THE SPECIFICATION OF OPTIMAL URBAN TRANSPORT STRATEGIES

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Abstract

Using a formal optimisation method, optimal transport strategies have been developed for nine European cities. Initial optimisation focused on two objectives of economic efficiency and sustainability, and six transport policy measures : public transport infrastructure, frequency and fares, low cost road capacity charges, road pricing and parking charges. The results were discussed in detail with the city authorities, and policy conclusions drawn. A subsequent study considered an enhanced objective function which addressed local environmental impacts, and also developed a series of objective functions reflecting the role of the private sector in the financing of transport strategies.

BACKGROUND

There has been growing interest in recent years in the development of Integrated Transport Strategies (May, 1991). These studies have demonstrated that an integrated approach, in which infrastructure provision, management of existing infrastructure, and pricing of use of that infrastructure are co-ordinated, can significantly reduce the scale of urban transport problems.

The key to development of a strategy is the specification of the objectives which it is designed to meet, and demonstration that there is benefit to be gained from an integrated approach, when compared with the piecemeal implementation of individual measures. The purpose of integration must be to achieve a higher performance against the objectives of the strategy than could be achieved by the individual measures on their own. The strategic objectives will vary from study to study although the most common ones are : efficiency in the use of resources; improved accessibility; environmental protection; sustainability; safety; and financial feasibility (May, 1991).

There is a wide range of potential measures which can be incorporated into Packages; a recent design guide (IHT, 1996) lists over 50, under the broad headings of :- land use; infrastructure; management; information; and pricing, and assesses the contribution of each to the objectives listed above.

The task of strategy development is made more complicated when it is realised that each of these measures can be implemented at a range of scales and intensities. Infrastructure projects can be designed on different corridors and with differing capacities. Management and pricing measures can operate in different areas, at different times of day, with differing impacts on groups of users, and at differing intensities.

Typically, integrated transport studies have involved identifying an appropriate list of measures and testing them, in a range of combinations, using a strategic model. Professional judgement is used to determine the set of initial combinations to be tested, and the variants which are likely to perform best in meeting the specified objectives. May and Roberts (1995) describe the process, and provide examples of the resulting strategies, including those for a study of Edinburgh (May, Roberts and Mason, 1992) in which some 70 strategic model runs were conducted in order to identify those strategies which performed best in terms of economic efficiency within given financial constraints.

Even with such a large number of model runs there was, of course, no guarantee that the optimum set of measures had been identified; different scales and intensities for infrastructure, management or pricing measures might well have achieved greater benefits. To tackle this problem a new methodology has been developed for streamlining the optimisation process (Fowkes et al, 1998). This treats the relationship between the objective function (say economic efficiency) and the policy variables (say fare, service level) as a regression model, and uses a series of runs of the strategic model to produce a regression model from which an optimum policy specification can be estimated. Iterations of this sequence of model runs and regression are then conducted until the process is sufficiently converged. When applied to Edinburgh, this process was able to predict an economic efficiency optimum using only 24 strategic model runs, and with a net present value of benefits some 20% higher than the best strategy generated in the original study.

This approach has since been adopted in a EU study of nine cities, OPTIMA, to identify the sets of measures which are optimal in terms of economic efficiency and sustainability in each city and the factors restricting the implementation of such strategies (May et al, 1997; Shepherd et al, 1997). A subsequent study, FATIMA, has assessed the effects of constraints on finance, and the potential for private sector finance.

PROJECT OPTIMA : THE STUDY METHOD

Objectives of OPTIMA

Project OPTIMA : Optimisation of Policies for Transport Integration in Metropolitan Areas had the following objectives

(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 nine case study 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.

Description of case study cities

As indicated in Table 1, the nine case study cities represent a wide range of conditions. Five are Metropolitan Areas (MA) which include a major city and its suburbs. Three are large in population terms, three medium and three small. Three have much lower population density than the others. Car ownership varies widely, with much higher levels in Eisenstadt and Torino. Car use is highest as a percentage of trips in Oslo, Merseyside, Torino, Eisenstadt and Tromsø.

Table 1 - City characteristics

	Edin-burgh MA	Mersey-side MA	Vienna	Eisen-stadt	Tromsø	Oslo MA	Helsinki MA	Torino MA	Salernc
Population (k)	420	1440	1540	10	57	919	891	1454	157
density/ha	29.9	22.2	37.9	2.4	0.3	1.7	12.0	23.7	26.2
cars ownership per person	0.32	0.27	0.32	0.66	0.38	0.44	0.32	0.63	0.40
Trips by car (%)	51*	78*	37	56	54	62	47	67*	40

The Study Method

The starting point for the optimisation procedure is to define the objectives against which strategies are to be optimised and then to specify the set of policy measures to be tested. The next step is to conduct transport model runs 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 using an orthogonal design so that as many different types of combination of measure as possible are tested (subject to the limit on the overall number of initial runs).

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 curve defined by the equation will have a maximum value either within the range of feasible values or else at the minimum or 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 within the ranges specified.

The transport model is next run to determine the true value of the objective function for this predicted optimum package. The true value is likely to differ significantly from the prediction at this stage, because the prediction is based on only the minimum number of policy runs. To improve on the estimate, the model run for the predicted optimum run, and runs for other packages close to the estimated optimum, are added to the set of model runs. Then, 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 model 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 (Shepherd et al, 1997).

The selected objective functions

Based on initial discussions with the city authorities, two policy objectives, economic efficiency and sustainability, were chosen as the basis for optimisation.

The Economic Efficiency Function (EEF) reflects the cities' objectives of overall efficiency of the transport system, economising the use of resources, accessibility within the city and at least the possibility of economic regeneration. Essentially, the EEF performs a cost benefit analysis of the tested policy. The optimisation with regard to this function is to find the policy with the best Net Present Value (NPV) of social benefits and costs after including a shadow price for Present Value of Finance (PVF, defined below).

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. The higher than market-price shadow price of fuel consumption used in the SOF could also be taken to reflect approximately the impacts of local and regional pollution that follow from the use of fossil fuels.

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".

For each of the tested transport strategies, the transport model of the city is run for the target year (2010 for most cities, 2015 for some). To provide a benchmark against which the other strategies can be assessed, a "Do minimum" strategy is carefully specified. The "Do minimum" strategy consists of investment projects and land use changes already decided upon or implemented, as well as present levels for other policy variables. As is conventionally done, a 30 year planning horizon is assumed. The discount rate used to form the present value of the benefit and cost elements of all the 30 years, varies between the cities. Whenever an official or recommended discount rate for a country exists, it has been used. The discount rate varies between 6% and 9%.

EEF

The Economic Efficiency Function (EEF) is defined as :

$$\begin{aligned} EEF &= B - I + 0.25PVF && \text{if } PVF < 0 \qquad (1) \\ &= B - I && \text{if } PVF \geq 0 \end{aligned}$$

where B, the present value of net benefits over a 30 year period, is given by

$$B = \sum_{i=1}^{30} \frac{1}{(1+r)^i} * (f + u) \qquad (2)$$

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 and government 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, and
u is the net benefit to transport users in the target year, compared with the do-minimum scenario, calculated as described above; and
PVF, the Present Value of Finance, is defined as

$$PVF = -I + \sum_{i=1}^{30} \frac{1}{(1+r)^i} * f \qquad (3)$$

SOF

The Sustainability Objective Function (SOF) is defined as

SOF = b - y - z (if fuel consumption exceeds do-minimum) (4)
= b - y (otherwise)

where b is the benefit in the horizon year to travellers, operators and governments, given by

b = f + u (5)

y is the "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 the "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).

Policy Measures

An inventory of measures in use, planned or already rejected was conducted in the nine OPTIMA cities. Based upon this inventory 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 by distinguishing between long-term and short-term parking charges and between peak and off-peak public transport frequency. Estimates were obtained from each city of the implementation and operating costs of each of these measures.

Table 2 - Measures tested

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

Table 3 - Modal splits in the do-minimum case

Measures / Cities	Infrastructure investment - High, Medium or No	Road capacity (CAP)	PT frequency (FREQ) †	PT fares (FARE)	Road Pricing (ecus) (RP)	Parking charges (PCH) @
Edinburgh	Medium	+20%#	+85%	-60%	1.6	~
Merseyside	Medium	+5%	+60% -30%	-100%#	0#	-100% +30%
Vienna	No	+10%#	+100%#	+31%	0#	+226%
Eisenstadt	*	+10%#	+100%#	-100%#	0#	+149%
Tromsø	*	+20%#	-35%	-50%	0#	0%
Oslo	No	+20%#	-26%	-70%	1.2	-100%
Helsinki	No	+20%#	-30%	+25%	0#	0%
Torino	No	+10%#	0%	-25%	0#	+500%#
Salerno	No	+10%#	+50%#	-50%	1.0	-50%

~ indicates that the measure was irrelevant at the optimum
* indicates that the measure was not tested
# indicates a boundary value of the measure
† peak/off peak for Merseyside
@ long term/short term for Merseyside

Table 4 : Summary table - best EEF

Measures / Cities	Infrastructure investment - High, Medium or No	Road capacity (CAP)	PT frequency (FREQ) †	PT fares (FARE)	Road Pricing (ecus) (RP)	Parking charges (PCH) @
Edinburgh	High	+20%#	+100%	-100%#	2.8	~
Merseyside	Medium	+20%#	+59% -42%	-100%#	0#	-100% +144%
Vienna	High	+1%	+100%#	+1%	0#	+250%
Eisenstadt	*	+10%#	+100%#	-100%#	0#	+149%
Tromsø	*	+20%#	-28%	-100%#	2.5	-100%#
Oslo	High	+20%#	-20%	-100%#	7.0	-100%#
Helsinki	No	0%	0%	-100%#	0#	+92%
Torino	High	+10%#	-30%	-50%	0#	+500%#
Salerno	High	+10%#	+50%#	-100%#	2.0	-100%#

~ indicates that the measure was irrelevant at the optimum
* indicates that the measure was not tested
# indicates a boundary value of the measure
† peak/off peak for Merseyside
@ long term/short term for Merseyside

Table 5 - Summary of beneficial measures

	EEF	SOF	BOF
Public transport infrastructure	-	**	*
Low cost road capacity improvements	***	**	**
Increase in public transport frequency	*	**	**(Peak) *(off-peak)
Reduction in public transport fares	**	***	*(Peak) **(off-peak)
Road pricing and/or increased parking charges	**	***	**

* indicates there is (overall) a small benefit to using the measure
** indicates there is (overall) a medium benefit to using the measure
*** indicates there is (overall) a strong benefit to using the measure

Table 6 - Trips by car (%) for the do minimum and the EEF and SOF optima

	Edin-burgh	Mersey-side	Vienna	Eisen-stadt	Tromso	Oslo	Helsinki	Torino	Salerno
Do Min	63	62	39	45	73	68	49	57	59
EEF	52	59	35	41	72	67	52	50	56
SOF	47	59	31	41	65	53	35	49	53

PROJECT OPTIMA : RESULTS FOR THE NINE CITIES

Individual city results

Table 3 gives the set of measures for each city that leads to the best EEF (the *EEF optimum*), whilst Table 4 gives the set of measures leading to the best SOF (the *SOF optimum*). A simple overview of the results from Tables 3 and 4 is given in Table 5. Table 6 compares the impacts on modal split.

The Economic Efficiency optimum

From Table 5, the economic efficiency optimum is likely to involve :-

- no new public transport infrastructure investment;
- low cost improvements in road capacity;
- no use of road capacity reductions to discourage car use;
- improvements in public transport by increasing frequency and/or reducing fares; and
- restrictions on car use involving either road pricing or increased parking charges.

Public transport infrastructure investment is included in the two UK case studies, where the level of public transport subsidy is currently lowest. However, they are included only at the medium level, which implies bus-based improvements. Elsewhere, the high resource cost of investment makes such measures economically inefficient. **Road capacity improvements** are included in all nine cities, on the assumption that the cost of implementing them would be small. Increased road capacity can in fact be achieved relatively cheaply through traffic signal co-ordination and improvements, telematics measures, parking bans and a number of other "low cost" traffic management measures. The implication of the OPTIMA result is that it is worth increasing road capacity to generate increased efficiency provided that the costs of doing so are low, and the growth of car use is controlled by other means.

Public transport changes generally include an increase in frequency and a decrease in fares. Exceptions to this are Vienna (which has an increase in fares), Tromsø and Oslo (which have a decrease in frequency) and Helsinki (which has both an increase in fares and a decrease in frequency). There is some correlation between such changes and high levels of public transport subsidy, suggesting that some reduction in the resources used for public transport may improve efficiency. In particular, this appears to be the justification for the strategy in Helsinki. **Restrictions on car use** may involve introduction of a road pricing charge, or an increase in parking charges, but never both. For a large number of trips these measures are essentially interchangeable. In two cases (Tromsø and Helsinki) no extra financial restriction is imposed on car use suggesting that current parking charge levels are optimal. In Merseyside, parking charges are disaggregated between short-term and long-term: an increase in the former and a decrease in the latter are recommended. However, this appears to be associated with lower levels of congestion in the do-minimum conditions.

The Sustainability optimum

When compared with the economic efficiency optimum, Table 5 shows that the sustainability optimum is most likely to involve :-

- investment in new public transport infrastructure;
- similar levels of low cost improvement in road capacity;
- further improvement in public transport by increasing service levels and/or reducing fares; and
- further restrictions on car use, involving either road pricing or increased parking charges.

Public transport infrastructure investment becomes more acceptable when no emphasis is given to initial investment costs (which are given no weight in the SOF) and the importance of reducing fuel consumption, and hence car use, is increased. Of the seven cities testing such investment, all but two included the high level of investment (typically rail-based) while Merseyside included the bus-based medium level, and Helsinki included high investment in several close to optimal strategies. **Road capacity improvements** are typically at the same level as for the economic efficiency optimum, and the arguments above apply. **Public transport changes** may still include service level reductions (in Tromsø, Oslo and Torino) but the reductions are typically lower than with the economic efficiency optimum. The one exception is Torino, where the service level is reduced to reflect the provision of an extensive new underground system. Fares are reduced dramatically in all cases except Vienna, where there is a small increase. In all cases, the public transport service provided (considering service levels and fares combined) is better than for the economic efficiency optimum. **Restrictions on car use** still involve either road pricing charges or increases in parking charges, and the same arguments as above apply. However, the charges now apply in all cities and are (except for Eisenstadt and Torino) higher than in the economic efficiency optimum.

PROJECT OPTIMA : CONSULTATION WITH CITY AUTHORITIES

The process

Based on the model results, consultations were held with officials in each of the nine cities, who were invited to assess them against a set of criteria which focused on issues of feasibility and acceptability. Inevitably there was some overlap between the concerns under these two headings. The officials were also invited to suggest alternative strategies which they would wish to have tested, and the opportunity was taken to discuss these results. None of the alternatives proposed performed better than the predicted optima.

Financial feasibility

By far the most frequent concern of the city authorities was the financial feasibility of the proposals. It is important to note that this was reflected in part by including a shadow price of 0.25 on the PVF, hence indicating that strategies with a positive EEF were a justifiable use of the public funds required. Generally, though, this has not been a problem for the EEF optimum, except in Merseyside and Salerno.

For the SOF optimum, the problem is more widespread. Only Oslo generates sufficient finance from other measures to pay for its optimal strategy, and most cities express concern about the financial costs. However, Vienna considered the financial cost worth incurring to achieve a more acceptable strategy. It is clear that pursuit of the most sustainable strategies will imply substantial financial outlay in most cities, and that there is a need to try to find slightly sub-optimal strategies which are significantly more affordable.

Practical feasibility

In a few cases, city authorities expressed doubts about the feasibility of the measures tested, and this was reinforced by the tendency to include the upper or lower bound measures in the optimal strategy. Specific concerns included the higher levels of road capacity increase, which were considered in some cases only to be achievable by new road construction and potentially to cause environmental damage; public transport service reductions, which would result in increased loadings; and zero fares and zero parking charges, which would both result in major changes in operating practices and costs.

Legislative feasibility

In the UK and Italy examples were identified of the need for new legislation to enable optimal strategies to be implemented. These concern ability to introduce road pricing and to control private parking (for which legislation would in practice be needed in all countries), changes in the UK bus deregulation regime to permit city authorities to influence service levels and fares more directly, and changes in the Italian anti-inflation legislation, which currently requires public transport operators to increase fares and reduce subsidies. These are important conclusions, and imply that legislative changes should be sought to facilitate optimal strategies.

Public and political acceptability

Several cities expressed concern over the public acceptability of certain measures. It is important to stress that these views are based on officials' judgements rather than on public consultation. The main concerns related to road capacity increases and, as might be expected, reduced services, increased fares, road pricing and increased parking charges. Not surprisingly the deterioration in public transport in Helsinki was considered particularly unacceptable. Where strategies are fully justified, it will be important to present the arguments clearly and allay the fears of the public. Where a strategy involves both positive and negative measures, the latter need to be preceded, where possible, by the former.

City officials' assessments of political acceptability were inevitably influenced by their views of feasibility and public acceptability, as reported above. However, Vienna commented that the SOF optimum was more acceptable than the EEF, since it accorded more closely with their overall approach. Some cities expressed doubts about the objective functions used. The most frequent concern was with impacts on the local environment and safety; some would also have preferred a greater emphasis on accessibility and land use. Some city officials would also like to have seen more inclusion of measures to improve conditions for cyclists, pedestrians and disabled travellers. These latter measures are, in practice, better designed within the context of an overall optimal strategy.

PROJECT FATIMA : THE STUDY METHOD

Objectives of FATIMA

Arguably the most important feedback from the city authorities in the OPTIMA project was that the optimum policies were often unaffordable in the sense that they had high negative values of PVF. The EEF-optima for Merseyside and Salerno were both unacceptably expensive with respect to their size, as were the SOF-optima in these two cities and Edinburgh, Vienna, Tromsø, Helsinki, Torino and Salerno. This unacceptability was not due to the lack of value resulting from the transport measures (or else they would not have been considered as optimal) but was simply due to the lack of public finance available to support them. As a consequence, the central aim of the follow-up FATIMA project was to examine how this problem might be ameliorated by using private finance
The formal objectives of FATIMA were:

(i) to identify the benefits to the private sector of optimal urban transport strategies, and the potential for obtaining private sector funding the reflect those benefits;

(ii) to determine the differences between strategies optimised using public funds and those optimised within the constraints imposed by private funding initiatives;

(iii) to propose mechanisms by which private sector funding can be provided so as to achieve appropriately optimal transport strategies while maintaining quality of operation; and

(iv) to use the results to provide more general guidance on the role of private sector funding for urban transport in the EU.

The Study Method

The same study method was adopted in FATIMA as in OPTIMA, but with new objective functions. In addition, enhancements had been made to some of the transport models and, in response to the city authorities' comments, changes were made in the ranges, and costs, for certain measures, and more cities differentiated between peak and off peak levels.

The selected objective functions

FATIMA uses five objective functions which are defined below: BOF, COF, ROF, DOF and HOF. The first two of these consider a world in which there is only public finance, whilst ROF, DOF and HOF take into account different aspects of the inclusion of private finance. All objective functions except HOF have a standard definition throughout the project, whilst HOF is defined specifically for each case study.

BOF

While the main focus was on alternative financing regimes, the opportunity was taken to enhance the objective functions used in OPTIMA as a Benchmark Objective Function (BOF), which reflected city authorities' comments by :-

- assigning a shadow value to revenue generated
- including the external costs of local environmental and safety impacts
- combining EEF and SOF in a weighted formulation.

It is defined as follows :

$$BOF = 0.1*EEFP + 0.9*SOF \qquad (6)$$

where

$$EEFP = NPV + 0.25PVF + \gamma(veh.kms) \qquad (7)$$

other terms as in OPTIMA

The term γ(veh.kms) represents the combined environmental/safety effects resulting from a change in policies and is positive if there is a reduction in veh-kms. In calculating this term a differentiation is made between vehicle-kms by different modes, to take into account, for example, that underground systems do not cause on-street accidents.

COF

COF (Constrained Objective Function) is an extension of BOF that takes into account that public money is limited. For the sake of simplicity, it assumed that public finance is constrained to the level implied in the do-minimum scenario.

$$COF = BOF \text{ if } PVF > 0 \qquad (8)$$

$$= a \text{ highly negative number if } PVF < 0$$

ROF

ROF (Regulated Objective Function) is an extension of COF, and recognises that extra (private) finance can be input to the transport system through value capture (VC). The transport system is regulated in the sense that the private finance has no direct control over the levels at which fares, frequencies, road pricing etc. are set, which remain firmly under overall public control.

VC is defined as a percentage of user benefits, which are seen as a measure of overall accessibility. The logic here is that companies in the city should (collectively) be prepared to pay for overall city-wide accessibility due to the benefits that they gain from this in terms of efficiency of commuter trips and business trips, inward investment (due to city attractiveness) and general city regeneration. The political issue as to whether VC should be raised by compulsory means (through taxes) or voluntary means is not directly addressed in this objective function.

$$ROF = BOF \text{ if } PVF + VC > 0 \qquad (9)$$

$$= a \text{ highly negative number if } PVF + VC < 0$$

where

$$VC = \beta^* \textit{ user benefits if user benefits} > 0 \quad (10)$$

$$= 0 \textit{ otherwise}$$

For the main tests in FATIMA, β is fixed at 0.1.

DOF

DOF (Deregulated Objective Function) is an extension of COF. It assumes that control of public transport is handed over to the private sector, who are free to set fares and frequencies, and to take any profits that result. On the other hand, there are no public subsidies for running public transport. The other measures in the transport system (road pricing, parking charges and road capacity changes) are assumed to stay under public control.

The public transport market is assumed to be a contestable imperfect market (i.e. somewhere between a perfect market and a monopolistic situation). Under these conditions, the Internal Rate of Return (IRR) for the public transport market is assumed to be close to 15%.

$$DOF = BOF - (\textit{penalty if } IRR_{PT} \textit{ is not } 15\%) \textit{ if } PVF^* > 0 \quad (11)$$

$$= \textit{a highly negative number if } PVF^* < 0$$

where: PVF* is the PVF for all publicly controlled transport sectors
IRR_{PT} is the Internal Rate of Return for public transport

HOF

HOF (Half-regulated Objective Function) is an extension of DOF, loosening the rule on subsidy for public transport. Under HOF, subsidies can be paid for public transport when in private control, subject to PVF* being positive. The precise purpose/mechanism for providing subsidy will vary between each city. However two examples are :

- Subsidy is paid for off-peak public transport
- Subsidy is paid to help finance the investment costs of public transport infrastructure

The assumption about profits to the private sector is the same as in DOF. Thus subsidy is not being used to increase private profits but (hopefully) to improve social benefit.

$$HOF = BOF - (\textit{penalty if } IRR_{PT} \textit{ is not } 15\%) \textit{ if } PVF^* - S > 0$$

$$= \textit{a highly negative number if } PVF^* - S < 0 \quad (12)$$

where S is a subsidy paid to the private sector for running public transport.

Preliminary Results

The FATIMA project was underway at the time that this paper was drafted, and the results have been reported more fully elsewhere (May et al, 1999a, b). The results for the Benchmark Objective Function (BOF) are most relevant for comparison with those from OPTIMA, and Table 5 includes a summary of the measures which were typically included in the optima. The benchmark optima were most likely to involve :-

- limited public transport infrastructure investment;
- low cost improvements in road capacity;
- improvements in public transport by increasing frequency and/or reducing fares; and
- restrictions on car use involving either road pricing or increased parking charges.

The results from Project FATIMA largely reflected those for Project OPTIMA, and the policy conclusions above were therefore endorsed, with the following exceptions :-

- low cost reductions in road capacity may be justifiable where full allowance is given to the resulting time savings for pedestrians; this result requires further study;
- the higher cost strategies recommended for the sustainability objective (SOF) in Project OPTIMA are in most cases no longer justified when economic efficiency, local environment and future sustainability are all considered together;
- the inclusion of local environmental costs strengthens the case for improvements to public transport and increases in the costs of car use;
- the assignment of a shadow benefit to revenue generation may on occasion, as in Vienna, lead to a recommendation for strategies which increase the costs of both public and private transport users. The implications of this require careful consideration, since they suggest that transport policy can be used to subsidise other areas of public policy.

CONCLUSIONS

The most important conclusion to be drawn from all the nine cities is that the optimal strategies involve a combination of measures, and rely on synergy to be gained from implementing them together. There is no single best measure for any city, and there is certainly no best solution for European cities more generally. The study has generated recommendations which should be broadly relevant to urban areas throughout the EU:

- strategies should be based on combinations of measures, and should draw fully on the synergy between such measures;
- economically efficient and sustainable measures can be expected to include low cost improvements to road capacity, improvements in public transport levels or reductions in fares, and increases in the cost of car use;
- public transport infrastructure investment is not likely, in the majority of cases, to be a key element in an optimal strategy;
- use of reductions in road capacity to discourage car use is unlikely to be beneficial (although the Austrian FATIMA results raise some questions on this);
- the scale of changes in service levels and fares will be influenced by the current level of subsidy; in some cases a reduction in service levels or an increase in fares may be justified on economic grounds;
- the scale of increase in costs of car use will depend in part on current levels of congestion; the study suggests that road pricing and parking charge increases are broadly interchangeable, but this needs assessing in more detail;
- revenue from such measures must be made available for financing other strategy elements;
- legislation will be needed to enable implementation of road pricing and to control parking charges; in the UK and Italy there is also a case for changing legislation to permit economically more efficient public transport strategies;

- public acceptability will be a significant barrier with those measures which reduce service levels or increase costs; this implies the need for effective public relations campaigns, and carefully designed implementation programmes;
- in most cases economically efficient strategies can be designed which are financially feasible, provided that revenues can be used to finance other strategy elements;
- availability of finance will be a major barrier to implementation of many sustainability-optimal strategies, and further work is needed to investigate the extent to which financial costs can be reduced by strategies which are slightly sub-optimal.

ACKNOWLEDGEMENTS

The research reported in this paper has been financed by Directorate General VII of the European Commission under the EU's Fourth Research Framework. The research is co-ordinated by the Institute for Transport Studies at the University of Leeds. The other partners are the Institute of Traffic Planning and Traffic Engineering of the Technical University of Vienna; the Technical Research Centre of Finland; the Centre for the Study of Transport Systems, Turin; Turin Transport; and the Institute of Transport Economics, Oslo. The authors are grateful to colleagues in all of these organisations for their major contributions to the project.

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