townscape and landscape are taken care of in the formulation of the land use scenarios, as explained in chapter 3. The resources of clean air and silence are easily renewable and need not be considered in this context.

Regarding point 2, instead of defining directly what is to be meant by stable global atmospheric conditions, we use expert opinion on what reductions in fossile fuel consumption is necessary to bring this about. We then assume that at least the same reduction that is required in the overall level of fuel consumption for the European countries, is required in the sector of urban transport (point 3).

5.4.3 Sustainable fuel consumption

To formulate the target level (the restriction of point 3) for fuel consumption, we assume that CO_2 emission levels and fuel consumption levels are proportional. This means that there is no change in the type of fuel used. Despite experiments with electric cars etc., such proportionality is not too unrealistic for transport in the time period we are considering.[1]

A fairly *strong* assumption on what the sustainable fuel consumption level is, is 40 % of present consumption levels. An overall (not transport specific) target for CO_2 of this magnitude has been advocated by The Intergovernmental Panel on Climate Change. (Still higher targets for transport may be expected from OECD in the near future).

The base year of our transport models vary between 1988 and 1995, but most of them use 1990 or 1991 as the base year. Broadly, this accords with the base year of most official goals on CO_2 emission. For transport in our cities to be sustainable in the horizon year (2010 - 2015), it seems reasonable, then, to require a fuel consumption of 40% of the level of the base year of the transport model.

Assumptions must be made as to how much can be achieved through increased fuel efficiency, and how much by changes in travel behaviour. We assume that fuel consumption per vehicle kilometre is halved in the period between the base year and the test year (approximately 25 years). This technical development is not reflected in our models. That is, if our models show for instance zero change in fuel consumption from the base year, a 50% reduction will in fact have been accomplished.

The remaining reduction from the 50 to the 40% level is therefore achieved if our models can show a 20% reduction from the base year. However, we want to compare fuel consumption not with the base year level, but with the level of the «do minimum» of the horizon year. Taking into account the growth of traffic from the base year to the horizon year in the «do minimum», a reduction of 40-50% from the «do minimum» is probably required.[2]

By this admittedly very loose reasoning we reach the conclusion to use a *50% reduction from the «do minimum» level* as the sustainability fuel consumption target level.

It seems doubtful, however, that a 50% reduction can be achieved by the measures that we are considering.

5.4.4 The function of the penalty function

In the sustainability objective function we have introduced a penalty for transgressing a certain fuel consumption level (point 7). Strategies that incurs this penalty will either simply be thrown away or get a very small weight in the weighted regression to find optimal strategies. Of course we do not want most of our initial transport model runs to be largely wasted or

[1] Some of our cities has plans to expand the use of electric cars, natural gas driven buses etc.. Assuming proportionality when deciding on the fuel consumption constraint, this measure can easily be modelled as a softening of the constraint on fuel consumption.

[2] If traffic grows by 1% annually and there is no change in modal split, a reduction of 40% is required. If traffic grows by 2%, 50% is required.

ignored in the subsequent work. As it obviously will be difficult to find even an optimal strategy that is able to reduce fuel consumption by 50%, the penalty must not be incurred at this level.

We *do* however want to ignore or throw away strategies that is not able to fullfill even the weakest requirements on sustainability. Applying a weak concept of sustainability, the required reduction in fuel consumption should perhaps be 25% from the base year. Again assuming a doubling of fuel efficiency, this translates to a 50% *increase* in fuel consumption as measured in our transport models. If the fuel consumption of the horizon year in the «do minimum» is 50% above the base year, this means that *the penalty is incurred if a strategy increases fuel consumption from the «do minimum»*. This is our proposal concerning the penalty function.

5.4.5 Shadow prices of fuel

In theory, the shadow price of fuel (point 6) should be the price that was able to reduce fuel consumption to the sustainable level (50%) if applied as a market price. Obviously, what price this is depends on the level of the other instruments. I assume that the fuel price will be an instrument in our strategies. The shadow price of fuel is set right if it is possible to achieve a 50% fuel reduction when we use the shadow price level as the level of our fuel price instrument and use the *optimal level* of all other instruments.

Only experiments can show what the right shadow price is. For a start, we try a shadow price of fuel of 4 times the current level.

5.4.6 Strong and weak sustainability

In the sustainability objective function, the constraint that urban transport should be weakly sustainable is absolute. Therefore a high penalty is attached to fuel consumption levels that breaks this constraint. To put it differently, all strategies that breaks this constraint are discarded. Strong sustainability is sought for, but not at any cost. The shadow price of fuel is the penalty paid for not reaching strong sustainability. It is much lower than the penalty. By using both the penalty function and the correction term with the shadow prices, we are able to uphold two different concepts of sustainability.

At the same time, we also have an instrument to shift emphasis from weak to strong sustainability. This is the parameter α (see chapter 7). Although the coefficient of the correction term and the penalty function is the same, as α goes from 1 to 0, emphasis is shifted towards strong sustainability by dimishing the importance of investment costs and increasing the importance of the constraints.

5.4.7 The sustainability objective function

We remember from (5.3) of section 5.3.8 that W denotes the value of the social efficiency objective function. That is, W is the net present value of a strategy, calculated by ordinary cost benefit analysis. Letting α be the weight attached to the welfare of the present generation, b be the net benefit of the horizon year, y the correction term that we use to convert the perceived fuel costs into real resource costs (the weak penalty), and z the strong penalty imposed on a strategy that is not even weakly sustainable, the sustainability objective function becomes:

$$(5.4) \quad V = \begin{cases} \alpha W + (1-\alpha)(b-y-z) & \text{if fuel consumption exceeds Do Minimum level} \\ \alpha W + (1-\alpha)(b-y) & \text{otherwise} \end{cases}$$

The reasoning behind (5.4) is more fully explained in section 7.3.

5.4.8 Conclusion

The sustainability objective function takes as its basis the economic efficiency objective function, but with the added restrictions that fuel consumption for transport purposes is to be kept within sustainable levels. Two target levels are defined. The easiest level to achieve is associated with a very high penalty if the level is not reached. This level may be associated with the concept of weak sustainability. The hardest level to achieve is associated with a shadow price of fuel that is set tentatively at 4 times the present level. This restriction is derived from targets set by climate experts, and may be associated with the concept of strong sustainability.

Instead of discounting the net benefits of the horizon year, the sustainability objective function applies a weight on investments relative to the net benefits that is derived from the mathematical expression of the Chichilnisky criterion by assuming that the horizon year is sustainable. This topic is treated in chapter 7.

5.5 What objectives do the functions reflect?

The economic efficiency objective function can be said to reflect the cities' objectives of overall efficiency of the transport system, economising with resources, accessibility within the city and at least the *possibility* of economic regeneration.

The sustainability function reflects the same objectives, too, but in addition reflects concerns about the global environment, and (at least to the extent that public transport is more energy saving than private car) the needs for a modal shift away from the private car mode.

5.6 Comments from the cities

The broad outline of the objective functions are found acceptable by the cities that have commented them. However, as we have already noted, Edinburgh stated that accidents had to be included for the optimisation to be of interest to them. This comment has led us to open up the possibility of including accidents for the cities that can do so.

5.7 Adaptions to each city, and the possibility of making changes in the objective functions as work on the project progresses

We have opened the possibility for each city to use values of time that are more consistent with the implied values of the transport model or the official values in use in their countries than the standard EVA manual values. Discount rates can also be chosen in accordance with standard practice of each country, but within the bounds of 6-9%. Accidents may be included in the objective functions provided it can be ascertained how this inclusion affects the optimum.

The tentative shadow price of fuel may have to be revised in the light of experience with the models.

6 INDICATORS THAT ARE NOT OPTIMIZED IN THE PROJECT

As shown in chapter 7, the results of each run of the model are gathered into two tables. The benefits to travellers from a transport strategy are given for each mode and travel purpose, and the monetary benefits are shown separately from the travel time benefits. The benefits to operators and the government are also shown separately, providing an opportunity to assess financial feasibility. Other objective functions than those optimised in this project are easily obtained by omitting some of the entries (for example time savings) and adding other indicators not entered in the table, but easily obtained from the models.

For each city's model, the available indicators not included in the objective functions are listed below:

Edinburgh: CO_2, noise, accidents, accessibility indicators

Merseyside: CO_2, noise, CO, accidents, accessibility indicators

Wien: travel performance, environment, accidents, accessibility indicators

Eisenstadt: travel performance, environment, accidents, accessibility indicators

Helsinki: CO_2, CO, hydrocarbons, NOXes, particles. Noise model under construction.

Torino: noise and other emmissions

Salerno: noise, private vehicle emmissions

Oslo: CO_2, NOXes, CO_2 equivalents, accessibility indicators

Tromsø: public transport operating costs

7 OVERVIEW OF THE ELEMENTS OF THE OBJECTIVE FUNCTIONS, AND DISPLAY OF THE RESULTS

7.1 The efficiency objective function

7.1.1 Table 1

Table 1 shows how the results of a run of the transport model are evaluated using the effiency objective function, and what kind of information is needed to do so. The table is adapted from table 4.3 in «The Common Appraisal Framework» (MVA Consultancy et al 1994). We first go through the table on the assumption that it is the benefits and costs of the horizon year that is to be entered in the table (sections 7.1.2-7.1.9). Then in section 7.1.10, these yearly benefits and cost are converted to present values for the whole calculation period, using discounting and an appropriate interpolation procedure. (See table 1.)

7.1.2 Darkly shaded cells

In the darkly shaded cells, nothing is entered. For example, no time savings accrue to operators and providers, and no capital outlays are required for travellers. We also assume that, for instance, the public transport operators does not invest in highways, and that neither public transport companies, nor parking operators or toll collection companies have vehicle operating costs.

7.1.3 Numbered cells

In the cells numbered 1-9, capital costs and operational costs that are not obtained from the transport model are entered. The particular set of measures that are tested in this run, will imply a certain amount of investment *beyond the do-minimum level*, and a *change* in the cost of operation for the highway authority (government), the parking and the toll collection agencies. Adding up the costs of each measure from information gathered in Work package 20, the appropriate numbers to enter are obtained.

Observe that the cost of a change in land use for transport purposes is included in the investment costs. Both erecting a toll ring, providing parking space and increasing road capacity uses land. The market price of land plus the present value of property taxes on it, is used. These calculations must be done outside this table, as land is not specified a a row of its own.

Table 1 Economic and financial benefits

Run number ....

All entries are present values at 1996 prices

Source of benefits (costs)	Travellers				Operators/providers					Total
	Non-working	*Working*	*Freight*	*All*	*PT operator*	*Parking*	*Toll*	*Government*	*All, adjusted*	
Capital assets										
Highway								1		
Public transport					2			3		
Other						4	5	6		
Total capital assets										
Money savings										
Maintenance and other cost, highways						7	8	9		
Toll revenue	A	A	A				A			
Parking fee revenue	A	A	A			A				
Fuel costs	A	A	A					A		
Other vehicle operation	A	A	A					A		
Sub-total highways										
Operating cost public transport					B			B		
Other money savings public transport	A	A	A		A					
Sub-total public transport										
Total money savings										
Time savings										
Time savings highway	A	A	A							
Timesavings public transport	A	A	A							
Time savings cycling	A	A	A							
Time savings walking	A	A	A							
Total time savings										
ALL MONEY AND TIME										

7.1.4 Cells marked «A»

The numbers to enter in these cells are calculated from the formulas given in the Appendix. The information needed consists of OD-matrixes from the transport model, both for the «do minimum» and for the particular set of measures tested, plus information on costs and time for each {origin, destination, mode, travel purpose, time of day}-combination. A set of values of travel time is needed to monetarize the cost of travel time.

Observe that it is necessary to split fuel and other operating costs. This may have to be done in an approximate way.

Observe that parking fees and toll revenue are entered twice - as a cost to the travellers and income for the operators. It is assumed that parking companies and toll collectors pay no tax (darkly shaded areas in the «government» column). On the other hand, the two «A»'s in the government column is the change in tax revenue from fuel taxes and other car taxes. The tax element of fuel and other elements of vehicle operating costs must therefore be identified.

The row «Other money savings public transport» contains four «A»'s. The first three is the benefit from changes in fares for travellers, while the fourth is changes in income for the public transport operator.

All of the «A»'s for travellers are calculated using the rule of a half, as the formulas show.

7.1.5 Cells marked «B»

These cells have been marked out because to calculate them, we need information that may not be so easy to get. On one hand, the measures include a certain level of service of the public transport companies. It should be possible to get estimates of operating costs from these companies based on this. On the other hand, the output from the transport model may indicate that in some cases, the originally planned level of service is insufficient to transport all passengers that choses public transport. This may call for revisions of the tested strategy.

The tax element of operating costs must also be identified and entered in the «government» column.

7.1.6 All, adjusted

For each row, the entry in this column is the sum of all entries for operators, providers and government. For the row «Total money savings», the horizontal sum over operators, providers and government is multiplied by 1.25 if it is negative. This is why the column is called «All, adjusted». No such multiplication is made if the sum is positive, though. The reasoning behind this is set out in section 5.3.7.

7.1.7 Totals and sub-totals

Blank cells are either totals or sub-totals. The summation is easily done by inserting the summation formula in the spreadsheet.

7.1.8 The sign of the entries

For any agent (column), costs are given a negative sign and benefits a positive sign.

7.1.9 Adaption

Table 1 may easily be adapted to the needs of each city. For example, many cities have more than one public mode, so the public mode rows should be expanded accordingly. A couple of cities (Oslo, Helsinki) have car ownership submodels. They may want to add a row to record time dependent (distance independent) car costs and car taxes, but this is by no means necessary, as the «total» of the row will be 0.

7.1.10 Conversion to net present value

The calculations are carried out for a 30 year period. The year when measures begin to take effect, is set at, say, 14 years ahead of the horizon year. The discount rate should be set at between 6 and 9 %, as indicated above. It is assumed that the net benefit of the horizon year is obtained in every year of the 30 year period. This coarse approximation may on one hand overestimate the benefits of the first years, as it takes some time to phase in the measures and for travellers to adapt their behaviour. On the other hand, this overestimation may be offset because the net benefit of the horizon year is obtained at a certain level of exogenous factors like income levels and car ownership levels. In the earlier years of the period, exogenous factors probably would have given a higher net benefit if the measures had been fully operational at that time.

If the undiscounted net benefit of the horizon year is b and the discount rate is r, the formula for the present value of the net benefits of all years (excluding investments) is

$$(7.1) \quad B_1 = \sum_{i=1}^{30} \frac{1}{(1+r)^i} b$$

The formula for the net present value (the economic efficiency objective function) is then

$$(7.2) \quad W = B_1 - I$$

where I is investment costs. Investment costs should include interest in the construction period, using the discount rate as the rate of interest.

All prices should be 1996 prices.

Observe that W for the cities with 2015 as horizon year is the net present value of year 2001, whereas the W of cities with 2010 as horizon year is a net present value of year 1996. As the difference in 0-years is only a matter of convenience (easier comparison between cities), the W of the former should not be discounted to 1996.

To fill in table 1 with present values rather than benefits of the horizon year, the formula (7.1) is applied to each relevant cell of the table, rather than to the total net benefit b. It might, however, be better to keep table 1 as a table of the costs and benefits of the horizon year, and makes the conversion to present values outside the table.

7.2 The sustainability objective function

7.2.1 Table 2

Computing and displaying the sustainability function is a matter of some small changes from the table 1. The changes are entered in table 2.

1. Table 2 consists of four columns. The first one is an adjusted version of the «Total» of table 1. The adjustment first consists of a weighting of the entries in the capital assets rows. The weight is discussed in section 7.3.3 and is shown in formula (7.6) of that chapter. The second adjustment consists of the conversion of the yearly net benefits of table 1 into net present benefits.
2. The second column gives the correction term for the fuel costs. The correction term for fuel has the form (minus shadow price) x (fuel costs) plus (shadow price) x (half the DO minimum fuel costs). It is a penalty for transgressing the strongly sustainable fuel consumption level.
3. The third column gives the penalty for transgressing the weakly sustainable level of fuel consumption. It is entered in the only unshaded cell.
4. Both the second and third columns are weighted using a weight that is shown in formula (7.6) of section 7.3.3.
5. The fourth column gives the new totals.

Table 2. Sustainability

Run number ....

All entries are present values at 1996 prices

Source of benefits (costs)	Totals from table 1	Shadow price correction	Penalty function	New total
Capital assets				
Highway				
Public transport				
Other				
Total capital assets				
Money savings				
Maintenance and other cost, highways				
Toll revenue				
Parking fee revenue				
Fuel costs				
Other vehicle operation				
Sub-total highways				
Operating cost public transport				
Other money savings public transport				
Sub-total public transport				
Total money savings				
Time savings				
Time savings highway				
Timesavings public transport				
Time savings cycling				
Time savings walking				
Total time savings				
ALL MONEY AND TIME				

7.3 Applying the Chichilnisky criterion

7.3.1 The criterion

The Chichilnisky criterion tells us to maximise an intertemporal welfare function that is a weighted average of the utility of present and future generations, the utility of each generation being a function of both the consumption of resources and the services they render as stocks. By future generations, we mean generations living under sustainable conditions, and by the utility level of future generations we mean the utility from a consumption pattern that can be continued forever. It can be shown that if we want our welfare function to incorporate the principles of «no dictatorship of the present generation», «no dictatorship of the future generations», Pareto optimality and some more technical principles, the Chichilnisky criterion must be applied.

Mathematically, the criterion can be expressed as

$$(7.3) \quad Max\left\{\alpha\int_0^{\infty} u_t(c_t,s_t)e^{-rt}dt+(1-\alpha)\lim_{t\to\infty}u_t(c_t,s_t)\right\} \text{ given resource constraints.}$$

Here, $u_t(.)$ is the utility level at time t, and c_t and s_t are consumption and stock levels at this instant. So the first term is an ordinary present value function, and the second term is the undiscounted utility level that prevails in the distant future. The two terms are weighted by α and $(1 - \alpha)$. If $\alpha = 1$, the welfare function is called a «dictatorship of the present», and if $\alpha = 0$, it is called a «dictatorship of the future».

7.3.2 Problems of application

Formally, our interpolation procedure gives us the increases in social utility from a certain package of policies for each year of a period of thirty years. If a sustainable situation is reached within this time period, the data for the application of the Chichilnisky criterion is at hand.

From the very nature of sustainability, the interpolation procedure that we apply should be B_2 (see section 7.3.3), that is, from the horizon year on, nothing is assumed to change. We cannot assume that once a sustainable situation is reached, the development in the years after is away from sustainability. This is the meaning of taking limits in the second term of the Chichilnisky criterion.

For simplicity, we have, however, decided to use B_1, that is, the interpolation rule (5.2), in the sustainability function also, giving us the rather simple formula of (5.4).

Of course, it must be conceded that the social utility of 29 of these 30 years is only assumed and not actually predicted from model runs. The application of the Chichilnisky criterion would undoubtedly be less of a formality if the model was run for more than one test year. The last of the test years would then have to be «sustainable» for the criterion to be applied. With only one test year, checks to secure that this year is «sustainable» must be incorporated for the criterion to be applied.

Regardless of the number of test years, the strong assumption underlying our application of the Chichilnisky criterion, and in fact underlying *any* sustainability objective function for transport policy evaluation, is that the policy outside the transport sector is able to secure a sustainable situation in the economy as a whole from the very moment when transport policy is sustainable. This means that exogenous factors in the transport model remain constant from the last test year on, and that these constants have a certain maximum value.

There is one more problem with applying the formula (7.3) when constructing the sustainability objective function. The formula tells us to include the utility derived from the level of stocks in the objective function. Our transport models do not produce data on these kinds of benefit (the benefits of clean air, the recreational value of forests and parks, etc.). This problem is solved by incorporating a shadow price of fuel and land in the objective function.

Fuel consumption means consumption of stocks like stable atmospheric conditions, forests in the region, the stock of urban environmental qualities and the health of the urban population. Likewise, land use draws on the stock of agricultural land, recreational sites, old urban buildings etc. Fuel consumption can perhaps even be used as a proxy for accidents. In principle, when the shadow prices are set at the right level, a marginal reduction in the consumption of fuel and land for transport purposes has a value in the objective function that reflects the marginal utility derived from stocks like these. Of course, in practice it will be impossible to fix the shadow prices that reflects the marginal utility of stocks in an adequate way.

7.3.3 Application in the case of only one test year

To see how the Chichilnisky criterion is applied in our case, we introduce the following terminology:

b is the net benefit of the test year.

B_1 and B_2 are present values of the stream of net benefits from a policy package, the first one using the constant benefit b for the whole 30 year period, the second one using linear interpolation up to the test year, and constant net benefits thereafter. The formulas for B_1 and B_2 are given below. If we introduce δ_1 and δ_2 by setting

$$\delta_1 = \sum_{i=1}^{30} \frac{1}{(1+r)^i} \cdot \quad \text{and} \quad \delta_2 = \sum_{i=1}^{t} \frac{1}{(1+r)^i} \cdot \frac{i}{t} + \sum_{i=t+1}^{30} \frac{1}{(1+r)^i},$$

then we can set

(7.4) $B_1 = \delta_1 b$ and $B_2 = \delta_2 b$.

y is the annual correction terms for fuel and land, that is, a term that is the difference between the shadow cost of these resources and the perceived costs of them. y is subtracted from the economic efficiency objective function to arrive at the real long term social cost of fuel and land consumption.

-z is the penalty that is subtracted from the economic efficiency objective function in case of fuel consumption above the sustainable level.

V* is a first version of the sustainability objective function. It is a function of the chosen weight of present versus future generations' utility. Let I be investment costs.

(7.5)

$$V^*(\alpha) = \alpha(B_2 - I) + (1-\alpha)(b - y - z) =$$

$$\left(\frac{1-\alpha}{\delta_2} + \alpha\right)B_2 - (1-\alpha)(y+z) - \alpha I = \left(\frac{1-\alpha}{\delta_2} + \alpha\right)\frac{\delta_2}{\delta_1} B_1 - (1-\alpha)(y+z) - \alpha I$$

The first equation in (7.5) is a direct application of (7.3), given that the test year is sustainable. The last equation in (7.5) shows how the sustainability function is derived from the economic efficiency objective function W = B_1- I. It seems reasonable to rescale V* by dividing through with $\left(\frac{1-\alpha}{\delta_2} + \alpha\right)\frac{\delta_2}{\delta_1}$. It also seems natural to demand that the sustainability objective function is 0 for the do-minimum alternative. Let us call the shadow price correction term in the «do minimum» for y_0 and the penalty function of the «do minimum» for z_0. This gives us second version of the sustainability function:

(7.6) $$V(\alpha) = B_1 - \frac{(1-\alpha)\delta_1}{1-\alpha+\alpha\delta_2}\left((y-y_0)+(z-z_0)\right) - \frac{\alpha\delta_1}{1-\alpha+\alpha\delta_2} I$$

If, for simplicity, we use B_1 instead of B_2, we immediately get formula (5.4) from formula (7.5). This is the course that was decided upon in the OPTIMA project. Virtually the same formula is arrived at by setting $\delta_1 = \delta_2 = \delta$ in (7.6). The only difference is that this modified (7.6) is bigger than (5.4) by a factor of $\delta/(1 - \alpha + \alpha\delta)$, and that it will be 0 for the Do Minimum. Any of these formulations - (5.4), modified (7.6) or modified (7.5) - will give the same results in the optimisation process.

7.3.4 Differences between V and W, and how V changes with parameters

If α is equal to 1, there is no difference between V and W. If on the other hand $\alpha = 0$, the only things that matter is the net benefit and the resource use in the sustainable situation. Investments carry a zero weight, reflecting the total disregard of the utility of present generations.

The nearer α is to 0, the stronger can our concept of sustainability be said to be. For any α below 1, investments cost less in the sustainability function than in the economic efficiency function. This is a reflection of our concern for future generations. Also, obviously, investments that are able to bring about a more sustainable situation are more rewarding than other investments.

These characteristics of the objective function are exactly what we want.

Were it not for the weight attached to investment costs, it would be of no importance to fix the shadow prices and the penalty accurately. An adjustment of α could counteract any change of the shadow prices and penalty. For the moment, therefore, we consider it good enough to fix the shadow prices in a subjective way. What matters is the general structure of the objective function. Also, parameters of (7.6) can be experimented with easily without having to rerun the transport model. The aim of such experimentation is to see what changes from W to V is necessary to change the ranks of the different initial runs. The changes that we may consider is in α, the discount rate and thereby δ_1 and δ_2, the shadow prices and penalty, and the level of fuel consumption that we consider to be sustainable.

Much of this experimentation can be carried out algebraically from (7.6). The weight attached to the middle term is convex and dimishing in α, while the weight on investment is concave and increasing in α.

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Formulas — Appendix 1

A.1 Indices

Let indices i and j refer to zones, m to modes, p to travel purposes and k to time of day. Index the runs of the transport model by n, and let n = 0 be the «do minimum» run for the horizon year.

A.2 Generalised cost and its elements

A.2.1 Constants

We use the following notation:

Constants are greek letters. They are the same in all strategies. The constants that go into generalised costs are:

- ρ_{mp} is the pre-tax fuel cost per vehicle kilometre of mode m and for purpose p. The reason that it differs among purposes, is to allow for a difference between trucks and private cars in the private car mode.
- σ_{mp} is the pre-tax- non-fuel cost per vehicle kilometre of mode m and for purpose p.
- φ_{mp} is the fuel tax rate for mode m and purpose p. Of course, it may be the same for all or most modes and purposes.
- χ_{mp} is the tax rate on distance dependent car costs other than fuel, if such taxes exist.
- μ_{ijmpk} is the toll or road pricing fee on travel from i to j by mode m, for purpose p and by time of day k. Of course the only m for which it is non-zero is private car.
- π_{jmk} is the parking fee at destination j and at time of day k for mode m. Of course, the only m for which it is non-zero is private car.
- β_{ijmk} is the public transport fare for a trip from i to j by mode m and at time of day k. Of course it is non-zero for public modes only.
- τ_{mp} is the value of in-vehicle travel time for mode m and purpose p. It may be taken from EVA or official national values.
- υ is the proportional increase in the time value τ_{mp} that is used for access (walking) to and from the mode.
- ω is the proportional increase in the time value τ_{mp} that is used for waiting time.

A.2.2 Policy variables

Policy variables are lower-case x-es. We may not use all the policy variables defined here. However, it is better to keep the opportunity of using them open. By the definition of the policy variables, we have excluded the possibility to study changes in the *structure* of taxes and fares, though. The policy variables are fixed for each strategy, and is therefore of course indexed by n. They are:

- x_1^n is the fuel tax rate level (= 1 in the «do minimum» case).
- x_2^n is non-fuel distance dependent car tax rate level (= 1 in the «do minimum» case).
- x_{3k}^n is the level of tolls at time of day k (= 1 in the «do minimum» case).
- x_{4k}^n is the level of parking fees at time of day k (= 1 in the «do minimum» case).
- x_5^n is the level of public transport fares (= 1 in the «do minimum» case).
- x_{7m}^n is the frequency of public transport mode m (= 1 inthe «do minimum» case).

For the sake of brevity, let x(n) be the vector of (continous) policies of strategy n. **x**(0) = (1,1,...,1).

A.2.3 Strategy dependent variables

Strategy dependent variables are not policy variables in themselves, but may be influenced by the policy variables. They are either output from a run of the transport model, input to a run of the transport model or are created by some simple manipulation on these inputs and outputs. We denote the strategy dependent variables by upper case letters. To begin with, we define eight types of them:

- D_{ijm}^n is the distance between i and j using mode m.
- H_{ijmk}^n is the in-vehicle travel time from i to j by mode m at time of day k.
- A_{ijm}^n is the access (walking) time when going from i to j by mode m.
- W_{ijm}^n is the waiting time when going from i to j by mode m.
- C_{ijmpk}^n is the monetary cost of going from i to j by mode m for purpose p at time of day k.
- F_{ijmk}^n is the fare when going from i to j by mode m at time of day k. Of course, it is zero for all but the public modes.
- E_{ijmpk}^n is the time cost of going from i to j by mode m for purpose p at time of day k.
- G_{ijmpk}^n is the generalized cost of going from i to j by mode m for purpose p at time of day k.

Both for constants and for strategy dependent variables, tables (matrixes) of these data will consist of all zeros for some modes, for example. Also, tables for different purposes and times of day may be identical. We think this is harmless and may make it easier to set up a computation programme that is flexible enough to be used together with different models.

A.2. 4 Formulas

(1) $[(1 + x_1^n\, \varphi_{mp})\, \rho_{mp} + (1 + x_2^n \chi_{mp})\, \sigma_{mp}]\, D_{ijm}^n + x_{3k}^n\, \mu_{ijmpk} + x_{4k}^n\, \pi_{jmk} = C_{ijmpk}^n$

(2) $(H_{ijmk}^n + \upsilon\, A_{ijm}^n + \omega\, (1/x_{7m}^n)\, W_{ijm}^n)\, \tau_{mp} = E_{ijmpk}^n$

(3) $x_5^n \beta_{ijmk} = F_{ijmk}^n$

(4) $G_{ijmpk}^n = \begin{cases} F_{ijmk}^n + E_{ijmpk}^n & \text{if m is a public mode} \\ C_{ijmpk}^n + E_{ijmpk}^n & \text{otherwise} \end{cases}$

Formula (1), that gives monetary travel costs, is largely irrelevant for all other modes than private car. For example, slow modes (walking/cycling) will have $C_{ijmpk}^n = 0$. For public modes, the constants ρ_{mp} and σ_{mp} may be available or not. They will, however, have rather little economic meaning, because there are economics of scale and scope in the production of public transport. If the constants are unavailable, (4) shows that this will not influence the calculation of generalised cost for public modes. The cost of operators and providers are treated in section A.5.

A.3 Time dependent car costs

A.3.1 Variables

For models with a car ownership module, changes in time dependent car taxes may be of interest. Although such changes do not influence travel behaviour of those owning a car, it influences the number of car owners. Through this it influences modal split. Although there is no need to record changes in time dependent car ownership taxes in table 1 (a mere transfer), car taxes can be an instrument.

The mean annual pre-tax cost of car ownership is taken as a constant. Annual car tax in «do minimum» is also taken as a constant. When multiplied with the policy variable x_6^n it produces the annual car tax in strategy number n. The resulting figure is probably an input in the car ownership model.

The variables are.

- η is the mean annual pre-tax cost of car ownership.
- ξ is annual car tax in «do minimum».
- x_6^n is the level of annual car taxes (= 1 in the «do minimum» case).
- J^n is the annual cost of car ownership.

A.3.2 Formula

(5) $(1 + x_6^n \xi)\eta = J^n$

A.4 User benefits

A.4.1 Variables

- T_{ijmpk}^n is the number of trips by from i to j by mode m and for purpose p at time of day k.

- UB_{mp}^{n} is the user benefit for all travellers using mode m for purpose p.
- UBT_{mp}^{n} is the benefits from time savings part of Ub_{mp}^{n}.
- UBC_{mp}^{n} is the benefits from monetary savings part of Ub_{mp}^{n}.
- UB_{m}^{n}, UBT_{p}^{n} etc. are defined naturally by summing over all modes or purposes.
- UB^{n} is defined by summing over all modes and purposes.

Run number 0 of the model, the «do minimum», is special in that its elements of cost and its number of trips enter all formulas below. These data are therefore an additional required list of variables.

A.4.2 Formulas

$$(6)\quad UB_{mp}^{n} = \frac{1}{2}\sum_{k}\sum_{i}\sum_{j}(G_{ijmpk}^{0} - G_{ijmpk}^{n})(T_{ijmpk}^{n} + T_{ijmpk}^{0})$$

$$(7)\quad UBT_{mp}^{n} = \frac{1}{2}\sum_{k}\sum_{i}\sum_{j}(E_{ijmpk}^{0} - E_{ijmpk}^{n})(T_{ijmpk}^{n} + T_{ijmpk}^{0})$$

$$(8)\quad UBC_{mp}^{n} = \begin{cases} \frac{1}{2}\sum_{k}\sum_{i}\sum_{j}(F_{ijmk}^{0} - F_{ijmk}^{n})(T_{ijmpk}^{n} + T_{ijmpk}^{0}) & \text{for public modes} \\ \frac{1}{2}\sum_{k}\sum_{i}\sum_{j}(C_{ijmpk}^{0} - C_{ijmpk}^{n})(T_{ijmpk}^{n} + T_{ijmpk}^{0}) & \text{otherwise} \end{cases}$$

Formulas (7) and (8) follow from (4) and (6).

In table 1, four modes (entered in rows) and three travel purposes (entered in columns) have been defined. Models with a different number of modes or purposes may want to adjust table 1 to get all modes and purposes into the table. The present value of the results of formula (7) for every mode and purpose can now be entered in the mp = 12 cells of the «Time savings» part of table 1. This of course requires that the number of trips and time costs of run number 0 has been recorded.

The present value of the result of formula (8) for the public transport mode (or summed over all public modes) can also be entered in table 1. Its place is the row «Other money savings public transport».

We now turn to the «highways» part of table 1. In it, the monetary costs of the private car mode(s) is split into toll, parking fees, fuel costs and other costs. Substituting for C_{ijmpk}^{n} in (8) by inserting (1), this split is easily obtained, and the «Money savings/travellers» part of table 1 can be filled in. The explicit formulas for this split are not written down here. It is the present values that are to be entered.

Summing horizontally and vertically, the various (present value of) UBC_{p}^{n}, UBC_{m}^{n}, UBT_{p}^{n}, UBT_{m}^{n}, UB_{p}^{n}, and UB_{m}^{n} is obtained. UB^{n} will be the «All money and time/travellers all» cell.

A.4.3 The car passenger mode

Our models treat car passengers differently. If car passengers is a mode of its own, the formulas given above should apply.

If on the other hand an average number of passengers per car is assumed, then this may already have been reflected in the values of time for car travel, given as constants earlier. The level of T_{ijmpk}^{n} for m = private car should then be obtained by dividing the number of trips made by private car by the average number of passengers per car plus one (the driver). If this is what is done, the formulas given above should again apply.

To obtain a data programme that caters for all possibilites, we will formally enter car passengers as a mode of its own, whether or not it is modelled as such. This mode will not be used if passengers' value of time has already been included in the private car mode. Consequently, we assume now that car passengers retain their own values of time (which might be identical to the values of time of other modes, of course), but their number of trips may or may not stand in a fixed proportion to the number of drivers' trips.

Denoting the car passenger mode m*, formula (1) will become $C_{ijm*pk}^{n} = 0$. Formula (2) and (4) will apply to this mode as to any other. Formula (8) will apply, but the result is 0. Formula (7) will apply, but T_{ijm*pk}^{n} and T_{ijm*pk}^{0} that are inputs to the formula, may stand in a fixed proportion to the number of trips for car drivers' mode.

A.5 Operators and providers' cost

A.5.1 Variables

We need now to define a list of new variables that are purely external to the transport models. They are not instruments, not output or input to the transport models, but are specific for each strategy and therefore not constants. We denote these variables by lower case letters.

The input to the numbered cells of table 1 are such variables, but for brevity's sake we do not give them names (there are no formulas for them). It suffices to remind that all these entries are to be multiplied by $(1 + \lambda)$, the shadow price of public funds, but that this is done in the «all, adjusted column».

Constant

- $(1 + \lambda)$ is the shadow price of public funds. $(1 + \lambda) = 1.25$.

Lower case variables

We can now turn to the «A» and «B» cells of the operator part of table 1.

- c^{n} is the operating cost of public transport operators.
- k^{n} is the operating cost of parking facilities' operators
- q^{n} is the operating cost of road pricing and toll schemes.
- u^{n} is the pre-tax fuel cost of public transport operators.
- o^{n} is the pre-tax other cost of public transport operators.

- g^n is the financial result of public transport operators.
- h^n is the financial result of parking facilities' operators
- j^n is the financial result of road pricing and toll schemes operators.
- i^n is the tax revenue from PT operators.
- p^n is the tax revenue from fuel taxes.
- r^n is the tax revenue from other distance dependent car taxes.

A.5.2 Parking

$$(9)\quad h^n - h^0 = \sum_k \sum_p \sum_m \sum_i \sum_j \left(x_{4k}{}^n \pi_{jmk} T_{ijmpk}{}^n - x_{4k}{}^0 \pi_{jmk} T_{ijmpk}{}^0 \right) - \left(k^n - k^0 \right)$$

The present value of the result is entered in the «A» cell of the parking column of table 1.

A.5.3 Toll

$$(10)\quad j^n - j^0 = \sum_k \sum_p \sum_m \sum_i \sum_j \left(x_{3k}{}^n \mu_{ijmk} T_{ijmpk}{}^n - x_{3k}{}^0 \mu_{ijmk} T_{ijmpk}{}^0 \right) - \left(q^n - q^0 \right)$$

The present value of the result is entered in the «A» cell of the toll column of table 1.

A.5.4 PT operator

$$(11)\quad c^n = \left(1 + x_1{}^n \varphi_{m''p}\right) u^n + \left(1 + x_2{}^n \chi_{m''p}\right) o^n$$

where m'' is the public transport mode. In case of more than one public mode and different tax rates for each of them, a further subdivision of costs is called for.

Naturally, the tax rate does not vary across travel purposes in (11), but as the constant is taken from the list of constants, it has two indices.

By multiplying through in (11) by $1 \Big/ \sum_{ij} D_{ijm''}{}^n$, the $\rho_{m''p}$ and $\sigma_{m''p}$ of formula (1) may be had.

But as the variables of (11) and the factor of multiplication depend on the strategy n, for the most part it will not be appropriate to enter $\rho_{m''p}$ and $\sigma_{m''p}$ in the list of constants.

$$(12)\quad g^n - g^0 = \sum_i \sum_j \sum_m \sum_k \left(F_{ijmk}{}^n \left(\sum_p T_{ijmpk}{}^n \right) - F_{ijmk}{}^0 \left(\sum_p T_{ijmpk}{}^0 \right) \right) - \left(c^n - c^0 \right)$$

The present value of the income part of (12) is entered at «A» and the present value of the cost part at «B» in the «PT operator» column of table 1.

A.5.5 Government

The present value of the change in the tax revenue from PT operators is entered at «B» in the Government column of table 1. It is the present value of:

(13) $$i^n - i^0 = \left(x_1{}^n \varphi_{m''p} u^n + x_2{}^n \chi_{mp} o^n - x_1{}^0 \varphi_{m''p} u^0 - x_2{}^0 \chi_{mp} o^0\right)$$

The present values of the change in fuel tax revenue from private cars and the change in other distance dependent car tax revenue are entered at the «A»'s.

These changes are:

(14) $$p^n - p^0 = \sum_i \sum_j \sum_p \sum_k \left[x_1{}^n \varphi_{m'p} \rho_{m'p} D_{ijm'}{}^n T_{ijm'pk}{}^n - x_1{}^0 \varphi_{m'p} \rho_{m'p} D_{ijm'}{}^0 T_{ijm'pk}{}^0 \right]$$

(15) $$r^n - r^0 = \sum_i \sum_j \sum_p \sum_k \left[x_2{}^n \chi_{m'p} \sigma_{m'p} D_{ijm'}{}^n T_{ijm'pk}{}^n - x_2{}^0 \chi_{m'p} \sigma_{m'p} D_{ijm'}{}^0 T_{ijm'pk}{}^0 \right]$$

where m' is the private car (driver) mode.

When summing across operators and modes in table 1, the economic efficiency indicator is found as the sum total in the corner cell of the table.

A.6 Discounting and interpolating

Except for investment costs (the «capital assets» entries) it is the present values of the results from these calculations that are to be entered in table 1. An interpolation procedure is used to ascribe benefits to years other than the horizon year.

This calls for another constant in the list of constants. By deciding on a discount rate r the appropriate constant can be found by setting b = 1 in formula (5.2) of chapter 5. We have called it δ_1.

Constant

- $\delta_1 = \sum_{i=1}^{30} \frac{1}{(1+r)^i}$, which is a constant once r have been decided upon.

Strategy dependent variables

- $B_1{}^n$ is the sum of the totals column in table 1, except the «capital assets» entries. It depends on both strategy n and strategy 0.
- I^n is the negative of the sum of the «capital asset» entries of the totals column of table 1. It depends on both strategy n and strategy 0.
- W^n is the economic efficiency indicator.
- b^n is the undiscounted net benefit of the horizon year.

Formulas

(16) $W^n = B_1{}^n - I^n$

(17) $B_1 = \delta_1 b^n$

A.7 Formulas for sustainability

A.7.1 Variables

- $\delta_2 = \sum_{i=1}^{t} \frac{1}{(1+r)^i} \cdot \frac{i}{t} + \sum_{i=t+1}^{30} \frac{1}{(1+r)^i}$
- α is a chosen weight between 0 and 1
- y^n is a «correction term»
- z^n is a «penalty function»
- V^n is the sustainability indicator
- p_1 is the shadow price of fuel. A level of 4 is suggested.
- p_2 is the shadow price of land.In Optima, it is set to 0.
- p_3 is a penalty. A level of 1000?
- l^n is the market value of land used for transport purposes.

A.7.2 Formulas

$$(18) \qquad V^n = B_1^{\ n} - \frac{(1-\alpha)\delta_1}{1-\alpha+\alpha\delta_2}\left(\left(y^n - y^0\right) + \left(z^n - z^0\right)\right) - \frac{\alpha\delta_1}{1-\alpha+\alpha\delta_2} I^n$$

Formula (18) computes the sustainability indicator. How the different parts of the formula is to be entered in table 2, is covered in chapter 6.

In OPTIMA, we have decided to use δ_1 instead of δ_2 and B_1 instead of B_2 for the sustainability calculations. After rescaling, this gives the formula (5.4).

When $z^n - z^0$ is negative (fuel consumption is less than the do-minimum), we do not want this to be counted as a benefit. Although it has not been explicitly stated in (18), if this term is negative, it is in fact removed from the formula in the spreadsheet version of table 2. This is also reflected in formula (5.4). *For manual calculations, please note that z^n should be set to 0 if it is negative.*

$$\begin{aligned} y^n = p_1 \Bigg(& \left(1 + x_1^{\ 0}\varphi_{m''p}\right)u^n + \sum_i \sum_j \sum_p \sum_k (1 + x_1^{\ 0}\varphi_{m'p})\rho_{m'p} D_{ijm'}^{\ \ n} T_{ijm'pk}^{\ \ n} \\ (19) \qquad & - \frac{1}{2}\left(\left(1 + x_1^{\ 0}\varphi_{m''p}\right)u^0 + \sum_i \sum_j \sum_p \sum_k (1 + x_1^{\ 0}\varphi_{m'p})\rho_{m'p} D_{ijm'}^{\ \ 0} T_{ijm'pk}^{\ \ 0}\right)\Bigg) \\ & + p_2\left(l^n - l^0\right) \end{aligned}$$

The first two terms of the big parenthesis of formula (19) gives you fuel expenditure in the n-th run valued at the «do minimum» tax rate, that is, 1996 market prices. Half of the fuel expenditure of the «do minimum» is then deducted. The whole of the big parenthesis is then an indicator of fuel consumption above the weakly sustainable level. A penalty of p_1 is imposed on fuel consumption exceeding half of the «do minimum» level. A similar term for land use is added.

y^0 is positive. Its purpose in (18) is just to scale the objective function so that $V^0 = 0$.

(20)
$$z^n = p_3\Bigg(\left(1 + x_1{}^0\varphi_{m''p}\right)u^n + \sum_i\sum_j\sum_p\sum_k (1 + x_1{}^0\varphi_{m'p})\rho_{m'p}D_{ijm'}{}^n T_{ijm'pk}{}^n$$
$$-\left(1 + x_1{}^0\varphi_{m''p}\right)u^0 - \sum_i\sum_j\sum_p\sum_k (1 + x_1{}^0\varphi_{m'p})\rho_{m'p}D_{ijm'}{}^0 T_{ijm'pk}{}^0\Bigg)$$

Formula (20) imposes a high penalty for transgressing the «do minimum» fuel consumption level. $z^0 = 0$, but is retained in (18) for symmetry.