WCTR

DELTA/START: ADDING LAND USE ANALYSIS TO INTEGRATED TRANSPORT MODELS

DAVID SIMMONDS
David Simmonds Consultancy
10 Jesus Lane
Cambridge CB5 8BA
England

BEN STILL
David Simmonds Consultancy
10 Jesus Lane
Cambridge CB5 8BA
England

Abstract

This paper outlines a dynamic land use / transport / environment modelling package recent developed in response to the need to more closely integrate land use and transport strategic planning in the UK. The model is described as implemented for Lothian region in Scotland, and illustrative model results are presented. The paper concludes that inclusion of land use response into the development of integrated transport models is extremely relevant given the need to combine land use and transport policies for sustainable development objectives.

INTRODUCTION

This paper describes how a new land use model has been added to a strategic transport model to form a dynamic land-use/transport interaction model, and presents some results obtained from an initial application of that model. The presentation of the results considers the effects of a number of policy alternatives, with particular reference to effects which would be omitted from a transport-only model. A parallel paper (Still *et al*, 1998) examines the potential value of land-use/transport interaction modelling in strategic planning.

The transport model upon which this is based is the application of MVA's START (STRategic And Regional Transport) package to Edinburgh (May *et al*, 1992). The approach embodied in START was described in a paper presented to the last WCTR (Roberts and Simmonds, 1997). The dynamic land-use/transport modelling system described here is also being applied, with significant enhancements, to the Greater Manchester area.

THE DESIGN OF THE NEW MODEL

Objectives

The main objectives behind the development of the new package were to create a model system in which:

- the transport modelling characteristics of the START package are retained, i.e. it deals with choice of route (at a very broad level), mode, destination, time of day, frequency, and car ownership;
- the exogenous land-use inputs to START are replaced by forecasts from a land-use model, now called *DELTA* (Development, Employment, Location, Transition and Area quality model);
- the land-use model represents processes of change over time (such as demographic change and physical development);
- transport changes affect accessibility, which influences some processes of land-use change.

It is important to note that many aspects of the land-use model are *not* directly influenced by transport. The impact of a transport change depends on the interaction between processes that are influenced by accessibility (e.g. location of new households) and those that are not (e.g. natural change in the population).

The structure of the model

Within the DELTA/START package, START is run at two-year intervals (instead of being run for a single horizon year). As far as possible, the changes to START were limited to ensuring that the output from one run would provide a suitable base for the next run.

The DELTA model predicts changes in land-use over each of the two-year periods (see Figure 1). DELTA calculates all the information which START requires about households, population, employment and floorspace; this replaces what was previously a process of exogenous input followed by a START procedure to allocate households to categories. The outputs of DELTA at the end of each time period, and the outputs of START for that moment in time, are accumulated in a set of database files. DELTA looks back at previous changes (of up to 12 years) in predicting land-use change.

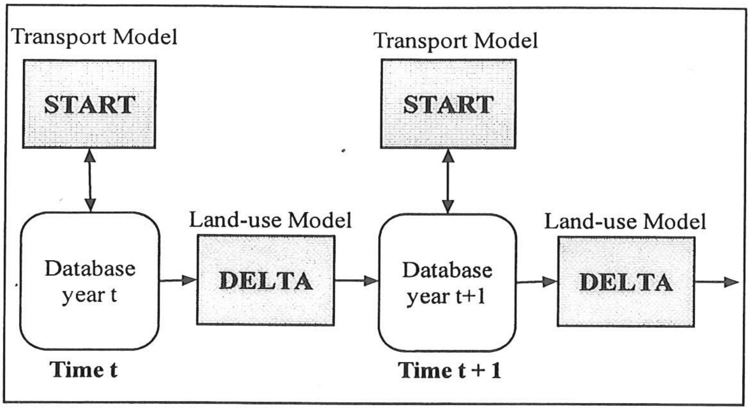


Figure 1: Operation of DELTA/START over time

DELTA consists of five sub-models. These estimate:

1 the development of buildings on land;
2 demographic transition and economic growth;
3 location and relocation of households and jobs;
4 employment status changes;
5 changes in quality of urban areas.

The first and last deal with changes in the quantity and quality, respectively, of space that is available for households and firms to occupy. The other three model changes in activities. The basic linkage of these in modelling one period of change is illustrated in Figure 2. The initial letters of Development, Transition, Location, Employment and Area-quality can be rearranged to give the name DELTA, which of course is also, appropriately, the mathematical symbol for change. The following sections describe the five sub-models in turn.

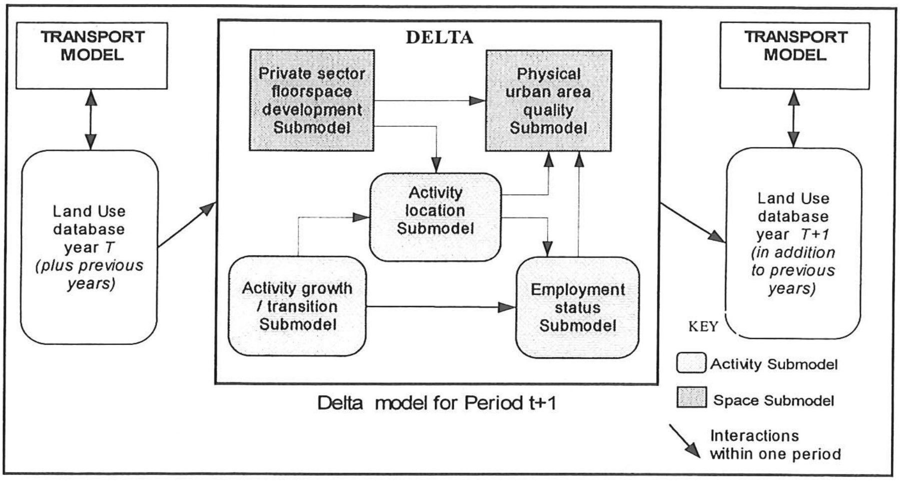


Figure 2: Operation of the DELTA sub-models in one period

Development Sub-Model

The development sub-model seeks to predict the normal operation of the private sector development process. It takes into account the effect of the planning system, measured through planning permissions and indications of longer-term policy. The model estimates the total amount of development of each kind that will be proposed in each period, constrains it by planning effects, and allocates it to individual zones. Developers are motivated by the profitability of development, estimated by comparing current rents with construction costs. Time-lags in the development process mean that developments initiated when rents are high may not become available until rents have fallen again. The model can therefore simulate the 'boom-and-bust' cycle of the development industry.

Public sector development and exceptional private sector schemes are exogenously input to the system, together with information about planning decisions and policies.

Transition and Growth Sub-Model

This sub-model represents processes of demographic and economic change. For households, it is based on a simplified description of the human life-cycle. Put in stark terms, individuals are born, live in various kinds of households, and eventually die. There is no attempt to track persons or households over time. For employment, no such life-cycle concept applies: the model considers only the numbers of jobs in each sector at each point in time.

Demographic change is expressed in terms of rates of household formations, transitions (from one composition of household to another, e.g. couple-without-children to couple-with-children) and dissolution. More complex changes are implied by combinations of these. Economic change is represented as growth or decline by sector. Both are largely independent of other factors within the model. Migration from and to the study area is defined by means of a proportion of each household type by socio-economic group that will leave in each period, plus a ratio of arrivals to departures.

These changes influence mobility and hence the response to transport changes. Newly-formed and newly-arrived households have to find a home; modified households are more likely to relocate than wholly unchanged households. A proportion of the unchanged households is assumed to be wholly immobile in each period; they and the housing they occupy are excluded from the workings of the location model.

Location Sub-Model

The location sub-model is both the "location and relocation sub-model", and the "property market sub-model". Mobile activities respond to changes in four variables:

- accessibility;
- quality of the local environment (as affected traffic/transport);
- quality of the area (particularly of housing); and
- the cost or utility of location.

The first two of these variables are calculated from outputs of the transport model, whilst the area quality is predicted by the quality model (see below). The cost or utility of location is calculated within this sub-model. Mobile households choose both their location and the size of dwelling they occupy, given a fixed budget (modified by housing benefits and other factors) and the current level of rent or price in each zone. The operation of the model involves adjusting the rents until all the locating households and all the available housing are accounted for. The market mechanism uses a consumption function and rentadjustment process similar to those in MEPLAN and TRANUS (see Hunt and Simmonds, 1993), but deals only with the households and housing that are "in the market" during this period.

Relocating households will tend to remain in the same location unless there are changes in one of the four influential variables. Newly locating households will similarly tend to locate in proportion to the previous location of similar households. Concentrations of particular kinds of households will therefore tend to persist unless their numbers decline or they are dispersed by other modelled factors.

The location process for employment is similar, but instead of using utility of consumption it uses a simple measure of cost per employee in the location function. The cost is calculated as a function of floorspace rent and floorspace per employee. Floorspace per employee is elastic with respect to rent. As in the residential part of the model, the rents are iteratively adjusted until a combination of density and location changes equilibrates the current demand and supply of floorspace.

Employment Sub-Model

The employment sub-model calculates the demand for labour, given the new number and location of jobs, and adjusts the employment status of individuals and households until that much labour is supplied.

Area Quality Sub-Model

This area quality sub-model attempts to capture something of the quality of different areas of the city. This is much discussed in planning, but has until now been under-represented in urban modelling. The model suggests that the inhabitants of an area themselves influence its characteristics and, over time, affect its desirability as a place to live. Positive influences include maintaining and improving buildings, cultivating gardens, planting trees, etc. Negative effects are neglect and misuse, such as use of residential property for "industrial" purposes (such as breaking up cars in the front garden). At present, positive influences are associated mainly with rising average incomes, and vice versa. Vacant property has a marked negative effect, especially if it represents a significant proportion of the total.

This sub-model is important to the overall design of the model, because it represents a process of "positive feedback" to represent the virtuous or vicious circles that tend to maintain or to enhance the differences between prosperous and deprived areas within cities.

Model implementation

Space constraints meant that this section had to be omitted from the published proceedings. Full details of the implementation of the model can be found in Still and Simmonds (1997).

ILLUSTRATIVE MODEL RESULTS

This discussion of the results aims to address two issues concerning the addition of land use to integrated transport models:

1. what are the difference in transport performance indicators when land use is allowed to respond; and,
2. what are the impacts on the distribution of land uses from the hypothetical transport policies?

Note that other planning issues which can be tested in a land use transport model, for example how land use policies can affect the distribution of activities, are not addressed in this paper. The study area is shown in Figure 3, divided into the 25 zones used in the model. This includes both Edinburgh and the adjoining areas of Fife.

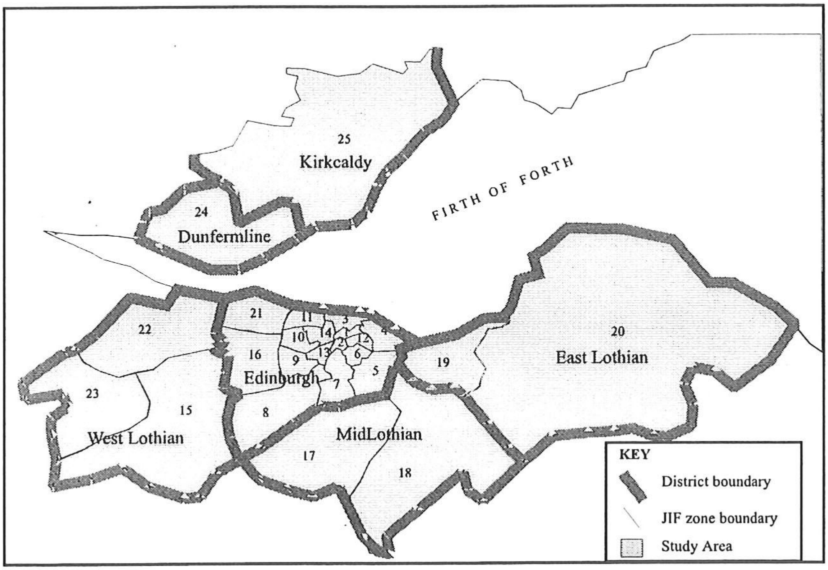


Figure 3: Lothian Study Area

The tests

Five model tests are outlined in this paper. There are two elements to each test; the transport strategy and the land use scenario. Within this paper the land use scenario (which, as outlined in Section 4, includes the employment, population, physical floorspace growth forecasts) remained constant, and only the transport strategy was altered. Note that this is a very simple use of the model's capabilities. Much more complex strategies are possible, and moreover, many more variations on the these tests would be required before clear policy inferences could be drawn.

Table 1: The transport tests

Test code	*Description*
DM6	Do-minimum transport strategy, with land use response
DM0	Do-minimum transport strategy with no land use response
RP6	Road pricing test, with two way city centre cordon at £1.50
LT6	Two Light Rapid Transit routes
LR6	LRT and road pricing combined.

These tests were devised as simple demonstrations of large changes in transport supply. The policies were based upon the best performing measures from the consultants' study in developing 'cartoon' scenarios for an integrated transport strategy for Edinburgh (May *et al,* 1992). The hypothetical transport strategies tested are described in Table 1. The do-minimum (DM6) involved several features, including:

- parking charges rising by 50% over the 20 year period;
- bus fares rising by 30% over the 20 year period;

- several major committed highway improvements including western radial road widening.

With the model representing two year periods, this allows policies to be implemented gradually, or policies (especially infrastructure) of a 'lumpy' nature (such as new road or LRT schemes), to come into effect in specific years. For the sake of simplicity, the do- minimum infrastructure changes were introduced in the first time period (1993), while pricing policies were implemented incrementally over the 20 year forecast period.

Test DM0 was identical to DM6 in every respect except that households and employment were made totally insensitive to transport factors (accessibility and the transport related pollutants). For this reason it can be termed the 'no-response' test. This made DM0 representative of running the land use model independently of the transport model, and hence mimics running a standard strategic transport model. Note that this is not identical to running START in its original form, as it is being run for 10 two-year steps rather than one ten-year step.

The first policy test (RP6) consisted of a road pricing cordon around the city centre zones (1,2,12). A charge of £1.50 (1991 prices) was applied each time the cordon was crossed. Thus a trip to zone 3 from zone 6, via the city centre and crossing the cordon twice, incurred a £3.00 charge. The second test (LT6) introduced a light rapid transit (LRT) scheme running in two lines meeting at the city centre. LRT fares were set equal to bus fares.

The final test (LR6) combined the road pricing and LRT policies together in one test, to examine whether the synergy typically found in modelling such strategies (e.g. May *et al*, 1992) also appeared in the land use transport model. For each test, the policy elements were introduced in 1997, and maintained until the horizon year.

The main study area transport indicators for all the tests are given in Table 2.

Table 2 : Study area transport forecasts: % difference from 2011 Do minimum

(Absolute trips in '000's of trips).	*Do-min (DM6)*	*No-response (DMO) % change*	*Road pricing (RP6) % change*	*Light rail (LT6) % change*	*LT6 + RP6 combined (LR6) % change*
Total person trips	(1077.6)	0.6	-1.0	3.7	2.8
Total car trips	(677.0)	0.5	-9.5	-1.7	-10.8
Total bus trips	(333.0)	1.4	15.4	-19.8	-6.0
Total train trips	(54.5)	-1.1	4.0	-3.3	2.8
Park and ride trips	(13.1)	-1.5	4.6	55.0	60.3
Total LRT trips	N/A	N/A	N/A	(112.2)	(114.1)
Total person trip km	(14184.7)	0.1	-0.2	1.6	1.2
Total car trip km	(10003.4)	0.0	-5.6	-1.9	-7.4
Total bus trip km	(2421.4)	1.0	18.1	-16.7	-0.3
Total train trip km	(1549.7)	-0.8	5.3	-1.0	5.0
Park and ride trip km	(210.1)	-2.1	4.6	82.1	90.9
Total LRT trip km	N/A	N/A	N/A	(658.3)	(657.0)

Notes: Figures in brackets are absolute values. Other values are % changes.

Comparison of the Do-minimum with the No-response test

The percentage differences (in Table 2) from the DM6 run for DM0 show that at the overall study area level, the transport forecasts are very similar, with trip totals differing by no more than around 1.5%. This is to be expected given that the total scenario growth (in terms of population, car ownership and employment) is identical between the runs, and the transport supply is also identical. This result illustrates that the existing pattern of land uses, even given relatively fast rates of change, is a very strong determinant of the pattern of future travel.

However, clearly there are some differences occurring, as some of the results in Table 2 differ by around 1-2%. When not responding to transport conditions, overall there are slightly more trips being made, and more trip km being travelled. There is more bus usage, but less train (and train park and ride) usage. This suggests that within the aggregate results some more complex land use interactions are occurring.

To investigate these results further, it is necessary to examine the distribution of activities. The difference in households and employment from DM6 and DM0 are shown in Figure 4. This shows the differences in zonal growth 1991 to 2011, with DM0 subtracted from DM6. Those zones in which there are more activities in DM6 (as indicated by a positive bar in Figure 4) would be generally expected to have an overall better accessibility in DM6 relative to DM0. As an illustration, to examine this for employment location choice, Figure 5 gives the two main types of accessibility to which employment are sensitive in DELTA. This bar chart gives the change in destination accessibility (i.e. from all other zones to a given zone) over time for DM6, in generalised minutes. Thus a fall in accessibility (i.e. a negative bar) should be interpreted as an improvement in accessibility for that zone. Note also that the 'average SEG to workers' accessibility measure is the average across access to work by the four SEG's represented in DELTA.

By comparing the zonal employment total in Figure 4 with the changes in Figure 5, it is apparent that the major zones with additional growth in DM6 do have accessibility improvements, especially for the key zones of 3, 15, and 24. In many zones where accessibility does not improve over time, especially south of Edinburgh (zones 6-8 and 17-18), then there are relative decreases in employment. However, this is not the whole story: other factors such as the workings of the property market, the mixture of employment between zones and the differing space requirements of different employment sectors can influence the final distributions. This is why the changes in Figure 4 (especially in terms of magnitude) are not wholly explained by Figure 5.

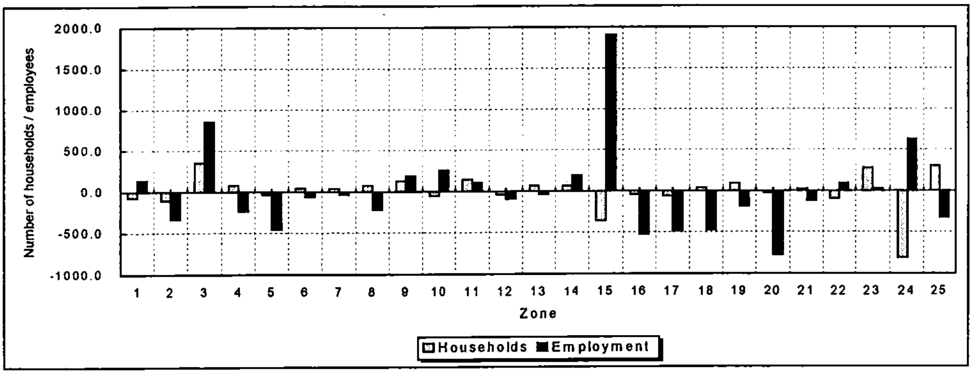


Figure 4 : Absolute difference in household and employment by zone: DM6 - DM0

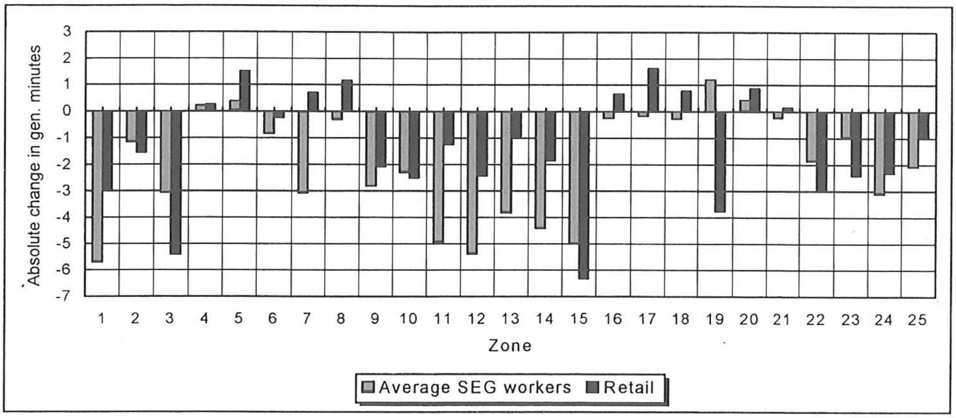


Figure 5: Changes in destination accessibility 1993 to 2009 DM6

However, the large improvement in both employment and accessibility in zone 15 is clearly a related effect. This is due to the positive feedback effect of available floorspace (this zone has the largest increase in available commercial floorspace in the study area), which, as activities move in, increases the accessibility of the zone, and hence increases the zone's attractiveness. Employment in DM6 can respond to this, while employment in DM0 cannot. As a result the two totals diverge, as shown in Figure 6, for the employment level, and Figure 7 for the impacts on commercial floorspace rents. The rent levels show how in both tests rents increase as floorspace increases in the second decade, but the effect is greater in DM6, as accessibility increases the attractiveness of the zone.

The same general pattern also holds for the relationship between household change and origin accessibility changes (i.e. the accessibility from a given zone to all other zones). However, here the relationship is more complex because of the additional interactions of changes in environmental quality. Thus for example there is a decline in environmental quality in zones 15 and 24 (in both tests), which is likely to be detracting from the attractiveness of the zones in DM6, but does not affect location choice in DM0, leading to the different zonal household totals for these zones in Figure 4.

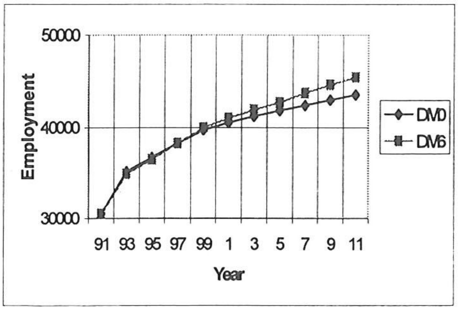


Figure 6: Employment growth in zone 15 DM6 v DM0

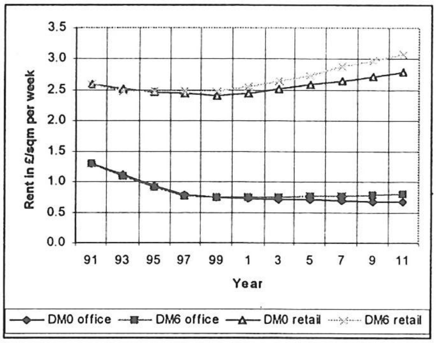


Figure 7: Office and Rent levels in Zone 15: DM6 v DM0

In conclusion, this brief analysis has found that in comparing DM6 with DM0, there are significant differences in the distribution of activities (in some cases involving thousands of jobs), which affect the overall transport forecasts by a small amount. In a study area where the mobility of the households is very high (i.e. a small area, coupled with relatively low levels of congestion), these land use changes can occur without significant transport impacts (as demonstrated, for example, in Simmonds and Coombe, 1997). Moreover, just because the DM6 v DM0 comparison has shown relatively small changes, this is not necessarily the case when certain transport policies are applied, as shown in the next section.

Clearly the importance of these differences will depend upon the study area, or group of zones of most interest, coupled with the sensitivity of these results to other factors. Therefore, incorporating land use response is useful if the subject of study is the distribution of impacts (both land use and transport). The results have also shown that many factors interact in affecting location choice. Factors such as floorspace availability place absolute constraints. The remaining influences on location choice are more complex to assess given that factors (e.g. accessibility and environmental quality) may be moving in different directions.

Comparison of the transport tests.

The hypothetical transport tests had a much larger effect on the study area transport indicators than the DM6 v DM0 comparison, as shown previously in Table 2. The road pricing cordon reduced car trips by nearly 10%, while increasing the mode share for public transport, and reducing (slightly) overall person trip km. The LRT test (LT6), did not have a great influence on the number of car trips, instead capturing existing bus users. When the road pricing and the LRT policies are combined, some interesting results occur from the policies complementing each other. Car trips are reduced by about the same amount as the sum of the individual policies. Bus trips are not reduced as greatly as in LT6, as travellers switch mode from car to bus.

These results are borne out by the trips entering (and terminating in) the city centre. This is shown in Table 3.

Table 3: Trips destinating in the city centre: % difference from do-minima by illustrative years)

	1997 Do-min total (in `000s)	*1997 % change (from 1997)*	*2001 % change (from 2001)*	*2009 % change (from 2009)*
RP total trips		-3.2	-5.1	-4.8
LT total trips	238.2	0.8	9.3	10.3
LR total trips		-2.2	7.1	8.8
RP car trips		-21.6	-23.7	-24.6
LT car trips	117.1	-3.4	4.1	4.1
LR car trips		-24.3	-17.0	-16.3
RP bus trips		16.3	15.3	18.7
LT bus trips	104.3	-29.8	-23.0	-20.0
LR bus trips		-15.3	-5.8	-0.9

The key point from Table 3 is the change in LRT trips by car. In 1997, the year that the policy is implemented, there is a reduction in car trips destinating in the city. However, this is a short term effect only. After this, the increased population attracted to the city, coupled with rising car ownership, means that car trips once again increase, made more attractive by the initial improvement in road conditions following the introduction of the LRT. In addition, increased employment improves the accessibility of the zone. Thus over time, car trips increase to the city centre as shown in Table 3.

The land use impacts from this strategy are also significant. Summary land use forecasts are given in Table 4 below. This shows that road pricing reduces city centre commercial rents, overall employment and (by a small amount) office floorspace development relative to the 2011 DM6. Households however, move into the city centre, although note that the increase in households is greater than the increase in population. In other words there is a decrease in average household size.

Table 4 : Land use indicators: % difference from 2011 DM6

Indicator	*Do-Min*	*RP*	*LT*	*LR*
Retail rents in city centre	5.9	-4.1	23.6	24.4
Office rents in city centre	1.8	-11.7	57.3	58.7
Households in the city centre	26,149	2.5	1.1	4.2
Population in the city centre	36,466	0.9	13.5	19.3
Resident workers in city centre	18,097	-0.3	10.4	14.4
Office / other floorspace in city	1,183,000	-0.3	2.4	2.7
Population in Edinburgh	433,945	0.6	2.9	3.1
Households in Edinburgh	225,126	0.3	0.4	0.7
Employment in city centre	101,130	-3.5	12.6	13.2
Employment in West Lothian	68,789	0.5	-2.8	-2.2

The LRT test, by contrast, causes a large increase in commercial rents in the city centre, and a 13% increase in population, but only a 1% increase in households. This suggests much larger households moving in, with much larger numbers of resident workers. At the same time, employment is also attracted into the city centre. It can be seen that these factors work in a 'virtuous circle', both household and employment increases improving the accessibility for the city centre, and hence increasing the attractiveness for the other. In considering these results, it is important to bear in mind three factors:

- First, that the hypothesised LRT system provides a very much improved level of public transport service with no increase in fares;
- secondly, that it operates within the existing urban area, and therefore does not directly encourage the kind of decentralisation with which suburban railways are historically associated;
- thirdly, unlike many other cities, the centre of Edinburgh is potentially a highly attractive residential environment.

All three of these factors contribute to the inward movement predicted.

For the combined LRT and road pricing test, Table 4 shows that the increase in activities and rents in the city centre are increased. Again, this land use effect is caused by the combination of road pricing and LRT making the city centre more attractive. (Note that Table 3 showed that car trips are reduced most with the combined strategy, while bus trips actually regain some patronage by 2009).

Thus the land use model shows that with road pricing and LRT, it is not just the absolute numbers of households that are different in the city centre, but also the composition of households, both by type and socio-economic group. This can be illustrated with Figures 8a and 8b. These figures show the differences in household numbers (by type) compared to the 2011 DM6 for the city centre (zones 1,2 and 12). Both percentage and absolute results are given as they give different impressions of the true picture of forecasted changes. What is clear here is that with road pricing here is an increase in single person households, hence giving the overall decrease in household size. However, in terms of percentage changes these impacts are small, given that this type comprise the largest household type in the city centre (over 14,000 households).

With the LRT tests, there is a large percentage increase in 3+ adult households and couples (especially those with workers), outbidding and displacing other types of household especially single person households. Within the model, these 3+ adult households place a higher weight on the accessibility improvements, and some of them have sufficient income (typically higher SEGs), or are prepared to live at high densities (typically lower SEGs), in order to take advantage of these benefits. Given that the amount of floorspace in the scenario is identical between the strategies (as the land market within the city centre is extremely constrained), this means that the composition of households in the city centre can vary markedly between strategies. Moreover, note that indirect effects over the longer term (such as households changing type but remaining in the city centre), can further complicate the pattern of changes.

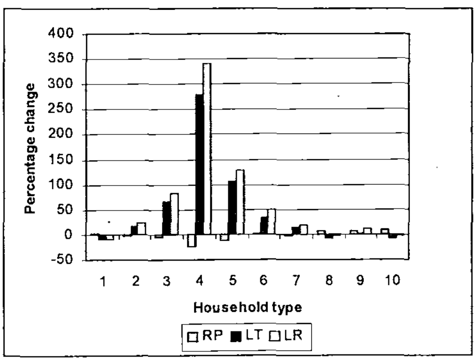


Figure 8a: Percentage change in households by type from DM6 2011

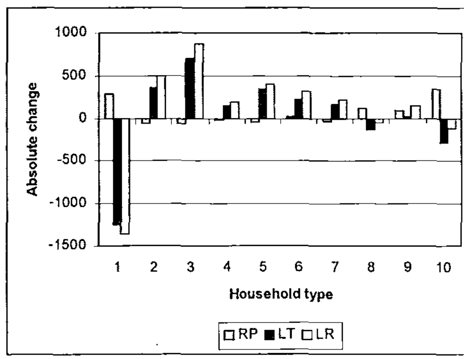


Figure 8b: Absolute change in households by type from DM6 2011

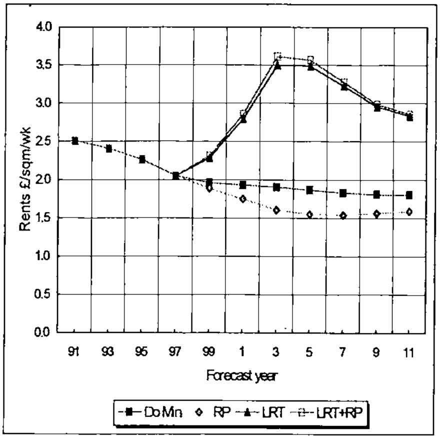
Key for Household types in the above figures:

1 – Young single	5 – 3 adults and no children	9 – Retired couple
2 – Young couple no children	6 – Single with children	10 – Retired single
3 – Young couple with child	7 – Older couple no children	
4 – 3 adults and children	8 – Older single	

In terms of employment, a more detailed analysis again shows that the differences from the do minimum involve several interesting effects. Firstly, as Table 4 showed, office rents in the city centre are enhanced by the LRT tests, and reduced by road pricing. More detail of this is shown in Figure 9, which gives city centre average office/other rent changes over time.

This shows that LRT causes a strong surge in rents, indicative of a large rise in demand for central office floorspace, and reversing the downward trend prevalent in the early modelled years. This growth is marked, but reaches a peak in 2003, before falling. The rise in rents also caused an increase in the amount of office floorspace developed in the city centre. This plateau is caused by partly by a slowing in employment growth from 2001 (an exogenous input to the model). However, perhaps a more important reason is that from 2001 development increases in West Lothian, lowering rents there, and hence, during the second decade (2001-2011), facilitating employment growth in this area (zone 15).

This last point is illustrated by Figure 10, which shows employment by district for the LRT strategy. This shows the initial increase growth in the city centre after 1997, to the detriment of the rest of the study area, especially the rest of Edinburgh. City centre employment growth peaks in 2003, and the city centre declines after this (although even by 2011 it is still at a much higher level than 1991). It is West Lothian which captures much of the growth in employment after this time, primarily due to available floorspace as discussed above.



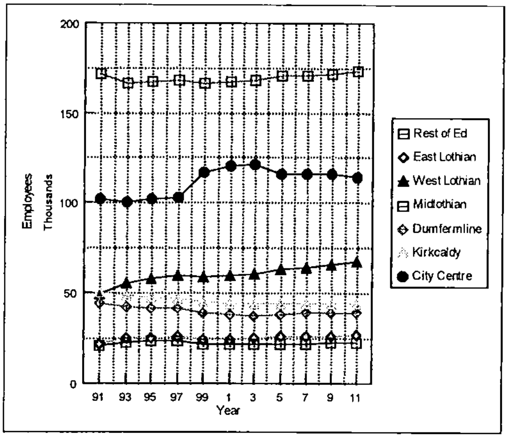


Figure 9: Office rents in the city centre **Figure 10:Employment by District (LRT)**

This analysis of the impacts of the transport strategies has shown the general land use and transport trends that emerged from DELTA/START, as well as investigating some particular results in more detail to show some of the complex interactions that the model takes into account.

CONCLUSIONS

This paper has outlined the DELTA/START model, the model implementation as well as presenting some sample results. It has been shown how the model has been developed from a successful strategic transport model, and builds upon the best elements in land use modelling. The results presented are clearly only a subset of that which the model produces. For example the area quality, environmental and employment by sector outputs have barely been discussed at all. Other indicators, such as rents and accessibilities, can only be given cursory treatment in the space available. Space constraints also prevented the use of other output formats such as mapping.

The results presented in this paper have shown some of the complexity in the operation of land markets and location choice by activities in the model. The net result of these interactions can have effects on the distribution of households and employment groups, greatly changing the zonal compositions, and yet not have a great impact at the aggregate level.

It is hoped that this paper has demonstrated that adding land use to integrated transport analysis can bring strong benefits into transport forecasting. These consist of two main areas:

- improving the theoretical basis of strategic transport forecasting via the incorporation of land use, especially related to the distribution of impacts; and,

- forecasting the growth and decline of land users, and land use development.

Of course, this is in addition to the use of DELTA as a stand alone planning tool in its own right. However, it is hoped that by combining DELTA with START, the new dynamic land use transport model will assist in better planning decision making, and facilitate a better integration of transport and land use planning processes.

ACKNOWLEDGEMENTS

The START model of Edinburgh was used by permission of its original client authorities, namely the City of Edinburgh Council and the Scottish Office. The development of DELTA was carried out by David Simmonds Consultancy, with assistance from those authorities, and with a major input from Ben Still as part of his PhD research at the Institute for Transport Studies in the University of Leeds. Necessary modifications to START (mainly in terms of input and output arrangements) were carried out by MVA.

The resulting model was used first by Dr Still, and subsequently as the central method in a project carried out by ITS for the Engineering and Physical Sciences Research Council as part of the latter's "Sustainable Cities" programme (with additional sponsorship from MVA, DSC and Lothian Regional Council). That project was described in May *et al*, 1997. The results presented here incorporate the refinements made during that project, and the contributions from EPSRC and ITS are acknowledged with thanks. The authors remain responsible for the model, its results and their interpretation.

REFERENCES

Hunt, J. D., and Simmonds, D. C. (1993): Theory and application of an integrated land-use and transport modelling framework. **Environment and Planning** *B*, vol. 20, pp 221-244.

May, A. D., Roberts, M. and Mason, P. (1992) The Development of Transport Strategies for Edinburgh, **Proc. Instn. Civil Engineers: Transportation** , No. 95 pp. 51-59

May, A. D., Bristow, A. L. and Shepherd S. (1997) 'Towards the Sustainable City: The impact of land use transport interactions', **European Transport Forum**, PTRC Brunel University 1-5th Sept 1997.

Roberts, M. and Simmonds, D.C. (1997) A strategic modelling approach for urban transport policy development, **Traffic Engineering and Control**, vol. 38, pp 377-384. (earlier version presented to the **7th World Conference on Transport Research**, Sydney, 1995).

Simmonds, D. C. and Coombe D. (1997) Transport effects of urban land use change, **Traffic Engineering and Control**, vol. 38, No. 12, pp 660-665.

Still B. G., May, A. D., Bristow, A. L., (1998) Transport impacts on land use: potential methods and their relevance to strategic planning, proceedings of the **8th World Conference on Transport Research.**

Still, B. G. and Simmonds, D.C. (1997): **Implementation of the DELTA/START model**. Working Paper 494, Institute for Transport Studies, University of Leeds.