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ABSTRACT

This working paper outlines the steps undertaken to develop a dynamic land use transport model. The model is based around an existing transport modelling suite, called START, which has been applied to many urban areas in the UK and abroad. However, its integration with an explicit land use model (called DELTA) was new, and this paper describes the first implementation of the combined dynamic land use transport model for the study area of Fife and Lothian region. The model was used in a PhD thesis and an EPSRC 'Sustainable Cities' research project at the Institute for Transport Studies.

The paper discusses the processes involved in the full implementation of this model, involving both software development, modification to existing software, and implementation. However, it focuses in particular upon the data requirements and calibration of the various submodels in DELTA. In general the model dataset has been generated using existing study area data from past START applications, plus data from the 1991 Census of population and employment. Not all the disaggregations of data required by the model were available from published, or on-line, sources, and so several disaggregations were undertaken.

A feature of the model is that the calibration is undertaken for each submodel individually. In general, the model made use of past research into the relationships that it represents, combined with the judgement of the model developers where no other data was available. The implementation of the location model is discussed in detail, including the use of environmental variables in location choice. This fulfils the main aim of this paper; to provide the technical background for the research projects that make use of this model implementation.

I INTRODUCTION

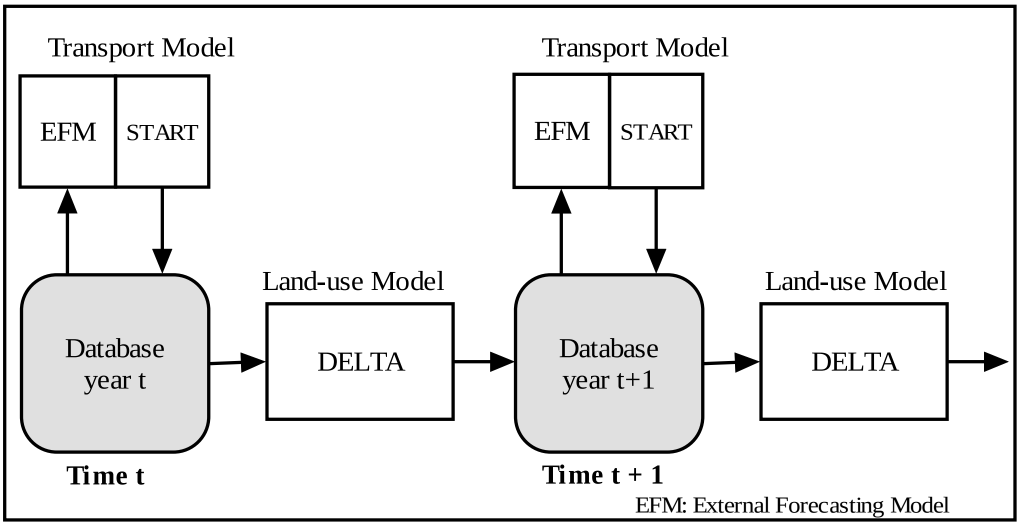
This working paper outlines the implementation of the DELTA/START model that was undertaken as part of a PhD thesis; 'Transport impacts on land use: towards a practical understanding for urban policy making' (Still, 1997). A description of the entire implementation process was not necessary for the arguments of the PhD, but was deemed useful as a record of the process and the assumptions that were made, particularly as the model was used by another ITS research project entitled 'Towards the sustainable city: the impacts of land use - transport interactions' (May, Bristow and Shepherd, 1997). This working paper serves as a source document for both projects, presenting information about the assumptions and processes used in the model.

This paper begins with a brief description of the strategic modelling system (adapted from Still, 1997). A full description of the DELTA model and its rationale can be found in Simmonds (1997: forthcoming). The implementation itself was a large task, which although initiated by the need for a interactive land use model for the purposes of the PhD, then involved several individuals from The MVA Consultancy and David Simmonds Consultancy.

II Overview of the DELTA/START strategic transport land use model

Figure 1 shows the links between the land use (DELTA) and transport (START) elements of the model. The model moves forward over time in successive periods (2 years for the Lothian application). Each period, DELTA provides the land use inputs to START. In turn, START supplies accessibility and environmental information to DELTA. Thus each model treats the other as a black box.

Figure 1: Operation of the DELTA / START model over time



The START strategic transport model was developed by The MVA Consultancy to facilitate transport planning using the 'top-down' approach, appropriate when an overall transport strategy for an area needs to be formulated (Coombe and Copley, 1993). As such it is designed to be able to test a large number of strategies in as short a time as possible. The model is designed to encompass all the major elements of a transport strategy, plus all the expected effects of these policies on the transport system. It has been applied in many urban areas both in the UK and abroad, including Edinburgh, Bristol, Merseyside and Sao Paulo.

The model represents a 16 hour 'average day' as three time periods, for three modes, car availability, and six purposes. It is able to represent mode choice, destination choice, time of day choice and frequency of travel, as well as limited route choice, the effects of congestion, parking, public transport capacity and operator responses.

There are two parts to the START model; (1) the external forecasting model (EFM), which calculates growth in trips from the base year to the future year, and (2) the transport model proper, which determines what will happen to the transport system.

The EFM functions as a trip generation and distribution model. It assumes that if there was no change in transport conditions, then demand for travel would be a function of:

- changes in the households and persons living in each zone;
- changes in the employment in each zone;
- changes in car ownership (influenced by household income and structure).

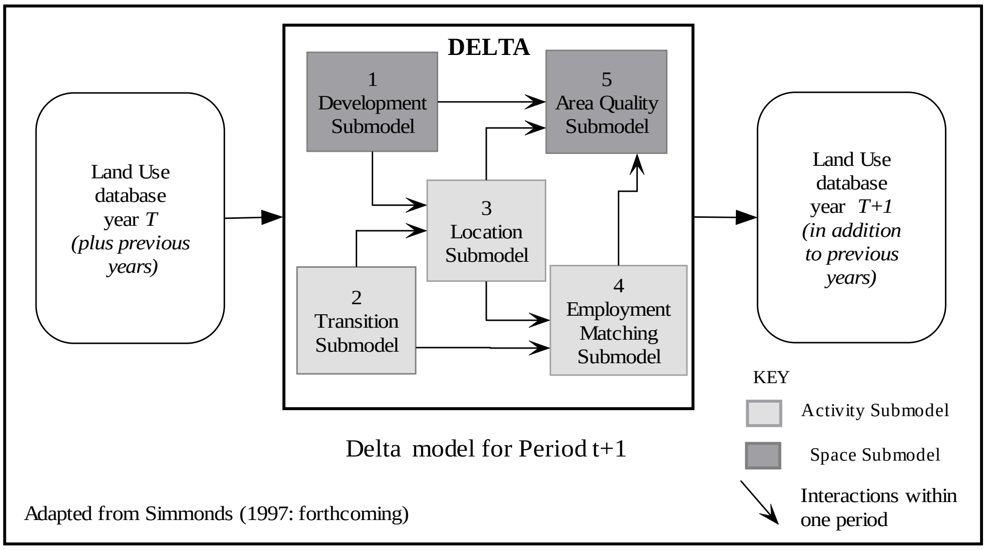
The transport model proper works on the basic premise that all travel responses to changes in the transport system can be represented by changes in components of generalised cost. It consists of two basic elements, a demand model and a supply model. The demand model responds only to changes in generalised cost, and reassigns trip makers by route, mode, time of travel and trip frequency (the latter only for certain purposes: e.g. shopping and retail). This is then fed into a supply model, which contains the transport supply conditions from the 2010 transport policy. The supply component calculates the changes in congestion on the roads and on public transport, and in turn modifies the generalised costs. The model iterates until the components of generalised cost have reached a convergence criteria.

Figure 2 gives the basic structure of the land use model, which shows the five major submodels that comprise DELTA. The submodels reflect, as far as possible, urban processes with which planners (and others) should be familiar. Figure 2 shows that there is relatively little interaction between the submodels in any one time period. That which does take place is related to competition or constraint (shown by the arrows within the DELTA box), for example the effect of available space in constraining activities' location choice. Instead, most interactions take place over time, with activities responding to changing conditions of past periods. This follows a characteristic of many urban models, which comprise a set of relatively simple submodels, but with a complex set of linkages between them.

DELTA requires land use data not only for the base year, but for successive years before the base year, in order that the location choice in the early years is responding to a previous situation. The model does not therefore begin from a static equilibrium point (as compared to START, which begins from a converged 1991 base). DELTA then works forward using the differences between previous database years.

As Figure 2 shows, DELTA operates by reading a 'database' of land use, activity, transport and environmental data for the end of the last period. It then calculates the changes in land use and outputs this data to the 'database' for the new 'end' year. These successive databases provide the data points for the changes with which the model works. The five submodels are shown in the DELTA box in Figure 2, with the number indicating the sequence of running.

Figure 2: Sub-model structure of the DELTA land use model



The **development** submodel represents the private sector construction process. The amount of land that is available per zone in each space category is specified exogenously as part of the land use strategy. The submodel predicts the quantity of floorspace that the construction sector would build in each zone on the basis of zonal profitability. Developments outside the normal market system, both as available floorspace or specific developments, can be entered exogenously.

The **transition and growth submodel** deals with the distinct processes of employment and population change over time. Employment percentage growth and decline by sector for each period is input exogenously. The population change model works in terms of households. The model deals in total with 72 different types of household, although different parts of the model use different aggregations of these. The maximum 72 types arises from 18 household categories (including both an age and employment status split) each divided into four socio-economic groups (SEGs). The four SEG types were as follows:

(1) Professional and managerial
(2) Other non manual
(3) Skilled manual workers
(4) Other semi or non skilled workers.

The transition model itself calculates changes in each household type given a series of exogenous transformation rates from one type of household to another. Households may **form** (e.g. children leaving home), **transform** from one type to another (e.g. by ageing, or the birth of a child) or **dissolve** (i.e. if the last member dies). **Migration** is allowed for as a rate of departure and a ratio of arrivals to departures by household type. A feature of this approach is that only part of the total households (i.e. formations, immigrations and all transitions) will be viewed as 'mobile' by the model, and hence be relocated in the location model. Note that the transition model does not represent the transfer of households between SEGs, which was considered too difficult to attempt to do within the resources of the associated PhD project[1]. However, it should be noted that while the household transition model is complex, it is not intended as a sufficient demographic model in its own right. The intention from the outset was that independent population forecasts from other sources would be applied as constraints in developing the transition rates.

The **location submodel** represents the location choice process of activities. It is given the households and employment to locate or relocate within the available space. These space constraints are firstly from space made available from planning policy, secondly from space released by household transitions, and thirdly from new floorspace completed. Activities choose a location based upon:
1. changes to the rent of floorspace, expressed along with all other goods and services (OGS) costs in a utility of consumption function, (or a cost minimisation function for employment activities);
2. changes in accessibility (but rather than accessibility of a single type, as in the LUCI model, each activity type in DELTA uses a weighted average of accessibilities by several purposes);
3. changes in an index of transport related environmental outputs;
4. changes in area quality, as calculated in the area quality submodel.

The utility of consumption function works on the basis that households behave so as to maximise the utility they gain from a combination of floorspace and the costs of all other goods and services. Note that the location choice is based upon changes in the zonal attributes.

The **employment submodel** deals with the match of employment to population. It takes as input the new jobs by sector and zone, and has to turn this into jobs by SEG. The zonal totals of jobs by SEG are then used to alter the employment status of households until there is a match of total workers by SEG to total jobs by SEG. The outputs of this submodel thus affect the next time period, as they generate 'potential relocators', i.e. households who have changed their employment status and thus may relocate.

[1] The primary reason for this was a lack of estimates concerning how the SEG mixture of employment would change in the future, and then reconciling this with the SEG of the available worker households.

A feature of this submodel should be made clear. The submodel assumes that the study area is a single labour market. In other words all workers can reach any job, and hence accessibility does not influence whether a household will obtain a job or not. This has the implication that if employment is created in a given zone, workers in or near that zone will not automatically gain a high share of the new jobs, even if they are of the correct SEG. Location will only have an influence via the change in accessibility.

Finally, the **area quality** submodel represents the 'desirability' of parts of the city, as influenced by the activities that take place there. For the Lothian DELTA model, this is only implemented for residential floorspace, and is determined by the average income of residents. It assumes that increasing average income will lead to improvements in the quality of the built environment, and vice versa. The area quality is expressed as an index with an arbitrary starting value of 100, and represents the premium (or discount) on the rent that is paid for such quality. This submodel was thought highly desirable by the model architect, as it moves away from the assumption that urban quality is constant over time.

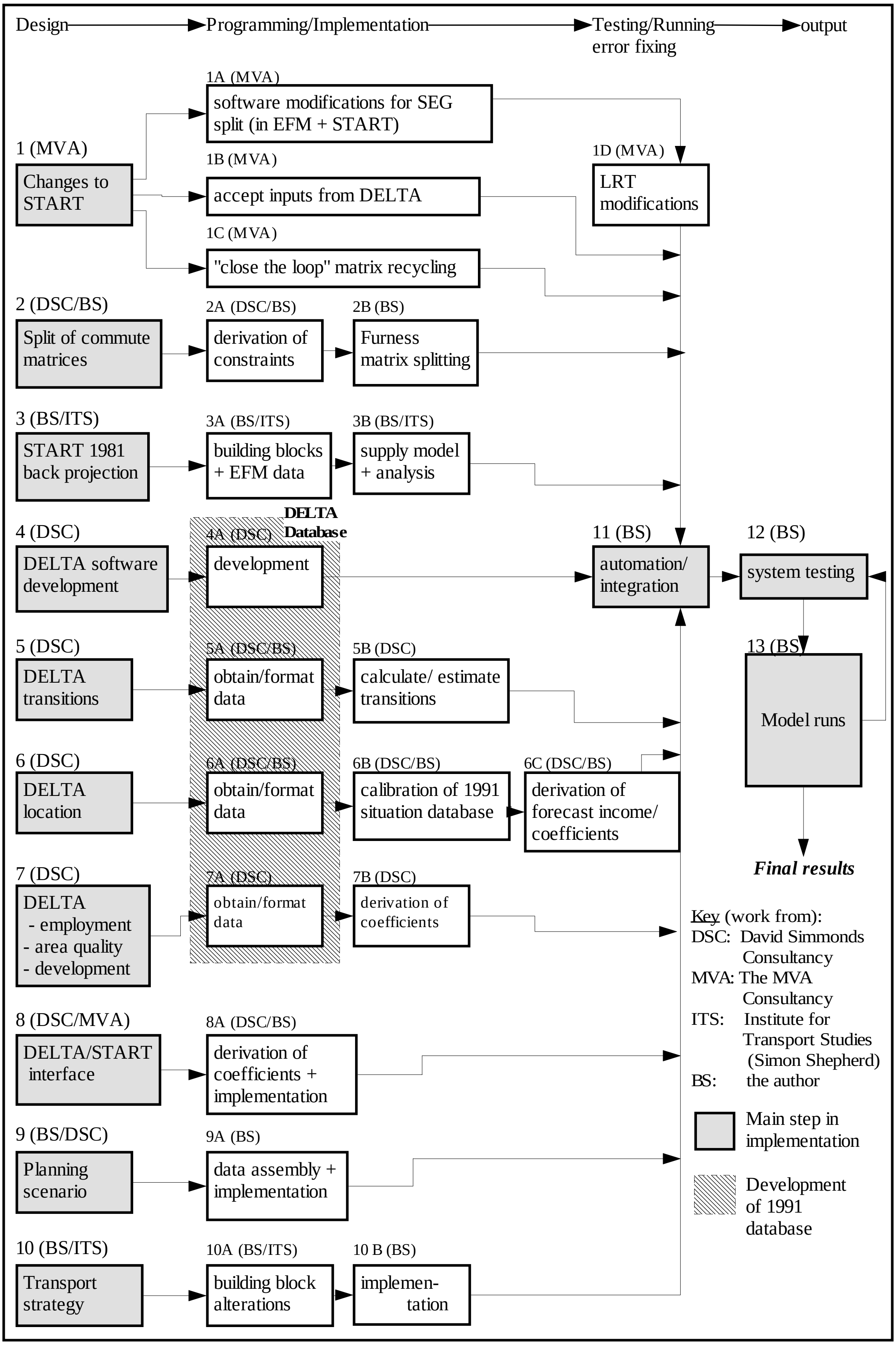
III Outline of the model implementation

This process outlines the details of the model implementation. It follows the structure outlined in Figure 3, dividing the implementation process into the following 13 steps:

1. software and data changes to START;
2. split of the START commute matrices
3. creation and implementation of the START 1981 back projection test;
4. writing and testing of the DELTA software;
5. assembly of the DELTA land use database;
6. derivation of the DELTA transition rates;
7. derivation of the location model parameters;
8. derivation of the parameters in the employment, area quality and development submodels;
9. development of the START / DELTA interface;
10. derivation of the planning scenario;
11. derivation of the transport strategy tests;
12. automation and integration of the software elements; and
13. system testing.

These steps are now discussed in turn. Note that the discussion presents an overview of the implementation process, with a focus upon the scenarios, transport strategies and location model parameter derivation. This reflects the focus of the associated research projects that are using the model, and does not reflect the work required to produce complete the various stages of the model implementation.

Figure 3: Implementation of DELTA/START



1 Changes to START

The START model as outlined above required several software alterations, all undertaken by The MVA Consultancy in Edinburgh. As Figure 1 boxes 1A to 1C show, there were three main tasks, which appear simple in concept, but were very time consuming to implement.

The first task was modifications to take account of the split of workers by SEG. This involved increasing the trip purposes in START and the EFM from six to nine, hence allowing four SEGs to be represented. The rationale for splitting work trips by SEG was to allow for distinctions in the labour market (e.g. professional workers are assumed to respond to the location of 'professional employment').

The second task was to alter the EFM to accept the more detailed activity and space data that would be available from DELTA. This included more detail on the trip makers in households than had been used in JIF previously. The EFM also needed to be altered to accept growth factors (for study area growth, car ownership etc.) in two year steps. A list of the files and their growth factors is given in Appendix 1. This shows that the EFM requires 17 input files for each period that the model is run, most of which change for each two year period.

The third software modification was to write (from scratch) the procedure to take the 'forecast future year' output matrices from START, and convert them into a format suitable for use by the EFM in the next period. This was called the 'close the loop' procedure, and involved converting the future forecast JAVELIN matrices from origin/destination to production/attraction format, and into a TRIPs compatible format (i.e. the format used by the external forecasting model).

In addition to these three areas of software modification, came an additional issue that was not foreseen in the original specifications. This was the problem of implementing an LRT system, or indeed any 'new mode' (Figure 1, box 1d). The problem was that if LRT is implemented in the 'transport supply' for 1997, then a series of LRT trip matrices (by purpose, segment and time of day) are generated, in addition to the matrices for the other 'existing' modes. In the next time period (1997-99), these new matrices must be taken into account in the growth factoring and START procedures. However, this required a different version of START (with an extra set of arrays to handle the extra mode), and additions to the EFM.

2 Split of the commute (travel to work) matrices

Although MVA created the software to allow for four travel to work trip purposes, they did not have the necessary trip end data to split the work-trip matrices. This was done by the authors and involved two steps. Firstly the necessary employment and population data by SEG was assembled to act as 'splitting factors', and secondly splitting the matrices and ensuring consistency using a Furnessing technique.

The land use data that was used was from the 'activity' database being assembled for DELTA. This made use of employment in the workplace by SEG, and population at the residence by SEG. More complex splitting factors using population by car ownership were tested, but ultimately were abandoned due to non convergence issues. The Furnessing technique then was applied to the 15 travel to work matrices, resulting in 60 output matrices (15 for each SEG). The details of this factoring process are presented in Appendix 2.

3 START 1981 'back projection'

DELTA required accessibility and transport related environmental data for years before 1991, in order to have changes to respond to in the first period run. Such data was output from START, and was not available elsewhere. Therefore, START had to be run to produce a set of 'past' outputs. This was undertaken by running the original JIF version of START for the same 'base year' (i.e. 1991), but for a 'future' year of 1981. Resources did not permit an extensive search for data on the 1981 situation, nor for labour intensive tasks such as route capacity re-coding within START itself. Fortunately, MVA had already undertaken a similar exercise in order to validate START against historic traffic flows across the Forth, but their model could not be used directly as it used an older version of the START (transport-only) software. Thus in order to capture the major changes in the transport system between 1981 and 1991 the following strategy was implemented (Figure 3, box 3a):

- Planning data and car ownership data for 1981 was already held by MVA. Therefore, the car ownership constraints for 1981 could be used directly, as could the population and employment data from the 1981 Census.
- The growth factor files outlined in Appendix 1 were set to zeros where no other data was available (e.g. the 'no change' versions were used for external trip growth factors).
- The main change in the route network was the absence of the city bypass. A suitable file for the 'routes' was obtained from MVA in Edinburgh.

Thus the 1981 historic model was not very dissimilar to the 1991 do-minimum, apart from the removal of the bypass. The main change was use of 1981 population, employment and car ownership data. This model did successfully produce a fall in car ownership, reduced traffic flows, and a set of accessibilities. However, resources did not permit any comparison between this and historical empirical data to test the 'goodness' of fit.

4 DELTA software development

The DELTA software was designed and coded by DSC. The DELTA software consists of a series of FORTRAN programs, one for each submodel. They are linked via output database files, and several data manipulation programs. The programs are shown in Table 1 below.

Table 1: DELTA Program Components (order in which run)

	Program	Description
1	MD1.exe	Development sub-model: outputs space under development
2	PD1.exe	Outputs new and surviving floorspace for present period.
3	MT1.exe	Transition and growth sub-model
4	PL1.exe	Assembles activity data (from other files) for use by location sub-model
5	PS2.exe	Assembles land use data (from other files) for use by location sub-model
6	ML1v.exe	Location sub-model
7	ME1.exe	Employment sub-model
8	MQ1.exe	Area quality sub-model
9	PZ2.exe	Writes new space-activity database file
10	UT1.exe	Utility to output household data by zone for analysis
11	UT2.exe	Utility to output space data by zone for analysis
12	IZ1.exe	Prepares inputs for START model

5 Assembly of the DELTA land use database

The land use database comprises all the activity and floorspace data for the base year (1991). The derivation of the database appears as the shaded area around boxes 4a-7a in Figure 3. This is to reflect the fact that the database information is often used by more than one submodel. For example the household cross classification was derived for the transition model (box 5a and 5b), but was also used in the derivation of the base year density and utility of consumption calculations in the location model coefficients (Figure 3; boxes 6A and 6B).

Table 2 outlines the 'land use' data that DELTA requires, and what sources were used. What should be noted from this table is that the household data cannot be obtained directly from the published Census, although special cross tabulations could (in theory) be commissioned. This may well occur for commercial applications, but was not possible here. As a consequence, many of the categories had to be estimated from available Census data, often on the basis of some simple assumptions, several of which will be outlined in the following sections.

Table 2: 'Land use' data required by DELTA or START

	Activity / Space	Source
1	Households by type, zone, SEG	Published Census, LRC
2	Employment by sector and zone	NOMIS: Census of Employment
3	Floorspace by space category and zone	*Pieda* data from JATES, and some estimation.
4	Floorspace rent by space cat. and zone	JATES, and synthesised data
5	Development undertaken in 1991-93	Lothian Report of Survey
6	Education places by zone	JIF planning data (LRC)
7	Transition, formations and mergers of households	BHPS, GRO(S)
8	Activity mobility rates	Estimated
9	Activity migration rates	Census of Migration
10	Growth and decline of employment sectors	Lothian Report of Survey
11	Employment proportions by SEG	Published Census
12	Number of workers by household type	Published Census
13	Children and retired persons per hhd.	Published Census

Key: GRO(S) General Registrar's Office: Scotland
BHPS British National Household Panel Survey
NOMIS National On Line Manpower Information Service

The household disaggregation required households by composition, employment status, and SEG. As mentioned above, this could not be obtained directly from Census data, although Lothian Regional Council had tabulated eight household types by JIF zone and composition, and this was re-used as control totals for creating the divisions by SEG. Estimation from published census data was used to generate 18 household types, split into 25 zones and four SEGs.

An area of particular conceptual difficulty here was in calculating the SEG of households. SEG is related to the occupation and status of workers. The Census classifies household SEG by the SEG of the head of household. If the head of household is not a worker, then the household is not given an SEG. To avoid this problem, the SEG proportions of households in a given zone were determined using the travel to work Census tables, with the assumption that the SEG of the worker reflects the zonal household SEG. Clearly this is a simplification, but it gives a good example of how the assumptions were made to obtain the data in the correct disaggregations within the limited resources available.

The residential rent data was assembled by DSC using data from the JATES study, expanded using Edinburgh Solicitors Property Centre (EPSC) data on advertised housing prices in 1991. This led to a sample of nearly 900 advertised property prices. These were then converted to weekly rents by dividing by 10 (due to the observation that annual rents are around a tenth of selling prices), and then by 52. Commercial rent data was used directly from data collected as part of the JATES study (The MVA Consultancy 1990). All rents were input into DELTA in £ m^2 per week.

Floorspace is treated in the model as a continuous variable, in the sense that households do not consume dwellings, but an amount of floorspace. This simplifying assumption means that the model does not need to attempt to match particular types of households to particular types of dwellings. Floorspace data was obtained for the study area from the JATES study, for commercial land uses. For residential data the number of dwellings was obtained from the 1991 census, and converted into floorspace using the average dwelling sizes shown in Table 3, which were derived using data from Napier University.

Table 3: Average dwelling sizes

Dwelling Type	Estimated average size m^2.
Detached house	120
Semi detached house	100
Terrace	80
Flat	60

6 DELTA transition submodel implementation

The data on the transition rates were derived by DSC from the ESRC British National Household Panel Survey (BHPS), (Buck *et al*, 1994). Further information from the Census and/or General Registrar Office for Scotland (GRO(S)), was used to generate birth, death, marriage and divorce rates for Scotland and Lothian region. The full set of transitions are presented in Appendix 3.

Changes over time in employment activities were derived from the Lothian Report of Survey (Lothian Regional Council, 1994), and are shown in Table 4 below. These factors were derived from Employment forecasts in the Lothian Report of Survey (1994, page 19). They were checked for consistency with the other literature sources. The existing employment totals (for all 25 zones) come from the NOMIS data, and are presented only for illustration. The growth rates 1991 - 1993 are from observed data. The Lothian data gives forecasts for 2001 and 2005. Thus it has been possible to use this to give differing growth rates around these periods. The 2001-2005 factors were used to 2011. Note also that the Lothian growth rates are used for Fife as well, due to lack of forecasts for Fife.

Table 4: Employment Change Factors

	Sector	Employment (1991)	Growth: 91-93	93-2001	2001-11
P	(73) Agriculture	2139	-0.02131	-0.02346	-0.01681
U	(74) Energy and Water	1541	-0.04568	0.00952	0.01990
P	(75) Mining	2836	-0.02131	-0.02346	-0.01681
M	(76) Basic Manufacturing	30318	-0.08349	-0.02210	-0.02460
M	(77) Other Manufacturing	20984	-0.08349	-0.02210	-0.02460
C	(78) Construction	26329	-0.18032	-0.02736	0.00392
D	(79) Distribution/Catering	94143	0.00797	0.02006	0.02565
U	(80) Transport	19197	-0.04568	0.00952	0.01990
B	(81) Banking and Finance	75576	0.07636	0.00500	-0.00823
S	(82) Other Services	186235	0.01700	0.01483	0.00363

Note that the code in the first column is the sector estimated by Lothian. P= primary, M= manufacturing, C= construction, D= distribution, U= utilities and transport, B= banking insurance and finance, S= other services. See Lothian Report of Survey fig 2.15, p19)

The remaining data required for the forecast years of the transition model were the mobility rates of the different activities and the migration rates in and out of the study area. For households mobility rates were derived by DSC from the BHPS data. Much less data was available for employment activities. After some experimentation, it was decided to set all the employment activities as mobile, replicating the process used in models such as MEPLAN for non-basic employment.

The numbers of people in and out migrating had less data available. Migration itself is related to future economic vitality of the study area, as well as 'quality of life' and other factors. The Lothian Report of Survey commented that migration 'changes markedly from year to year' (p12), but also that migration is '*often the largest determining factor of population change'*. Disappointingly, there was no data on the contribution of migration to total change given in the Lothian forecasts, and hence some very simple assumptions needed to be made.

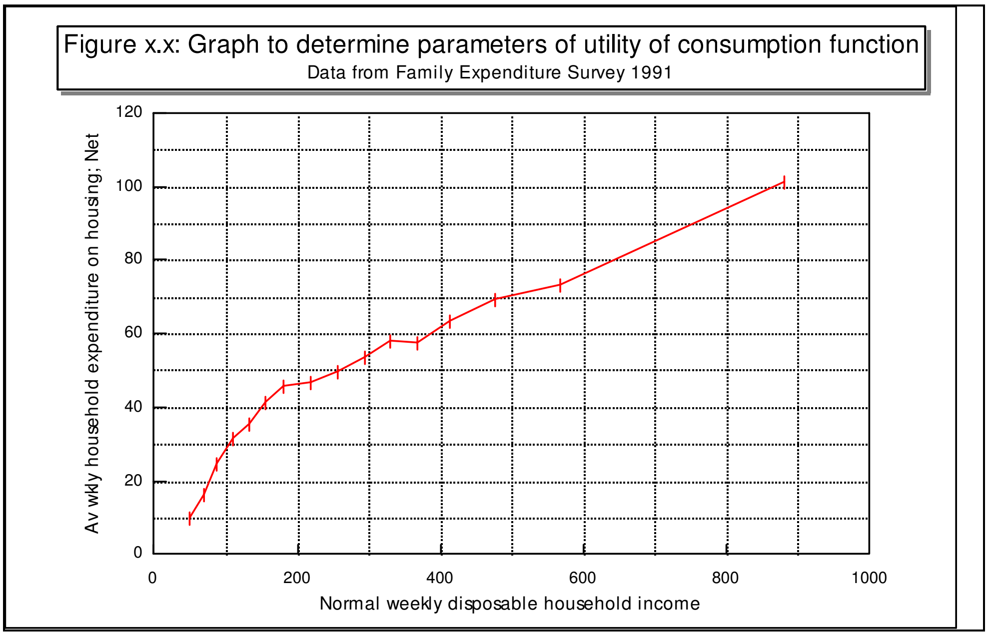
The 1991 Census migration tables were examined , and found quite high rates of in-migration relative to out migration, of about 1.5. For the purposes of this implementation the arrival rate (relative to departures) was set to 1.5 for the following household types: young single people (all SEG's), couples 16-44 no children (all SEG's), and couples with young children (all SEG's). The result of this change is to increase the ‘young’ population of the study area over time, offsetting the natural decrease that the transition model was predicting without in-migration.

7 DELTA location submodel implementation

The implementation of the location model centred around producing the parameters for the residential and employment location choice. These are dealt with in turn.

For the **household location model** the "**utility of consumption**" coefficients were initially developed from Family Expenditure Survey (1991, Table 20). A Cobb-Douglas function is used, with just two goods - housing and other. The coefficients estimated were simply the proportion of income spent on housing at each income level. All other income is assumed to be spent on other goods and services (OGS). This is shown in Figure 4, via tangents and intercepts on a curve of income against the net expenditure on housing. While the Stone Geary utility function was seen as the best fit of the data, the minimum values prevented the location model from converging.

Figure 4: Graphs to determine the parameters in the utility of consumption function



Notes: the graph shows the amount of floorspace consumed by households rising with income, but by a decreasing amount. Ideally, at the income level for each household, the tangent to the curve at that point (relative to the origin) gives the marginal propensity to spend money on housing as income rises (i.e. the α parameter). Where the tangent intercepted the y-axis gave the minima for the Stone-Geary function. However, in the event this substituted by the more simple Cobb-Douglas function, due to convergence problems in the location submodel.

Once these values had been estimated, the activity-space relationship data could be calculated directly, for example for the demand for space for each household type:

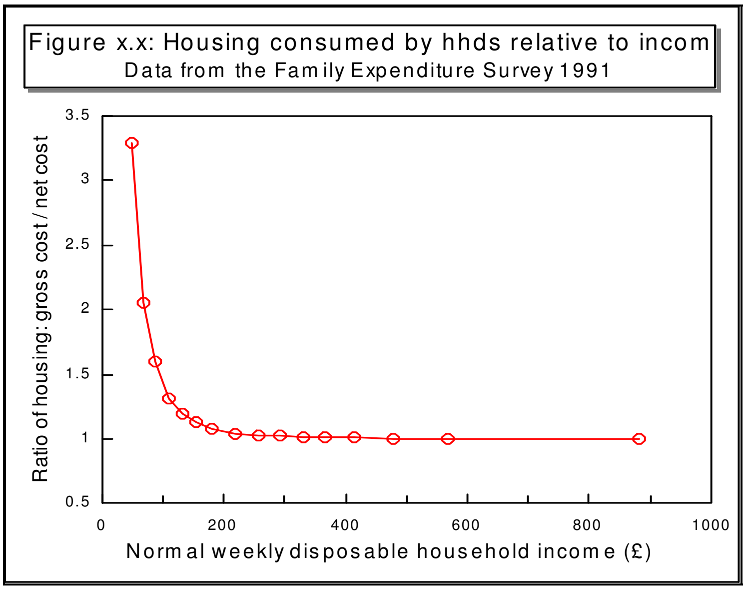
$$a_i^{h(H)} = k^h \left\{ \frac{\alpha^{hH}\left(y_t^h\right)}{r_i^H} \right\} \qquad \text{(Eqn. 1)}$$

Where:

$a_i^{h(H)}$ space (H) demanded by household type h, for zone i;
k^h the adjustment factor for housing subsidy;
y_t^h the income per household type;
r_i^H the (observed) rent for space in a given zone in 1991;
α^{hH} parameter on the utility function.

The Family Expenditure Survey was also used to calculate the ‘k’ factor in equation 1. This is shown in Figure 5, and represents the amount of housing subsidy (e.g. council tax exemption) that households of a lower income receive, by plotting household income against the ratio of gross over net housing cost (i.e. the what a family’s housing really costs, over what they actually pay for it).

FIGURE 5: Graph of housing consumed by households relative to their income



This graph shows that as household incomes rise, so the amount they pay for housing matches their consumption.

However, at lower income levels, notably under £100 a week, people actually consume more housing than they pay for, indicating that a subsidy is being paid to them.

The ratio of supply of available floorspace against the demand for floorspace calculated above, was termed Q_i. This represents the 'unexplained' take up of floorspace in particular zones, perhaps representing differences in quality or dwelling sizes. This term was then merged with k^h to give a single factor (q_i^{hH}), for input as a constant term in the location model for future periods.

The residential location model itself requires four coefficients in order to weight the different components of the key "utility of location" equation. These apply to changes in:

1. utility of consumption;
2. area quality;
3. accessibility, and
4. the (transport-related) environmental measure.

Note that given the way the logit model is formulated, the *relative* values of the four coefficients should reflect households' willingness to pay for (or to avoid) the above properties, whilst their *absolute* values reflect how sensitive households are to these properties in making their locational decisions.

The existing coefficients were brought together from two different sources. The coefficients on utility of consumption and on accessibility were derived from a cross-sectional calibration carried out on data for Bristol, as part of a DSCMOD[2] implementation. The values were initially estimated using the ALOGIT program for just four income groups. These values are shown in Table 5 below.

[2] DSCMOD is a static land use model developed by DSC that uses the horizon year accessibility outputs from a transport model.

Table 5: Outputs from ALOGIT calibration for Bristol
(c1_12/Technical note 7 NAJ/4/101)

SEG	Utility Parameter	T-ratio	Accessibility to work	T-ratio	Accessibility to shop	T-ratio
1	0.005473	N/A	-0.01135	-2.1	0	-
2	0.03036	N/A	-0.01046	-2.6	0	-
3	0.02140	10.1	-0.03296	-3.6	-0.008997	N/A
4	0.02561	12.1	-0.07327	-9.4	-0.01249	N/A

Note that where ALOGIT failed to converge, the best estimate of the coefficient was used (no T-ratio was produced). These parameters suggest that lower income groups are more sensitive to changes in utility and accessibility, but as utility is calculated separately for each group, such a simplistic relationship cannot be assumed.

In order to apply them in DELTA, a relationship between the coefficients and the household incomes was hypothesised, and the coefficients were accordingly interpolated or extrapolated. The absolute values of the coefficients were taken, not just the relationship between them, so these determine the overall sensitivity of the model.

Note that the two coefficients derived from the Bristol work deal with the effect of the variables that *must* change for the model to work at all, i.e. accessibility and housing rent. The coefficient on utility of consumption was particularly important, because given this, it is possible to derive the coefficient for any of the other variables that will reproduce an exogenously researched willingness-to-pay.

The "area quality" was defined in terms of a premium on the rent. An increase of 1 in the quality variable for an 'average' zone was set to produce, on average, a 1% increase in the rent (note the average zones in question were 1, 6, 11, 16, 21 and 25). Note that in the present formulation of the model this is only valid for relative changes: increasing the quality variable by 1 in all zones will have no effect at all! The average coefficient on area quality required to produce this effect was found by running the model with test coefficients on a trial and error basis. The average coefficient was then adjusted to vary with income.

The transport-related environmental variable was calculated in two steps. Firstly a single variable was needed from combining several environment outputs from the transport model (noise, carbon monoxide, oxides of nitrogen and volatile organic compounds). This was done by weighting the individual elements. Secondly, a coefficient was required for this compound variable in the location function.

The overall effect was to make the transport-related environmental variable have an effect equal but opposite to the area quality variable; i.e. an increase of 1 will typically produce a rent decrease of 1%. The coefficient for each household type is therefore the negative of that on area quality.

For the 'compound variable' the weights are described in Appendix 4. Briefly, the following was undertaken. The weight on noise was set at 0.8, so that a (localised) 1dBA increase in noise will produce, on average, a 0.8% decrease in rents (a relationship reviewed by Tinch, 1995). The weights on the different components of air quality were calculated using two pieces of information. Firstly the relative toxicity of different emissions, as a means of estimating their relative importance. Secondly the overall willingness-to-pay for a reduction in atmospheric pollution. It has been assumed that willingness-to-pay varies with income.

The final element in the household location function was the change in incomes over time. The income growth factors were taken from those levels explicit in JIF, that is a rise of 1.8 in real incomes over the study period. All household types were assumed to rise in income equally (i.e. the rich do not get relatively richer than the poor).

The **employment activities** in the location model are considered simply in terms of employment by sector and zone. This is a significant limitation on what can be done to develop a "behaviourally-based" set of models. Changes in employment are only one of a range of ways in which businesses and other organisations may respond to changing circumstances, and that range is much wider than the range of location responses faced by households. The present DELTA model (like most, if not all, other land use transport models) ignores all these options, and all the implications of employment being related to organisations of different sizes and different objectives. Employment location in the model is therefore treated much more simply than household location; in an ideal model it would be much more complex.

The present model considers changes in only two variables: the cost of location and the accessibility. Cost of location is the product of rent per unit space and units of space per worker. There are

therefore just two sets of coefficients to consider: one group for the density functions, and the other for the location function. (Note that the exclusion of quality and environmental variables is the result of a decision in implementing the model; the software can apply these variables in the location process in the same way as for households).

The essential requirement of the model for the density function is an elasticity measure, specifying the reduction in space per worker that will result from an increase in rent. No empirical evidence for such elasticities could be found within the resources available for this research. The values used therefore reflect a combination of what, *a priori*, was felt to be reasonable with what seems to give sensible results from the model runs. The values now in use are fairly high. This has the consequence that a given change in rent[3] will produce a significant decrease in space per worker, and hence only a small increase in the cost of location that is passed to the location function. (Note that if the elasticity of space per worker with respect to rent were -1, cost of location would not be influenced by rent at all.)

The coefficients in the employment location function are the result of thinking and experimentation by DCS, initially influenced by the results of the Bristol DSCMOD calibration. The experimentation involved some work on getting the model to converge at all. There is a problem here that seemingly reasonable values for the coefficients can produce a model that will not converge on any one solution.

8 The other DELTA submodels

The remaining three DELTA submodels, employment, development and area quality are discussed together because they either required little external data, or were given synthesised data derived by DSC.

The employment model required average numbers of retired persons and children in households by type, as well as the average number of workers in each household type. This was estimated from the

Census data. It also required the SEG proportions per sector to calculate the new demand for labour. This data had been estimated as part of the calculations for the attraction end constraints to split the travel to work matrices, and is shown in Table 6.

[3] Note that whilst the idea of a "given change" in rent is useful for explaining the mathematical characteristics of the density function, one cannot introduce a "given change" in rents in DELTA. Changes in rent are only generated endogenously by changes in demand, changes in supply or changes in accessibility.

Table 6: SEG proportions by sector

	1	2	3	4	5	6	7	8	9	10
Prof and Mang	0.387	0.202	0.154	0.250	0.137	0.123	0.261	0.126	0.305	0.288
Other non man	0.136	0.366	0.216	0.226	0.226	0.121	0.528	0.246	0.628	0.489
Skilled man	0.172	0.252	0.204	0.232	0.301	0.537	0.083	0.121	0.035	0.077
Non skilled man	0.305	0.180	0.425	0.293	0.336	0.219	0.128	0.506	0.032	0.146
Sum	1	1	1	1	1	1	1	1	1	1

(file reference CENCOC_IN.wk4: 26/7/95).
(description of process in book 5, page 71: (21/7/95).

The **development model** required various calibrated parameters that determined the rates of floorspace development, the constraints on development, and the sensitivities to profitability of developers. However, these were estimated with 'best guesses' for the purposes of this model, as resources were not available for a full calibration. Construction costs by space category were also estimated by DSC using data from Spon's Construction yearbook (1995). The development model considers only greenfield development (i.e. not redevelopment or regeneration) in its current implementation.

The **area quality** model required parameters on the relationship between income and area quality, and also an estimate of the proportion of change in quality that occurs in the current period. Again, these values were not calibrated, but test values estimated by DSC for the purposes of this implementation. Further research into these parameters is currently being undertaken.

9 The START/DELTA interface

The land use data estimated by DELTA is read directly into the EFM. However, the accessibility and environmental outputs from START need to be converted from measures by zone (and purpose for accessibility), to a measure by household. For the accessibility measures, the weights are an estimate (taken from NTS data) of the average number of trips per week for a given household type and a given purpose. At present, each household type is influenced by three of the accessibility purposes from START, while employment responds to two. Some examples are given in Table 7, where it can be seen that more weight is given to accessibility to work for working households (where the two adult households, both working, in the table make an average of just over 12 trips to work per week) compared to non-working households (the table shows that non-working single person households make, on average, just under half a trip).

Table 7: Example of weightings on accessibility measures from START

Activity	*Accessibility Measure*	*Weight (trips per week)*	*Accessibility Measure*	*Weight (trips per week)*	*Accessibility Measure*	*Weight (trips per week)*
SEG1 Single person hhd, non working	SEG1 to work	0.491	Education	1.123	Shopping	3.549
SEG2 Young Couple no children, working	SEG2 to work	12.384	Education	0.658	Shopping	4.2
SEG 4 Retired couple	SEG 4 to work	1.228	Education	0.092	Shopping	7.828
Retail	Non home based	0.5	retail to SEG1 population	0.5		
Financial Services	Non home based	0.5	work to SEG1 population	0.5		

For the environmental indicator, different procedures were developed for each of the environmental measures that comprise the indicator, and this is discussed further in Appendix 4. The basic process was that weightings for each environmental improvement were applied representing a willingness to pay (WTP), which was then converted into a utility measure comparable to those already in the model. This is another area where improvements are being investigated as part of the ITS ‘Sustainable Cities’ project.

10 Development of the planning scenario

The planning scenario (Figure 3, box 9) required five main elements:
1. The rates of change for activities, including migration rates.
2. The rates of change of people's income over the forecast period
3. The amount of floorspace under construction in the base period.
4. The supply of floorspace in the base period (i.e. outstanding consents)
5. Land use policy, represented by the granting consents over time.

Strictly speaking, only the last of these is a policy instrument. However, the others are variables which in reality would be dependent upon the economic performance of the study area. Element 1 refers to the growth rates of employment sectors, and the migration rates discussed in Section III.6.

Element 2 was set at the overall growth rate already assumed in the START, and discussed in Section III.7. For **income** changes, this was 1.8 over the 20 year period. This produces a 2 year compound factor of 1.06054. For simplicity, it is proposed to increase each household’s income by this factor, despite this being a little unrealistic (on the grounds that the higher SEG's income will probably rise faster than the lower SEG's).

It should also be borne in mind that changing the income affects the parameters in the model that are influenced by income. This is primarily the Utility of Consumption function and the demand for floorspace (and hence associated parameters such as 'q'). These factors are not being altered over time, as they currently represent the 'calibrated' situation in the base year.

Elements 3 and 4 are part of the development of the 1991 database. Data was obtained from the Lothian Report of Survey, although some estimation was required where the data was not given at a disaggregated spatial scale. The details of these disaggregations are given in Appendix 5.

The planning policy itself (element 5) was specified as two components. The first involves increases in the amount of land that is made available for development via the granting of planning permissions. This does not guarantee that development will actually occur, and was estimated for each of the space categories, using the Lothian Structure Plan as a guide for the expected supply of land. The second component is development that occurs outside the mainstream development process. This is input directly as new floorspace, and is intended to represent large developments that the model could not be expected to predict. The Scottish Office moving to Leith would be a good example. From the Lothian Structure Plan three major retail developments were added in this category.

Two points need to be made here. Firstly the available planning forecasts from the Structure Plan only consider the period until around 2005. After some consideration, it was decided to initially test the model with no further land allocations, but to spread this allocation over the entire forecast period. Adding new development was intended to be undertaken in later tests, but has not been implemented to date.

11 Development of the transport strategies

The PhD work using this model required several illustrative transport strategies. The two selected were based upon previous JIF tests and comprised a do-minimum, a road pricing and an LRT strategy. These policies already existed as 'supply' files from the JIF study undertaken by MVA. The main implementation task was that rather than have a single ‘supply’ file, the ten time periods required ten 'supply' files, one for each period. This allowed policies to vary over time, or be implemented at certain years. For the strategies to be consistent with the Delphi, it was decided to introduce the changes in 1997, and have the strategy remain in effect thereafter.

Box 10a from Figure 3 refers to a step called 'building block' alterations. This refers to the process by which a supply model is constructed, taking inputs from a series of strategy specific building block files each representing an element of the transport system. For example different building blocks dealt with highway routes, bus routes, bus fares and road charges. The changes to the building blocks depended upon whether START 'remembered' the cost changes through successive iterations. For example a road pricing charge need only be entered in 1997. Unless the strategy required another charge level, the model would continue to include the charge in the generalised costs for successive years. However, infrastructure elements, such as routes or parking spaces, needed to be given each period.

The situation was further complicated by the underlying growth rate in real incomes over time. This meant that any changes in prices had to be offset against the income growth. For example parking charges were set to increase by 50% over the 20 year period, but incomes rose by 80%, so the following calculation had to be applied to each period to give the charge in 1991 terms:

$$\text{Parking charge year X} = \text{1991 charge} * (1.5/1.8)^{(\text{year X}-1991)/10}$$

In other words parking charges would fall relative to the rise in real incomes. Thus START included no explicit time trends, and the effect of income rises on charges is only apparent through calculations of the type above. This is necessary as then trip makers in START are only responding to changes in generalised cost, rather than also to changes in their income.

The **do-minimum strategy** had the following features, all implemented in 1993:

- parking rising by 50% over the 20 years;
- bus fares rising by approximately 30% over the 20 years;
- numerous highway improvements to the major radials including the M8 extension and A71 widening to dual carriageway;
- zero tolls on the Forth bridge (for simplicity of implementation).

The **light rapid transit** was identical in terms of infrastructure to the version in the JATES application by The MVA Consultancy (1991). The fares were set equal to the bus fares, and an extremely low headway of two minutes was used (as in the previous work by The MVA Consultancy). The **road pricing** strategy had a charge of £1.50 in 1991, and rising in line with incomes thereafter. A **combined** strategy of road pricing and LRT was also implemented. Some other test strategies were also run, such as reducing all bus fares by 50%, and implementing different road pricing charge levels in order to check the model sensitivities, but these are not discussed further.

The EPSRC ‘Sustainable Cities’ project undertook several more variants on this tests, including one way cordon road pricing charges. These are reported in Shepherd et al (1997).

12 Integration and automation of the modelling system

As Figure 3 has shown, all of the elements discussed so far only formed one cohesive model at the stage of integration and automation. Integration was the process of adding the elements into the modelling system. This occurred incrementally as and when procedures or datafiles were completed. In addition procedures were written to automate the process. This was simplest with regard to DELTA, which was written to run automatically. For the links between them and for START itself, a number of JAVELIN and DOS 'batch' procedures were required to link submodels together, or to manipulate data files into suitable formats.

13 System testing and model runs

The initial model runs were dominated by testing the component submodels, to assess whether they were working correctly. Then the various model parts were combined, and again tested to ensure that they ran correctly. Once the full DELTA/START system had been assembled the tests could be undertaken. A description of the testing and a discussion of the initial results can be found in Still (1997), and later tests in May *et al* (1997)

IV SUMMARY

This paper has presented an outline of the implementation process, and described the calibration procedures where they were undertaken. It should be stressed that the model was developed with minimum resources, and as such should be seen as useful in a research context only. Several of the submodels have not been 'calibrated' at all, but at this stage have 'best estimate' parameters only. The transition and location models are slightly different. The former because this model provides the forecasts for the combined model, and latter because it was the subject of the PhD and EPSRC projects that made use of the model.

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Appendix 1

START EXTERNAL FORECASTING INPUTS

Table 1.1: Forecasting inputs

User created files required to run XFORE2: *(Note that DELTA routine IZ1 outputs LANDff.dat, POPNff.dat, and HHff.dat)* *These other files are intended to emulate the growth factors of the original JIF model, and should not need changing other than for the 'No-Change' run.*	
1	**Car*bbff*.dat** (10 files: 1 per 2 yrs.): car ownership constraints, created by SPS (LFACT) This replaces the single Car*bbff* file that existed for the stand alone START model. Note that this file uses a **study area** constraint for car ownership, allowing car ownership rates to vary between zones. (this contrasts to JIF where they are fixed for each zone on the basis of 1991 census data).
2	**Seg_rate.dat** (1 file) trip rates per person, fixed over time for this application, but could be set to change over time if data was available (LFACT).
3	**Segcopar.dat** (1 file) car ownership regression parameters, same for each SEG, fixed over time (LFACT). Unchanged from JIF.
4	**Segistrt.dat**: (1 file for 20 yrs) minimum income per hhd. Assumed not to change over time (or rather rises with inflation only) (LFACT)
5	**Leisure.dat** (1 file) fixed over time regression coefficients for attraction growth in leisure trips (purpose 8 or 5) (DOATTRCT). Unchanged from JIF.
6	**Nhb.dat** (1 file) fixed over time regression coefficients for attraction growth in non home based trips (purpose 9 or 6) (DOATTRCT)
7	**P5P6xfac.dat** (1 file) fixed factors to determine the proportion of outer zone matrix to be factored for external trips. (DOATTRCT)
8	**P6extgrw.dat** (1 file with 2 yr. factors for all 20 yrs) Growth in external trips for non home based purpose, controlled by P5P6xfac. (DOATTRCT)
9	**P5extgrw.dat** (1 file with 2 yr. factors for all 20 yrs) Growth in external trips for business purpose, controlled by P5P6xfac. (DOATTRCT)
10	**Selfmply.dat** (1 file with 2yr factors for all 20 years) Factors to increase work trip attractions due to self employed workers. (DOATTRCT)
11	**Newsf6.dat** (1 file relating to external zones, fixed over time): Factors determining the proportion of external zone trips to be factored by following 2 files: (NEWSF6)
12	**Xpfaco.dat** (1 file with 2 yr. factors for all 20 years): factors to increase external zone matrices (car trips) by trips from outside study area. (NEWSF6)
13	**Xgfacs.dat** (1 file with 2 yr. factors for all 20 yrs): as above: but for attraction (?) (NEWSF6)
14	**Xpfacn.dat** (1 file with 2 yr. factors for all 20 years) as above for non car trips (NEWSF6)
15	**G6_H6c.dat** (1 file fixed for 20 years): NHB adjustment factors, SPS and DC agreed that remain unchanged. (G6_H6)
16	**G6_H6n.dat** (1 file fixed for 20 years): NHB adjustment factors, SPS and DC agreed that remain unchanged. (G6_H6)
17	**Multigro.dat** (1 file, factors for all 20 years): growth factors by purpose for multi car owning households. (C:\DATA\XFORE\MATRCIES: MULTIGRO)

(Ben Still Feb 1996, File_chk.doc)

Key:

The names in brackets (e.g. LFACT) in each box refer to the EFM FORTRAN program which uses the growth factor file.
SPS = Simon Shepherd working for the EPSRC ‘Sustainable cities project’.

Note that in many of these files the growth estimated by MVA for the 20 year period for a twenty year period was divided up between the periods. A constant compound factor was used, in other words to get to a constraint of 0.701 in 2011 the 10th root of 0.701 was applied to each time period.

APPENDIX 2

SPLITTING THE TRAVEL TO WORK MATRICES

1.1 Derivation of the splitting proportions

The START purpose of 'commute', had to be divided into four segments, reflecting the travel to work patterns of each of the four SEGs. In START, the split was treated by adding three more 'purposes'. The split by SEG was required in the land use model so that people of a given SEG only fill jobs of the same SEG (in other words preventing a labour supply and demand mismatch). The SEG was implemented in START so that:

- workers could respond to accessibility changes in jobs that they could take.
- the different car ownership, income, and demographic growth rates between SEG could be modelled.

However, the splitting of the original travel to work matrices was a complex process. The initial situation is of a set of 15(25x25) matrices T_{ij}^{omt}, where *o* is car availability, *m* is mode and *t* is time of day.

Firstly, these trip totals at the **attraction end** must be scaled so that they match the employment by SEG from the DELTA database. This is shown below:

$$k_j = \frac{\sum_i \sum_o \sum_m \sum_t T_{ij}^{omt}}{\sum_g E_j^g} \qquad \text{(Eqn. 2)}$$

where: k_j is the scalar used to reconcile the DELTA with the trips data
$E^g{}_j$ is the employment by SEG (g) for each destination zone.

The attraction trip totals by zone must then be split by the SEG. This is undertaken on the sum of the total trips, as shown below:

$$a_j^g = \frac{k_j E_j^g}{\sum_m \sum_o \sum_i T_j^{gom}} \qquad \text{(Eqn. 3)}$$

This gives four sets of zonal destinations, which sum to the original destination totals by zone.

For the **production end**, a similar set of calculations must be applied. However, here it is important to keep the distinction between car available and not available. This is because information was available at the residence end concerning the availability of cars between SEG's.

A similar scalar to k_j must be calculated to relate the DELTA database to the trip totals. This is shown in the function below with calculates the production factors for car owners:

$$b_i^{go} = \frac{q_i P_i^g c_i^g}{\sum_m \sum_i T_i^{gmo}} \qquad \text{(Eqn. 4)}$$

Where: b_i^{go} is the production factor by SEG, CO and zone;

q^i is the scalar between the DELTA database and trip matrix totals;
P_i^g is the population by origin zone and SEG;
c_i^g is the car ownership by origin zone and SEG.

In JIF, there are only two levels of car ownership, so for non car owners, c_i^g would be replaced by $(1 - c_i^g)$.

In addition to the above production constraint, it was felt useful to include a further production constraint, this time related to the mode. This was possible as the Census travel-to-work data included information of mode by SEG (although only for the household from Census Table 86). The function is similar to that above:

$$c_i^{gm} = \frac{q_i P_i^{gm}}{\sum_o \sum_i T_i^{gmo}} \qquad \text{(Eqn. 5)}$$

Where: c_i^{gm} is the production factor by SEG, CO and zone.
q^i is the scalar between the DELTA database and trip matrix totals.
P_i^{gm} is the population by origin zone and SEG.

Note therefore, that this assumes that car ownership of the household is equivalent to that of the worker.

The presence of two production constraints is not ideal. It would be much nicer to have one P_i^{gmo} set of factors, but this was not possible due to the lack of appropriate cross tabulations in the census data.

One other constraint was also possible, which is to ensure that each cell in the original summed matrix equals the total from the derived matrices by SEG. This can be done with another, individual cell factor d_{ij}^{mo} as follows:

$$d_{ij}^{mo} = \frac{T(observed)_{ij}^{mo}}{\sum_g T_{ij}^{gmo}} \qquad \text{(Eqn. 6)}$$

Where the observed trip total are the original matrices.

1.2 Furnessing

The aim of applying the Furness technique is to split the 15 original work matrices using the SEG constraints, thereby ending up with 60 matrices. The process that was designed operated as follows:

1 - Split each of the original 15 matrices into 4x15 equal proportions;
2 - Factor each matrix using a_j^g;

3 - Recalculate the matrix row and column totals, calculate new b_i^{go} ;

4- Factor each matrix using b_i^{go};

5 - Recalculate the matrix row and column totals, calculate new c_i^{gm};

6 - Factor each matrix using c_i^{gm};

7 - Recalculate the matrix row and column totals, calculate new a_j^g;

8 - Repeat 2-7 until convergence criteria (see below) are satisfied,

9 - Factor using d_{ij}^{mo}.

10- If convergence criteria satisfied then stop, otherwise goto 8.

The simplest measure of convergence that could be used would be the difference between the desired row and column totals (e.g. $q_i P_i^{gm}$ term for the production totals), and the original trip totals (e.g. $\sum_o \sum_i T_i^{gmo}$). To give a single measure for each constraint across all the tables, these differences were squared and summed, and then rooted. Thus for the production constraints, the function used to assess convergence was:

$$\sqrt{\sum_i \left[\left(\sum_j T_i^{'go=1} + \sum_j T_i^{'go=0} \right) - \left(q_i P_i^{go=1} + q_i P_i^{go=0} \right) \right]^2} \qquad \text{(Eqn. 7)}$$

With similar convergence functions for the attraction constraints, and the individual cell constraints.

This set of calculations were implemented in a spreadsheet following the iterations as outlined above. However, it was soon evident that the system was not converging was one would expect from this type of Furnessing technique. Instead, the system was simply shifting between three states, depending upon which constraint was last applied.

The central problem was due to the car ownership constraints in the productions. The fact that these worked on different matrices (i.e. car owning and non-car owning), meant that the totals could not move towards a stable solution. It was essential to operate on all the matrices simultaneously. The step taken to rectify this situation was to merge the production constraints, and hence drop the information that was known from the census about car ownership. Thus the final function was of the form:

$$b_i^g = \frac{q_i P_i^g}{\sum_m \sum_i T_i^{gm}} \qquad \text{(Eqn. 8)}$$

The second step that was taken to simplify the working of the spreadsheet was to aggregate the matrices by time of day. This meant that rather than 60 matrices from 15, 20 matrices were produced from five. Once the 20 converged SEG tables had been created, then the same proportions were applied to split the tables by time of day.

These 60 matrices were then supplied back to MVA for converting into TRIPS (production and attraction) format.

Appendix 3

HOUSEHOLD TRANSITION RATES AS IMPLEMENTED IN DELTA

Table 2.1: Rates in the transition and growth submodel (part 1)

	Household Composition	Description of Event	Prob.	Result	Process
-6	Young single	young couple moving in together, 0 child Have child to old single couple moving in together, 0 child, older (error here: this should be yng) dissolve depart study area: S1 S2 S3 S4	0.1172 0.006 0.030 0.1172 0.1172 0.0669 0.0433 0.0138 0.0295	Couple 0 child 16-44 (-7) Single parent + child (-11) Old single (-13) Couple 0 child 45-64 (-7) No household No household?	Transition Transition Transition Transition Results from transitions if combine with other single household Unknown
-7	Couple 0 child 16-44	divorce/separation birth of first child older dissolve depart study area: S1 S2 S3 S4	0.053 0.053 0.18 0.010 0.00 0.0669 0.0433 0.0138 0.0295	Young single (-6) Young single (-6) Couple with children (-8) Couple 0 child 45-64 (-12) No household No household	Transition Formation *(note these rates should have been doubled)* Transition Transition Unknown Unknown
-8	Couple with children	first child - adult divorce/separation departure of children	0.116 0.056 0.014	3 adults + child (-9) Single parent + child (-11) Young single (-6)	Transition Transition Formation
		dissolve depart study area: S1 S2 S3 S4	0.00 0.0669 0.0433 0.0138 0.0295	No household No household	Unknown Unknown

Table 2.1: Rates in the transition and growth submodel (part 2)

-9	3 adults + child (based on 2.1 children per family)	last child - adult	0.50	3 adults no children (-10)	Transition
		divorce/separation includes departure of children for O/S	0.056	Single parent + child (-11)	Transition
				Young single (-6)	
			0.056	Older single (-13)	Formation
			0.044		Formation
		dissolve	0.00	No household	Unknown
		depart study area:		No household	Unknown
		S1	0.0669		
		S2	0.0433		
		S3	0.0138		
		S4	0.0295		
-10	3 adults no children (based on 2.1 children per family)	child leaves home	0.1962	Couple 0 child young	Transition
			0.1962	Young single (-6)	Formation
		divorce/separation	0.014	Older single (-13)	Transition
			0.014	Older single (-13)	Formation
			0.014	Young single (-6)	Formation
		dissolve	0.138	No household	Unknown
		depart study area:		No household	Unknown
		S1	0.0669		
		S2	0.0433		
		S3	0.0138		
		S4	0.0295		
-11	Single parent + child (based on 1.8 children per family)	couple moving in together	0.1172	Couple with children (-8)	Transition
		child leaves home	0.08	Older single (-13)	Transition
			0.08	Young single (16)	Formation
		dissolve	0.1172	No household	Unknown
		depart study area:		No household	Unknown
		S1	0.0669		
		S2	0.0433		
		S3	0.0138		
		S4	0.0295		
-12	Couple 0 child 45-64	divorce/separation	0.042	Older single (-13)	Transition
		death/separation	0.042	Older single (-13)	Formation
		retire	0.2	Retired couple (-14)	Transition
		dissolve	0.038	No household	Unknown
		depart study area:		No household	Unknown
		S1	0.0064		
		S2	0.0042		
		S3	0.0013		
		S4	0.0028		

Table 2.1: Rates in the transition and growth submodel (part 3)

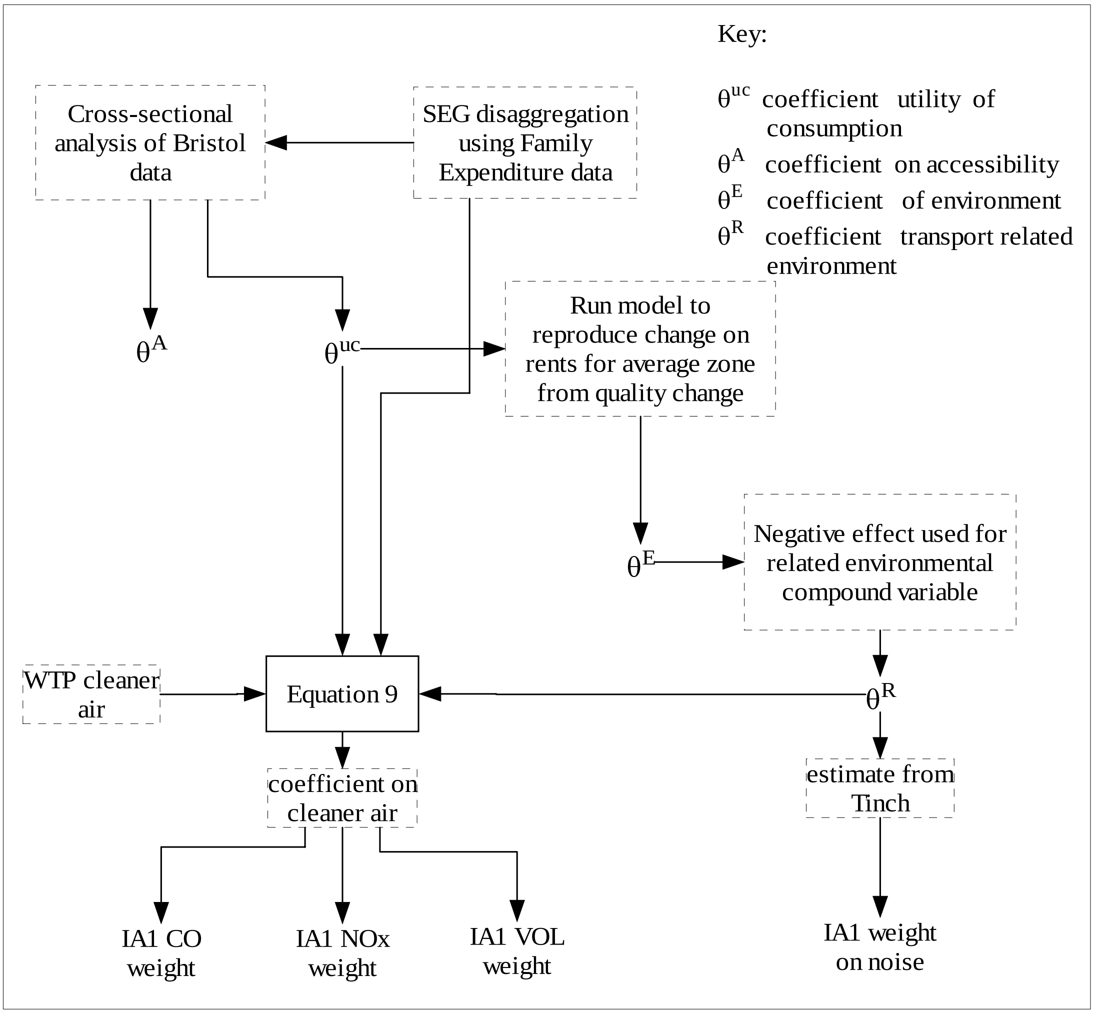
-13	Older single	couple moving in together retire dissolve depart study area: S1 S2 S3 S4	0.012 0.268 0.00 0.0064 0.0042 0.0013 0.0028	Couple 0 child 45-64 (-12) Retired single (-15) No household No household	Transition Transition Unknown Unknown
-14	Retired couple	death of one dissolve depart study area: S1 S2 S3 S4	0.14 0.0170 0.0021 0.0014 0.0004 0.0009	Retired single (-15) No household No household	Transition Unknown Unknown
-15	Retired single	dissolve depart study area: S1 S2 S3 S4	0.08 0.0021 0.0014 0.0004 0.0009	No household No household	Unknown Unknown

Appendix 4

TREATMENT OF ENVIRONMENTAL EFFECTS

Figure 6 shows the derivation of the coefficients used in the location model. This can assist in explaining how the terms were obtained. Note that the basis for all the environmental terms was the calibrated coefficient for the utility of consumption function.

Figure 6: Derivation of the environmental coefficients for DELTA



Overall, the coefficient on the environment was defined as the negative of the coefficient on area quality (as outlined in Section III.6). This is shown by the right hand downward arrow in Figure 6. This meant that a 1% increase in the environmental variable would lead to (on average) a 1% decrease in the rent (i.e. the opposite of the effect produced on environmental quality). This provides the initial overall scaling for the coefficient on the environmental variable.

Noise

Having done this, it was possible to define the weight on noise for the weighting on the compound variable in line with the Tinch evidence. Thus an increase of 1dBA would produce a 0.8% decrease in rents. Note that the L10 dBA scale output from START was logarithmic, and thus a 1dBA increase represents the same proportional increase in noise irrespective of the starting noise level. If there is an x% increase in traffic

noise on the roads within a zone that are represented by the START "links", then it was assumed, given the nature of noise and the nature of traffic, that there will be an x% increase in traffic noise **throughout** the zone.

Atmospheric pollutants

This left the derivation of the weights for the other atmospheric pollutants. The following emissions variables are output by JIF:

- carbon monoxide levels (8-hour maxima in ppm)
- "total" nitrogen oxide levels (8-hour maxima in ppm)
- volatile organic compounds (VOCs) (ditto).

For the inclusion of the environmental variables into DELTA it was necessary to interpret 'willingness-to-pay' (WTP) results from previous existing research, and determine the relative

importance of each of these elements[4]. This is because there was little evidence linking air quality to property values, but WTP evidence from several sources, including Tinch (1995, para 10.12.1) and Schulz and Wicke (1987: quoted in Rothengatter, 1990).

"*WTP is defined as the maximum payment an individual will make to secure a gain or to avoid a loss*" (Tinch, 1995, para 2.3.1). To use WTP results in DELTA, it was assumed that it could be converted from individual to household WTP. After this, the key assumption was that:

> **an environmental improvement in zone i, for which a household's WTP is x should increase their utility of locating in i as much as if locating in i would give them an increase of x in their income.**

This statement can be applied separately for each household type (thus taking care both of income-related differences in WTP and in the effect of cost on utility of location), but can only be exact for one level of environmental improvement in one zone.

The effect of a change in income was converted into a change in the utility of consumption (i.e. consumption of floorspace and of other goods and services) and hence into a change in the utility of location. The effect on utility of consumption was greatly simplified by the fact that the Lothian model used Cobb-Douglas utility functions, i.e. setting the minima to zero. Given this, the WTP as a change in utility can be devised as follows:

[4] Note that one of these three could be used as a proxy for air pollution in general. However, the latter would cause problems if a policy was tested which tended to increase one of these three pollutants in order to reduce another.

$$z^h = \frac{\theta^{hU}}{\theta^{hR}} \cdot \left[\frac{q_i^{hH}}{r_i}\right]^{\alpha^{hH}} \cdot (\alpha^{hH})^{\alpha^{hH}} \cdot (\alpha^{hO})^{\alpha^{hO}} \cdot \frac{x^h}{Q} \qquad \text{(Eqn. 9)}$$

Where:

x^h is the willingness to pay for an environmental improvement Q, by household type
z^h is the adjustment factor (by household type h),
q_i^h is an adjustment factor reconciling densities and rents in the base period (see page 12)
r_i is the rent by zone
α^{hH} is the propensity of households type h to spend available income on space H
α^{hO} is the propensity of households type h to spend available income on other goods.
θ^{hU} and θ^{hR} are coefficients on the utility of consumption and on the transport related environmental measure in the main utility of location equation.

This was interpreted as follows. When an improvement in an air quality indicator was scaled by z, it was (starting from the right):

1. converted from an environmental measure into the equivalent WTP;
2. converted from WTP into the extra utility-of-consumption that would be produced by an equivalent increase in income (the three middle terms); and finally
3. the coefficients were then adjusted so that, in the utility of location equation, it was treated like a change in utility-of-consumption.

The x^h values were based upon the Norwegian results in Tinch (para. 10.12.1), by setting up the model coefficients so that households are willing to pay £282 to £561 for a 50% reduction in traffic-generated pollution in an "average" zone. The assumption that WTP varies with income was based upon the work of Schulz and Wicke (1987; quoted in Rothengatter, 1990).

The WTP is thus represented by the z^h values. This was split across the three pollutant measures on the basis of the ‘toxicity’ estimates, from Tinch (Table 25). These weights were 0.003 for carbon monoxide, 0.548 for nitrogen oxide, and 0.449 for VoC’s, thus CO appears of negligible importance compared to the other measures, from Tinch’s relative weights.

Note therefore that DELTA has two places where weightings can be applied, in the IA1 file, and in the θ^R value in the location function. The choice of where to undertake the scaling is arbitrary (this all the scaling could have been represented in the IA1 coefficients, and the θ^R parameter set to -1).

Appendix 5

DEVELOPMENT OF THE LAND USE SCENARIO

1 Floorspace under construction in 1991-1993 (used in file DVZN9100.DAT)

There are three 'categories of land use': housing, retail, and other commercial, for which figures have to be derived. Note that for all space categories, Fife is treated as similar to Lothian. The decisions made were as follows:

1.1 Housing: (Space category 1)

Firstly, this only concerns private sector housing; public sector housing is omitted. The data required on housing was the quantity under development, its 'quality' and the space occupied.

Housing under construction 1991-93 was taken from the Lothian Report of Survey, Table 5.10. To transform this data into a form a suitable for DELTA, the following steps were taken;

1. The data was allocated to zones on the basis of the housing land supply data (which was the only data available on a more disaggregate spatial basis). This means that existing construction has been allocated on the basis of where future construction is most likely. An alternative assumption would have been to allocate on the basis of the existing housing floorspace, but this was felt to represent historic trends, rather than the current patterns of development.
2. The data was split from districts into START zones using the percentage share of available land.
3. The data needed to be converted from dwellings to floorspace. This was done by assuming an average floorspace from the various dwelling sizes used in the model. Using figures supplied by David, this was **110sq m.** per dwelling (as described in main text).

The environmental quality was assumed to be at 100 (i.e. the starting neutral quality) in all zones. The space occupied describes the land on which available floorspace stands. For the purposes of this study, land is ignored, and hence was assumed to be equal to the floorspace under development. Thus the density of all development is 1.

1.2 Retail (Space category 2)

The retail data again came from the Lothian Report of Survey, however, there was much less available data. In fact the report only commented on 'major' developments in three zones: 15 (Livingstone and west Lothian), 16 (around the airport and Kirkliston), and 14 (inner Edinburgh near Murrayfield). Most of these comprised retail parks. 10% of the total planned retail development was assumed to be under construction in the base period. No retail growth in Fife was added.

1.3 Other Commercial (Space category 3)

This involved summing data for office and industrial development from the Report of Survey (summarised in Table 12). From this 34,000 sq.m. was under construction in December 1992, of which 50% was included in the DVZN file. 208,000 sq.m. was under construction in 1990, of which 33% was assumed under construction during 1991-1993. This gives a total of 85,640 sq. m. The remaining consents for office and industrial were

distributed to the remaining zones on the basis of information given in the Report of Survey. Practically all of this growth was within Edinburgh, although there are large expansion possibilities in Livingstone. The Report of

Survey commented explicitly about the large amount of office consents available in the region, and this is reflected in the figures. Data for fife were estimated on the basis of the Lothian data.

For industrial floorspace, the Report of Survey was again used, which gave the current consents and supply. This is summarised in Table 5.2 below. We assumed that 10% of the consents were 'under construction' in the base period, the remainder being allocated to the consents file. The data was disaggregated from district into START zones by simple equal proportions (e.g. for Midlothian equal splits between zones 17 and 18). Data for Fife was estimated on the basis of the Lothian data.

Table 5.1: Construction and Consents: Office

Office Space	Under construction 1991 (to allocate: 85640 sq. m)	Outstanding Consents (for SPZN9100) (total to allocate: 527000 sq. m): see Section 4.3
Zones 1,2,12	32,543.2 (38%)	189,720 (36%)
Zone 9	14,559 (17%)	84,320 (16%)
Zone 3	15,415 (18%)	89,590 (17%)
Zone 3-8, 10-14, 16-19, 21	231,222 (27%)	105,400 (20%)
Zone 15 (Livingstone)	n/a	52,700 (10%)
Other zones	n/a	5,270 (1%)
Fife (24,25)	10,000	50,000

Table 5.2: Industrial Construction and Consents

Industrial Land	Industrial Land (and conversion[5] to Floorspace: sq. m (x.5))	Under Construction in 1991 (10%)	Consents for SPZN
Edinburgh (Zn 1-14)	26 (130,000)	13,000	117,000
E Lothian (19,20)	201 (1,005,000)	100,500	904,500
Midlothian (17,18)	99 (495,000)	49,500	445,500
W Lothian (15, 22-23)	165 (825,000)	82,500	742,500
Livingstone (15)	174 (870,000)	87,000	783,000+290,000
Fife (24,25)	900,000	90,000	810,000

[5] 1 hectare = 10,000 sq m

2 The Space Database File (SPZN9100.DAT).

This file holds the data for the total quantity of available space that has permission (in terms of permissible development), but is not yet built upon. Data is required for each space category. The distinction between 'greenfield' (i.e. new) and 'brownfield' (i.e. redevelopment) is to be ignored for this study.

2.1 Housing (Space category 1)

The Lothian Report of Survey, as mentioned before, gives a table of 'established land supply' (Table 15.5. p.166). This data for was converted into START zonal values. The percentage splits in the second column were estimated from the text of the Report of Survey. This data replaced the test data in SPZN9100.DAT, (block two: previously set to 1% of total floorspace). Note that this data represents that land which is available (via permissions) for housebuilding, but has not yet been built upon.

2.2 Retail: (Space Category 2)

The structure plan policy for retail development is to contain retail growth within the existing retail centres. That said, there are several large outstanding consents granted, notably in zones 14,15 and 16. These all take the form of 'retail' parks. Little other information in terms of floorspace expansion is given in the structure plan.

David set test allowances of 'available' (but undeveloped) floorspace at 1% of the developed total per zone. It is proposed to keep this for the retail category to emulate the notion that some expansion of district and regional centre floorspace is likely during the forecast period, and thus to allow for it. However, the major developments in zones 14,15, and 16 will be added via the PLAN.POL file (see below). In later tests it was decided to make an additional 1% available per period.

2.3 Office/Industrial (Space category 3)

Consents for office development are 527,000 sq.m. (5,670,520 sq. ft). This needed to be allocated to zones, and was undertaken using the proportions used for the DVZN file, presented previously in Table 5.1. Thus for example 36% goes to zones 1,2, and 12. On the basis of the discussion in the structure plan and Report of Survey, 10% of growth was allocated to Livingstone, where office growth is likely.
Industrial consents need to be added to the above dataset. This data is presented in the Report of Survey as land area. A density of 0.5 is assumed to convert this into floorspace. Table 5.3 shows the break down of this data between the DVZN file and the amount added to office for the SPZN file. The data for Fife is estimated on the basis of Lothian data, as we have no other useful data to hand.

Table 5.3: SPZN House Supply Data for 1991

Zone	Data of effective supply (Fig 5.15) comprising total	Final Figure :Factor for DELTA 110 (av. Size (sq.) per dwelling)		Comments
1	.4*900	(360 dwellings) = 39600 sq.m.		Central Edinburgh: New Town
2	.4*900	(360 dwellings) = 39600 sq.m.		Central Ed: Haymarket
3	.5*580	(290 dwellings) = 31900 sq.m.		Leith, Inverkeith, Granton (NE)
4	.5*580	(290 dwellings) = 31900 sq.m.		Portabello, Meadowbank (E)
5	.5*1170	(585 dwellings) = 64350 sq.m.		Glimerton, Gracemount (SE)
6	.5*1170	(585 dwellings) = 64350 sq.m.		Newington, HW, Royal Obs
7	.25*830	(207.5 dwellings) = 22825 sq.m.		Morningside, Coniston
8	.25*830	(207.5 dwellings) = 22825 sq.m.		Currie, Colinton, (SW)
9	.25*830	(207.5 dwellings) = 22825 sq.m.		Sightill, S. Gyle (W) Ed Pk
10	.33*890	(294 dwellings) = 32340 sq.m.		Corstorphine (W)
11	.33*890	(294 dwellings) = 32340 sq.m.		Crammond, Muirhouse (NW)
12	.2*900	(180 dwellings) = 19800 sq.m.		Central Ed: Old Town, High St
13	.25*830	(207.5 dwellings) = 22825 sq.m.		Steinhouse, Gorgie (W)
14	.33*890	(294 dwellings) = 32340 sq.m.		Murrayfield, Craigleith (W)
15	1030+250+.5*360	(1460 dwellings) = 160600 sq.m.		Livingstone, West Calder (W Lothian)
16	.5*270	(135 dwellings) = 14850 sq.m.		Airport, Gogar (W Ed))
17	160+130+.5*200	(390 dwellings) = 42900 sq.m.		MidLothian: Penicuik
18	170+130+180+.5*200	(580 dwellings) = 63800 sq.m.		MidLothian : Dalkeith
19	.5*140+1140	(1210 dwellings) = 133100 sq.m.		East Lothian
20	.5*140+110+110+180+ 70	(680 dwellings) = 74800 sq.m.		East Lothian: Haddington, Longniddry, Dunbar
21	.5*270	(135 dwellings) = 14850 sq.m.		South Queensferry
22	360+.5*360	(540 dwellings) = 59400 sq.m.		W Lothian: Linlithgow, Winchburgh etc.
23	950	(950 dwellings) = 104500 sq.m.		W Lothian: Whitburn. Blackburn
24	1% of 1991 total	701542.8 sq.m.		Dumfermline, N Queensferry
25	1% of 1991 total	8371542 sq.m.		Kirkcaldy, Glenrothes

3 The PLAN.POL file: Exogenous Land Use Policies

This file contains any land use planning policies, implemented in one of two ways:
1 - increases in the amount of land made available for development (thus presenting say, an incentive to develop in a particular location).
2 - exogenously specified development (i.e. outside the development model), for example, the Scottish Office 'effect' in Leith.

3.1 Increases in Housing Land Allocations (Cat 1)

This data is specified in exactly the same way as the SPZN9100 data (which specifies the base situation existing permissions). The housing data was derived from the Structure Plan report of survey. It was decided, for ease of implementation, and interpretation of results, to maintain constant increases in permissions over time. LRC comment that they wish to maintain a supply of approx.

2500 dwellings pa until 2010, 3000 dwellings pa until 1995. Our results actually produce slightly higher results, at 2833 new dwellings per annum[6].

The procedure was as follows:

- The remaining effective supply was divided for 10 years. This is shown in column 2 of Table 5.4 in numbers of dwellings. This is the total supply, minus that allocated to SPZN, divided by 10 (see footnote).
- Additional possible housing space (i.e. that requiring additional utilities, greenfield sites or change of use) was allocated according to the discussion in the LRC Structure Plan and Report of Survey.
- The public sector completions by zone were derived from the Report of Survey (fig 5.35, p185). This gives the data by district, and it was split in equal proportions for the START zones. Fife was omitted from this calculation.
- The above data was summed, and then doubled to give the 2 year PLAN.POL file requirements. Annual figures are given in Table 5.4.

Table 5.4: Housing Allocations representing Lothian Planning Policy

Zone	Yearly allocation of existing supply (in dwellings)	Additional Housing Allocations (from LRC Report of Survey: fig 5.37+text) (converted to annual)	Public Sector Housing Supply (annual)	Final Plan.Pol total (yearly dwellings)
1	380	0	4.6	42.58
2	380	0	4.6	42.58
3	410	0	4.6	45.58
4	410	0	4.6	45.58
5	240	333.3	4.6	361.91
6	240	0	4.6	28.58
7	32.5	0	4.6	7.83
8	32.5	46.6	4.6	54.50
9	32.5	0	4.6	7.83
10	151.8	0	4.6	19.76
11	151.8	0	4.6	19.76
12	190	0	4.6	23.58
13	325.7	0	4.6	37.15
14	151	0	4.6	19.76
15	394	120	123.3	282.70
16	265	0	4.6	31.08
17	1275	100	40	267.50
18	785	200	40	318.50
19	1430	46.6	0	189.67
20	590	166.6	0	225.67
21	265	0	4.6	31.08
22	880	0	18.3	106.30
23	830	173.3	18.3	274.63
24	1594	0	0	159.44
25	1902	0	0	190.25

Total: 2833.8

[6] This could be due to the average house size estimated, or that the Audit 12 supply may extend beyond 10 years.

3.2 Increases in Retail Allocations

The only changes to retail are increases in Livingstone (Zone 15), and also zones 14 and 15. It is assumed that all of this development is allocated by 1999. The inputs for PLAN.POL thus appear as shown in Table 5.5.

Table 5.5: Retail Planning (all figures in sq.m.)

Zone	Total to allocate	Plan93tt.pol	Plan95tt.pol	Plan97tt.pol	Plan99tt.pol	Plan01+tt
14	**7650 sq.m.**	1912.5	1912.5	1912.5	1912.5	0
15	**19350 sq.m.**	4837.5	4837.5	4837.5	4837.5	0
16	**17100 sq.m.**	4275	4275	4275	4275	0

3.3 Increases in Office and Industrial Allocations

The Report of Survey estimates average annual **office** development take-up at about 60,000sqm p.a. The current office consents as input into SPZN are however, large enough to meet this demand for about a decade. LRC argue that is this not sufficient, given the quality and size not always matching demand. However, for the modelling the issue is complicated by the summing of office and industrial land together. This enlarges the potential pool of available floorspace (especially in zones where office and industry can be together, such as zones 15 and 16).

In the city centre, most 'gap sites' have consent, and thus there is unlikely to be much growth in office in zones 1,2, and 12 (although there are many vacant properties). It is decided therefore to allocate about 60,000 sq.m. among the other zones (including Fife). This policy of dispersing office developments is consistent with FCR's estimate of demand decentralising due to congestion and environmental quality.

Industrial growth is very difficult to predict. The Report of Survey comments that broad predictions of demand can be met by the existing consents, although this would bias the distribution towards the west of the city and the region.

The policy is stated to widen the choice for industry (especially away from the west), and therefore it is proposed to allocate 1% growth to all zones. In zone 15 (Livingstone), 2% growth is more likely. The totals used were those already in the SPZN for total floorspace, as separate figures for industry alone were unavailable. This means that industrial floorspace is probably somewhat over estimated. However, given the small size of this sector and the lack of a 'total land market' in the model this should not be a problem. The data translates into floorspace allocations as shown in Table 5.6.

Table 5.6: Plan.Pol additional office/industrial space

Zone	Growth in Office Space(in 2 yrs. in sq. ft)	Growth in Industrial Space (2 yrs. in sq. ft)	Total
1	0.00	4634.88	4634.88
2	0.00	1588.39	1588.39
3	343113.32	4676.53	347789.85
4	28861.88	1022.70	29884.58
5	28861.88	593.58	29455.46
6	28861.88	933.79	29795.67
7	28861.88	1487.17	30349.05
8	28861.88	665.75	29527.63
9	322930.18	1980.35	324910.53
10	28861.88	1000.12	29862.00
11	28861.88	2308.86	31170.74
12	0.00	4535.01	4535.01
13	28861.88	1396.67	30258.55
14	28861.88	3952.47	32814.35
15	201831.36	8156.72	218143
16	28861.88	1508.61	30370.49
17	28861.88	1500.14	30362.02
18	28861.88	1267.58	30129.46
19	28861.88	1144.04	30005.92
20	6660.43	1747.13	8407.56
21	28861.88	541.52	29403.40
22	6660.43	476.27	7136.70
23	6720.98	1792.86	8513.84
24	0.00	7405.57	7405.57
25	0.00	8585.95	8585.95