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MODELLING THE IMPACT OF TRANSPORT PLANNING POLICY UPON LAND USE

by

R. L. Mackett

This paper was presented at the PTRC Summer Annual Meeting, University of Warwick, Coventry. July 1979

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CONTENTS

ABSTRACT

MACKETT, R.L. (1979) Modelling the impact of transport planning policy upon land use. Leeds: University of Leeds, Inst. Transp. Stud., WP 115.

In this paper the results from the validation of an integrated land use and transport model are described. The goodness-of-fit for the forecasts are considered not only for the time horizon, but also in terms of the change over time, which is a much more sensitive test. The sensitivity of the land use and transport forecasts to changes in the monetary cost of travel are examined to see to what extent the location of housing, population, employment and jobs, and the journey to work respond to such changes. The spatial effects of these changes are demonstrated by finding the land use distribution for three concentric rings. The influence of land use changes upon time and money expenditure are examined by using the relevant elements of the generalised cost functions with the trip matrices computed under three different assumptions when the monetary cost of travel is varied: keeping modal split and land use constant, keeping only land use constant, and allowing both to respond. The paper is concluded with discussion of further model improvements and applications of the model.

MODELLING THE IMPACT OF TRANSPORT PLANNING POLICY UPON LAND USE

1. INTRODUCTION

This paper is concerned with measuring the validity and sensitivity of an integrated land use and transport model. It includes the interaction between population, housing, employment, jobs, shopping and transport. Consequently, the model is fairly complex and a full description is beyond the scope of this paper. We shall concentrate upon two aspects - measuring how good the forecasts are over a five year period and examining how much effect changes in the monetary cost of travel by public and private modes influence the location of urban activities and infrastructure.

This research has reached a stage where criticism is particularly welcome. Consequently the weaknesses as well as the strengths are outlined with the intention that this will provoke discussion and consequently further our knowledge and understanding of the behaviour of urban systems.

2. THE MODEL

The model being used in this study was originally developed in the Institute for Transport Studies at the University of Leeds on a research grant from the Science Research Council. It has been further developed and applied under a contract from the Transport and Road Research Laboratory. The model started out as a form of Lowry model (1) but has been modified considerably since then with the introduction of modal split and car ownership and the distinction between houses and jobs on the one hand, and the location of people in them on the other. Housing is located on the basis of the availability of land, the extent of existing residential development and measures of accessibility to jobs and other residential areas. The industrial sectors are divided on the basis of degree of responsiveness to changes in accessibility (2), from mining which has no short-run response, to shopping for which the spatial distribution of employment is fairly volatile. The model has been fully described elsewhere (3, 4) and so will not be further outline here except in details relevant to this analysis of results.

3. TRANSPORT COSTS

In this model interzonal trnasport costs are represented in a similar way to those in the conventional transport model, for two modes: public and private transport. For private transport (mode 1) we have:

$$c_{ij1} = t_{ij1} + \frac{c^o}{vr} d_{ij} + \frac{p_j}{v}$$

and for public transport (mode 2):

$$c_{ij2} = t_{ij2} + \frac{e + f\, d_{ij}}{v} + w^{(1)}(t^w_i + t^w_j) + w^{(2)} x_{ij} t^s$$

where

- c_{ijk} is the generalised cost of travel between zones i and j in minutes by mode k;
- t_{ijk} is the travel time between zones i and j in minutes by mode k;
- d_{ij} is the distance between zones i and j in kilometres;
- p_j is the cost of parking in zone j in pence;
- c^o is the perceived operating cost of a car in pence per vehicle km;
- v is the value of time in pence per minute;
- r is the mean private vehicle occupancy rate;
- e is the bus fare boarding element in pence;
- f is the bus fare distance element in pence per km;
- t^w_i is the walking element of the public transport trip in zone i, in minutes;
- t^s is the mean waiting time for public transport in minutes;
- x_{ij} is the number of buses used to travel from zone i to zone j;
- $w^{(1)}$ is the value of walking time relative to in-vehicle time;
- $w^{(2)}$ is the value of waiting time relative to in-vehicle time.

Peak travel times are used for the journey to work, off-peak for other trips. At present fixed travel time and distance matrices are used for each time period, but work is proceeding on the incorporation of capacity restraint assignment so that the effects of congestion can be assessed.

The values of the various parameters in the above equations were based upon those used in the WYTCONSULT transportation study of West Yorkshire (5). Information about changes in the road network has been taken from the Leeds Development Plan and the West Yorkshire T.P.P. Information about public transport times and fare levels has been based upon the published timetables and related documents. All prices have been converted to a 1975 level using the retail price index. The road distances were measured on ordnance survey maps. Work is currently proceeding to use the generalised cost matrices developed in the WYTCONSULT study.

4. CALIBRATION

The model is calibrated in four stages. The journey to work distance deterrence parameters are found first, using special tabulations of the journey to work from the Census of Population. Parameter values are obtained for three social groups and two car ownership groups (that is, those with and those without a car). These parameters are obtained by the maximum likelihood method (6, 7), and are used for forecasting the residential and employment location choice processes. Similarly, the spatial demand for shops and other services are calibrated against a small household survey (8) to obtain parameter values representing distance deterrence and the scale effects of different sizes of shopping centres. The calibration of housing and primary and secondary industrial location is to obtain parameters representing non-linearities between the variables being located and the factors determining those locations. The calibration process is described more fully elsewhere (3).

5. GOODNESS-OF-FIT STATISTICS

A model must be shown to be a good representation of the system under consideration before it can be used for forecasting. This should be done at both the calibration and the forecasting stages. Furthermore, the tests on the forecasts should not just be on the values obtained at the future date, but on the <u>change</u> over the period being considered. This applies to both the distribution of activities and infrastructure, and the trip pattern. The author does not know of any studies where such comprehensive tests have been carried out. Generally only the goodness-of-fit on the calibration is measured.

A whole range of statistics can be used to measure the goodness-of-fit, each with advantages and disadvantages. In this paper, as well as comparing the means and standard deviations the coefficient of determination (R^2) and the U-test are used. The coefficient of determination is probably the most widely used measure, and represents the proportion of variation in the dependent variable explained by covariation with the independent variables. It does tend to be rather insensitive at high values and, strictly speaking, requires the data to be normally distributed. It takes values from 0 (no correlation) to 1 (perfect correlation) but a value of 1.0 implies an exact linear relation, rather than a perfect fit. The U-test (9) is similar to the coefficient of determination but does not have the problem of the linear relationship. A value of 0 represents a perfect fit, 1 is 'maximum inequality' and according to the authors a value of less than 0.1 is considered good, 0.1 to 0.3 average, and greater than 0.3 poor.

6. FORECASTING WITH THE MODEL

The model has been applied to the city of Leeds, with 28 zones in the city (in fact the old County Borough), plus 12 external zones for which only interaction with Leeds is modelled (see reference 10 for details of the external zone methodology). The zones in Leeds are the wards in existence at 1966. The enumeration districts used in the 1971 Census of Population have been aggregated to these zones so that the model can be calibrated against 1966 data and the forecasts to 1971 compared with the real situation. Data on population and housing have been taken from the Ward and Parish Library, on the journey to work and employment from the Workplace Analysis and on the distribution of land between activities from land use maps supplied by Leeds CB and MD Councils.

A model as complex as this yields vast quantities of results, so various devices have to be adopted to permit analysis of the changes going on. Three social groups are considered - social group 1 are professional and managerial, social group 3 are unskilled manual workers and social group 2 the rest. This, together with the car ownership/non car ownership dichotomy, means that the impact of planning policies and other changes upon different groups in the community can be examined. Another device that is used is the aggregation of the zones into three areas - area 1 being the central area and surrounding inner city, area 2 is the inner suburbs, largely built before the last war, and area 3 the post war development, plus some 1930's council estates.

The model has been calibrated against data for both 1966 and 1971. The latter is used for forecasts, in five yearly increments, to 1991 to consider the impact on Leeds of policies such as those put forward in the West Yorkshire Structure Plan. In this paper the results being considered are those based upon the 1966 calibration with a forecast to 1971, so that the validity of these can be assessed.

The study area is specified in detail for the base year in terms of the spatial distribution of population, housing, employment and land allocation, plus survival rates for the residential and employment locations. The total population in each social group and the total number of jobs in each industrial sector, are specified exogenously (but can, of course, be kept constant) together with the policy variables which can be specified for one or more zones, such as the number of new houses, the number of new jobs, the release of land for development, the demolition of housing or a particular social mix in the population. These can be used either to represent known information or as part of a planning policy option for testing. The model has been designed to produce a forecast taking these variable values into account.

7. MEASURING THE GOODNESS-OF-FIT OF THE MODEL FORECASTS

It was decided to compare the goodness-of-fit of as many sectors of the model as possible, and since this is a research exercise rather than a planning study as such, to show results whether good or bad, so that an assessment of the validity of the model can be made, and thought be given to why the fit is poor for some sectors. In view of the limited space available the fit of the calibration will not be considered here.

In Table 1 the goodness-of-fit against data for 1971 is shown from a calibration in 1966. It will be noticed that the means are identical with the exception of the employment disaggregated by social group and the trips to work by each mode and in aggregate. The former difference is because the proportion of people in each industry who are in each social group is kept constant in the forecasts, so must be kept constant here. There has clearly been an increase in the number of people in the top social group which is hidden by the assumption in the model.

	Real mean	Model mean	Real standard deviation	Model standard deviation	R^2	U
New housing	526.6	526.6	540.2	554.3	0.59	0.24
Population						
total	17758.8	17758.8	8497.9	8576.6	0.98	0.03
social group 1	2559.8	2559.8	2961.3	2762.2	0.99	0.05
social group 2	13845.7	13845.7	6504.4	6025.4	0.91	0.06
social group 3	1353.3	1353.3	637.4	1526.9	0.67	0.30
Employment						
total	9131.8	9131.8	17474.6	15790.1	0.99	0.07
social group 1	1090.3	1061.0	2348.8	2051.5	0.98	0.09
social group 2	7319.2	7362.3	14279.6	12597.7	0.99	0.07
social group 3	622.3	708.5	1184.4	1148.3	0.98	0.07
Jobs						
agriculture	22.5	22.5	34.4	34.4	0.52	0.31
mining	5.0	5.0	12.0	16.5	[0.01]	0.70
gas, water, electricity	214.3	214.3	555.1	592.0	0.93	0.13
manufacturing	3386.1	3386.1	5421.6	5115.6	0.95	0.10
construction	561.8	561.8	680.9	641.7	0.76	0.19
transport and communications	577.1	577.1	1999.3	1521.9	0.98	0.14
public admin.	455.0	455.0	1300.2	1089.5	0.95	0.13
convenience retail	399.0	399.0	436.4	275.5	0.68	0.24
durable retail	549.3	549.3	1752.4	1907.7	1.00	0.05
business services	1026.8	1026.8	3090.2	3396.4	0.99	0.06
education	578.6	578.6	752.1	617.6	0.89	0.15
personal services	1356.4	1356.4	2213.8	1573.8	0.91	0.18
Trips to work						
total	252.4	253.7	586.7	562.5	0.92	0.13
private mode	56.9	63.9	152.2	124.4	0.86	0.20
public mode	195.5	189.8	464.3	456.5	0.92	0.13

Table 1. Goodness-of-fit of prediction against 1971 data

Note: Square brackets around the value of R^2 indicate that the value of R is negative.

The forecast of the distribution of housing is fairly good, considering that housing location is dependent upon policy considerations. Normally one would expect at least some housing to be located exogenously, with the model being used to locate the rest on the basis of land availability, existing housing and relative accessibility to jobs and other residential areas.

The location of population has a very good fit, with the exception of social group 3. The model allocates new residents in the top social group first, in effect letting them choose from the available housing on the basis of the number of vacant houses, the social class of the people already living there, the accessibility to shops and the accessibility to employment by the modes available. The second social group has the choice of the remaining housing, with the bottom social group having to locate in the rest. Consequently the bottom social group is, in some ways, a residual category.

For employment, the goodness-of-fit statistics are very similar for the three social group because of the disaggregation method used. All are a good fit.

There are some wide differences in the fits for the twelve industrial categories. Mining and gas, water and electricity are not, in the short run, likely to respond to changes in accessibility, and are fairly small. Mining has a very poor fit, but is too small to worry about. Agriculture is also small, and the change in location is partly a function of the amount of agricultural land taken up by new urban development. The fit here is not very good. The categories manufacturing, transport and communication and public administration all have good fits. Construction is not such a good fit, but this is a very difficult sector to locate in reality, because some workers may give the address of their firm as their workplace, others the particular site they are working on, so the problem may be with the data rather than the model.

Durable retail has an almost perfect fit, while convenience is only moderate. The three non-retail service sectors all have good fits. The tests on the journey to work matrices all yield good fits, comparable with most transport studies. Examination of the means shows the underprediction in the number of trips by public transport. If the modal split were forecast more accurately (the model predicts 38.8% using private transport, compared with 30.7% in reality for the whole study area in 1971), then the spatial distribution of trips might be even better.

	Real mean	Model mean	Real standard deviation	Model standard deviation	R^2	U
Population						
total	-264.4	-264.4	2389.1	2296.8	0.70	0.28
social group 1	122.2	122.2	538.6	345.2	0.47	0.43
social group 2	-156.0	-156.0	2019.1	1891.2	0.26	0.49
social group 3	-230.6	-230.6	351.5	1151.7	0.14	0.67
Employment						
total	-534.3	-534.3	2584.7	4025.6	0.65	0.37
social group 1	94.6	-34.8	225.3	373.4	0.01	0.70
social group 2	-524.0	-480.8	2068.5	3482.5	0.62	0.40
social group 3	-104.8	-18.7	285.7	345.4	0.74	0.30
Jobs						
agriculture	2.5	2.5	24.5	17.1	0.08	0.61
mining	-37.9	-37.9	143.2	125.2	0.99	0.08
gas, water, electricity	-24.6	-24.6	196.0	73.7	0.43	0.57
manufacturing	-496.0	-496.0	1452.2	1211.1	0.32	0.44
construction	-93.3	-93.3	370.2	183.9	0.18	0.57
transport and communications	-24.7	-24.7	379.3	160.0	{0.75}	0.97
public admin.	19.3	19.3	309.0	57.0	{0.26}	0.92
convenience retail	-53.2	-53.2	127.7	314.8	0.35	0.57
durable retail	-110.0	-110.0	572.9	420.5	0.95	0.18
business services	129.7	129.7	178.0	423.6	0.03	0.65
education	123.2	123.2	179.9	285.0	0.18	0.50
personal services	30.0	30.0	431.5	1093.2	0.46	0.56
Trips to work						
total	-29.1	-27.9	159.9	161.0	0.33	0.46
private mode	8.7	8.1	43.2	30.2	0.07	0.61
public mode	-37.8	-36.0	155.1	159.7	0.46	0.39

Table 2. Goodness-of-fit of change over the period 1966-1971

Note: Square brackets around the value of R^2 indicate that the value of R is negative.

Overall, it can be said that the fit of the model, as shown in Table 1 is good. Turning to Table 2, the comparison of the forecasts change over the period 1966 to 1971 with the actual change, shows a different picture. A look at the mean changes illustrates one very important feature, namely, that the model can handle decline as well as growth. Both population and employment levels in the city of Leeds have dropped between 1966 and 1971, but with growth in some sectors and decline in others - a good argument for using such disaggregations in the model. Once again the main differences between the model and real means are for employment by social group. This suggests that a better method is required for this process, for example attaching spatial labels to the conversion matrix might help. The trips to work have mean changes that are closer than would be expected from Table 1, suggesting that the cause of the problem is the definition of transport costs in 1966, rather than the changes introduced between 1966 and 1971.

There is much greater variation between individual pairs of real and model values when the change over time is being considered, as a comparison of the standard deviations in Tables 1 and 2 shows.

As would be expected the fits, as shown by the R^2 and U values are much poorer. Ironically, the best fit appears to be for mining ($R^2 = 0.99$, $U = 0.08$) which had a negative value of R in Table 1. In fact only 8 of the 28 zones had any mining employment in 1966. This does illustrate the need for care in interpretation of this type of result.

The fit on the population forecast changes are not particularly good, but the overall figure of $R^2 = 0.70$ is fairly reasonable, and the fits are better the higher the social group. As would be expected the fit for the employment change for social group 1 is very poor, again suggesting the need for further thought on the disaggregation method. Otherwise the fits are fairly good.

There is a very wide variation in the results for the industrial sectors. Two cases, transport and public administration actually have a negative correlation and some others almost none, and yet the equivalent fits on Table 1 were very good. Durable retail again comes out best (apart from mining, which must be regarded as a freak result), with a very good fit.

Notwithstanding the comments above about the changes in the mean values for the trips by each mode, the fit for private trips is poor, and only fair on public trips. This suggests it is the spatial distribution of costs that is at fault, or the terminal costs. The aggregate value is dragged down by the poor showing by the private mode.

In conclusion, the fit of the model is fairly good, when the levels in the forecast year are compared with the actual values. This suggests that this model can stand comparison with any other similar model. However, the results from Table 2 suggest that when a much more sensitive test is applied the good fits of Table 1 may be hiding more than they show. This has very important implications for transportation and land use modelling. How many firms of consultants have computed the fit on the change in the number of trips over time in their various studies around the world? The author would like to suggest that some might become rather worried if they did. The rather poor fits in Table 2 should not be seen as an indictment of this model, rather as a warning to others to take care in the interpretation of the validity of their models. They may not be as good as they think.

8. SENSITIVITY OF LAND USE TO CHANGES IN TRANSPORT COSTS

In this section the amount of change induced in the location of population, housing, jobs and employment brought about by changes in the monetary cost of travel will be considered. For the sake of consistency with other results the changes will be over the period 1966 to 1971, with the adjustments made to the car operating costs and bus fares. There are a whole range of possible changes that could be tested, but these have the advantage of being both fairly simple and policy sensitive, in the sense that the government (central or local) does have some control over the price of petrol or bus fare levels. There is the slight disadvantage that the private costs include the cost of parking in monetary units. This is kept constant even when the perceived operating cost of cars is varied since there is no reason to assume that, for example, reducing the cost of travel by car would result in an identical reduction in the cost of parking. Indeed, the relationship may be an inverse one.

	Car operating cost				Bus fare			
	x 0.0	x 0.5	x 1.5	x 2.0	x 0.0	x 0.5	x 1.5	x 2.0
Housing								
new	16.7	8.6	6.7	11.9	8.8	4.2	6.7	12.9
total	1.4	-0.7	0.6	1.0	0.7	0.4	0.6	1.1
Population								
total	1.4	0.7	0.7	1.2	0.9	0.4	0.6	1.1
social group 1	3.6	1.6	1.1	1.9	1.7	0.6	0.5	0.9
social group 2	3.0	1.7	1.2	2.5	1.4	0.6	0.5	1.0
social group 3	11.9	9.1	8.0	18.1	13.1	4.8	3.3	3.9
Employment								
total	3.5	1.7	1.5	2.9	8.2	4.3	4.3	8.1
social group 1	3.7	1.8	1.6	3.1	10.4	5.5	5.6	10.5
social group 2	3.5	1.7	1.5	2.9	7.8	4.1	4.1	7.7
social group 3	3.6	1.7	1.5	2.9	9.1	4.7	4.5	8.3
Jobs								
agriculture	0.9	0.4	0.4	0.6	1.5	0.7	0.6	0.9
mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
gas, water, electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
manufacturing	3.2	1.5	1.3	2.7	2.2	1.3	1.8	3.5
construction	3.8	1.8	1.6	3.1	2.5	1.5	2.2	4.3
transport and communications	4.4	2.1	1.8	3.6	2.3	1.4	2.1	4.3
public admin.	5.0	2.4	2.1	4.1	2.3	1.6	2.3	4.8
convenience retail	2.9	1.3	1.1	2.1	14.4	6.6	4.9	8.4
durable retail	5.1	2.4	2.1	4.0	12.4	6.9	7.8	15.1
business services	4.8	2.3	2.0	3.8	13.7	8.0	9.8	19.6
education	3.3	1.6	1.2	2.2	19.3	9.1	7.2	12.4
personal services	4.3	2.1	2.0	3.8	20.9	9.9	7.8	13.2
Trips to work								
total	7.4	3.6	3.1	5.4	10.9	5.3	5.2	9.7
private mode	14.5	7.5	7.6	12.8	14.6	6.3	5.3	9.2
public mode	6.5	3.7	4.1	7.2	19.7	9.5	8.9	16.7

Table 3. Percentage net displacement in the location of new housing, population, employment and jobs and the work trip pattern in response to changes in the monetary cost of travel

The first test, illustrated by Table 3, is to see how much change is brought about in each sector by a change in the cost of travel. The perceived operating cost and fare levels have been reduced to zero, halved, increased by a half and doubled.

The first general comment on the effects is the symmetry of the results - an increase or a decrease has a similar effect in terms of the net displacement. Housing has been shown in terms of the effect on both new and total housing. Clearly the effect on new housing is rather greater. The displacement of total population is very similar to that for total housing, which is not surprising since housing largely determines the location of population. However, the location of the individual social groups is much more sensitive, which is good reason for such a disaggregation. As mentioned above, social group 3 is located after the others, and is numerically the smallest, so tends to be the most sensitive. Because housing is more sensitive to changes in private transport costs, population is also. However, the population is the top social group, who have the highest car ownership level, are rather more sensitive to changes in private car costs than in bus fares, relative to the other social groups.

Interestingly, the location of employment is rather more sensitive to public transport cost changes. This is because of the very high level of sensitivity of retail and service activity to changes in public transport. For the reasons mentioned above there are fairly small differences between the three social groups. There is an interesting difference between the secondary industrial sectors (manufacturing and so on) and the shopping and service sectors. The former are more sensitive to the cost of private transport while the latter are affected more by changes in public transport. This is quite reasonable since manufacturing and similar firms are concerned about access to other firms whereas shops and services need to be near their customers, who tend not to use a car.

Similar measures can be calculated for the journey to work pattern. The overall value represents the change in the distribution (and land use) pattern, those by mode include both this effect and

	Basic costs		
	Area 1	Area 2	Area 3
Housing			
new	1438	4462	8846
total	25649	63253	85927
Population			
total	72179	179393	245676
social group 1	4269	19830	47575
social group 2	60860	146654	180167
social group 3	7051	12909	17934
Employment			
total	139728	60313	55649
social group 1	16491	6365	6851
social group 2	112748	49276	44122
social group 3	10489	4672	4676
Jobs			
agricultural	3	67	560
mining	6	81	53
gas, water electricity	4697	753	551
manufacturing	53114	27752	13944
construction	6740	4280	4711
transport and communications	11144	2730	2286
public admin.	7849	2645	2246
convenience retail	2958	3536	4677
durable retail	11147	2047	2184
business services	21426	2570	4755
education	6177	3755	6268
personal services	14468	10097	13415

Table 4. Spatial distribution of housing, population, employment and jobs resulting from basic costs

Note: area 1 = inner city
area 2 = inner suburbs
area 3 = outer suburbs

	Bus fare x 0.0			Bus fare x 2.0		
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
Housing						
new	1513	4130	9104	1045	3766	9936
total	25724	62921	86184	25256	62557	87016
Population						
total	72355	178243	246649	71008	177474	248765
social group 1	4477	19668	47527	4159	19564	47950
social group 2	61416	147266	179000	59965	144503	183213
social group 3	6463	11308	20122	6885	13407	17601
Employment						
total	159972	54060	41658	120060	66331	69300
social group 1	19473	5465	4769	13521	7252	8934
social group 2	128263	44458	33424	97614	59318	54614
social group 3	12236	4136	3465	8925	5161	5752
Jobs						
agricultural	1	71	559	6	66	558
mining	6	81	53	6	81	53
gas, water electricity	4697	753	551	4697	753	551
manufacturing	54856	27131	12823	50024	28674	16112
construction	7094	4195	4441	6119	4336	5275
transport and communications	11471	2577	2113	10486	2935	2739
public admin.	8132	2545	2063	7242	2792	2706
convenience retail	4369	3212	3590	2232	3776	5163
durable retail	12960	1387	1032	8910	2733	3736
business services	25148	1604	1998	16022	3993	8736
education	9190	2901	4110	4410	4442	7348
personal services	22051	7604	8325	9908	11751	16322

Table 5. Effects on the spatial distribution of housing, population and employment and jobs of changes in the bus fare.

Note: area 1 = inner city
area 2 = inner suburbs
area 3 = outer suburbs.

	Car operating cost x 0.0			Car operating cost x 2.0		
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
Housing						
new	861	2918	10967	1954	5499	7293
total	25072	61710	88047	26165	64291	84373
Population						
total	70570	174843	251834	73897	181774	241576
social group 1	5801	20338	45534	3742	19359	48573
social group 2	58477	144205	184999	57837	148515	181329
social group 3	6291	10301	21301	12318	13900	11675
Employment						
total	131810	61588	62293	146219	58235	51236
social group 1	15531	6493	7683	17281	6137	6289
social group 2	106414	50338	49394	117941	47576	40629
social group 3	9865	4757	5216	10997	4522	4318
Jobs						
agricultural	5	70	555	1	66	563
mining	6	81	53	6	81	53
gas, water electricity	4697	753	551	4697	753	551
manufacturing	50530	28580	15700	55250	26737	12823
construction	6182	4322	5336	7204	4175	4351
transport and communications	10505	2851	2804	11648	2564	1947
public admin.	7244	2706	2790	8339	2527	1874
convenience retail	2756	3478	4936	3124	3521	4526
durable retail	10501	2157	2722	11665	1879	1835
business services	20359	2735	5655	22293	2365	4092
education	5749	3732	6719	6475	3729	5996
personal services	13276	10121	14582	15517	9839	12624

Table 6. Effects on the spatial distribution of housing, population, employment and jobs of changes in the car operating cost.

Note: area 1 = inner city
area 2 = inner suburbs
area 3 = outer suburbs

mode switching. Because the majority of trips are by public transport, these changes have a greater effect.

As well as the degree of net displacement of the land uses by changes in transport costs it is useful to examine the spatial distribution of the changes as shown in Tables 4,5 and 6. This is most easily done by using the three areas - the inner city (including the central area), the inner suburbs and the outer suburbs (referred to as areas 1,2 and 3 respectively). The monetary costs have been reduced to zero and doubled, and are compared with the basic application The results from Table 3 suggest that applying half the changes would have approximately half the effect.

Perhaps the most noticeable overall effect is that the changes in monetary costs by the two modes work in opposite directions. A decrease in car costs has a similar effect to an increase in bus costs as explained below.

It is easier to consider the effects in terms of a rise in transport costs (since this is the general trend in public transport at least). Let us consider public transport costs, as shown in Table 5, first. As bus fares rise, people are reluctant to make such long trips to the shops and services, so that these tend to decentralise, moving closer to their customers. In practice, this means new shops will open in the suburbs replacing those nearer the city centre and existing shops will alter their employment levels. To a lesser extent, manufacturing industry and similar sectors will also demonstrate decentralisation to be near a suitable supply of labour. Again we are not talking of firms moving physically, rather the replacement of existing firms in new locations and adjustment in the relative employment levels. House builders would find areas defined as the outer suburbs and most attractive, because the jobs would tend to move outwards and travel has become more expensive. The top social group, who have first choice of housing would tend to move to this area, as would the middle social group. As ever, the bottom social group has to choose from the rest.

When car costs rise the effects are rather different as shown in Table 6. This is because over the periods being considered, the real cost of public transport in Leeds rose dramatically while the real cost of travel by car dropped. The general trend to decentralisation is encapsulated in the calibration process of the model, and this is then reflected in the behaviour when these trends are continued. Consequently the reduction in car costs leads to further decentralisation of economic activity and housing, and consequently of population.

The scenarios spelt out here for the changes in the spatial distribution of employment, housing and population in response to changing transport costs are quite plausible. There is a need for further information on the behaviour of urban systems so that the effects of such responses can be studies. One way to do this is to ask people and firms about their past and potential responses to such changes. While accepting that this task is fraught with difficulties it is intended to carry out research in this field in the Institute for Transport Studies, with particular reference to London and South-East England, where the effects of changes in transport costs on locational behaviour are likely to be much more severe.

9. THE INFLUENCE OF LAND USE CHANGES UPON TIME AND MONEY EXPENDITURE

As described elsewhere (4) this model has the advantage that transport planning policies being tested with the model will not only induce a change in trip distribution and modal split, but also in the location of the trip ends. In the conventional transport model, the number of people living and working in each zone will be determined prior to consideration of the cost of travel. Consequently, the effects of a change in transport costs will be over-estimated using the conventional transport model. For example, if transport costs rise, activities tend to locate closer together, so that the increase in the overall expenditure on travel will be less than that given by the conventional model. This may partly account for some of the overpredictions made by transportation studies in the past. Table 7 illustrates these points. The table shows the effects of varying travel costs on the modal split and the total money and time expenditure on each mode and in aggregate. The effects on time and

	basic costs	car operating cost x0.0	x0.5	x1.5	x2.0	bus fare x0.0	x0.5	x1.5	x2.0
Land use and modal split fixed									
Modal split	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8
Total money									
all	2.86	1.66	2.26	3.46	4.06	1.49	2.17	3.54	4.22
mode 1	1.49	0.29	0.89	2.09	2.09	2.69	1.49	1.49	1.49
mode 2	1.37	1.37	1.37	1.37	1.37	0.00	0.68	2.05	2.73
Total time									
all	9.46	9.46	9.46	9.46	9.46	9.46	9.46	9.46	9.46
mode 1	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
mode 2	7.27	7.27	7.27	7.27	7.27	7.27	7.27	7.27	7.27
Land use fixed									
Modal split	38.8	41.7	39.5	33.9	30.5	27.3	32.7	39.9	42.0
Total money									
all	2.86	1.53	2.28	3.26	3.51	0.97	2.09	3.39	3.81
mode 1	1.49	0.32	0.97	1.71	1.82	0.97	1.23	1.59	1.70
mode 2	1.37	1.21	1.30	1.55	1.69	0.00	0.86	1.80	2.11
Total time									
all	9.46	9.42	9.49	9.86	10.14	11.35	10.37	9.11	8.73
mode 1	2.20	2.73	2.43	1.80	1.51	1.47	1.83	2.31	2.46
mode 2	7.27	6.69	7.06	8.06	8.63	9.88	8.54	6.80	6.28
Land use responsive									
Modal split	38.8	43.9	41.5	36.4	32.6	28.1	34.0	42.2	45.1
Total money									
all	2.86	1.45	2.25	3.30	3.58	1.03	2.14	3.32	3.62
mode 1	1.49	0.31	1.00	1.81	1.92	1.03	1.29	1.61	1.72
mode 2	1.37	1.14	1.25	1.50	1.66	0.00	0.85	1.70	1.90
Total time									
all	9.46	9.23	9.31	9.66	9.99	11.26	10.26	8.88	8.40
mode 1	2.20	2.85	2.52	1.91	1.59	1.51	1.89	2.41	2.58
mode 2	7.27	6.38	6.79	7.76	8.40	9.76	8.37	6.48	5.81

Table 7. Expenditure in money and time on the journey to work trip under alternative assumptions about the response of the urban system to change in the monetary cost of travel.

Note: 1) units: modal split is the percentage of trips to work made by private transport.
money expenditure is in £10^4 per day
time expenditure is in 10^6 minutes per day.
2) for private transport only the operating cost, not the parking charge is being varied.

money have been calculated by using the relevant elements of the generalised cost functions with the trip matrices computed under three different assumptions. The top set of figures show the effect of keeping both land use and modal split constant. Consequently the time expenditures are constant and the money expenditures vary in direct proportion to the change for the particular mode being considered. (As previously, parking charges are not being varied). The second set of figures shows the effect of letting people switch mode and varying the trip distribution matrix subject to the fixed trip ends, as in the conventional transport model. The third set of figures show the effects of letting the land use respond as well as the modal split and the trip distribution. The total amount of money spent has implications in terms of public transport revenue and fuel tax, while the time spent is a measure of total travel in the system and so has social implications since travel in itself has little or no benefit, it is only the opportunities it makes available that are important. The model can be used to compute the mean money and time spent by members of each social group so that the impact in travel terms of particular policies can be computed and compared with the opportunities made available by the policies.

As implied above, allowing land use to respond reduces the shift in modal split in response to a change in travel cost. There is also less change in total travel, as shown by the amount of time spent in response to a particular change. This has consequent implications for the amount of money spent.

Comparisons can be made between the effects on the two modes. As shown by the modal split, the majority of travellers are using public transport, hence overall changes tend to be greater for this mode.

10. FURTHER MODEL IMPROVEMENTS

While this model includes some interesting features there is scope for further research. Firstly, the model has locational choice as a function of transport costs, but migration may be regarded as a two-stage process - the decision to move, then the choice of destination. The second stage is included, but not the first. In other words, the number of survivors at each end of the work trips is independent of changes in the cost of travel. As far as is known, nobody else has done this with this type of model, and hopefully the new project mentioned in section 8 will help. A second, related topic for further work is to link together behaviour patterns within the household, for example, in terms of car availability for the different trip purposes, the locational and household formation decision processes particularly of members of households who work, but are not its head. A third, more general problem, is to relate the overall level of activity (population, employment and so on) of the study area to its spatial distribution and relevant planning policies, that is, to move away from just distributing activities to defining functional relationships at different levels of resolution. This would, almost certainly, make this type of model much more attractive to policy makers, for whom the spatial distribution of activities is secondary to the overall level in their city or region. Hierarchical modelling is only a small step towards this.

11. APPLICATION OF THE MODEL

As mentioned above, this model is being applied as part of a TRRL contract. So far two study areas have been used - Leeds and Harrogate. For each a variety of land use/transport policy 'bundles' have been defined and the model is being used to examine the implications of these, the latter study in conjunction with North Yorkshire County Council. The model is being used for Harrogate to see the implications of a particular policy, for example a new hypermarket or by-pass. In Leeds one of the most important aspects is to consider the influence of policies upon the inner city, both transport policies of the type considered in this paper and the land use/transport policy bundles. At present the forecasts are taken forward from a base year of 1971 to 1991 in five yearly increments. In parallel with this exercise a study of the changes in Leeds from 1891 to 1971 in twenty year increments with a simpler version of the model, is being carried out. The objective of this is to examine the influence of change in transport, both technologically and spatially, on urban morphology. There are great problems obtaining suitable data and there is insufficient time to go into great depth, so the exercise is being kept as simple as possible (which still involves a great deal of effort).

12. CONCLUSION

The author has tried to demonstrate some results from a rather complex model, in order to show the type of results obtained, the problems encountered and to provoke discussion of the issues raised. It is quite clear that there are many questions still to be answered; nevertheless, the type of result produced here certainly seems to be one approach to some fairly fundamental questions about the behaviour of urban systems, particularly in response to changes in transport costs.

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