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METHODS TO IDENTIFY OPTIMAL LAND USE AND TRANSPORT POLICY PACKAGES: A COMPARISON OF AREA-WIDE AND SPATIALLY CONSTRAINED POLICIES

Anthony D. May, Guenter Emberger, Simon P. Shepherd
Institute for Transport Studies, University of Leeds, UK
gemberge@its.leeds.ac.uk

Abstract

There is widespread interest in the design and implementation of integrated urban transport strategies, which acknowledge the wide range of policy instruments available, and accept that no one instrument on its own is likely to be effective in tackling urban transport problems. However, there are few tools available to help in identifying the most effective combinations of these policy instruments. This paper describes the results of the most recent in a series of results from a research programme designed to develop methods for optimising integrated transport strategies and to use them to produce policy advice for cities. The optimisation process involves specifying an objective function, a set of available policy instruments and the ranges in which they can be applied. Combinations of these policy instruments are then tested in a transport model, assessed against the objective function, and then input into the optimisation routine which suggests variations in the levels of the policy instruments to improve their performance. The optimal combination is that set of levels of the policy instruments which performs best against the objective function. In this study we have used the same transport land use interaction models in eight cities. Here we report the results for the MARS strategic model applied to two cities, Edinburgh and Leeds. Our earlier work had demonstrated the importance of public transport frequency and fare changes, low cost road capacity increases and road pricing in achieving optimal strategies. However, all except road pricing had been applied city-wide. In the tests reported here we consider limiting frequency and road capacity changes to radial movements or to the urban core of the study area. We show in both cities that limiting road capacity increases in this way is more realistic, but substantially reduces the predicted performance of the strategy. In Edinburgh, where the study area includes an extensive travel to work region, we also find that it is more cost effective to limit the changes in frequency to the urban area. The same is not the case in Leeds, suggesting that the effectiveness of frequency changes is dependent on population density.

Keywords: Optimisation; Integrated strategies; Frequency; Capacity
Topic Area: E1 Assessment and Appraisal Methods

1. Introduction

The UK 1998 Transport White Paper advocated the use of integrated transport strategies, including transport infrastructure, management and pricing measures as well as land use interventions, as ways of achieving the government’s objectives in urban areas (DETR, 1998). That approach was subsequently reinforced in the government’s guidance on the Local Transport Plans (and their equivalents) which all local authorities outside London submitted in 2000 and in the revised version of Planning Policy Guidance 13: Transport (DETR, 2001).

The concept of integrated transport strategies is not new; many local authorities were developing them in the early 1990s (May, 1991) and they were a key element in the first

ECMT report on transport and sustainability (ECMT, 1995). However, few Local Transport Plans (LTPs) can be considered as truly "integrated" as yet in their approach; they are limited in particular by the resources available, the unacceptability of demand management measures, the need to negotiate with operators on public transport service levels and fares, the lack of understanding of interactions between transport and land use, and the timescale for implementing innovative solutions.

There thus remain significant challenges both in the short term design of strategies and in the longer term fundamental understanding of their performance. Among the key issues are the need to understand how best to combine the wide range of different policy instruments; how to identify the optimal combinations of these, given that most can vary substantially in the ways in which they are implemented; how to reflect constraints of finance, institutional responsibilities, technology and public acceptability in their design; how to develop implementation sequences which enhance their performance; and how far it is possible to transfer strategy specifications from one city to another.

These issues have been addressed in our previous work where we have made significant advances in understanding the design of optimal transport strategies. In our initial research we developed a regression-based methodology for determining the optimal combination of policy instruments, using the predictions from a conventional transport model (Fowkes et al, 1998). Subsequently we applied this method to nine European cities, each with its own model, and were able to draw conclusions about the relative merits of different policy instruments (May, Shepherd and Timms, 2000). However, a weakness of that study was the use of different transport models, which made it difficult to compare results between cities.

In a current project, we are using the same models in eight cities. These incorporate, in addition to the transport system, the development in land use over time. To be able to do so, we use time marching land use transport interaction models and simulate future development paths of cities over a 30 year period. An automated assessment of these development paths is used to identify an optimal city specific policy package. The methodology presented is based on an ongoing UK research project, where it is applied and tested for eight cities.

In this paper we compare optimal policies generated using area-wide applications of policy instruments to those generated by allowing spatial variation for some of the policy instruments. In both cases the policy performance is optimised using a modified CBA approach, developed by Minken et al (2003), as the objective function to be maximised.

Section 2 describes the general approach, section 3 describes the appraisal framework, section 4 introduces the model used and section 5 describes the case study results for Edinburgh and Leeds. Finally section 6 draws conclusions and describes the next steps in our study.

2. The general approach

The method involves a state of the art transport policy appraisal framework with a dynamic (time marching) land use and transport interaction model and an automated multidimensional optimisation technique. This approach enables city authorities in collaboration with transport-planning experts to simulate future development paths of cities and regions and provide guidance for the implementation of optimal transport and land use policy packages.

Figure 1 shows the overall process. One or more city-specific scenarios are specified in terms of population, economic activity, spatial distribution, incomes and car ownership, and other factors influencing demand for travel. A land use transport interaction (LUTI) model is then calibrated for the city. An appraisal framework is then specified which reflects the city's objectives, and their relative importance (section 3). A set of policy instruments which can be used in the strategy is then defined, together with the ranges within which they can be implemented. Different combinations of these policy instruments are tested in the LUTI model and appraised against the objective function. An optimisation routine is then applied to generate that combination of policy instruments which performs best in terms of the objective function.

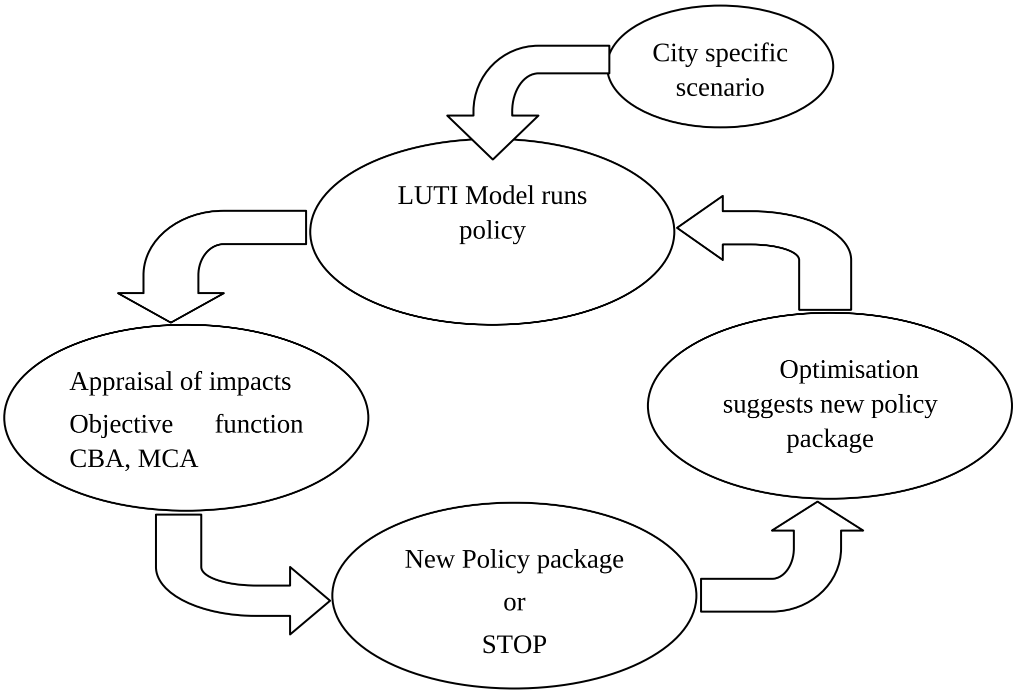

Figure 1 : The general approach

In the project we use three different LUTI models (START/DELTA (Simmonds and Still, 1999), MARS (Pfaffenbichler and Shepherd, 2003), and TPM (TRL, 2001)) which operate at different levels of detail. In this paper we only compare results for the Cities of Leeds and Edinburgh in the UK using the MARS model.

3. The appraisal framework

To be able to appraise the different transport strategies, a set of objectives against which the policies are appraised had to be defined. The objectives of all the UK cities are based on suggestions made in the UK Government's White Paper on the Future of Transport (DETR, 1998). Based on this, we agreed with our partner cities to use sustainability as an overarching objective, and took the five underlying policy objectives to be:-

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

Traditionally strategies are assessed using a cost benefit analysis, however the local authorities have more recently moved to a target based approach partly in response to national guidelines for monitoring impacts and partly due to the lack of available monetary values for some of the indicators proposed in the NATA (New Approach To Appraisal) approach (DETR, 2000b). We have, within this project, developed an alternative approach to CBA which is based on goal achievement with respect to targets for indicators which reflect the policy objectives stated above. A comparison of policies resulting from these two appraisal approaches is presented elsewhere (Emberger et al, 2003). The results in this paper are based on the CBA based approach alone.

3.1 CBA-based approach

To be able to work with these five objectives we had to translate them into an objective function. The objective function (OF) tries also to balance the interests and needs between present and future generations (Minken et. al., 2003). The OF consists of an economic efficiency term, a CO_2 costs term and a term for monetised values for local pollution and accidents. All these costs are discounted over a 30 year evaluation period. Additionally the needs of future generations are considered through a weighting mechanism (α - value) within the objective function.

In formal notation the OF used is:-

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

Where:

$\alpha_t = \alpha \dfrac{1}{(1+r)^t}$ for all years between 0 & 30 except year t*

t* is the last modelled year (year 30)

r is the discount rate

α is the intergenerational equity constant, $0 < \alpha < 1$, to reflect the relative importance of welfare at present as opposed to the welfare of future generations, and:

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

b_t is the benefits in year t and

c_t costs in year t, including user benefits, producer surpluses, benefits to the government, and external costs.

I_t is the Investment.

γ_t is the shadow cost of CO_2 emissions, reflecting the national CO_2 target for year t

g_t is the amount of CO_2 emissions in year t

μ_{it} is the shadow cost of reaching the year t target for indicator i

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

The user benefits for the households are calculated using the "rule of a half" or logsum formulas and including the benefits from land use (Minken et al, 2003). Producer surpluses are derived by annual revenue minus cost including taxes for all firms, operators and entrepreneurs. For the case studies presented here we use a discount rate of 3.5% and α=1.0, i.e. no intergenerational equity consideration, so that results are more in line with UK practice.

4. The strategic land use transport interaction model MARS

MARS (Metropolitan Activity Relocation Simulator) is a strategic, interactive land-use and transport interaction (LUTI) model. It was developed as a time-saving alternative to traditional four-step transport models. MARS can model the transport and behavioural responses to several demand and supply-side instruments. These impacts can then be measured against targets of sustainability. MARS assumes that land-use is not a constant but is rather part of a dynamic system that is influenced by transport infrastructure. The interaction process is modelled using time-lagged feedback loops between the transport and land-use sub-models over a period of 30 years.

Two person groups, with and without access to a car, are considered in the transport model. The transport model is broken down by commuting and non-commuting trips, including travel by non-motorised modes. The land-use model considers residential and workplace location preferences based on accessibility, available land, average rents and amount of green space available. A rather high level of spatial aggregation is used in MARS. In most case studies this means that the wards/districts are chosen as travel analysis zones. The outputs of the transport model are accessibility measures for each zone while the land-use model yields workplace and residential location preferences per zone. The interaction between land-use and transport modelling components is influenced through a set of policy instruments. For example new road infrastructure will change the location of housing and workplaces in the long term.

5. The case study results

5.1 The models

The results shown here are for MARS models of Edinburgh and Leeds. The following table provides some basic information used in the models to describe the cities in terms of size and population and in modal split (SL = Slow modes, PT = public transport, PC = private car). The Edinburgh model covers the travel to work area beyond the city itself, which has a population of about 450,000.

Table 1: Overview case study cities

City / Model	Population				Area (km^2)			Modal split			Cars / 1000 population
Zone / Mode	Inner	Outer	External	Total	Inner	Outer	total	SL	PT	PC	All zones
Edinburgh MARS	n/a	n/a	n/a	1,071,768	n/a	n/a	2305	22%	25%	54%	371
Leeds MARS	n/a	n/a	n/a	727,700	n/a	n/a	559	23%	24%	53%	307

The MARS model for Edinburgh is made up from 25 zones with 14 zones representing the urban area and 9 larger zones to represent the surrounding regions. The MARS Leeds model is made up from 34 zones with 24 representing the urban area and 9 larger zones representing the surrounding regions.

5.2 The tests conducted

In earlier work (Emberger et al. 2003) we distinguished between two types of strategy which could be pursued in the UK context :-

A) simply varying road capacity, public transport frequency and road pricing, all of which are able to be influenced by UK local authorities;

B) adding to A changes in public transport fares, which are currently outside local authority control (except in London).

In discussion with the local authorities it was agreed that these four instruments should be applied within the ranges specified in table 2, and for the movements listed under movements (1).

Table 2 : Application of policy instruments.

Instrument	Range	Movements (1)	Movements (2)	Movements (3)
Road capacity	-20% to +5%	Whole city	Radial	Urban
PT Frequency	-50% to +200%	Whole city	Radial	Urban
Road Pricing	0 to 10 euros	City centre	City centre	City centre
PT fares	-50% to +200%	Whole city	Whole city	Whole city

Subsequently it was realised that city-wide application of road capacity changes might prove infeasible, and that city-wide changes in public transport frequency might prove inefficient. This led to two further strategies in which the changes for these instruments were limited to :-

C) radial movements between the city centre and the surrounding urban area (movements (2) in table 2)

D) movements throughout the urban area, with the exception of those wholly within the city centre (movements (3) in Table 2).

In all cases the instrument levels may be varied within the given ranges for both peak and off-peak periods and over the 30 year evaluation period using a linear time profile. This profile is determined by the levels in the implementation year 5 and long run year 15. The change in instrument level is applied in the short run year 5 and allowed to increase or decrease linearly to the value given for year 15; thereafter the level applied remains constant. Thus we optimise the level of each instrument by period (peak or off-peak) and by short and long run values. This linear profiling approach was adopted to simplify the optimisation process by reducing the number of possible variables per instrument from one per year to two over the whole evaluation period. This simplified policy profile is also easier to present to the local authorities involved. For all case studies we report the results of strategies A, C and D, i.e. first with area-wide application and optimisation of policies, then with spatial variation of the policies in (A) and constraints on policies in the outer areas.

5.3 Edinburgh case study results

Figure 1 shows the Edinburgh study area, zones and population distribution.

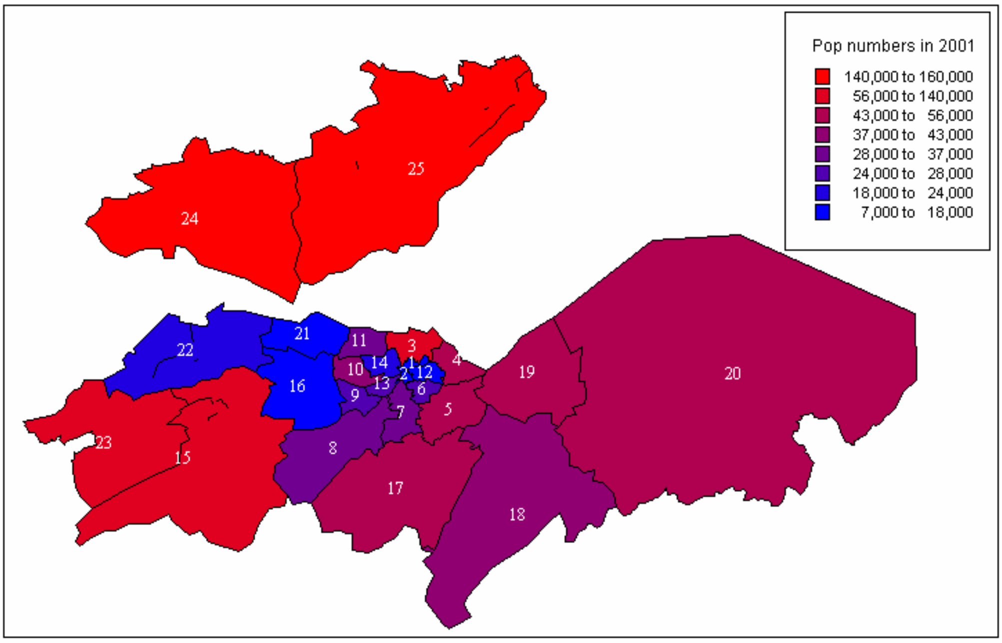

Figure 1 : Population and zone numbers for the Edinburgh study area (MARS)

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5.3.1 Results for strategy A

Table 3 shows the percentage changes in peak and off-peak frequencies in year 5 (P05, OP05) and year 15 (P15, OP15), the peak and off-peak cordon charge in euros in years 5 and 15 and the percentage change in road capacity for all periods and all years – note that the upper bound of 5% is always met so the presentation is simplified to one column. The final three columns show the objective function value (OF), the change in the present value of finance (PVF) and the change in the value of finance for the public transport operator (PT-PVF).

Table 3 : Strategy A: optimisation results.

Run number/code	Freq P05	Freq P15	Freq OP5	Freq OP15	Road Price P05	Road Price P15	Road Price OP05	Road Price OP15	Road capacity all periods and years	OF(Million Euros)	PVF (Million Euros)	PT-PVF (Million Euros)
S1	25	50	30	40	3.2	5.75	0.0	0.0	5	2067	798	-222
S1-2	25	50	30	40	3.2	5.75	0.0	0.0	0	569	551	-379

The optimal unconstrained solution S1 consists of a 5% increase in road capacity across the whole study area – which is the upper bound for this instrument, increases in public transport frequencies in both periods which increase over time, and the introduction of peak period cordon charges which also increase over time. Note that there are no charges in the off-peak as the model assumes that there is no congestion in the off-peak – hence the optimal charge is zero.

As the road capacity change is on the upper bound, test S1-2 was conducted to show the effect of removing the additional area-wide road capacity. The OF value drops by 72% which shows the dominant instrument to be the road capacity changes. The fact that the road capacity increases of 5% contributed over 70% of the OF value brings into question the feasibility of such a change over the whole study area. This issue is dealt with in section 5.4 where capacity changes are applied along corridors and within the urban area only.

5.4 Spatial variations in Edinburgh – Strategies C and D

Figure 1 above shows the zones and population distribution for the MARS study area around Edinburgh. As mentioned previously it was thought that area-wide increases in capacity were not feasible and that the use of area-wide frequency increases might not be the most efficient approach to increasing overall benefits.

In this section we devise two spatial variations based on dividing the study region into three distinct areas and then looking at movements between these areas as either radial or urban as defined in table 2.

The study region was split into a central area (zones 1,2,12), an urban area around Edinburgh, (zones 3-14 except 8) and an outer area (zones 8,15-25). This creates three concentric areas. These groups of zones are now referred to as groups 1-3 from inner to outer.

The first spatial variation test is based on ***radial*** movements only between groups 1 and 2 (both directions). The second spatial variation test is based on ***urban*** movements between 1 and 2 and within group 2 (2 to 2) as depicted in figure 2. Note that within the central zone (zones 1,2,12) no changes in capacity or service levels take place as it is assumed that current capacity will not be improved upon further and that current bus services within the central core are sufficient in terms of headways. Note also that we do not vary the policies in the outer group of zones.

Groups:
1=1,2,12
2=3-7,9-14
3=15-25

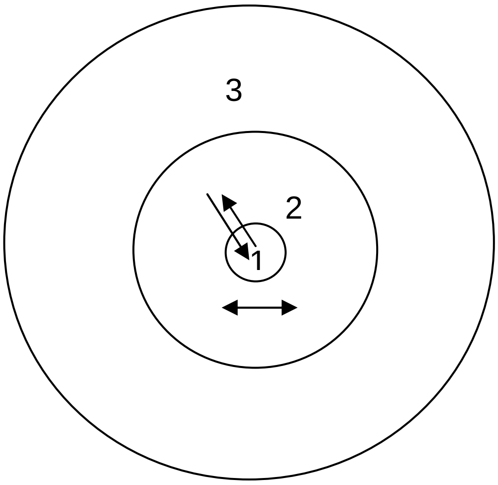

Figure 2 : Spatial variation movements.

5.4.1 Variations in capacity

For the spatial tests of low cost capacity improvements, it was decided to leave the capital and operating costs the same as for an area-wide implementation. This was because the costs involved were small relative to the benefits being observed with the area-wide results. It was also decided to simply test a 5% increase for each case and compare with the area-wide increase of 5%.

Table 3 compares the OF value and its sub-elements for the area-wide increase with the two spatial variations. The radial application only manages 3.5% of the area-wide OF value whereas the urban application gives 15.5% of the area-wide value. These benefits are in line with the proportions of trips and trip-km affected for both modes. It shows that the majority of the area-wide benefits were for trips starting or ending in the outer areas.

One minor problem with the way in which these two tests were implemented is that the changes were applied on an OD pair basis and so trips from the outer to central zones were not affected by the increased capacity on part of their journey. To represent this would require some form of network. It also highlights the fact that a 5% increase in speed for a longer trip generates much greater time benefits than for a short trip.

Table 3 : Spatial variations in road capacity

Run number/code	Road capacity all periods and years	OF(Million Euros)	PVF (Million Euros)	PT-PVF (Million Euros)
Area wide	5	1465	231	142
Radial	5	52	4.2	6
Urban	5	229	29	25

5.4.2 Variations in PT frequencies

Again it should be noted that no changes are made to service levels within the central area (zones 1,2 and 12). For changes in PT frequencies it was necessary to estimate the capital and operating costs associated with the two spatial tests (and also the changes in CO_2 emissions from increased service levels). This was done by simply apportioning the costs with passenger-trip-km in the base case. For the radial application the peak and off-peak radial movements accounted for 3% and 2% of the total trip-km by public transport respectively. The proportion of trips was 12% and 5% for peak and off-peak respectively.

For the urban test the proportion of trip-km were 8.5% and 13% carrying 28% and 32% of total PT trips for peak and off-peak respectively. It is obvious from these figures that the average occupancy in the urban area is greater than in the outer areas and that this gives a possibility for greater benefits per unit of investment.

A number of model runs were conducted for both spatial variations in order to find the optimal increase in frequency. These were found to be +120% and +110% for radial and urban respectively which is more than double the optimal increase for an area-wide change (found to be 50% when used in isolation). Table 4 compares the benefits for the two spatial variations against the optimal area-wide increase of 50%. It can be seen that both tests give better value for money and that for the urban application the OF value is actually higher than for an area-wide increase in frequencies. This indicates that using an area-wide policy for frequency changes is sub-optimal as the costs for outer areas increase more rapidly than the benefits for those areas. These results indicate that bus service improvements should be concentrated on the urban area where waiting times can make up a relatively large part of the generalised cost of travel.

Table 4 : Spatial variations in frequencies.

Run number/code	Freq P05	Freq P15	Freq OP5	Freq OP15	OF(Million Euros)	PVF (Million Euros)	PT-PVF (Million Euros)
Area wide Frequency	50	50	50	50	195	-742	-687
Radial Frequency	120	120	120	120	62	-47	-46
Urban Frequency	110	110	110	110	243	-173	-170

5.4.3 Feasible combinations

Finally it makes sense to test some feasible combinations which incorporate a road pricing cordon around the city centre and spatial variations in frequencies and capacity. Unfortunately the optimisation process is not yet set up to deal with optimisation of spatially limited policies so the best we can do is to look at combinations of instruments using the optimal single instrument levels.

Of the two road capacity tests the radial increase of 5% is thought to be more realistic in that it could be implemented at low cost with priority routes on the inbound radials. For the frequency tests both are considered using the optimal levels as reported above. The charges for the road pricing cordon are set at 3 euros in year 5 rising to 6 euros in year 15, taken from the area-wide optimum but rounded for presentation.

Thus we test two feasible combinations as follows :-

FC1 :

- 5% increase in radial capacity in the urban area
- cordon charges 3-6 euros
- 120% increase in radial PT frequencies in the urban area

FC2 :

- 5% increase in radial capacity in the urban area

- cordon charges 3-6 euros
- 110% increase in urban PT frequencies

Table 5 shows the results for these combinations. Note that the OF value (681 M.Euro) for the second combination exceeds that of test S1-2 (569 M.Euro) which is the most comparable test from the area-wide combinations (as it has no increase in road capacity). In summary the area-wide capacity results were seen as infeasible in reality and so were replaced with changes in radial capacity. The area-wide frequency changes were feasible but were shown to be sub-optimal. Thus a feasible combination was developed which varied capacity along the radials and frequencies over the urban area providing an increase in benefits compared to previous comparable results.

Table 5 : Feasible combinations.

Run number/code	Freq P05	Freq P15	Freq OP5	Freq OP15	Road Price P05	Road Price P15	Road Price OP05	Road Price OP15	Road capacity all periods and years	OF(Million Euros)	PVF (Million Euros)	PT-PVF (Million Euros)
FC1 –radial frequency	120	120	120	120	3	6	0	0	5*	506	1136	99
FC2-urban frequency	100	100	100	100	3	6	0	0	5*	681	1004	-25

* radial increases in capacity

5.5 The Leeds case study results

For the Leeds case study similar area-wide and spatial variations were conducted. Table 6 shows the results for all tests. The area-wide optimisation coded L1 compares well with Edinburgh in terms of road pricing charges in the long run and capacity changes, however the frequency increases are double those found for Edinburgh.

Table 6: Results for Leeds

Run number/code	Freq P05	Freq P15	Freq OP5	Freq OP15	Road Price P05	Road Price P15	Road Price OP05	Road Price OP15	Road capacity all periods and years	OF(Million Euros)	PVF (Million Euros)	PT Operator change in PVF (M.Euro)
L1 – area-wide	100	100	100	100	5.5	5.5	0.2	0.2	5	1888	137	-586
Area wide capacity									*5*	916	125	97
Radial capacity									*5*	38	10	7
Urban capacity									*5*	102	20	17
Area wide Frequency	100	100	100	100						552	-794	-764
Radial Frequency	60	60	60	60						21	-49	-49
Urban Frequency	90	90	90	90						103	-133	-133
FC1-radial frequency	60	60	60	60	5.8	6.4	1.4	0.3	5*	480	783	20
FC2-urban frequency	90	90	90	90	5.8	6.4	1.4	0.3	5*	562	698	-63

* radial increases in capacity

The radial and urban capacity runs reduce benefits by 96% and 89% respectively compared to the area-wide capacity increase of 5%. These results are in line with those obtained for Edinburgh.

The changes in frequency alone show that area wide increases are more efficient in Leeds than spatially constrained changes. This is the opposite of the result obtained for Edinburgh where changes to the outer area frequency was less efficient than radial and urban changes in frequency. The reason for these differences is due to the difference in study areas – the outer zones in the Leeds model being generally closer to the urban area of Leeds so that there is a shorter trip length from the outer zones than in Edinburgh. This difference feeds through to the costs involved for a one percent change in frequencies. It can be seen from the PT-operator losses in tables 4 and 6 that the cost of increasing frequencies area wide in Edinburgh is around twice that of Leeds per one percent change in frequency, whereas the cost for urban changes is the same, and for radial changes the cost in Leeds is double that in Edinburgh. These relative cost assumptions were derived from the distribution of PT trip-km in the base case and the high cost for area-wide changes in Edinburgh backs up the result which showed increases in the outer area to be less efficient than in the urban area.

The feasible combinations (FC1, FC2) confirm this message. The urban combination performs better than the radial combination, mirroring the results in Edinburgh. However, in the Leeds case the area-wide optimisation (L1) outperforms the urban combination (FC2) even when the whole of the benefits of area-wide capacity increases are removed. Conversely, these three options perform in the opposite order in terms of operator profits. The operator would make a net profit from FC1, but make a loss with FC2 and a much larger loss with L1.

In general it appears that frequency improvements are better applied throughout an urban area than simply on the radial routes. However, the justification of extending these beyond the urban boundary will depend on the extent of that area and, probably, its population density.

6. Conclusions and further steps

In this paper we have described briefly our programme of research into the design of optimal urban transport strategies and the optimisation methods which we have developed. We have applied them to two cities, Edinburgh and Leeds, using a common strategic land use transport interaction model, MARS, to identify optimal combinations of public transport frequencies, road pricing and low cost capacity increases.

In both cities the optimal strategy involves increasing frequencies, implementing road pricing and applying the maximum (5%) increase in road capacity. Leeds justified a slightly higher level of optimal road pricing charge, and a frequency increase between two and four times the level in Edinburgh. The reasons for these differences relate to differing levels of congestion and service provision, but also to the relative costs of frequency increases in the outer areas studied.

One limitation of these tests has been that the frequency and road capacity increases were assumed to be applied uniformly throughout the study area which, in the Edinburgh case, included an extensive travel to work area. Only road pricing was limited in its application, to the city centre. Two variants were tested in which frequency and capacity increases were limited to radial movements to the city centre, and to the defined urban area. It was not possible to apply the optimisation routine to these, but a series of combinations were tested which suggested where the optimum might lie.

For road capacity increases, limitation to the urban area removed between 85% and 90% of the benefits, while limitation to radial routes cut the benefits by over 95%. This suggests, paradoxically, that the majority of the benefits of such improvements lie outside the urban areas, where the need is least, presumably as a result of the increases in speed which are generated. This raises questions as to the way in which such benefits are appraised in an urban transport strategy.

For frequency increases, application throughout the urban area performed better than limitation to radial routes in both cities. In Edinburgh, limitation to the urban area, with a substantially higher optimal frequency, performed better than application throughout the travel to work area. In Leeds, where the study area extended over a smaller rural fringe, the converse was the case: area-wide application performed better and justified a higher frequency increase than limitation to the urban area. However, the impacts on operator profitability were in the opposite direction; the greatest losses were made with area-wide application, followed by urban application. Radial application imposed the lowest loss on operators in Edinburgh, and actually generated a profit in Leeds.

Both of these sets of results indicate that policy optimisation is sensitive to the area over which it is applied. The tests of road capacity increases emphasise the importance of looking critically at the apparent benefits of such measures in areas where speed improvements are least needed. The tests of frequency increases demonstrate that their justification depends on the nature of the study area and the costs of servicing it. Further work is needed to understand these distinctions.

These results form part of a wider study which is considering other policy instruments, optimisation against other objective functions, optimisation under constraints of acceptability and finance, and the inclusion of land use policy instruments. The overall results of the study should be available by the time of the conference.

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