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Optimisation Of Policies For Transport Integration In Metropolitan Areas

Report on Work Packages 30 and 40

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1. INTRODUCTION

1.1 Overall objectives

The overall objectives of Project OPTIMA are:-

(i) to identify optimal urban transport strategies for a range of urban areas within the EU;
(ii) to compare the strategies which are specified as optimal in different cities, and to assess the reasons for these differences;
(iii) to assess the acceptability and feasibility of implementation of these strategies both in the case study cities and more widely in the EU; and
(iv) to use the results to provide more general guidance on urban transport policy within the EU.

There is 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. It is now generally accepted that the overall strategy for achieving these objectives must include an element of reduction of private car use and transfer of travel to other modes. The policy instruments for achieving these objectives can include infrastructure provision, management measures to enhance other modes and to restrict car use, and pricing measures to make public transport more attractive and to increase the marginal cost of car use. It is now widely accepted that the most appropriate strategy will involve several of these measures, combined in an integrated way which emphasises the synergy between them.

The most appropriate strategy for a city will depend on its size, the current built form, topography, transport infrastructure and patterns of use; levels of car ownership, congestion and projected growth in travel; transport policy instruments already in use; and the acceptability of other measures in political and legislative terms. These will differ from city to city. Policy advice cannot therefore be generalised, but must be developed for a range of different types of city. This is the approach adopted in this study, in which nine different cities in five countries (Edinburgh, Merseyside, Vienna, Eisenstadt, Tromsø, Oslo, Helsinki, Torino and Salerno) have been studied in detail, using a common study methodology. This report summarises the output of two work packages in OPTIMA:

WP30: Test Combinations of Policy Instruments
WP40: Identify Optima

1.2 Overview of the optimisation process

The overall structure of the project can be understood by reference to the optimisation method used in WP40. A "basic method" for optimisation is illustrated in Figure 1.

Step 1 defines the objective functions used in OPTIMA: economic efficiency measured by Net Present Value (NPV) and the Sustainability Objective Function (SOF). The definition of these functions was part of WP10, and is fully described in the report from that work package. It is summarised in Section 2.

Step 2 specifies the policy measures that have been used for finding optima. The work involved with this was part of WP20, and is described fully in the report of that work package. It is summarised in Section 3. In particular, Section 3 lists the basic common set of measures tested in each city. These measures can be divided into "discrete" measures or "continuous" measures. Discrete measures are one-off infrastructure projects which are either fully built or not built at all. On the other hand, continuous measures could be implemented at any level within a range appropriate to the measure. Standardised ranges have been decided upon for OPTIMA. However, some cities have diverged slightly from some of the standard ranges where these were not considered appropriate. Section 3 also gives the cost assumptions made in each city for the measures.

Step 3 involves using a transport model in each city to model an initial set of 18 policy combinations, chosen according to an orthogonal design from the ranges specified in Step 2. A brief summary of the transport models used in OPTIMA is given in Section 4. In particular a distinction is made between two generic types of model used in the project: "strategic" models and "tactical" models. The work in Step 3 formed the early part of work in WP30.

Steps 4 to 6 involve an iterative process of transport model running and linear regression. This process, which formed the latter part of WP30 and all of WP40, is described fully in Section 5. In general, there is a "basic" optimisation method and a "comprehensive" optimisation method, with the basic method being illustrated fully in Figure 1. In the comprehensive method, further objective functions and further measures can be introduced to the method, without the necessity of starting the whole process from the beginning.

Section 6 gives summary results from the optimisation process by providing tables showing the optimum runs for each city in terms of both NPV and SOF. Comments are made on both a city-by-city basis and a measure-by-measure basis.

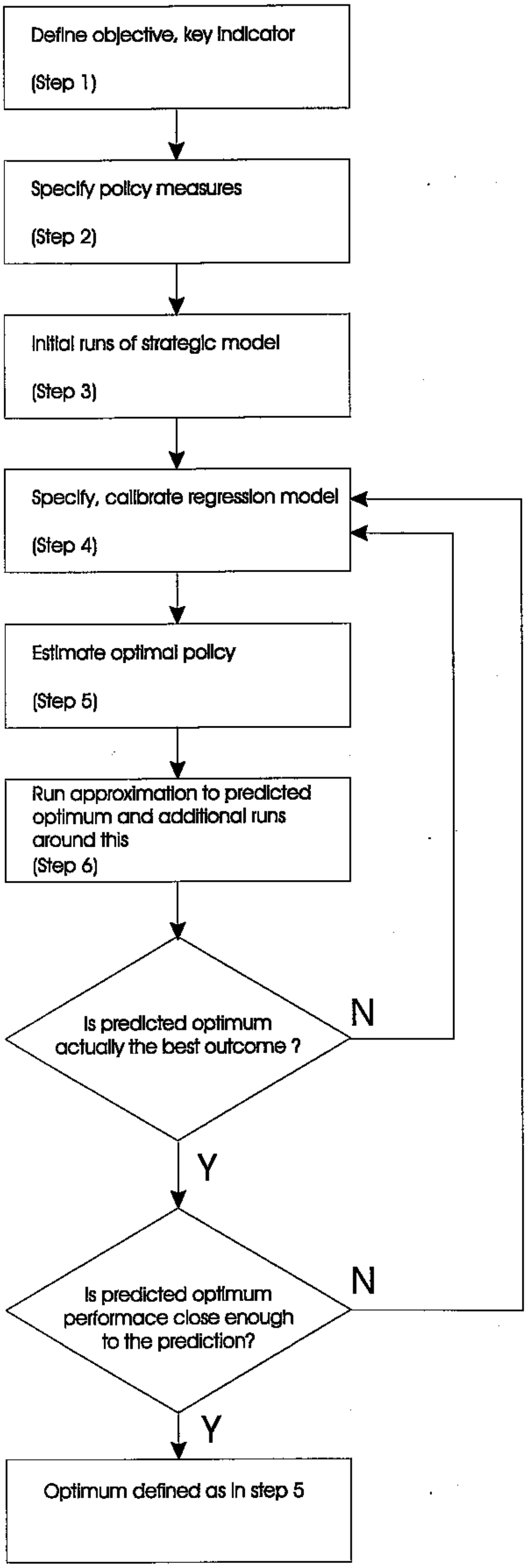

Fig. 1: The optimisation process

2. DEFINITION OF OBJECTIVE FUNCTIONS

Work Package 10 defined two objective functions: Economic Efficiency Function (EEF), measured by Net Present Value (NPV) and a Sustainability Objective Function (SOF). WP10 is fully documented in OPTIMA (1997a). This section summarises the most important inputs from WP10 to WP 30 and WP 40. Section 2.1 gives an overview of the rationale behind the objective functions. Section 2.2 defines Present Value of Finance (PVF) which is used in the calculation of the two objective functions, whilst Subsections 2.3 and 2.4 make definitions of NPV and SOF respectively.

2.1 Overview of objective functions

The Economic Efficiency Function (EEF) performs a cost benefit analysis of the tested policy. The optimisation with regard to this function is essentially to find the policy with the best NPV of social benefits and costs.

The Sustainability Objective Function (SOF) differs from the EEF in that the exhaustible resource of fossil fuel is valued more highly than its market price, and that a penalty is incurred for those policies that do not meet a certain minimum requirement on fossil fuel savings. These features of the SOF reflect the aim to reduce CO_2 emissions. Also, costs and benefits are only considered for the horizon year, representing the interests of future generations.

In the EEF, time savings are valued in the traditional way, by attaching a value of time to these savings. The value of time may differ between travel purposes. User benefits consist of travel time savings and monetary savings. Together they form a Consumer Surplus that is calculated by the so-called «rule of a half». Various operators and the government may also be affected by the policy. How the time savings and monetary benefits and costs are distributed among travellers, operators and taxpayers can be shown in a table for each policy tested (and feature in Appendix B).

In the SOF, the same elements are included, but their importance is diminished, as fuel saving becomes more important.

2.2 Present Value of Finance (PVF)

The Present Value of Finance (PVF) of a measure is defined as the net financial benefit of the measure to government and other providers of transport facilities, both public and private.

In the OPTIMA study, where only one future target year is being modelled, PVF is defined as:

$$(2.1) \quad PVF = -I + \sum_{i=1}^{30} \frac{1}{(1+r)^i} * f$$

where: I is the present value of the cost of infrastructure investment, compared to the do-minimum scenario;
f is the net financial benefit to transport suppliers in the modelled target year, compared to the do-minimum scenario, taking into account both revenue and operating costs;
r is the annual (country specific) discount rate.

2.3 Net Present Value (NPV)

The present value (NPV) of net benefits, B, over a 30 year period is given by:

$$(2.2) \quad B = \sum_{i=1}^{30} \frac{1}{(1+r)^i} * (f+u)$$

where: u is the net benefit (in money and time savings) to transport users in the target year, compared with the do-minimum scenario.

Two comments can be made here:

(i) Equations 2.1 and 2.2 implicitly assume that the transport strategy is implemented immediately and that benefits apply immediately. An alternative can be used in which revenues, benefits and costs are assumed to increase incrementally over the 30 year period.

(ii) The present value of net benefits for the do-minimum scenario is, by definition, zero.

The formula for NPV is then:

$$(2.3) \quad \begin{aligned} \text{NPV} &= \text{B - I} + 0.25{*}\text{PVF} && \text{if PVF} < 0 \\ &= \text{B - I} && \text{if PVF} > 0 \end{aligned}$$

Equation 2.3 reflects the concept of “shadow price of public money”, which is taken from the literature, as 1.25, and is brought into the NPV calculation if there is a net loss in supplier finance (as measured by PVF).

2.4 Sustainability Objective Function (SOF)

The "pure" sustainability objective function (SOF) is given by:

(2.4) b-y-z (if fuel consumption exceeds do-minimum)
b-y (otherwise)

where y is a "weak penalty" on fuel consumption in the target year (calculated by multiplying the fuel consumption cost by a shadow price of 4) and z is a "strong penalty" on fuel consumption in the target year (a large value taken as 1000 Mecu, which ensures that no package of measures can be selected if it increases fuel consumption from the do-minimum)[1].

In this 'pure' function, current investment is not considered at all. However, it is also possible to define an objective function V_α that is a weighted average of NPV and SOF.

Thus:

$$V_\alpha = \alpha NPV + (1-\alpha)SOF \quad (2.5)$$

3. POLICY MEASURES

3.1 Summary of measures

Work Package 20 made an inventory of traffic measures in each of the nine OPTIMA test case cities. A full description of this inventory is given in OPTIMA (1997b), and a summary is shown in Table 1. This inventory was based upon information supplied by city officials specifically for the OPTIMA project. It can be seen that there is a distinction between:

(1) Measures already in use
(2) Measures planned
(3) Measures already rejected.

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[1] If the assumption is made that vehicle fuel efficiency will increase by 100% between the base year and the target year, it follows that the strong penalty is implemented if fuel consumption falls by less than 50% between the base year and target year.

		Edinbı			Merse			Vienn			Eisen			Helsin			Torino			Salern			Oslo			Troms		
		U	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**	**U**	**P**	**R**
A	**Infrastructure measures**																											
1	New road construction		x	x	x	x		x			x				x			x			x		x	x		x	x	
2	Parking supply, off-street	x									x										x					x		
3	Rail services	x	x		x	x		x						x	x			x			x		x	x				
4	Light rail		x			x									x		x	x			x		x					
5	Bus (tram) lanes							x						x			x	x					x					
7	Park and ride	x	x		x	x		x						x				x			x							
9	Traffic calming (speed humps, wide pavements)							x			x			x									x	x				
10	Cycle routes, lanes, paths	x				x		x			x			x	x						x		x	x				
11	Pedestrian areas, pedestrianisation	x	x		x			x			x			x				x			x		x			x	x	
B	**Management measures**																											
3	Traffic calming in residental areas	x			x	x		x			x			x									x	x		x	x	
4	Traffic calming on radials			x																								
6	Regulatory restrictions on car use																x				x							
7	Reduce on-street parking	x			x	x								x										x			x	
8	Parking controls			x							x			x									x				x	
11	Bus (tram) priorities		x		x	x		x						x			x	x										
12	Bus lanes		x											x	x		x	x			x		x					
14	Modified service levels of bus and rail services		x		x						x			x	x						x		x				x	
15	Improve the reliability of bus services					x								x			x											
D	**Pricing measures**																											
2	Fuel taxes							x						x									x			x	x	
4	Parking charges	x			x	x		x			x			x			x	x					x				x	
6	Public transport fare levels		x					x						x			x	x					x				x	
8	Road pricing		x			x										x							x	x				x
E	**Land use measures**																											
2	Densities of population and employment																x	x			x						x	
3	Development within transport corridors													x									x	x				
4	Development mix																											
			U IN USE																									
			P PLANNED																									
			R REJECTED																									

Table 1. Summary of the measures most commonly mentioned by all cities.

Furthermore, there is a categorisation of measures into: infrastructure measures, management measures, pricing measures and land use measures[2]. An initial list of all possible measures was generated from an international review, which included practice in other EU countries. A brief description of the main measures in each of these categories (and their usage in the nine cities) is given in Section 3.2 below. A detailed description of the cities can be found in the fully-documented project report of WP20 (OPTIMA, 1997b).

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[2] Information measures were considered briefly. However, since it is not feasible to model them on the level required by the OPTIMA project, they are not considered further.

From this list of measures, a condensed common set of measures was identified for use in the optimisation process. This set is presented in Section 3.3, along with the cost assumptions made for the measures.

3.2 Types of measure

Table 1 groups the measures as they were categorised in the survey of city authorities. Only those measures which were discussed widely are listed.

3.2.1 Infrastructure measures

In all cities road construction is seen as an important measure, as well as the construction of pedestrian areas. Construction of public transport infrastructure depends on the present public transport system and on the size of the city (and thus varies from city to city).

Bus and/or tram lanes are used or planned in the larger cities. Light rail systems are being planned in many cities and are already in use in Torino and Oslo. Park and ride facilities are being constructed in the larger cities and off-street parking facilities are being constructed in the smaller cities. Traffic calming infrastructure measures are used in the Austrian cities, Helsinki and Oslo. Construction of cycle routes, lanes and/or paths has been reported for all cities except for Torino and Tromsø.

3.2.2 Management measures

Traffic calming through management measures is used in all other cities except the Italian ones. As an alternative, Torino has regulatory restrictions on car use; such a measure is also being planned for Salerno. On-street parking is being reduced in the British cities and in Helsinki, and there are plans to do likewise in the Norwegian cities.

Bus and tram priorities are used in many cities. Also promoting public transport by management measures such as improved level of service or reliability has been reported for all cities except for Vienna.

3.2.3 Pricing measures

All cities except Salerno are using parking charge levels as a demand management measure. Road pricing is used in Oslo, planned in the British cities but has been rejected in Tromsø and Helsinki.

Using public transport fare levels as a demand management measure has also been reported for most of the cities. Apart from the small cities, Merseyside is the only larger city not to report it.

3.2.4 Land use measures

Land use measures are reported vaguely. Control of development, development within transport corridors and making the city structure more dense are the most common measures reported.

The transportation models used in OPTIMA were not adequate for representing land use measures. However, some land use sensitivity analysis has been carried out for the optimisation work carried out in Tromsø, and this is reported in Section 6.2.6 below. Furthermore, there is a parallel project to OPTIMA, involving ITS, in which the OPTIMA transportation model is linked up to a land use model to create a combined land-use-transportation model. This combined model is being used to make a land use sensitivity analysis on the OPTIMA results for Edinburgh, and the results are reported in Deliverable 2 (OPTIMA, 1997c).

3.3 Measures tested in the optimisation process

Based upon the inventory of measures reported above, a set of common measures was selected for use in the optimisation process. Table 2 shows these measures and the maximum ranges considered (some cities used narrower ranges where it was felt that the maximum range was simply infeasible). The criteria for selection of measures were that the measures:

- Were common to all nine case study cities (either already used or planned)
- Could be modelled by all the nine city-specific transportation models
- Were likely to be used or planned in a large number of cities throughout Europe
- Were (or arguably should be) controlled by the city authorities

Extra measures were introduced into the Merseyside optimisation process (as part of the "Comprehensive Method" to be defined in Section 5 below) by distinguishing between long-term and short-term parking charges and between peak and off-peak public transport frequency. The ranges for all these measures were as given in Table 2.

Tables 3 and 4 show the assumed costs used in the calculation of the two objective functions. These costs are based upon currently used costs in the cities for the purposes of cost benefit analysis.

Table 3 shows the assumed capital costs (in each of the nine cities) for road capacity changes, public transport infrastructure, and road pricing. It can be seen that there was wide variation across cities for both public transport infrastructure and road capacity changes. In the case of public transport infrastructure, this is not surprising since the infrastructure measures being considered varied widely between cities. In the case of road capacity changes, there might have been expected to be some correlation between cost and city size. In the sense that the "small cities" (Eisenstadt, Tromsø and Salerno) all had negligible costs for road capacity changes, this expectation is borne out. However, there is clearly wide variation amongst the larger cities. A sensible way of dealing with this variation is to conduct sensitivity tests of the type which examine the impact on City A's results if City B's costs were to be used. Tests of this sort were carried out and are reported in Appendix B.

.Table 4 shows the annual operating costs (in each of the nine cities) for public transport frequency changes and road pricing. It can be seen by comparing Table 3 and Table 4 that (with the exception of Merseyside) road capacity increases were generally costed at a much lower level than public transport infrastructure. Furthermore, it can be seen that in some cities (notably Oslo and Helsinki) the cost of increasing public transport frequency (which must be paid out year after year) was high compared with the cost of a one-off increase road capacity.

Abbreviation	Name	Minimum Value	Maximum Value
IH	High public transport infrastructure investment	0	1
IM	Medium public transport infrastructure investment	0	1
CAP	Increasing/decreasing of road capacity (whole city/town)	-20%	+20%
FREQ	Increasing/decreasing public transport frequency	-50%	+100%
RP	Road pricing #	0	10.0 ecus
PCH	Increasing/decreasing parking charges	-100%	+500%
FARE	Increasing/decreasing public transport fares	-100%	+100%

Table 2: Measures tested

The value of the measure Road Pricing refers to the cost per trip incurred to the car driver (typically into a city centre)

Road capacity changes	Edin-burgh	M'side	Vienna	Eisen-stadt	Tromsø	Oslo	Helsinki	Torino	Salerno
-20%	50	176	40	4	12	93	5	137	0.02
-10%	31	88	20	2	6	46	4	69	0.01
-5%	16	44	10	1	3	23	2	34	0
+5%	2	44	53	0.2	6	46	11	28	0
+10%	15	194	106	0.3	12	93	22	48	0
+20%	34	494	*	*	25	185	86	*	*
P.T. infrastructure									
High p.t. infrastructure	564	360	4254	*	*	494	780	3459	45
Medium p.t. infrastructure	35	40	2127	*	*	*	420	671	0.5
Road pricing	2	4	52	3	0	0	4	0.3	0.1

* *indicates "not costed"*

Table 3:Capital costs of new measures (in million ecus)

Change in p.t. frequency	Edinburgh	M'side	Vienna	Eisen-stadt	Tromsø	Oslo	Helsinki	Torino	Salerno
-50%	-16	-69	-162	-1	-6	-170	-130*	-69#	-4
+50%	+16	+69	+163	+1	+6	+168	+130*	+54#	+2
+100%	+32	+139	+326	+2	+12	+340	+228*	*	*
Road pricing	+2	+3	+2	+0.1	+0.4	+9	+0.4	+0.03	+0.01

** indicates cost of public transport frequency changes with no public transport infrastructure measures*

 # The cost of a pt frequency decrease/increase of 30%, where this was the minimum/maximum considered.

Table 4: Operating costs of new measures (in million ecus per annum).

4. OVERVIEW OF TRANSPORT MODELS USED

The OPTIMA project has used several different transportation models. Some of them are implemented with commercial software like EMME/2 whilst some are implemented in software packages developed by the OPTIMA partners themselves (before the start of OPTIMA). A full description of the models used is given in Appendix A.

The approach taken by OPTIMA has been to use city-specific transportation models which had already been set up, calibrated and used by the city authorities before the start of OPTIMA. This has allowed the project to make the working assumption that the models used are properly calibrated and, on an appropriate level of aggregation, transferable.

Broadly speaking, the models fall into two main categories: strategic and tactical models.

Strategic models are used for running simulations at a very high level of aggregation. The physical transport network is not directly represented and the number of spatial zones is low (typically less than 40). Travel costs are either calculated in terms of "area speed-flow" curves or (at the highest level of aggregation) are fixed inputs for each origin-destination zone pair.

The main advantage of using these models is that they are very fast to run, which can be an important factor if a large number of runs are required. Furthermore, the preparation time for creating the input files is typically short.

The major disadvantage of strategic models for optimisation work (such as in OPTIMA) is simply that, given a particular city, it is unlikely that there will already be a strategic model ready for use.

In OPTIMA, Edinburgh, Merseyside, Vienna and Eisenstadt all used strategic models.

Tactical models are more detailed than strategic models. Typically they represent each (significant) road and public transport link in the network. The output of tactical models is more complex than the output of strategic models. For OPTIMA purposes, there is a need for much aggregation of this output, which can be extremely time-consuming if done manually.

The main advantage of tactical models for optimisation work (such as in OPTIMA) is that they are already used in a large number of European cities to help design and assess various specific transport schemes.

The cities of Tromsø, Oslo, Helsinki, Salerno and Torino all used tactical models.

5. DESCRIPTION OF OPTIMISATION METHODOLOGY

This section describes the optimisation methodology used in the OPTIMA project. Firstly, a simple overview of the approach is given. This is followed by a description of a "Basic Method", in which an optimum set of policy measures is found with respect to one objective function. Subsequently, this method is extended to a "Comprehensive Method" which allows the possibility to introduce extra objective functions and extra measures to the optimisation process after the process has started.

5.1 Overview

Once measures and their ranges have been defined as in Section 3, transport model runs are carried out to test an **initial** set of combinations of transport measures (*packages*). The number of packages in this set is the minimum number required to start up the optimisation process. The actual packages are chosen so that as many as possible different types of combination of measure are tested (subject to the limit on the overall number of initial runs); thus low values of one measure are always tested in combination with high values of another measure and vice-versa.

The values of the objective function are calculated for each package, using the results from the respective transport model run. It must be stressed that some packages are clearly ridiculous in real policy terms whereas others might, by good fortune, lead to good results. The important point of this step is to capture the effect that policy measures have on the objective function rather than to find an optimum.

Using the objective function values for these initial runs, a statistical regression is carried out, which aims to explain the (objective function) results in the form of an equation. The variables in this equation are the values of the measures. This equation has a quadratic form: i.e. it has linear terms and squared terms in it. It must be pointed out that this equation is a simplification: the true transport model results cannot be represented quite so easily (the actual true function representing them would be very complicated). The curve defined by the equation will have a maximum value either within the range of feasible values or else at the minimum/maximum values that have been specified. This maximum value of the curve gives an estimate of what set of transport measures give the highest value of the objective function, i.e. an estimate of the optimum set of measures.

The transport model is run again to test the estimate of the optimum package, and other packages that are close to the estimated optimum. For a number of reasons, the estimate of the optimum is unlikely to be the optimum. For example, the value of the objective function might be lower than the value of the objective function for one of the initial set of runs. This is because, as said above, the regression equation is only an approximation and at an early stage in the optimisation process it is probably not a very good approximation.

Thus, using the results of the new transport model runs as well as the initial runs, a new regression estimate is made, leading to a new estimated optimum. Further transport models runs are then carried out to calculate the objective function for this new estimated optimum. This procedure (involving transport model runs and statistical regressions) carries on iteratively until the user is convinced that a true optimum has actually been achieved.

5.2 Basic Method

The basic method is summarised by the flow chart given in Figure 1. For the sake of simplicity, it is assumed in the following description that the objective function being considered is NPV. However, exactly the same procedure is used for other objective functions.

Step 1 concerns the precise definition of the objective function (as summarised in Section 2). **Step 2** covers the selection of transport policy measures for the optimisation process as described in Section 3.

Step 3 involves making a set of initial transport model runs of various combinations of these measures, selected according to an orthogonal design (so that as wide as possible "space" of transport measures is covered). The minimum number of initial runs, n, can be derived from the following rule of the thumb:

$$n = (2 * c) + d + 5$$

where c is the number of "continuous" policy measures and d is the number of "discrete" policy measures. This number of runs will allow a linear regression to be made with both squared and linear terms for continuous measures and dummy variables for discrete measures. Hence in the case of OPTIMA, with five continuous variables and two discrete variables, the minimum number of initial runs is 18. Using the output from the transport model and other output, the NPV is estimated for each run.

Step 4 involves the creation of a regression model to explain the NPV in terms of the policy variables. Since there are five continuous variables and two discrete variables, the 18 runs will only (meaningfully) allow this regression to be made in terms of linear and squared terms: i.e. there is not enough data **at this stage** for cross-product terms (e.g. fare*frequency).

Step 5 uses the regression model from Step 4 to estimate the optimum set of transport policies.

Step 6 runs the transport model with the optimum set of transport policies estimated in Step 5. Other runs are carried out in this step which can be distinguished into two main types:

- packages that are "similar" to the estimated optimal set from Step 5, and which would be expected to yield high NPVs.
- sensitivity tests which can be carried out for two purposes. The first purpose is that they can help establish what is "driving" the optimal set of policies (i.e. which measures are dominating the attainment of high NPVs). The second purpose is that they can help identify if a local maximum has been achieved which is not globally optimal, thus indicating that "another hill must be climbed" in the optimisation process.

Steps 4 to 6 are then repeated iteratively until convergence is achieved. At this stage, cross-product terms are allowed in the regression in Step 4.

To test convergence, the user has the following **three** criteria (one subjective and two objective):

(a) Is the user satisfied that the latest regression model is satisfactory? For example, the user might be able to make a suggestion, by observation, for a new optimum based upon the results around the existing optimum.

(b) Is the regression model satisfactory? When creating a regression model, there are three conditions that should be satisfied, with the first being the most important:

(i) The standard errors for each variable should be less than half the absolute value of the estimated coefficient (otherwise the regression coefficient for that variable is meaningless).

(ii) The model should predict the highest runs (i.e. those with the highest NPV) better than lower runs.

(iii) Where possible the convexity or concavity of the quadratic function for each variable (i.e. whether they have a maximum or a minimum) should fit prior belief as to whether they would in fact be convex or concave; i.e. the regression should make sense in policy terms.

(c) Compare the "true" NPV for the latest optimal set of policies (as calculated by the transport model) with the "estimated" NPV (as calculated by the latest regression model). The process **has not converged** if[3]

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[3] These convergence criteria might need to be relaxed in certain cases. For example, it is sometimes difficult for the regression process to represent accurately the effect of a minor measure which contributes only a relatively small amount to the objective function. However, it is still useful for the optimiser to attempt to reach the criteria stated.

(I) the regression value is more than 10% greater than the true value from the transport model run;
or (ii) the regression estimate is less than the value from the transport model run[4];
or (iii) the NPV from the "optimal" transport model run is less than the NPV from another run already carried out.

Comments on this process:

(i) It is likely that there will be more than one regression model that satisfies the conditions in (b). It is the user's judgement as to how much time to spend finding the best. This judgement must be dependent on how long it takes to run the transport model. For transport models with long run times it is probably better to spend longer finding the best regression model than when a strategic model is used.

(ii) The number of extra runs to be carried out in Step 6 is inevitably dependent on how long it takes to run the transport model. If a transport model with a long time run is used (i.e. tactical models with large networks), it is probably best to do a regression after each run (since the time taken to do a regression is much less than the time taken to run the transport model).

(iii) The algorithm outlined here is a standard procedure for finding the maximum of a function where the function can only be calculated by simulation (i.e. there is no explicit analytical form to it), and where it is approximated at successive iterations by quadratic functions. Using available literature on optimisation theory, it should be possible to develop more sophisticated algorithms (for example the last two quadratic approximations could be used to specify new runs as opposed to just the last one). This issue is not so important when a strategic transport model (with a short run time) is being used in the optimisation process. However, it is very relevant if a tactical model is being used.

5.3 Comprehensive Method

Two main additions can be added to the process of the Basic Method in order to get the Comprehensive Method. What these additions have in common is that they can be seen as part of an ongoing process: they can be injected into the Basic Method whenever it suits the user.

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[4] If the regression estimate is less than the transport model run, it must generally be assumed that a better regression can be found by adding the "new" information from the latest transport model run. If a subsequent regression can represent this new run accurately, the regression is automatically superior to any other regression obtained before.

1. New objective functions can be added. Section 2 describes a sustainability objective function (SOF). Furthermore, it describes how other objective functions can be created by taking a weighted average of NPV and SOF. Whenever there is a desire to create an optimal set of policies with respect to a new objective function, the following steps can be inserted in the Basic Method:

> **Step 4a.** Create a regression model to explain the new objective function in terms of the policy variables.
>
> **Step 5a.** Make other transport model runs based upon the regression model from Step 4a.

The procedure then continues until both NPV and the new objective function are (separately) optimised. It is important to remember that it is probably not necessary to do twice as many runs (after Run 18) for two objective functions (compared to the Basic Method). Runs carried out for optimising sustainability will have useful information for runs carried out to optimise NPV, and vice-versa. This information will be particularly useful where a run yields high values for both objective functions.

2. New continuous variables can be added. It is the user's judgement as to which variables might be added. Typically they will be variables that were either left out of the original set of variables in order to minimise the number of initial runs or variables that merit inclusion as a result of the iteration results. Often they will be variables that are more disaggregated than those used in the original definition of transport measures. For example peak and off-peak public transport fares charges could be introduced (this will only lead to one extra variable since all-day public transport fares can then be dropped). It is the user's judgement when to introduce new variables. Certainly they cannot be introduced before the completion of 24 runs. When new variables are introduced, it should be straightforward to reformulate the results of previous runs in terms of 5+n variables (where n is the number of new variables to be introduced). In the bus fares example, the value of peak PT fare changes is the same as the value of off-peak fare changes for all those runs before the new variables are introduced.

Note on the statistical software packages used:
Three statistical software packages have been used in the OPTIMA project for the calculation of regression models: SPSS, SAS and GLIM. Tests have been carried out within the project to ensure that they are being used in exactly equivalent ways: i.e. given a set of input data, the resulting regression model is independent of which package is used.

6. RESULTS FOR THE NINE CITIES

6.1 Introduction

Table 5 gives the modal splits (both by trip and by distance travelled) for the modelled do-minimum case in each city. Table 6 gives the set of measures for each city that leads to the best NPV (the *NPV optimum*), whilst Table 7 gives the set of measures leading to the best SOF (the *SOF optimum*). These results are taken from the full set of results given in Appendix B.

Section 6.2 looks at the results on a city by city basis whilst Section 6.3 makes some comparisons across cities.

Modal splits	Edinburgh	M'side	Vienna	Eisen-stadt	Tromsø	Oslo	Helsinki	Torino	Salerno
MS (trips)-car	63%	62%	39%	45%	73%	68%	49%	57%	59%
MS(trips)-public transport	37%	15%	34%	3%	11%	22%	30%	43%	14%
MS (trips)-others	n/a	23%	27%	52%	16%	10%	21%	n/a	27%
MS-(distance) car	72%	67%	46%	58%	80%	69%	63%	60%	88%
MS-(distance) public transport	28%	15%	44%	4%	12%	25%	37%	40%	n/a
MS-(distance) others	n/a	18%	10%	39%	8%	6%	n/a	n/a	12%

Table 5: Modal splits in the do-minimum case

Measures	Edinburgh	M'side	Vienna	Eisenstadt	Tromsø	Oslo	Helsinki	Torino	Salerno
Infrastructure investment high (IH)	No	No	No	*	*	No	No	No	No
Infrastructure investment medium (IM)	Yes	Yes	No	*	*	*	No	No	No
Road capacity (CAP)	+20%[#]	+5%	+10%[#]	+10%[#]	+20%[#]	+20%[#]	+20%[#]	+10%[#]	+10%[#]
PT frequency (FREQ)	+85%	*	+100%[#]	+100%[#]	-35%	-26%	-30%	0%[#]	+50%[#]
Peak PT frequency	*	+60%	*	*	*	*	*	*	*
Off-Peak PT frequency	*	-30%	*	*	*	*	*	*	*
Road pricing (ecus)(RP)	1.6	0[#]	0[#]	0[#]	0[#]	1,2	0[#]	0[#]	1
Parking charges (PCH)	*	*	+226%	149%	0%	-100%	0%	500[#]	-50%
Long term parking charges (LTP)	~	-100%[#]	*	*	*	*	*	*	*
Short term parking charges (STP)	*	+30%	*	*	*	*	*	*	*
PT fares (FARE)	-60%	-100%[#]	+31%	-100%[#]	-50%	-70%	+25%	-25%	-50%
Modal splits									
MS (trips)-car	52%	59%	35%	41%	72%	67%	52%	50%	56%
MS(trips)-public transport	48%	22%	39%	8%	12%	24%	25%	50%	17%
MS (trips)-others	n/a	19%	27%	51%	16%	9%	22%	n/a	27%
MS-(distance) car	60%	61%	42%	53%	79%	67%	69%	55%	87%
MS-(distance) public transport	40%	24%	49%	9%	12%	28%	31%	45%	n/a
MS-(distance) others	n/a	15%	9%	38%	9%	5%	n/a	n/a	13%
Cost model output									
PVF (million ecus)	+5	-2361	+127	-1	-2	+29	+999	+940	-58
NPV (million ecus)	**+1847**	**+2963**	**+1294**	**+19,5**	**+37**	**+1230**	**+341**	**+1675**	**+167**
SOF (million ecus)	+266	+352	+444	+2.2	+17	+227	-1012	+230	+18

** indicates that the measure was not tested*

~ indicates that the value of the measure was irrelevant at the optimum

[#] *indicates a boundary value of the measure*

$ indicates that the value of the measure is uncertian (i.e. widely different values lead to similar NPV values at or near the optimum)

Table 6: Summary table - best NPV

Measures	Edinburgh	M'side	Vienna	Eisen-stadt	Tromsø	Oslo	Helsinki	Torino	Salerno
Infrastructure investment high (IH)	Yes	No	Yes	*	*	Yes	No	Yes	Yes
Infrastructure investment medium (IM)	No	Yes	No	*	*	*	No	No	No
Road capacity (CAP)	+20%[#]	+20%[#]	+1%	+10%[#]	+20%[#]	+20%[#]	0%	+10%[#]	+10%[#]
PT frequency (FREQ)	+100%[#]	*	+100%[#]	+100%[#]	-28%	-20%	0%	-30%	+50%[#]
Peak PT frequency	*	+59%	*	*	*	*	*	*	*
Off-Peak PT frequency	*	-42%	*	*	*	*	*	*	*
Road pricing (ecus) (RP)	2.8	0[#]	0[#]	0[#]	2,5	7	0[#]	0[#]	2
Parking charges (PCH)	*	*	+250%	149%	-100%[#]	-100%[#]	+92%	+500%[#]	-100%[#]
Long term parking charges (LTP)	~	-100%[#]	*	*	*	*	*	*	*
Short term parking charges (STP)	*	+144%	*	*	*	*	*	*	*
PT fares (FARE)	-100%[#]	-100%[#]	+1%	-100%[#]	-100%[#]	-100%[#]	-100%[#]	-50%	-100%[#]
Modal splits									
MS (trips)-car	47%	59%	31%	41%	65%	53%	35%	49%	53%
MS(trips)-public transport	53%	22%	46%	8%	17%	37%	46%	51%	22%
MS (trips)-others	n/a	19%	22%	51%	18%	10%	19%	n/a	25%
MS (distance) car	54%	61%	37%	53%	73%	49%	44%	53%	88%
MS (distance) public transport	46%	24%	55%	9%	18%	46%	56%	47%	n/a
MS (distance) others	n/a	15%	8%	38%	9%	5%	n/a	n/a	12%
Cost model output									
PVF (million ecus)	-1230	-2604	-7077	-1	-17	+1874	-2815	-4169	-176
NPV (million ecus)	+1012	+2722	-2100	+19.5	+16	-2146	-915	-1958	+132
SOF (million ecus)	**+295**	**+407**	**+745**	**+2.2**	**+20**	**+526**	**+240**	**+270**	**+23**

** indicates that the measure was not tested*

~ indicates that the value of the measure was irrelevant at the optimum

[#] indicates a boundary value for the measure

Table 7: Summary table - best SOF

6.2 Comments on individual city results

6.2.1 General comments

In this section the results for individual cities are reviewed. For each city the commentary considers in turn:

- the measures included in the NPV optimum;
- the measures included in the SOF optimum;
- the difference between these;
- the impacts of both on modal split;
- the differences between the NPVs;
- the differences between the SOFs;
- the differences between the PVFs.

Most of the results reported here are concerned with the NPV and SOF optima before they were reported to the cities as part of Work Package 50. However, as a result of the discussions with city representatives, a number of sensitivity tests were suggested. The results of these are reported below in cases where they are felt to be particularly significant.

6.2.2 Edinburgh

The NPV optimum involves medium infrastructure; the maximum increase (20%) in road capacity; an 85% increase in frequency; a road pricing charge of 1.6 ecu; and a 60% reduction in fares. Broadly these appear to be justifiable, and are reasonably consistent with previous policy recommendations. However, the question arises as to how far the maximum increase in road capacity is dependent upon the relatively low cost assumed for it. Sensitivity tests showed that the optimal change in road capacity only became less than +20% when the costs were multiplied by a factor of ten (which, from Table 3, would make the Edinburgh costs approximately the same as the Merseyside costs). Long stay parking charges were irrelevant, because parking activity was reduced to a minimum by road pricing and public transport improvements. Sensitivity tests showed that NPV could be increased from the NPV optimum by increasing short term parking charges, with the maximum increase in NPV arising from a maximum increase in charges of 500%.

The SOF optimum is similar, but with the high level of infrastructure investment; a 100% increase in frequency; a road pricing charge of 2.8 ecu and free fares. Long term parking charges are again irrelevant. Again these seem broadly reasonable. The main difference between the two optima is that that for SOF involves greater financial outlay. This is common to many of the cities studied, and can be explained by the exclusion from SOF of costs in other than the horizon year.

The NPV optimum reduces the car modal share from 63% to 52%, and the SOF optimum reduces it slightly further to 47%. Similar reductions, but from a higher base, occur in car-km. Since the Edinburgh model does not consider non-motorised modes, all of these transfer to public transport. These reductions appear consistent with the strategies implemented.

The optimum NPV is the second highest among the nine cities. The NPV for the SOF optimum is some 40% lower than this optimum, which can be explained by the high costs of the additional measures. However, this does demonstrate that there is a conflict between the two objective functions. The SOF for the NPV optimum is, however, only around 10% below the optimum, suggesting greater flexibility in the specification of the SOF strategy. The PVF for the NPV optimum is virtually zero, indicating that it is possible in Edinburgh to design an efficient strategy which is revenue neutral. Again, this confirms earlier strategy results for the city. The PVF for the SOF optimum is substantially negative, indicating the high financial cost of achieving optimal sustainability, principally through the high cost of LRT.

6.2.3 Merseyside

The NPV optimal strategy for Merseyside again involves medium infrastructure, this time together with a 5% increase in road capacity; a 60% increase in peak frequency and a 30% reduction off peak; free long term parking and a 30% increase for short term; and zero fares. These results are less immediately plausible. The increase in peak frequency and reduction off peak can be explained by the higher benefits of inducing modal change and higher loading levels in the peak; but it should be noted that the costs of additional peak provision will in practice be higher. The reduction in long stay parking charges and the increase for short stay can possibly be explained if the remaining long stay parkers are seen as captive, while those parking for shorter periods can be induced to change mode or destination. A policy of charging less for long stay parking than for short stay would clearly need to be well-designed, and would probably involve issuing long-stay permits at the workplace. This measure would be particularly attractive if joined together with a car-pooling measure: i.e. providing free long-term parking to registered car-poolers.

The SOF optimum differs in increasing the road capacity by the maximum of 20%; reducing the off peak frequency further (by 42%); and increasing the short stay parking charges further (by 144%). This does not show as much emphasis on high cost measures as in Edinburgh. The further reduction in off-peak frequency for SOF (compared to NPV) is explained by the extra emphasis of SOF upon fuel consumption: the reduction in fuel consumption through decreasing bus frequency outweighs the increase in fuel consumption due to bus users switching to cars in response to decreased frequency.

The NPV and SOF optima have identical impacts on modal split, with the percentage using cars falling from 62% to 59% and the percentage of journey length by car falling from 67% to 61%. These reductions are relatively small, and in part reflect the low level of congestion currently in Merseyside. However, they result in a 50% increase in public transport use, primarily induced by the zero fares.

The optimum NPV, at 2963 Mecu, is the highest of all nine cities. This is consistent with Merseyside's position as the most populous city, but is still surprising given the low level of congestion currently experienced. The NPV for the SOF optimum is within 10% of this optimum, while the SOF for the NPV optimum is around 15% below the optimum. These results suggest that there is little difference in practice between the two objective functions in this case. Both PVFs are very negative, with that for the NPV optimum by far the lowest of the nine cities; both PVFs are almost certainly untenable in political/financial terms. It is important to note, however, that the high PVF for the NPV optimum is fully justified if the shadow price of finance used (see section 2) is considered appropriate. Sensitivity tests showed that high NPVs could be still be obtained with dramatically improved PVFs by having a smaller reduction than 100% in fares. For example, if the reduction in fares was only 50% (with other measures the same as at the NPV optimum), an NPV of 2329 Mecus would be obtained with a PVF of -858 Mecus. Furthermore, a reduction in both fares and long term parking charges of only 30% (again with other measures at the NPV optimum) led to an NPV of 1465 Mecus with a PVF of only -281 Mecus.

6.2.4 Vienna

The NPV optimum for Vienna involved the maximum (10%) increase in road capacity; a 100% increase in frequency; a 226% increase in parking charges; and a 31% increase in fares. This seems broadly plausible, with parallel increases in both capacity and cost for public and private transport. Sensitivity tests showed that: if there were no fare increases, the NPV would fall by approximately 30% to 914 Mecus; and that if there were no increase in parking charges, the NPV would fall by approximately 65%.

The SOF optimum differs by introducing the high level of infrastructure investment; reducing the road capacity to virtually current levels; slightly increasing the parking charge; and reverting to approximately do minimum fare levels. Once again, the higher level of investment is explained by the concentration in SOF on future costs and benefits. The justification for reducing the road capacity is slightly less obvious, although it will limit the growth in fuel consumption, as will avoiding the fares increase.

The NPV optimum reduces the proportion of trips by car from 39% to 35%, and the SOF optimum reduces them further to 31%; in the former case all trips transfer to public transport, while in the latter public transport also attracts some travel from other modes. Broadly similar changes occur for the shares of trip-km. These changes are consistent with the policy changes introduced.

While the optimum NPV is the fourth highest among the cities, the NPV for the SOF optimum is strongly negative. It will be important to check the reasons for this. Conversely, the SOF for the NPV optimum is around 40% lower than the optimum; while this difference is still substantial, it suggests that SOF is less sensitive to policy specification than NPV around the optimum. The PVF for the NPV optimum is slightly positive, despite the high costs of increasing public transport frequency. However, the PVF for the SOF optimum is by far the most negative of all nine cities. This can be explained by the combination of the high costs of the high level of infrastructure investment, the maximum frequency increases (including the new public transport infrastructure) and the removal of the fares increase. A sensitivity test showed that if the frequency were to be decreased by 10%, the PVF would be at a much more acceptable level of -393 Mecus. However, the SOF would be reduced from 745 to 143 Mecus.

6.2.5 Eisenstadt

The NPV optimum and the SOF optimum for Eisenstadt are identical, involving a maximum (10%) increase in road capacity; a 100% increase in frequency; an increase of 149% in parking charges and a reduction of 100% in fares.

The combined optimum reduces the percentage of trips by car from 45% to 41%, and more than double the increase in the public transport share from 3% to 8%.

The combined optimum has a slightly negative PVF of -1 Mecu. Values of NPV, SOF and PVF are all small, given the small scale of the city.

6.2.6 Tromsø

The NPV optimum for Tromsø includes the maximum (20%) increase in road capacity; a 35% decrease in frequency; no change in parking charges; no road pricing; and a 50% fares reduction. The main focus is thus on using reduced fares to attract car users, and a reduced frequency to reduce resource costs. At first sight these appear incompatible but further checks have demonstrated that the public transport system is currently operating with excess capacity in the off-peak. A sensitivity test has shown that if frequency were to be reduced by a maximum 50% in the off-peak but increased by 10% in the peak, NPV would increase by 25%.

The SOF optimum involves a maximum road capacity increase; a decrease in frequency of 28%; a 100% reduction in both fares and parking charges; and a road pricing charge of 2.5 ecus. The main differences from the NPV optimum are an increase in the attractiveness of public transport and replacement of parking charges by road pricing. The first of these will be at the expense of an increase in financial costs. The second should increase the effectiveness of the strategy in reducing fuel consumption.

The NPV optimum generates a very slight reduction in the car share of all trips from 73% to 72%, whilst the SOF optimum induces a reduction to 65%. Virtually all of the transfer for the SOF optimum is to public transport; Tromsø is not well suited to encouraging an increase in walking and cycling. The effects on the car share of trip-km are similar.

The NPV optimum is 37 Mecus, and the NPV for the SOF optimum is 16 Mecus. The SOF optimum is 23 Mecus, and the SOF for the NPV optimum is 17 Mecus. This suggests that SOF is somewhat less sensitive to policy specification than NPV around the optimum.

The PVF is 17 Mecus for the NPV optimum, and -2 Mecus for the SOF optimum. This confirms that the NPV optimum is achieving greater economic efficiency primarily by reducing overprovision of public transport, while the SOF optimum is achieved at the expense of an increase in financial outlay.

6.2.7 Oslo

The Oslo NPV optimum includes the maximum (20%) increase in road capacity; a 100% reduction in parking charges; a reduction of 26% in frequency; a road pricing charge of 1.2 ecus; and a decrease of 70% in fares. As in Tromsø, the reduction in both public transport frequency and fares seems surprising, but checks have shown that most of this can be achieved by reducing frequency in outer areas where crowding is not affected. A sensitivity test has shown that if peak frequency were to be decreased by only 20% but off-peak frequency were to be decreased by 31%, there would be a 5% improvement in NPV. Sensitivity tests have considered separate levels of change for bus and rail, reflecting the much higher costs of frequency increases for rail. These suggest that the optimum frequency change for bus is -15%. The NPV optimum for Oslo also involves replacing parking charges by a road pricing charge, indicating that this is a more effective way of reducing congestion costs.

The SOF optimum has high public transport infrastructure investment, a public transport frequency reduction of 20%, zero fares, a road pricing charge of 7 ecus and, as in the NPV optimum, a 20% increase in road capacity and zero parking charges. The main differences from the NPV optimum are the much increased road pricing charge, designed to reduce car use and hence fuel consumption, and the improvements to public transport. Checks indicated that this strategy may in practice not be feasible, since the public transport would be over capacity. Sensitivity tests indicated that, with bus and rail optimised separately, the optimal frequency change for bus was +25%.

The NPV optimum reduces car use slightly, from 68% to 67% of all trips, and slightly increases the public transport share from 22% to 24%. The SOF optimum has a strong impact on car use, which falls to 53% of all trips, while public transport use increases to 38%. These differences from the NPV optimum reflect the major differences in overall strategy.

The optimum NPV is 1230 Mecus, while the NPV for the SOF optimum is strongly negative, reflecting the high costs of infrastructure and, possibly, restraint of car use to below the economic optimum. The optimum SOF is 526 Mecus, while the SOF for the NPV optimum is 227 Mecus, suggesting once again that SOF is less sensitive to policy specification. PVF for the NPV optimum is slightly positive, at 29 Mecus, while that for the SOF optimum is much higher, at 1874 Mecus. This result is in marked contrast to the PVFs for other cities' SOF optima. It appears that the high road pricing charge is more than sufficient to cover the financial costs of the strategy.

6.2.8 Helsinki

The NPV optimum for Helsinki includes the largest (20%) increase in road capacity; a reduction of 30% in frequency; no change in parking charges and a 25% increase in fares. This somewhat surprising result is explained by the current high level of, and high subsidy for, public transport. In other words, it is argued, resources can be saved by streamlining the public transport service.

The SOF optimum has no change in road capacity or frequency from the do-minimum; a 92% increase in parking charges; and introduces zero fares. This strategy is in marked contrast to the NPV optimum, since it removes the road improvements, reverses the public transport reductions and substantially increases the costs of car use. Sensitivity tests indicated that zero fares were the key element in any SOF strategy, and that the effects of parking charges, road pricing and infrastructure were to some extent interchangeable.

The NPV optimum increases the car mode share, from 49% to 52%, and also increases non motorised travel, both at the expense of public transport. With the SOF optimum, however, car use falls dramatically, to 35% of trips. These results are consistent with the marked differences in strategy.

The NPV for the SOF optimum is negative, emphasising the marked difference between the requirements of the two objectives. The SOF value for the NPV optimum includes the hard penalty for an increase in fuel consumption, which is to be expected given the increase in car use. This again reinforces the difference between the two strategies. The PVF for the NPV optimum is strongly positive, which can be explained by the reduction in the current high level of expenditure on public transport. The removal of fares inevitably imposes a large negative PVF on the SOF optimum.

6.2.9 Torino

The NPV optimum for Torino involves the highest (10%) increase in road capacity; no change in frequency; no road pricing; the highest (500%) increase in parking charges; and a 25% reduction in fares. this strategy aims to encourage a transfer from car to public transport to reduce congestion. It is perhaps surprising that the optimum did not include an increase in public transport frequency, but the costs of such increases are high.

The SOF optimum also includes the highest increase in road capacity, the highest increase in parking charges and no road pricing. However, it also includes a reduction in frequency of 30%, high public transport infrastructure and a reduction in fares of 50%. The main differences from the NPV optimum are in the construction of the underground rail network, which permits a reduction in frequency on the existing service and a further fares reduction. This strategy is explained by the lack of emphasis on capital costs in the SOF optimisation.

The maximum increase in parking charges and the reduction in fares in the NPV optimum have, together, reduced the car mode share from 57% to 50% of trips, and from 60% to 55% of trip-km. Since non-motorised modes are not modelled, all of these reductions are reflected in increases in public transport use. In spite of the decrease in frequency, the further reduction in fares and high public transport infrastructure in the SOF optimum reduce the car mode share marginally further to 49% of trips and 53% of trip-kms.

The NPV at the NPV optimum is the third highest, at 1675 Mecu; this is justifiable, since Torino is the second largest city tested. The SOF at the NPV optimum is, at 230 Mecu, approximately 20% less than the SOF for the SOF optimum (270 Mecu), suggesting that SOF is not very sensitive to policy specifications where these are relatively near the optimum. However, the NPV at the SOF optimum is, at -1958 Mecu, the second worst NPV for an SOF optimum. This is explained by the very high costs of running the underground system (2039 Mecus). This is reflected also in the differences in PVF. That for the NPV optimum is +940 Mecus, primarily because of the substantial increase in parking revenues. That for the SOF optimum is -4169Mecus, reflecting the high cost of the underground system and the further loss of fares revenue.

6.2.10 Salerno

The NPV optimum for Salerno involves the maximum (10%) increase in road capacity; a maximum (50%) increase in frequency; a road pricing charge of 1 ecu; a reduction of 50% in parking charges; and a reduction of 50% in fares. All of these are consistent with an overall strategy of diverting travel from car to public transport. Sensitivity tests indicated that the parking charge and road pricing maesures are largely interchangeable, since there is little through raffic in Salerno.

The SOF optimum also includes maximum increases in road capacity and public transport frequency, as well as high infrastructure investment; a road pricing charge doubled to 2 ecu; removal of parking charges and zero fares. These changes are consistent with the lack of emphasis in SOF on initial investment, and with the need to induce an additional shift to public transport in order to reduce fuel consumption.

The NPV optimum produces only a small reduction in car use, from 59% to 58% of all trips, with the transfer being to non-motorised travel. This suggests that the effects of road pricing and parking charge reductions are roughly in balance. The SOF optimum reduces car use to 53% and also reduces non-motorised travel from 27% to 25% of trips. This is consistent with the strong emphasis on public transport in the SOF optimum.

The NPV for the SOF optimum is around 20% lower than the optimum, while the SOF for the NPV optimum is around 25% lower than its optimum. Both of these suggest a relatively small trade-off between the two objective functions, even though the strategies are quite different in their emphasis. The PVF for the NPV optimum is slightly negative, suggesting that the change in revenue from car users is not quite sufficient to finance the capacity and frequency increases. The PVF for the SOF optimum is much more markedly negative, as a result of the removal of fares and parking charges, and the costs of new infrastructure, partly offset by the doubling of the road pricing charge.

6.3 Comparison across cities

6.3.1 Public transport infrastructure investment

No city had high public transport infrastructure investment in its NPV optimum, although medium infrastructure investment was included in the NPV optima of Edinburgh and Merseyside. The problem here for comparison is that the definition of "large" and "medium" public transport infrastructure is extremely city-dependent. Table 3 shows the cost of high and medium public transport infrastructure for all cities where it was tested, and it can be seen that there is a wide variation in costs. This variation is largely explained by the different nature of infrastructure measures. The problem of lack of comparability of public transport infrastructure, which also applies to road infrastructure investment, has been acknowledged since the start of the OPTIMA project, and explains why a majority of the measures being tested are "continuous" (which are by nature more comparable across cities).

With regard to SOF optima, five cities (Edinburgh, Vienna, Oslo, Torino and Salerno) had high infrastructure in their optimal sets of measures. Given that the Merseyside SOF optimum included medium infrastructure and that neither Eisenstadt nor Tromsø tested any form of public transport infrastructure, it follows that only one city (Helsinki) rejected public transport infrastructure for the SOF optimum. The difference here, compared to the NPV optima case above, can be explained by the fact that present day investment costs do not feature in SOF so that, in general, SOF would be more likely than NPV to favour infrastructure measures.

6.3.2 Road capacity changes

Eight of the nine cities included the maximum increase in road capacity in their NPV optima, while Merseyside had a marginal increase. The position for the SOF optima was similar, although Helsinki rejected the measure, Vienna substantially reduced it, and Merseyside increased its use. The different approach in Merseyside can be explained by the much higher cost of the measure, and the lower level of congestion in the do-minimum. This increase in road capacity is at first sight slightly counter-intuitive. However, it should be stressed that it provides a relatively low cost way of improving efficiency, while other measures in the strategy can be used to control car use.

6.3.3 Public transport frequency

The changes in public transport frequency in the NPV optima are extremely variable across cities. The Vienna, Eisenstadt and Salerno optima contain maximum frequency increases (100%, 100% and 50% respectively) and the Edinburgh NPV optimum contains a near-maximum increase (85%). On the other hand, the Helsinki, Oslo and Tromsø NPV optima all include a frequency reduction of around 30%. One explanation for the mixed results can be found by looking at the Merseyside results where there are clearly different results for peak and off-peak frequency. If this result were common to all cities, the aggregate frequency changes would be heavily dependent on the already-existing allocation of resources between peak and off-peak. Sensitivity tests in Oslo have confirmed this.

The public transport frequency changes in the SOF optima were the same as in the NPV optima for three cities (Vienna, Eisenstadt and Salerno). The frequency increases for the Edinburgh, Oslo and Tromsø SOF optima were approximately the same as for the NPV optima (within 15%), although in all three cases the frequency was higher in the SOF optimum than in the NPV optimum. In Merseyside the peak frequency change in the SOF optimum was approximately the same as in the NPV optimum, whilst the off-peak frequency change in the SOF optimum was slightly more negative than in the NPV optimum (-42% compared to -30%). Helsinki and Torino showed the greatest change, with Helsinki reversing the capacity reduction in its NPV optimum, and Torino introducing one. As noted in Section 6.2.9, the latter is explained by the replacement by high infrastructure provision.

Generally the policy on public transport frequency appears to be highly sensitive to the current level of provision, with those cities with over-provision of capacity most likely to have a reduction in frequency recommended.

6.3.4 Road pricing

Only three cities, Edinbugh, Oslo and Salerno, had a road-pricing charge in the NPV optima. All these charges were relatively modest (1.6, 1.2 and 1 ecu respectively). In the SOF optima, four cities (the above three plus Tromsø) had road pricing charges, all of which were at a higher level than for the NPV optima. The increase in Oslo, from 1.2 to 7 ecus, was particularly marked, and helps explain the substantially positive PVF and negative NPV of this strategy. Generally it appears, as noted below, that road pricing and parking charges are broadly interchangeable in their effects.

6.3.5 Parking charges

For the NPV optima, three cities (Vienna, Eisenstadt and Torino) had increases in parking charges of over 100%. On the other hand, the NPV optimum of Oslo had free parking; that of Salerno had a 50% decrease in charges; whilst the NPV optimum of Merseyside had free long-term parking but an increase of 30% in short-term parking. Moreover, the NPV optimum for Edinburgh was insensitive to parking charges because of the impact of road pricing. In all cases except Merseyside, low parking charges were consistent with the introduction of road pricing.

In the case of SOF optima, the results are even more polarised than in the NPV optimum case. The three cities with the largest increases in parking charges for NPV optima (Vienna, Eisenstadt and Torino) had approximately the same increases in the SOF optima.

On the other hand, the SOF optima in three cities (Tromsø, Oslo and Salerno) had 100% reductions in parking charges. Finally, the SOF optimum of Merseyside (where long-term and short-term parking charges were considered separately) had a 100% decrease in long-term parking charges and a 144% increase in short-term parking charges.

The likely conclusion from these results is that the optimum level of parking charges is highly dependent on synergies with other measures. It is significant that in the NPV optima, six cities (Vienna, Eisenstadt, Oslo, Torino, Edinburgh and Salerno) had either large parking charge increases (more than 100%) or road pricing, but that none of them had both. This result would confirm the intuitive expectation that the two measures would be roughly equivalent, since they both concentrate on restricting traffic into the city centre (however, road pricing clearly affects through-traffic in the city centre whilst parking charges do not). In the case of the SOF optima, all cities either had large parking charge increases (over 90%) or road pricing. This is arguably one of the two strongest results to be found from the study.

6.3.6 Public transport fares

There was wide variation between cities on the public transport fares policies in the NPV optima, although there was more emphasis upon fares reduction rather than fares increase. The Merseyside and Eisenstadt NPV optima had free fares, whilst in Edinburgh, Tromsø, Oslo and Salerno there were also substantial decreases in fare of at least 50%. On the other hand, Vienna and Helsinki had increases in fare. The result from Vienna is partly explained by the increase in frequency and the overall emphasis on increased cost. That for Helsinki appears to be due to current high levels of provision and subsidy.

On the other hand, seven cities (all except Vienna and Torino) had free public transport fares in their SOF optima, and this is arguably the second of the two strongest results to be found in this study, especially since Torino had a reduction of 50% and Vienna only had a tiny increase of 1%. Whilst free or reduced public transport fares are likely to have contributed significantly to the high negative PVFs of SOF optima in Merseyside, Edinburgh, Helsinki, Torino and Salerno, one city (Oslo) was able to achieve a highly positive PVF with a package including free public transport fares. Furthermore, it is ironic that the city with the highest negative PVF for an SOF optimum (Vienna with a PVF value of -7077 Mecus) was the only city to increase public transport fares.

It is interesting to note that three cities (Tromsø, Oslo and Salerno) all had “free public transport and free parking” policies in the SOF optima, whilst Merseyside had a “free public transport and free long-term parking” policy.

7. CONCLUSIONS

Work Packages 30 (modelling) and 40 (optimisation) were in practice pursued jointly. The time taken to carry out the work involved depended largely on the nature of the model being used. Four cities used strategic models and five used tactical models, with the former permitting much more rapid analysis and interpretation, but providing much less detailed output. It may well be desirable in future research of this kind to concentrate on strategic models, and to use tactical models to obtain greater detail on the optimal strategies. Despite this distinction, it has proved possible to generate efficiency-optimal and sustainability-optimal strategies for all nine cities. The results show, as would be expected, that the sustainability-optima place greater emphasis on current investment, and on controlling levels of car use, than do the efficiency-optima. The analysis has identified a series of issues that have been pursued with the city authorities in Work Package 50.

8. REFERENCES

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