Distillate Project F3b:
Mode Chain Modelling in TRL's Strategic Transport Model

by Andrew Ash

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Transport Research Laboratory

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by Andrew Ash (TRL)

Client: EPSRC

This Draft Report has been prepared for Client's Organisation for the sole purpose of Project Report Review. It may only be disseminated once it has been completed and issued with a final TRL Report Number.

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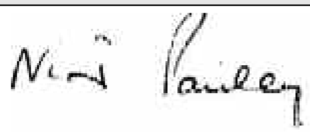
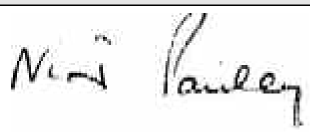
	Name	Date Approved
Project Manager		21.05.08
Technical Referee		21.05.08

Contents

Executive summary

DISTILLATE (Design and Implementation Support Tools for Integrated Local Land use, Transport and the Environment), was a UK EPSRC (Engineering and Physical Sciences Research Council) funded project which sought to enable significant improvements in the ways in which sustainable transport and land use strategies are developed and delivered in the UK.

This report describes case study work carried out as part of Project F (Decision Support Tools) of the DISTILLATE project. The Local Authority partner for this study was Strathclyde Partnership for Transport (SPT).

The object of the case study was the development of a 'mode chain' modelling facility within a strategic transport model for Strathclyde; this would permit travellers to interchange between different travel modes in the course of a trip rather than use only a single, main mode. The computer software development for this has been limited on practical grounds to developing this feature for park and ride at stations on the Glasgow Subway (underground). The case study chosen was, however, both timely and relevant to SPT's needs and sufficiently non-trivial to permit an exploration of the wider modelling issues. The design of the model was informed by SPT's interests and needs and TRL's understanding of these gained from discussions with them over a number of years as well as within the current project.

Modelling of park and ride is not, of course, something new. The modelling here is however innovatory in that:

- It sought to produce a realistic treatment of mode chaining within a 'sketch' strategic transport model lacking a network assignment model. Mode chaining is a complicated travel process hence its implementation in a sketch model represents a real challenge.

- It confronted head-on the difficulty of obtaining travel information for the base case by incorporating suitably constrained synthetic techniques within the transport model. This greatly enhances the economy of the model.

- It used a comprehensive integrated approach to park and ride and parking in the City Centre.

The platform for the study was TRL's Strategic Transport Model (STM) which SPT have run on their PCs for a number of years. The version adopted (Version 4.6) as a starting point uses fixed zonal routes between origin and destination zones and highway speeds are estimated within each zone using road-type dependent speed-flow equations. Since Version 4.6, STM has undergone considerable development on behalf of SPT and other clients.

STM has been developed to operate in conjunction with the DELTA land-use model created by the David Simmonds Consultancy (www.davidsimmonds.com) so as to form a Land-use and Transport Interactive (LUTI) system called SITLUM. We do not use DELTA with STM in the present study as its use does not add anything to the development or assessment of the proposed model. In its stand-alone mode STM forecasts travel patterns using exogenous (user supplied) planning data.

The development of the new model features required considerable work on the platform model. In order to more faithfully represent the spatial detail of the Subway system and its stations and the centre of Glasgow it was necessary to expand the zonal system from 173 zones to 233 zones (most of the new zones obtained by splitting central zones in Glasgow- the split zones being based on those in the 1000 zone SITM4 network model). This work required reconstructing the base trip and cost matrices for the new zonal system. The work also required a fair amount of routine recoding to allow the STM to easily handle the larger number of zones.

The case study succeeded in creating a functioning mode chain model within a Strathclyde STM based on park-and-ride from stations of the Subway system. Example results are presented as illustrations of the model's performance and the report concludes with a summary and suggestions for further work.

Abstract

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1 Introduction

DISTILLATE (Design and Implementation Support Tools for Integrated Local Land use, Transport and the Environment), was a UK EPSRC (Engineering and Physical Sciences Research Council) funded project which sought to enable significant improvements in the ways in which sustainable transport and land use strategies are developed and delivered in the UK.

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The model takes into account the possibility of park and ride from all stations on the Subway and simultaneously models the interaction between demand for

- Travel by car to the city centre and parking there.
- Travel by park and ride via the Subway
- Direct travel to the City Centre by public transport or slow modes.

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Integrated Land-Use Model (SITLUM) (Aramu et al, 2006). We do not use DELTA with STM in the present study as its use does not add anything to the development or assessment of the proposed model. In its stand-alone mode STM forecasts travel patterns using exogenous (user supplied) planning data.

Since Version 4.6, STM has undergone considerable development on behalf of SPT. The new model can now model, within STM, congestion on individual road links using updatable routes and routing factors imported from a SATURN model using a bufferised highway network. The demand models can also handle three time periods (a pm peak has been added) and a choice of hierarchical logit structures for demand modelling is available. The new SITLUM arising out of this STM development can provide planning data and growth factors to a large assignment model for detailed network forecasts. The modelling techniques described in this report can also be applied to this new version of STM.

2 The Local Authority partner: SPT

The following is based on SPT's website (www.spt.co.uk).

Strathclyde Partnership for Transport was formed by combining Strathclyde Passenger Transport Authority and Executive and the WESTRANS voluntary partnership. It was established by the Transport (Scotland) Act 2005 which created Scotland's seven Regional Transport Partnerships (RTPs). SPT retains many of the transport powers and functions which were previously exercised by Strathclyde Passenger Transport Authority/Executive.

SPT's role now involves planning and delivering transport solutions for all modes of transport across the region, in conjunction with its member Councils and industry partners. SPT is at the centre of the region's transport planning:

- Analysing all present and future travel needs
- Developing of the transport system.
- Integrating of all transport modes - road, rail, freight, ferry, cycling and walking.

SPT has direct operational responsibilities, such as running the Subway, supporting - and in some cases running - local bus services, and managing integrated ticketing. While the management of the franchise for the Strathclyde rail network has transferred to Transport Scotland SPT continues to have a role in promoting and developing rail projects to meet the region's needs, such as the Glasgow Airport Rail Link.

Under the Transport Scotland Act, SPT also has the responsibility on behalf of its member councils to consult with private bus operators on the registration of bus services and the provision of passenger information.

3 Model development: its location within the context of transport modelling and planning

The subject of the present case study is the development of a park-and-ride based mode chain model within a version of TRL's STM. It is a good example of the kind of more sophisticated model building problem that is likely to be faced by Local Authorities and the experts they call on to assist them. As already described, the Local Authority partner for this case study was Strathclyde Partnership for Transport. This case study was "artificial" in that it was not focused on a specific policy requirement, but the need for it was identified in discussion with SPT, who provided practical support for it.

It is useful to clarify where STM fits into the general scheme of model types. STM (Version 4.6) can be summed up by the following terms:

- Large scale.
- Strategic
- Sketch
- Non-network based.
- Equilibrium
- Non interactive land use

The term 'scale' refers to the area coverage (rather than size of program). The term 'sketch' is perhaps not very generous to STM – later versions of STM use a more detailed link based treatment of congestion (without compromising run times too much) so that the term 'sketch model' is less appropriate, but the spatial detail available in the model is relatively low when compared with very large network models. The other designations are straightforward and for clarification the reader is referred to Section 6 where a fairly detailed description of the platform model can be found.

We also need to consider the purpose of the model; this must ultimately be based on the interests and aims of the Client. SPT have been interested for some time in the modelling of rail/Subway stations as park-and-ride sites. The current non-DISTILLATE STM models make use of a rather simple approach which makes them unsuitable for the testing of some policies related to rail stations (i.e. their parking facilities). An associated interest of SPT is the performance of the Subway system arising out of its park-and-ride functions. The challenge of the case study was to design and, to some extent, to implement a workable model which could form the basis of a policy tool. This poses a number of challenges given that STM Version 4.6 is not a network model and current applications for Strathclyde have a fairly coarse zone system around the centre of Glasgow (the total number of zones is 173).

In summary, the questions which are of interest for the application of the model are:

- To what extent can park-and-ride facilities be used to relieve congestion in the centre of Glasgow?
- What are the demand implications for the Subway system?
- Is it worthwhile to extend specific park-and-ride facilities to more Subway stations?
- How large should car parks be and what will be the influence on demand levels will different levels of parking tariff?

No doubt this list of questions could be extended, but this is sufficient to define the scope of a model. Specifically it will be necessary to model individual stations (or combination of nearby stations as composites) and define tariffs and parking capacities as policy instruments. The model must simultaneously cope with demand changes due to changes in costs and changes due to capacity effects.

How would such a model be used by SPT? In general terms they would follow their normal practice of using STM as a policy filter (in keeping with its characteristics: strategic, sketch etc) to identify which policies are likely to be most promising and then subject the successful candidates to closer scrutiny. SPT have a number of models and techniques available for this purpose including using their large scale network model SITM4 to perform detailed highway and public transport assignments.

4 The Model Study Area

4.1 Main features of the Study area

The Glasgow conurbation has a population of about 2 million. It consists of Glasgow City and a number of satellite towns or areas such as Paisley, East Kilbride and Motherwell. It is well served by rail with the main Glasgow stations being Glasgow Central and Glasgow Queen Street. Bus services in Glasgow converge on Buchanan Street Bus Station. An underground service (the Subway) operates on a closed approximately circular circuit in clockwise and anti-clockwise directions and stops at 15 stations. The centre of this circle is off-centre with respect to Central Glasgow and is located near the Exhibition Centre. The eastern part of the route of the Subway passes through Central Glasgow; the main Subway station is Buchanan Street in the heart of the centre and adjacent to Queen Street Station. In the west the Subway passes through the main University area (Hillhead station) and the important interchange at Partick where rail and Subway coincide. Travelling in an anticlockwise direction the Subway crosses the River Clyde and passes through the dock area of Govan, and then Ibrox followed by 5 more stations before reaching Buchanan Street (having crossed back over the river when travelling north). Note that, as shown in Figure 4.1 only three of the Subway stations have dedicated car parks.

The highway system consists of an extensive network with a broadly radial system of A roads centred on Glasgow. These provide links to the main outlying settlements within the conurbation. The centre of Glasgow itself is a dense grid system. The M8 motorway links Glasgow to Edinburgh in the east (where there are M73 and M80 branches) and also provides links out to the west, including Glasgow Airport. The M8 also passes along the west and northern periphery of the City Centre, which can be accessed from junctions there. From the south west (Kilmarnock) Glasgow is approached by the M77 and from the south east by the M74, the main motorway link to England (providing a link to the M6 north of Carlisle).

4.2 DISTILLATE-related data gathering exercise

On June 7/8 and then on July 21/22 2006, TRL visited a number of public transport “interchange” sites in Strathclyde and Ayrshire. SPT staff provided commentary and also took many site photographs. The first visit consisted of flying visits to about 20 sites concentrated in the Glasgow area (covering the main stations and selected subway stations) but visits were also made to places further out such as Paisley, Johnstone, East Kilbride, Croy and Lenzie. At each site we took a number of photographs to capture the main characteristics of the site focussing on parking and the accessibility to bus, taxi and rail. Subsequent communications with SPT have provided data on parking spaces, station plans with details of access points to stations and additional photographs. The second visit covered a wider geographical area and focussed on Ayrshire and the public transport facilities in Ayr, Kilmarnock, Prestwick Airport, Gourock, Greenock, and Helensburgh. The coverage of this second visit is less detailed as it was clear that the main sites of interest for possible follow-up surveys were located in Glasgow.

The maps (Figures 4.1 and 4.2) below show the Subway system and the SPT rail network.

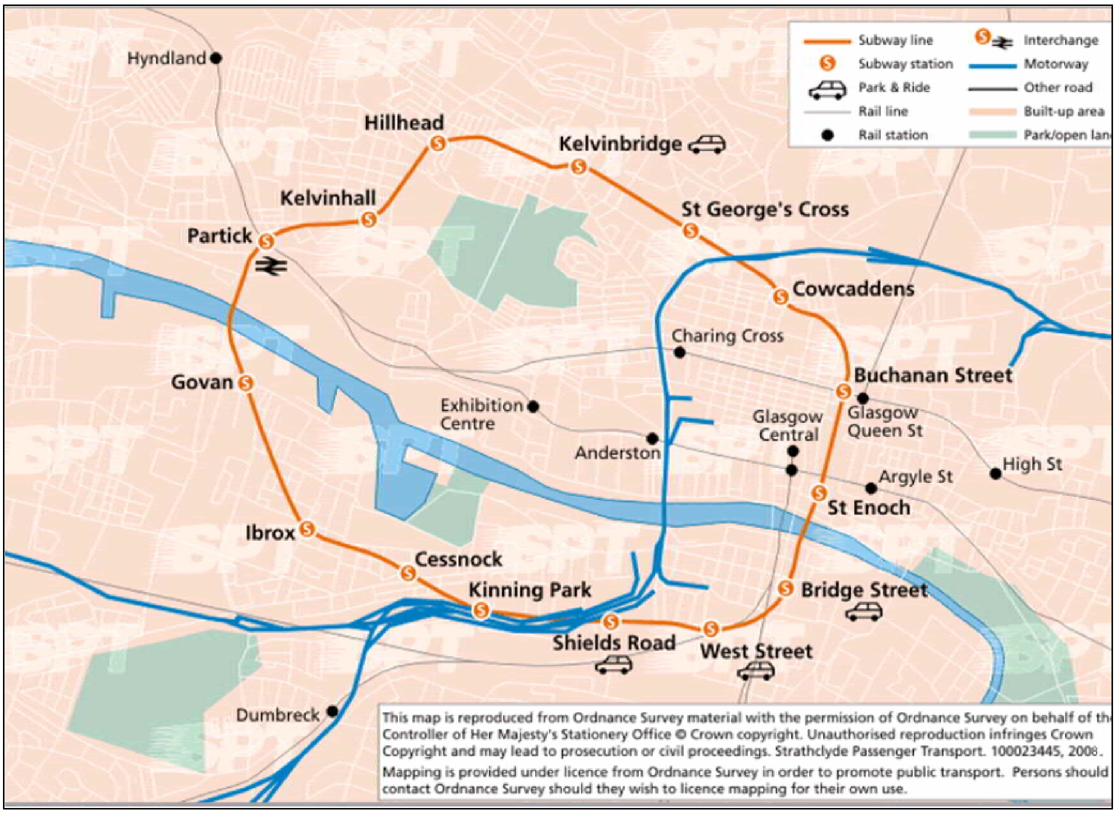

Figure 4.1: The Glasgow Subway System (Source: SPT)

The sites visited and recorded were as follows:

Braehead Shopping Centre	Govan bus station and subway
Buchanan Bus Station	Greenfaulds railway station
Buchanan Street Subway	Hamilton
Clydebank Shopping Centre	Hope St, Glasgow
Croy railway station	Johnstone railway station
Cumbernauld	Kelvinbridge subway station
East Kilbride	Lenzie railway station
Gartcosh Railway Station	Paisley
Glasgow Central Railway Station	Partick Interchange
Glasgow Queen Street Railway Station	Shields Rd subway station

The sites visited and recorded on the second visit were as follows:

Ayr	Greenock
Dumbarton	Helensburgh
Glasgow Prestwick Airport	Kilmarnock
Gourock	

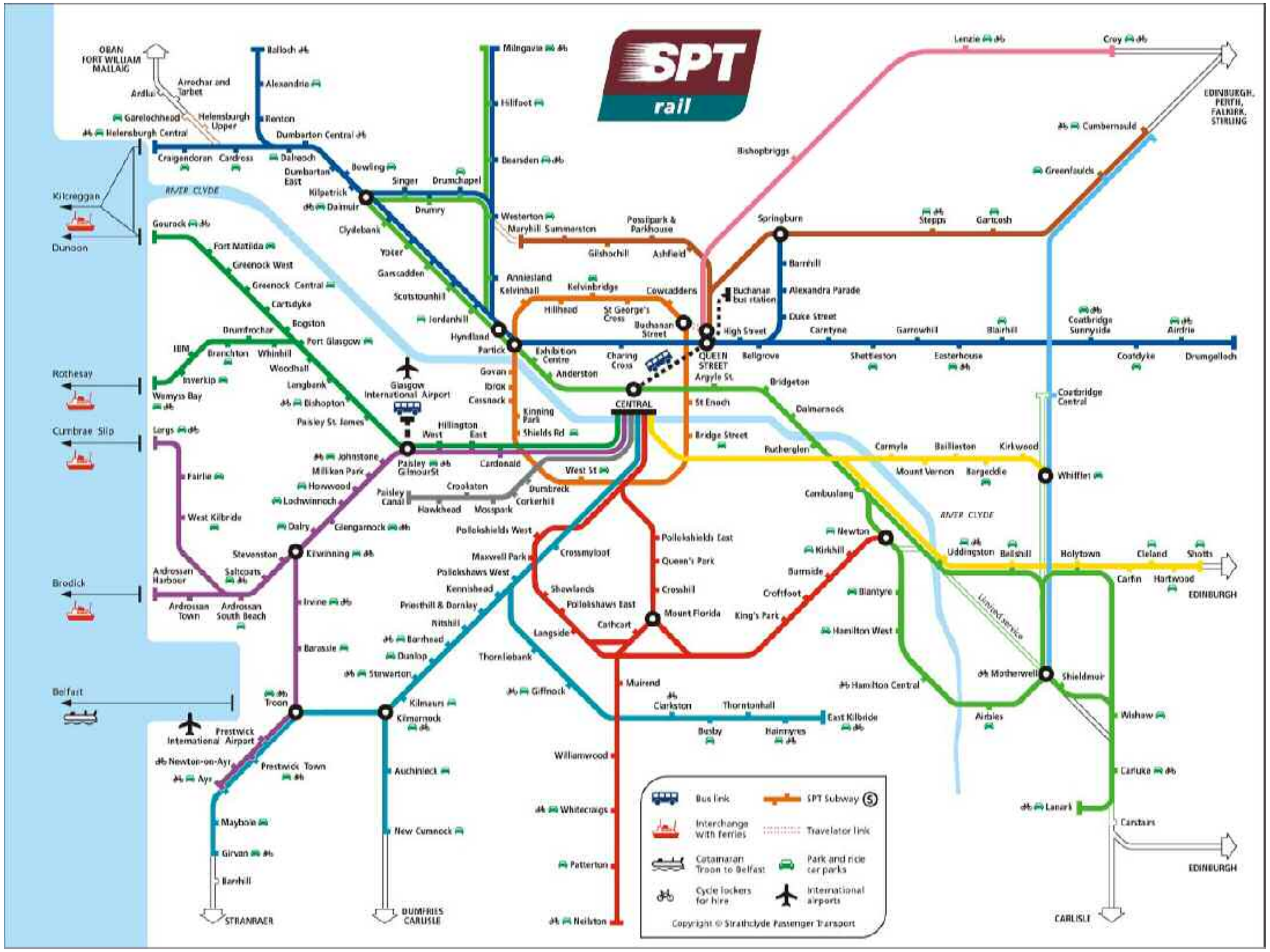

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Figure 4.2: The SPT Rail Network (Source: SPT)

5 Selection of the Case Study

5.1 Mode chaining

Transport policy is directed towards reducing the inherent costs and externalities associated with travel taking into account objectives for social and economic interaction. Policy may, for example, be directed at

- Travel times reductions
- Travel distance reductions
- The modes used to travel
- Reductions in the level of trip making by purpose

These and other transport policy directions can be used to reduce the environmental externalities associated with transport e.g. noise, air pollution and landscape and ecological impacts. Transport policy may also be complemented by land-use policy in which controls on planning aim to distribute residences and centres of social and economic activity in a way which promotes the achievement of the overarching environmental economic and social objectives.

An object of policy is to promote the substitution, in whole or part, of public transport trips for trips by private cars. A key element in public transport policy is therefore the improvement of the effective service levels through the integration of different public transport modes and the offering to car drivers of the possibility of easy transfer at park and ride sites to the public transport network.

Mode chaining is contrasted with 'activity chaining' in which a series of trip stages link together activities. For example, a mother may take her child to school (activity1 = drop child at school) and then carry on to work (activity 2) or to the shops (alternative activity 2). Some activities may be very short (e.g. activity 1) or quite prolonged (activity 2). The whole day could be seen as a tour in which the traveller leaves home, performs a series of activities and then arrives back at home. Each stage might be modal mode chain; in a simple case each stage would be by one mode and it is possible that the same mode might be used for all stages.

Both forms of chaining can be seen to have positive attributes which might lead to their promotion. In some circumstances it is conceivable that chaining might have undesirable effects such as promoting car use in the case of park and ride (undermining city centre parking policies). The possibility of activity chaining home-school-work might reduce the levels of walking to school.

5.2 Scope of the Modelling

In the present project we are only concerned with mode chaining and we have restricted ourselves to park and ride at underground stations in the Glasgow Subway system. The reasons for this were practical and reflect what could be achieved within the current study. In particular, by scaling down our ambitions we wished to avoid the project becoming a routine programming exercise leaving little room for creative thinking and analysis.

The modelling reported here represents a substantial extension of the methodology of the initial STM platform which assumed that trips can be analysed in terms of a main purpose (defined by the activity at the destination) and a main mode, which is the predominant mode. All trip making is reduced to this form with the exception of a special facility which permits the simulation of new park and ride facilities.

6 The Platform Software: TRL's STM (Version 4.6)

6.1 Zone system and attendant assumptions

STM is concerned with modelling trips between zone pairs. Each zone *ideally* represents an area of uniformly distributed land uses (preferably a single land use) and trips are treated as having their ends uniformly distributed within the origin and destination zones. STM also makes certain "averaging" assumptions about congestion levels within each zone. The model designer must choose a zone system (i.e. their number, shape and size) which limits the computational effort (which is proportional to the square of the number of zones) but allows a sufficiently high spatial resolution. Typically, zones are wards or convenient subdivisions of these; sometimes the zones may have been based on the zones of another model in order to achieve conformity with it.

The zone system comprises *internal* zones and *external* zones. As these terms suggest, internal zones form the core of study area. External zones are located at the periphery and serve to represent the influence of areas at the edge of or at some distance from the core area Movements between internal zones are fully modelled by STM i.e. all the trips between internal zones and all other zones are fully accounted for by STM. Trips between internal zones and external zones are modelled but STM does not model trips between external zones.

6.2 Trip representation

STM works in terms of person trips made per hour averaged over a suitable time period. Vehicle flows and their implications for congestion are obtained by division of person flows by vehicle occupancies. Freight demand is not modelled but a congestion effect due to freight can be added to that due to cars and buses by estimating the pcu-km contribution as a fraction of the total.

Trips are segregated by

- Mode
- Purpose
- Household car ownership
- Time of day

Modes

The mode used is the “main” mode for the trip. In practice trips will consist of a number of stages each with its own mode. Thus a traveller may walk to bus stop, catch a bus, and then walk to their final destination. In this case the trip would have as its main mode “bus” and the walk trips before and after would be the access and egress elements for this trip. Clearly more complex trips are possible in which a clear main mode is not possible. In this case the bus trip above might be followed by a rail trip of similar length. STM currently does not incorporate such trips explicitly. All trips are reduced to the “main mode” type.

The standard modes in STM are:

- car
- bus
- rail
- underground
- walk
- cycle

Taxi and motorcycle can also be included.

Purposes

Some trips may have stages with different purposes: e.g. dropping off children at school on the way to work. These are not explicitly modelled in STM. Each trip is idealised as having a single main purpose (the activity at the destination).

The home-based purposes included are

- work (mainly commuting)
- education (mainly school trips)
- social/leisure, shopping
- employer’s business
- other

STM models two non-home-based trip purposes:

- employer’s business
- other

Household car ownership

Travellers’ response to travel conditions will be influenced by a number of factors related to their socioeconomic status. Household car ownership serves as a measure of *income* and *car availability*. In the current STM we have used household car ownership of travellers i.e. the number of cars possessed by the household to which the traveller belongs. This currently has three levels: 0, 1, and 2+.

Time periods

Version 4.6 of STM currently has two time periods:

- am peak period
- inter-peak period

The am peak can be an average of the peak hour (0800-0900) where traffic levels tend to be highest or an average over 0700-1000. The inter-peak period is modelled as the average flow in the period 1000-1600. In the SITLUM STM, the am peak period is 0700-1000.

The home–based trips we model in the STM demand models are the “outward” stages i.e. the trip from home to the destination. Return trips can be estimated by applying trip-purpose-dependent “return factors” to the outward flows. These give the proportions of return trips in a time period generated by outward trips in the same or an earlier period.

Version 4.6 of STM does not model an evening peak (e.g. 1600-1900) (this is done in later versions); most trips at this time are probably return commute trips. STM could be extended to include this but some refinement in the model would be necessary if evening peak specific policies were to be applied.

STM models an average weekday (Monday-Friday). We have yet to construct a weekend travel model. At weekends the purpose mix and time distribution of trips will be very different from an average weekday.

6.3 Demographics, car ownership and employment

When DELTA and STM are run together the planning data and employment levels are provided to STM by the DELTA land-use model, both for the base and forecast years. DELTA incorporates its own sophisticated car ownership model which uses larger numbers of traveller/household categories as required by the land-use calculations.

6.4 Trip matrices

Within the STM, the base trip matrices are represented by

- zonal person trip rates (“trate” matrices)
- base planning data (exogenous or from DELTA).
- modal split matrices (split matrices)
- distribution matrices (pod matrices)

The ‘split’ matrices give the modal shares for each zone pair, purpose, household car ownership category and time period. The ‘pod’ matrices give the distribution of trips over destination zones by purpose and time period for each zone considered as an origin. Home based matrices can be generated by calculating trip generations from 1 and 2 and then applying split factors (3) and distribution factors (4). Non-home-based generations are then derived from *home-based attractions* and trip rates in (1) and the matrices finally obtained by applying (3) and (4) for non-home-based purposes.

The forecasting mechanism uses forecast year demographic and car ownership data, employment and travel to work data to drive the new trip generations and attractions using the base person trip rates; forecast travel costs are used to estimate new “split” matrices from the base “split” matrices in the modal split model and new “pod” matrices from the base “pod” matrices in the redistribution model.

6.5 Mechanisms - summary

The basic function of STM is to predict forecast trip matrices under policy and planning scenario assumptions. From the predicted travel costs measures of congestion and accessibility are possible. From speed and flow information predictions can also be made of vehicle emissions levels and "road safety".

STM is incremental in the sense that forecast trip matrices are calculated starting from *base trip matrices*, which must be supplied in input data files, and *base cost matrices,* which are constructed from input cost data files and forecast year policies and planning data.

STM is also an *equilibrium model* in the sense that the basic processes (excluding home-based trip generation- see below) are iterated until the starting costs (prior to modal split/redistribution) and output costs are sufficiently coincident.

STM incorporates four basic elements to make forecasts.

- Trip generation
- Modal split
- Redistribution
- Congestion calculations

Home-based (HB) trip generation is based on demographic and car ownership data and trip rates per person (in different household car ownership groups). These are created at the start of the modelling process. Non-home-based (NHB) trip generations are calculated from home-base trip attractions (which serve as trip generators for NHB trips) to each zone and trip rates per generator trip. This is carried out in the Modal split/Redistribution

The modal split/redistribution is performed "simultaneously" i.e. they occur within each iterative pass. After this each modal split/redistribution the STM calculates the traffic levels (pcu-kms in each zone). These are then used to calculate highway speeds which can then be compared, as a convergence test, with the speeds used at the start of the iteration.

6.6 Trip generation

Home-based trip generation is calculated within for each zone within the study area. This is the total number of HB trips starting within a zone by purpose, household car ownership and time period. The usual approach is to derive, for each zone, person trip rates, i.e. trips per person per hour by purpose, household car ownership and time period from the base year trip matrices and base year demographic data. These rates are calculated outside STM and are provided by the model builder in an input file. The normal assumption (in the absence of other data) is that the person trip rates (disaggregated by purpose etc - not the total trip rates) are stable over time. This *is an assumption one might wish to modify.* Changes in trip making (generation) occur because population changes and car ownership changes, shifting people from one category to another. The disaggregated trip rates could be made time dependent e.g. by applying time trend factors (to represent social trends) or by allowing travel costs to modify the rates (thus making HB trip generation part of the iterative loop).

In obtaining these trip rates, the total base year generations by purpose, household car ownership and time period are calculated from the base trip matrices and then divided by a purpose-dependent “generator” population to give the trip rates per person. The “generator” populations are chosen to correspond to the main generators for the particular trip purpose e.g. working age adults for work trips.

Non-home-based trip generations are treated in an analogous way to the HB trip generations except that in this case we do not have a generator population of people resident in a zone. Instead the “generators” are work and total attractions to each zone. As in the case of HB trips, a base calculation is made outside STM using the base matrices (for NHB trips). These provide base values for the generator attractions and are used to calculate trip rates per generator, analogous to person trip rates. These are supplied to STM in an input data along with the HB trip rates, discussed earlier. In the forecast case, the forecast year “generators” are calculated within each iterative modal split/redistribution pass. These can then be applied to the NHB trip rates to obtain the NHB generations. The user might consider alternative definitions for the NHB trip rates and the generators. Other NHB purposes might be considered.

6.7 Modal split and redistribution

These processes fall within the iterative loop of the model. The calculations are based on changes in generalised cost relative to the base. Generalised cost in STM is a combination of time and money costs in which time cost have been monetarised using value of time (VOT). The VOT are for the UK and were taken from figures provided by the UK Department for Transport. The elements in the generalised costs include access and egress costs and travel time. Private travel by car includes fuel cost – using formulae for fuel consumption given by the UK Department for Transport.

Car travel also includes possible cordon charges and parking charges. Parking charges are a combination of the money charge and costs relating to searching and accessing a parking place. Public transport costs do not include fuel cost or parking costs but there are elements for waiting time and fares. The model builder provides data on fares in the base – policy factors can then be applied to obtain forecast fares. The generalised cost for bus allows for bus crowding (a modification of bus frequency) and rail crowding (related to standing).

Also, it should be borne in mind, as indicated above, that the demand response is based on what is effectively the outward trip. It would also be possible to base the response on an average of the out and return trip.

The modal split model redistributes total trips between each zone pair over the different modes in the base in accordance with the way in which generalised costs have changed from the base. The approach is incremental in the sense that it automatically reproduces the base market shares. Calibration is achieved by running the model and performing sensitivity tests for fuel price and public transport fares. The outputs demand responses for the study area as a whole are then compared with published elasticities (*UK-based values*). Parameters (set in a data file) can then be adjusted to produce a match with the observed elasticities. Some comments are necessary here. The current STM practice relies on the model structure to imply most of the elasticities for different costs elements

– comparatively little data exists for some of these. The spatial variation of elasticities e.g. with distance is also implied. The parameters used in the modal split need to be disaggregated by purpose, household car ownership and time period – in practice we have usually worked from a full starting set of parameter values, taken from earlier TRL studies with STM and adjusted these with factors independent of purpose and car ownership so as to obtain a full set with the calibration of each new model.

Redistribution over trip destinations is based on changes in generalised costs from the base and changes in trip end factors. The impact of cost changes is modelled using "composite costs" (calculated over all modes) between zones in a model similar to that used for modal split except that "mode" is now replaced by "destination zone". Changes in costs therefore cause the allocation of trips to destination zones to change. The sensitivity of redistribution to changes in cost is controlled by a parameter which is currently set for work and non-work trips. The distribution of trips is also controlled by "trip end" attractions. Currently this control is only applied to work trips. In this case, changes in the distribution of jobs require the distribution of work trip ends to be distributed in a corresponding way.

6.8 Highway and Rail Routing

Highway

STM does not itself perform an assignment calculation for highway movements by car or bus. Normally, a calculation is made outside of STM of the likely strategic routes between each zone pair using a simple assignment. Each route is converted into a zonal route i.e. the sequence of zones through which the route passes. For each zone, the predominant road type on the route is also recorded along with the length of road through the zone. The model works in terms of motorways, A roads and other (essentially local roads). These are distinguished according to whether a road section is located in an urban or rural setting. These routes are used in STM as the basis for estimating the travel times between zones and it calculating the spatial distribution of congestion.

This information is stored in an STM "network" file. Often these routes are retained through all forecasting years for the purposes of estimating road speeds and journey times. It is also possible for STM to allow the network to be changed in forecast years so that a new network file can be defined for cases where it is felt that significant changes in the network have taken place.

Rail

In a similar way it is possible to construct a network for rail movements using a simple routing algorithm. Some care is needed to allow for the presence of significant interchange points. The model can be checked against routings suggested by railplanner software and timetable information.

6.9 Congestion modelling

Travel times for the routes specified in the highway network files are calculated using speed/flow equations. Each road type modelled within the STM has it own speed/flow equation.

The model requires various base year speed data for the highway network and parameter values relating to speed/flow equations. The base speeds are therefore an input for the base year. In a forecast year speed/flow equations are applied for each zone to each road type to calculate the speed. The speed/flow equations are functions of the pcu-kms in the base and the forecast cases. These equations are incremental in character in the sense that difference between the base speeds and the forecast speeds is driven by the pcu-kms in the forecast year relative to the base pcu-kms and that the model is guaranteed to give the base speeds when the base model scenario is run.

The speed/flow equations and their calibration are based, in part, on the link speed/flow in COBA but have a more sophisticated form for urban areas. For urban centres the equations are based on earlier studies in which the equations describe the area-wide variation of average speeds as congestion levels change. A minimum speed can be applied at very high traffic levels.

STM also includes a model of crowding on public transport.

6.10 Representation of freight

Within the current STM freight is as a loading on the highway network. Freight levels are treated as given proportions of all traffic.

6.11 Parking models

The detailed parking model is used to model the impact of parking policies and capacity limitations within a zone. Because the parking model slows down the process of convergence to equilibrium (being relatively more prone to oscillations when compared with other model components) it is not used in all zones. Instead, it is limited to certain "parking zones" which are normally town/city centres and coincide with or at least contain the main parking control areas. Parkers in other zones are treated more simply; each is subjected to a tariff based on the assumed duration of stay for each trip purpose.

Demand for travel by a mode into a parking zone is influenced by the generalised cost (GC) for travel by that mode between the origin zone and the parking zone. GC combines money and time costs into a single measure of money for a given trip by the mode. Both money and time costs are made up of separate component elements. For example, money could be a combination of fares, cordon charges and parking charges. Travel time can be separated into in-vehicle time, waiting time, access and egress time. It is converted to money using an appropriate value of time. Each mode has its own appropriate form of GC equation i.e. is a particular combination of these costs elements. In the case of car, we have

- fuel costs
- time costs
- cordon charges
- parking cost

The parking cost comprises a money cost (the effective tariff) and a component which relates to searching for a parking place. This element becomes more important as capacity is reached. The sum of the money and search cost equals the parking cost (PC) element. As the PC increases, the cost of travel by car into the destination zone increases. This can have two effects: a shift to other modes (typically to public transport) and redistribution to other zones. Redistribution would, for example, encourage movement of work trips to other destinations where jobs were available. This would imply a change in jobs by travellers (a long-term effect). The parking model does not, on the basis of generalised costs alone, cause travellers to maintain their ultimate destination zone, but move the location of their parking outside that zone. There is, however, a mechanism (outlined below) for relocating parking because of insufficient parking capacity.

In addition to calculating the PC the parking model estimates the impact on traffic congestion and travel times due to high parking demand. Normally parkers are assumed to park within the zone in which they ultimately destinate. An exception to this would be P&R when a new P&R is introduced in future years using the new mode facility. This does not apply to the base because no P&R sites are modelled in the base.

Another exception arises when overall parking demand is too high for the total capacity. In this case the parking model determines a proportion of "out-parkers" and assigns to these a penalty cost (a parameter of the model). Out-parkers are assumed to ultimately destinate in the destination zone (where their activity, e.g. work, is located) but park in an adjacent zone. This is achieved in STM using a simple mechanism in which out-parkers from the destination zone are allocated to pre-defined adjacent zones (out-parking zones); the proportions (parking distribution factors - PDF) allocated to each of these zones are set in a data file. Normally the PDF are not changed over time, but they could be made year-dependent. The PDF are applied to parkers independent of purpose, origin and household car ownership. The same factors are used in both the am peak and the interpeak periods.

In SITLUM we used the new parking model developed originally for the West Yorkshire STM for their LTP work. This model is able to represent parking demand and supply for

- PNR
- Long stay pay
- Long stay free
- Short stay pay
- Short stay free

The user can set policies for changes in the supply of these parking categories and the charges for them. PNR parking can also have charges applied.

The model starts from a base picture in which demand is defined across the parking supply types for each category of trip purpose and where the supply for each parking type is estimated. In a forecast year parking conditions may change as a result of changes in demand (e.g. due to increased retail opportunities, jobs and car ownership growth) and policies, such as increased tariffs and reductions in parking provision. These changes are accommodated in the model using a series of simple algorithms which, for example, distribute rising demand over the available spaces in sequence dependent on the types of places available. When supply is exhausted cars are forced to redistribute as described above.

6.12 Equilibrium modelling and convergence testing

The main loop of the STM model (see Flowchart A1, Appendix) balances transport supply and demand. Generalised costs for travel between zones determine the mode and destination choice of trips for each car ownership category, purpose and time of day. The new pattern of trips then leads to a new set of generalised costs through the application of the congestion model and capacity constraints. STM generalised costs are responsive to road capacity constraints (which affect speeds and thus travel times), public transport crowding levels (affecting perceived value of time for transit) and parking demand (affecting parking search time, access and egress costs, and additional traffic capacity effects). Many other components of costs are also modelled, but it is the supply-side costs that primarily influence the balance in the damped feedback loop. Convergence to equilibrium has been reached when measures of capacity (such as speeds, crowding, mean parking charge) are consistent within a specified tolerance level between successive iterations. The principal test is for the convergence of speeds. A number of damping calculations are also made to reduce oscillations in the convergence process.

6.13 Calibration and validation of the transport model

Calibration of STM is in terms of published elasticities for the responses of travellers to various costs factors. Parameters controlling modal split are adjusted to ensure that for trips within the study area the levels of response in the model match those observed for public transports and private car travel. In effect, the calibration determines the response of demand to generalised cost by changing certain elements in the generalised cost expression (e.g. bus fares). The ‘generalised costs elasticity’ in conjunction with the weight factors for the cost elements (most importantly value of time) then determines the response for those elements.

Validation of STM means comparison of STM outputs against expectation. 'Expectation' can mean

- known or expected forms of behaviour within certain ranges of response
- independent data (i.e. not used in setting up the model) such cordon counts, modal shares etc.

In addition, a model can be validated by performing a series of realism checks when specific policies are applied.

7 Building the model platform

7.1 Main features

It was decided that the standard 173 zone Strathclyde STM lacked sufficient detail in the centre of Glasgow and in the areas passed through by the Subway. A new model was therefore developed in which new zones were created (by splitting old ones) so as to improve the resolution. These zones were based on the zones for central Glasgow in the

SITM4 model. The new model (Figure 7.1 and 7.2) has 233 zones, more than any previous STM.

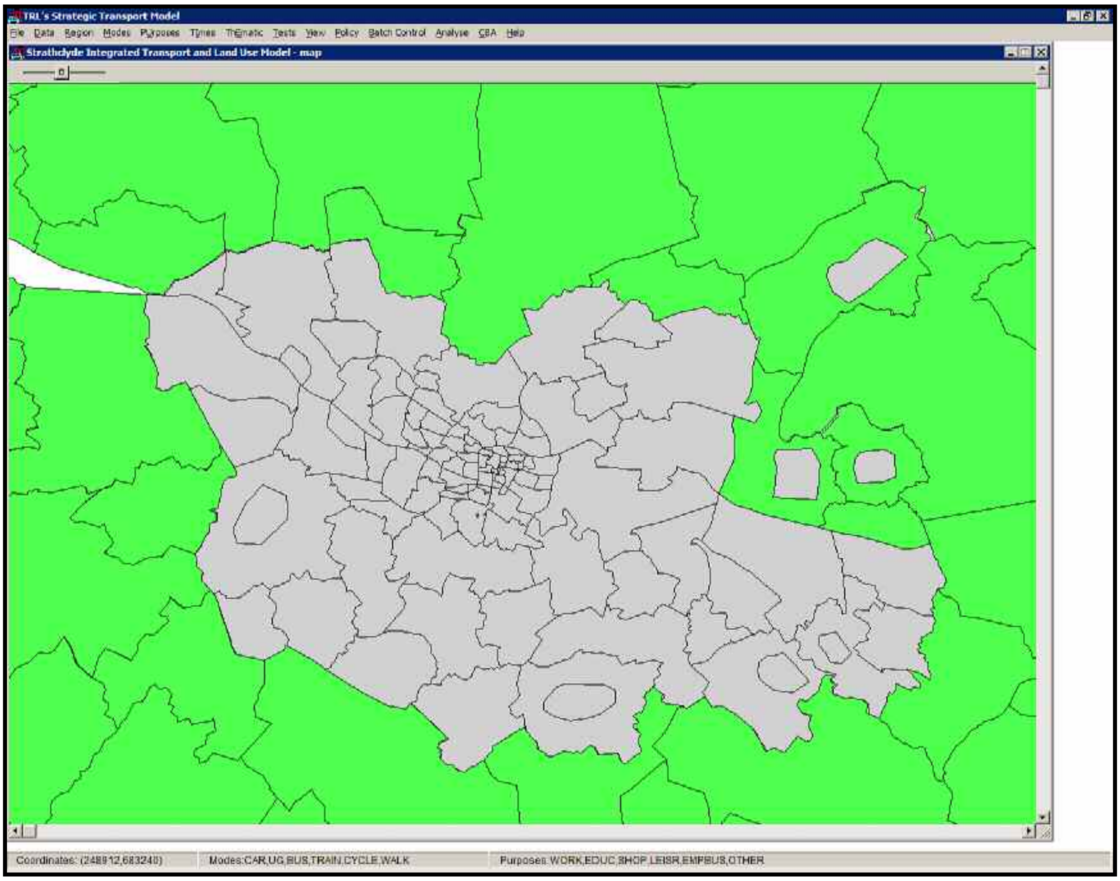

Figure 7.1: The GUI for the 233 zone STM (the large grey area is the Glasgow conurbation)

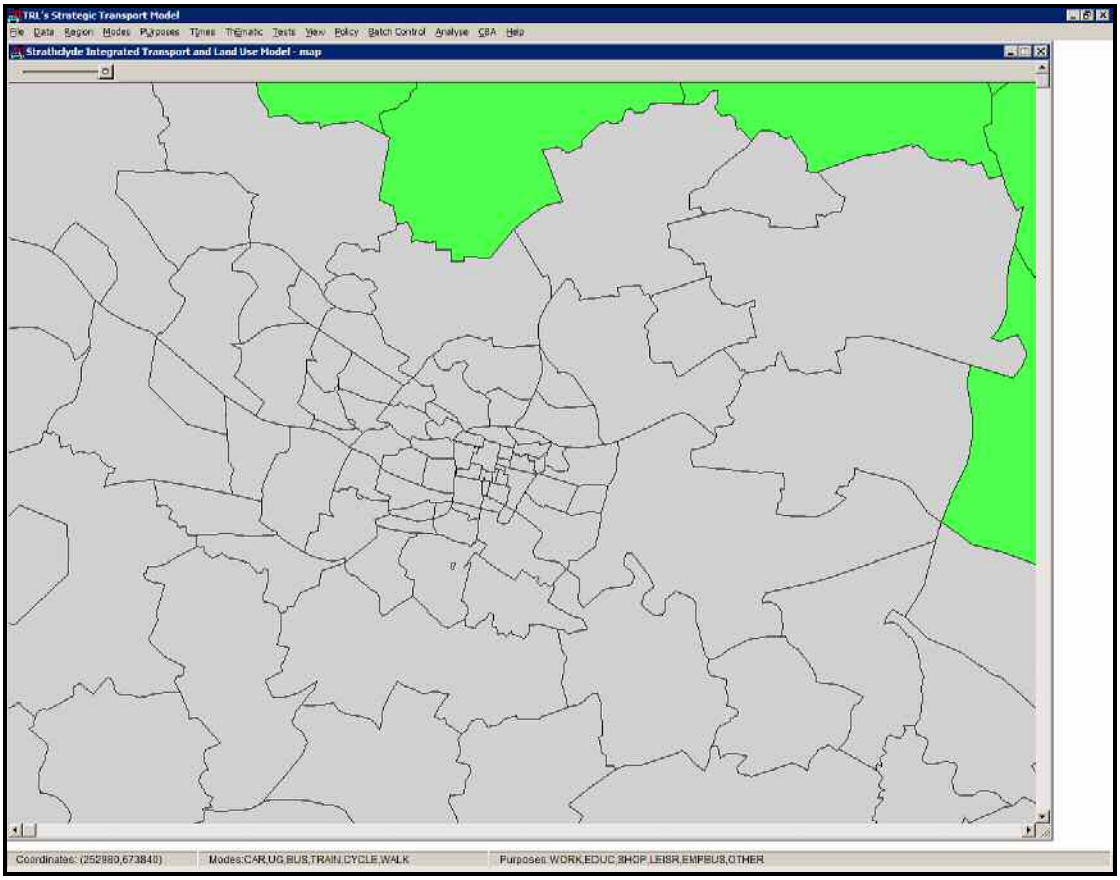

Figure 7.2: The GUI for the 233 zone STM with Central Glasgow in close up

7.2 Base generalised costs

The base network models (highway and rail) were constructed from data existing for the 173 zone STM. It was necessary to construct new matrices for base:

- Highway costs and routes
- Public transport fares and service levels and rail travel times
- Parking charges and supply

In some cases we recognised it would difficult to obtain the data required and have instead used reasonable values guided by professional judgement.

7.3 Base year matrices

The base year trip matrices were constructed using a combination of data

- 2001 Census population and car ownership data
- 2001 Census travel to work (TTW) matrices
- NTS and Scottish Household survey data (for trip rates)
- Floorspace figures and education places.

SITM4 data was used to assist disaggregation of existing data sets to the new zone system. The travel to work matrices used employment and job estimates for the new zones to convert commute patterns in the 173 zone model to the new model. The commute pattern was provided by the TTW matrices and work trip generations. Non-work trip patterns were derived using doubly-constrained gravity modelling.

7.4 Forecast year demographic scenarios

In forecast years the model requires

-
- Forecast demographic / car ownership data (from the land-use model)
- Zonal job data
- Policy data (user-defined inputs).

The forecast demographic are constructed for this project by applying TEMPRO-based factors to the base data.

8 Building the mode chain model

8.1 General approach

Before describing the general modelling assumptions it is necessary to preface this by some comments. As indicated, the mode chain modelling was to be restricted to explicit Park and Ride at Subway stations.

Park and Ride at (heavy) rail stations is not directly modelled normally – the use of car access to stations does not appear explicitly when modal shift to rail occurs; travellers are simply assumed to access the station by some means and incur a penalty for it. We use the term ‘normally’ because the strategic model does include a facility (unconnected to the present work) for modelling single *new* Park and Ride sites including those using heavy rail for the public transport leg. This model does not represent park and ride trips in the base and therefore is not applicable to most Routine Park and ride travel from rail stations.

In the platform STM model the proportions of person trips between each origin-destination zone pair (OD pair) are calculated by the modal split model. The modal shares are determined by the forecast and base generalised costs for travel between the OD pair and the base values for the modal shares. The model also includes a cost-driven trip re-distribution model which is based on composite costs (taken over all modes) from each origin to each destination zone and the corresponding base values for the proportions of trips. This cost-based calculation is modified by procedures to constrain the distribution trips to the forecast-year pattern of trip attraction factors (essentially land-use factors or proxies for them). The trip generation, modal shares and distribution factors determine the flows of car trips between each OD pair. The final output values for modal shares etc are the result of an iterative process in which the above calculation is repeated until convergence is achieved.

It is assumed in the mode chain model that the Park and Ride use of the Subway by car drivers and their passengers is only available for certain OD movements. Within the model, all other OD pairs do not have this possibility no matter what changes in travel costs occur. To improve realism of the model it was necessary to determine the range of OD pairs quite generously. For OD pair a table is constructed such that if an OD pair can 'use' the Subway then the entry in the table for that OD pair is set to 'true'. At the same time the Subway stations which are viable options for that OD movement are stored. 5 Subway stations are allowed for each OD pair which can use the Subway. These tables are used for both the base and forecast years. In principle they could be made a function of forecast year so as to allow for the addition of new stations.

In the present mode chain model the qualifying OD pairs are defined pre-selecting a set of destination zones for which the mode chain model is to be applied. This zone set was chosen to be fairly large and cover the zones in Central Glasgow. In this report we have called these 'Centre Zones' as a shorthand; strictly speaking they do not need to only in the centre, they qualify for inclusion on the basis of their significance. Other destination zones are excluded as a reasonable approximation. The effect of this selection is to concentrate the modelling on commuting (am peak) and shopping trips (interpeak) from outside the Central Glasgow.

The advantage of this approach is to make the calculation more economical and manageable for this project since the additional calculations required for mode chaining are then limited to a relatively small subset of all OD pairs. The realism of the model can be increased by simply broadening the choice of destination zones (these are set in an input file and can be easily changed).

For each OD zone pair version of STM carries out the demand modelling as described when an OD pair does not 'qualify' for Park and Ride at a Subway station. When an OD pair qualifies then additional choice modelling is applied to the travellers allocated as travelling by car (as their main mode) by the modal choice model.

The additional modelling has two components:

- A choice of whether to travel to a Centre zone directly (and to park in the centre) or to use Subway.
-
- The choice of Subway site if the second option is taken.

The first choice is determined by a binary logit model, the second by a multinomial model with a choice of 5 Subway stations.

Up to this point we have neglected to mention the role of parking supply constraints on the use of the Subway (or central parking). Each zone containing a Subway is designated as a parking zone and its capacity is set as an estimate of the number of parking places available to park-and-ride travellers. Similarly central zones are also designated as parking zones. In these cases the parking model will be applied to determine the levels of parking (given the demand) and generalised cost associated with it. A consequence of demand exceeding supply is that some car trips to a parking zone will be designated as 'outparking'. This means that although the parking zone in question would be the first 'port of call' (possibly the ultimate destination of the traveller) parking must be located in another zone. The simplest response to 'outparking' within iterative passes of the model is to impose an artificial penalty charge on drivers thus incentivising modal shift to public transport. Such an approach does not necessarily completely remove outparkers and one approach to this is to treat these as being absorbed elsewhere without significant impact. An improvement to this is to use an overflow model i.e. to allocate outparkers to specified zones as alternatives to the congested parking zone. The platform version of STM already had a facility for doing this (called the parking redistribution model). In the new mode chain model we have developed and applied a variant of this. In summary, outparkers from a given parking zone are allocated in sequence to alternative parking zones, at each step applying capacity constraint. If a parking zone is a 'centre' zone then the overflow zones will also be centre zones. Similarly, if they are Subway zones then overflow is to neighbouring Subway zones. The effect of this overflow arrangement is to increase 'conservatism' in car travellers towards moving from central parking to Subway parking and to reduce the tendency to transfer to public transport as the main mode from the origin to the final destination. Any residual outparkers (after overflow modelling) that remain incur a penalty cost which encourages modal shift to pure public transport (thus tending to suppress residual outparkers).

The new choice models in the mode chain modelling are incremental; that is, they are based on the differences of forecast and base costs and the base proportions which describe (for each OD pair):

- Proportion of travellers using Subway Park and Ride.
- Market shares for each Subway

The model uses an innovatory approach to synthesise these proportions using non-incremental logit models for the corresponding choices and constraints to match target values for the parking places occupied in the base. The forecast year model can then use these synthesised proportions as described. Use of synthetic methods was essential because there were no data available given this base year information.

8.2 Determining the 'qualifying' OD pairs and the feasible Subways

The qualifying OD pairs are determined by whether or not

- D was a selected Centre Zone
- At least one Subway station was feasible

The set of Centre Zones can be specified by the user. In practice they were the main central business district zones within Glasgow. Feasibility of Subway, in the present sense, was based only on 'spatial' criteria. Version 4.6 of STM uses routes defined as series of zones through which travellers must pass to travel from the origin O zone to the destination D zone. For a given network these routes are fixed and there is only one route for each OD pair. A program was written which made use of these routes to allocate Subway stations as feasible to each OD movement. If an inbound route passed through (as its first encounter) a Subway zone then that Subway was feasible and designated as to be the "mid-station". If this criterion did not produce a mid-station then zones on either side of the route, along the sequence of zones passed through by Subway, were checked. If a mid-station is found then additional stations (2 clockwise, 2 anticlockwise) are added as feasible stations. Each qualifying OD pair has 5 stations available to it.

This procedure is quite generous in the way it includes OD pairs and the Subways they can use. It has the advantage of limiting the mode chain calculations to movements which are considered to most important, thus saving computational time and storage when this is at a premium but also allowing greater sophistication where it is needed most.

8.3 Building the base case

8.3.1 The base model

The STM works incrementally from a base case in which the relevant flows (trip matrices) and travel costs (generalised costs matrices) are known. The flows may be obtained by processing survey data for the study area or by modelling (synthesis methods) based on more general input data, or a combination of both approaches. The absence of suitable data (in terms scope, detail and quality) is a frequent problem in building a model. This is no less true in this case where there did not exist (or at least it was not available) suitable flow data to construct a picture of park and ride use of the Subway system. In 2005 it was proposed to conduct surveys at Rail and Subway stations with the aim of acquiring a useful dataset (travel diaries) and a scoping study to this end was commissioned by SPT (Ash, 2005). These surveys would have been funded by SPT and therefore outside the DISTILLATE project. Unfortunately the surveys were not made due to unforeseen loss of survey staff at SPT. It was therefore essential to make use of synthesis techniques to construct the base case. Even with the surveys it would probably have been necessary to have made use of these techniques because of the detail of the information required.

In the base we needed to have for each *qualifying* OD movement an estimate of

- the proportion of trips going to the Centre Zone
- the proportions of trips not going to the Centre going to each available Subway station

We used as our starting point the base year trip matrices constructed for the Platform Version of the Strathclyde STM. We then took from these matrices, for *qualifying* OD pairs, the flows of persons travelling by car (as the main mode) into the Centre Zone and separated each of these into flows into the Subway stations (for Park and Ride) and a flow into the Centre Zones. The Platform Model (Version 4.6) does not make this distinction. The separated flows and the total flow of persons by car then give the above proportions for the base.

A non-incremental multinomial logit model was used to determine the flows, for each *qualifying* OD movement, into the Subways available to that movement.

$$f_i = F_{sub} \cdot \frac{w_i . \exp(-\mu . c_i)}{\sum_k w_k . \exp(-\mu . c_k)}$$

We have suppressed reference to household car ownership category, purpose and time period which, of course, feature in the disaggregation of demand. F_{sub} is the total flow of car travellers going via the Subway for a given OD pair; f_i is the flow to Subway station i. The w_i are weight factors which are related to the attractiveness of each Subway option park (e.g. reliability); in the present model we have set the w_i equal to 1.0. The $c_{i\ are}$ the generalised costs for travel from the zone O to D via the Subway using station i. These costs are calculated using specially written routines which combine the Platform Model's estimates of travel costs from O to the Subway zone by car and from then on to D by Subway. It is assumed that egress is by foot.

The proportion of trips using a given Subway is therefore $p_i = f_i / F_{sub.}$ If F is the total flow of car travellers then $F_{cen} = F - F_{sub}$ is flow to the Centre Zone D and the base proportion to the Centre Zone D is then $P_{cen} = F_{sub} / F$.

The trick used here was to first perform this calculation on the basis that the flow to the Centre Zones F_{cen} was zero i.e. all the person car flow for each OD movement into the Centre went to the available Subways in the proportions dictated by the Logit model. This, of course, generally results in parking levels at the Subway stations which are much higher than the available spaces (which are specified by the modeller). From the ratio of places taken (calculated with the Logit model) and places available and assumed utilisations we obtained factors (time period dependent, but independent of purpose and car ownership and age category) specific to each Subway station s_i which when applied to each flow to the station yield the target utilisation after summation over all contributing OD pairs. The factored flows $s_i . f_i$ from each OD movement could then be summed to give the resulting total flows to Subways

$$F_{sub}(adj) = \sum_k s_k . f_k$$

and the proportion of that total going to each available Subway station. The total flow to the Subway could then be subtracted from total flow for the OD movement (from the Platform Model’s matrices) to give the flow to the Centre Zone. The base proportions could then be calculated.

8.3.2 Base parking issues

The main parking model has 5 categories of parking supply: PNR, long pay, short pay, long free and short free. Normally the demand for parking in a zone is simply the estimated flow of cars into the zone; this demand is then allocated to the parking supply categories. When a parking zone is a Subway zone the demand for parking processed by the detailed parking model is restricted to the cars requiring park and ride. We have also restricted the parking categories at present to two: long pay and short pay. Free places can be modelled by setting the tariffs to zero, but at present a mix of free and pay is not available though this can be implemented fairly easily. The parking costs of other travellers parking in the zone can at present be handled by subjecting them to a simple tariff (background charge). This is the approach used for zones not modelled using the detailed parking model; it is most appropriate for zones where parking capacity is not under heavy pressure. The need to represent other parkers will tend to decrease if the zone containing the Subway is reduced to a small, notional size so that it can be considered as representing only the Subway. This has not been achieved with the current zone system though this is a considerable improvement on the 173 zone STM, which is the standard Strathclyde STM.

The parking supply at each Subway is treated as if was attached to the Subway station and only for Subway travellers use. In some cases this might not be the case and local car parks and on-street, available to all, could also play a role. At present, the best we can do is to use a proxy for the effective parking supply; more work is required on combining park and ride parkers and other parkers.

The techniques described in the last Section are quite flexible; in addition to setting the base to the actual 2001 case it is possible to create artificial situations in which Subways lacking parking facilities can be given parking places and in which actual Park and Ride facilities Subway stations can be enlarged in the base. This is a useful feature as it allows us to create model runs in which the mode chaining facility can be easily tested and demonstrated because their impact is increased.

With typical levels of parking (200-1000 places) the proportion of car drivers using the Subway will only be small (a few percent). For this reason it was considered reasonable to use the Platform Models matrices as “raw material” in the manner described rather than attempt to synthesis the matrices from scratch taking into account mode chaining.

8.4 The Forecast case

The last section showed how the elements for setting up two incremental choice models were calculated. We can now proceed to describe how the mode chain model functions when forecasting. This section deals with the demand functions and their use. The overflow model, essentially, an extension of the Version 4.6 STM parking model is taken up in the next section.

The choice between travelling directly to the destination and travelling by Subway is represented by the equation:

$$p_{cen} = \frac{p^0_{cen}}{(p^0_{cen} + (1 - p^0_{cen}).\exp(-\lambda_1.(\Delta c_{cen} - \Delta c_{sub}))}$$

where p_{cen} is the forecast proportion for travel by car for the whole journey and p^0_{cen} is the corresponding base value (as calculated in Section 8.3); the Δc are changes relative to the base in the costs. Δc_{sub} is a logsum value taken over the alternative Subway stations.

If F is the 'flow' of persons travelling by car (whether direct or via Subway) as estimated by the modal /distribution model and $F_{cen} = p_{cen}$ * F is the flow of persons traveling straight through to the destination. We then have F_{sub} = F - $F_{cen.}$ The split between Subway stations is applied to F_{sub} to give the flows (for the given OD by purpose etc) to each Subway.

The equation for the incremental model is

$$p_i = \frac{p^0_i \exp(-\lambda_2.\Delta c_i)}{\sum_k p^0_k.\exp(-\lambda_2.\Delta c_k)}$$

where the Δc are changes from the base in the generalised costs to each feasible Subway station. The p_i are the forecast proportions and p^0_i are the base proportions as calculated in Section 8.3. Note that this equation is not directly responsive to changes in parking spaces at each Subway. In principle it is possible to introduce into the above equation weight factors (attraction factors) for each Subway which are a function of the increase in parking supply at each Subway. The problem is knowing what values they should take – using the parking supply policy levers will overestimate the effect of changes in supply (among which is increased reliability of finding a place. These issues are taken up again in Section 8.5.

The modal split model (a single level power law logit type - as distinct from an exponential model) does not distinguish between park-and-ride and direct trips when calculating the mode share for car. It is therefore necessary to provide the mode split model with a composite cost for car for travel from zone O to zone D. In the present model we have used a simple weighted average of total generalised costs taken over direct travel and travel to each of the Subway stations. This is calculated each time after using the above equations but before calculating the modal split. As composite costs change the demand for car travel overall will change accordingly. Thus changes in policies on the Subway may have some effect on car use and longer distance public transport patronage.

The procedures described above are summarised in Flowchart A2 (Appendix A).

8.5 The Parking Model and Parking Overflow model

8.5.1 The models

The parking overflow model is an extension of the STM parking model. The purpose of the latter is estimate a generalised cost (money + time) for parking based on the level of demand in relation to the supply of places for different types of parking (long /short term, free/pay). The parking model is responsive to changes in supply and tariffs and to changes in levels of demand (which cause movements between different parking types). A problem which arises with every parking model is what to do when capacity is exceeded. There are a number of responses (see Section) but the outcome is that at the end of each iteration a number of cars are designated outparkers which incur extra costs (which encourages modal shift from car and suppresses outparkers in the next iteration). In the mode chain model we modified the 'parking redistribution' model (Section 6.11) by allocating to each parking zone alternative parking zones to which outparkers might go instead. The overflow calculations take place in each iteration after demand levels for travel by car have been performed and a first pass allocation of demand has been made in each parking zone. At this stage the model knows the (first pass) levels of utilisation in each parking zone and the numbers of outparkers for each of them. The extension to the parking model inserts outparkers into the alternative parking zones where space permits.

The algorithm has the following features:

- The outparkers are not 'inserted' into the alternatives in one go – instead, the numbers of outparkers are sliced up into small 'units' (say 1/10ths of the total) and the algorithm attempts insert the next unit after all other parking zones have had their turn.
- The alternative parking zones are ranked so that those earlier in the list are looked at first.
- The alternatives are specified by the modeller.

The effect of these procedures is that if car park zones have common alternatives the insertion of outparkers will occur more 'democratically' (in the overflow, we have not tried to model represent accessibility differences to the common alternative). This is to avoid spare places in alternatives being consumed by outparkers from one car park zone when there are competitors from other zones. The ranking of the alternatives was done 'by eye'; another possibility would be to rank alternatives on the basis of an accessibility calculation but this requires additional programming.

When these procedures have been completed the residual outparkers (which are formally attached to the 'first port of call' parking zone) are assumed to be absorbed without effect but they receive a penalty cost which is then compounded into the generalised cost for parking associated with parking when travelling to the given destination.

As mentioned earlier (Section *) the parking overflow model does not take into account tariffs (in effect, they assumed to be similar across the alternatives) when allocating parkers to alternatives – this is simply a matter of insufficient capacity.

8.5.2 The setup of the overflow model

We have, in the present model, chosen parking alternatives for the Centre Zones which are other Centre Zones and for Subway Zones alternatives which are Subway Zones. Movements between the Centre and the Subways take place purely through cost effects. Increasing outparkers in the Centre Zones will translate into higher costs for travel by car into the Centre – this will, ceteris paribus, push down demand for such movements and increase demand for use of the Subway and simultaneously produce some depression of demand overall for travel by car to the centre (whether by park and ride or not) and for travel into the centre by any model. How these possible reactions balance out depends on the details of specification and the calibration of the model components. The assumptions made here for the alternatives (“self containment” for Centre zones and Subway zones) can of course be changed by the modeller.

8.5.3 Capacity-increase model

A defect of the current parking model is its ability to drive changes in demand when the capacity of car parks is increased. If the size of car park is increased ceteris paribus i.e. without any other change in demography or travel costs than this will have very little effect on demand for travel by car. When forecasting over long periods and in a context of other policies changes in parking supply are important for determining travel behaviour and this is how the model is normally viewed. In an attempt to model the effect of increasing parking spaces ceteris paribus a cost element was introduced into the parking charge to represent suppressed demand. This cost element was a function of the utilisation (starting from zero at some specified level of utilisation). Unfortunately (and somewhat predictably) the approach was either insensitive or unstable. We have therefore put this model feature to one side for the present. The already existing search time component was insufficient for the purposes of providing constraint and is given a maximum value to prevent convergence instability. The outcome of this difficulty is that the model cannot be used to predict effect of introducing new car parks in the Subway system - this may require substantial modification of the model and require the use of non-incremental models in place of the incremental approach adopted.

8.6 Defining policies through the graphical user interface

There are many possibilities for developing the graphical user interface (GUI) of STM to exploit the mode chain facility in the ‘core’ algorithm. Time and budget restraints did not allow any significant development in the present project. Instead, we have made use of the fact that each Subway zone corresponds to a parking zone and for each these the GUI provides a window through which parking policies (changes in supply and tariffs) can be set. The parking zones also include the Centre Zones and they can also have policies applied to them. It is thus possible to control supply and tariffs in both cases in relation to one another. Figure 8.1 shows the GUI input window for parking.

In addition to parking policies it also possible to influence the mode chaining process by applying policies which effect the Subway (fares and service levels) and non-parking policies to car (cordons, fuel costs). The mode chain model is of course integrated into the STM as a whole so that mode chain behaviour can be influenced, in theory, by the whole range of public transport policies (e.g. heavy rail fares).

The upper scroll down box (‘Urban Area’) in Figure 8.1, lists parking zones (Centre and Subway) from which a selection can be made. The fields below allow the user to set the changes in places and tariffs relative to the base.

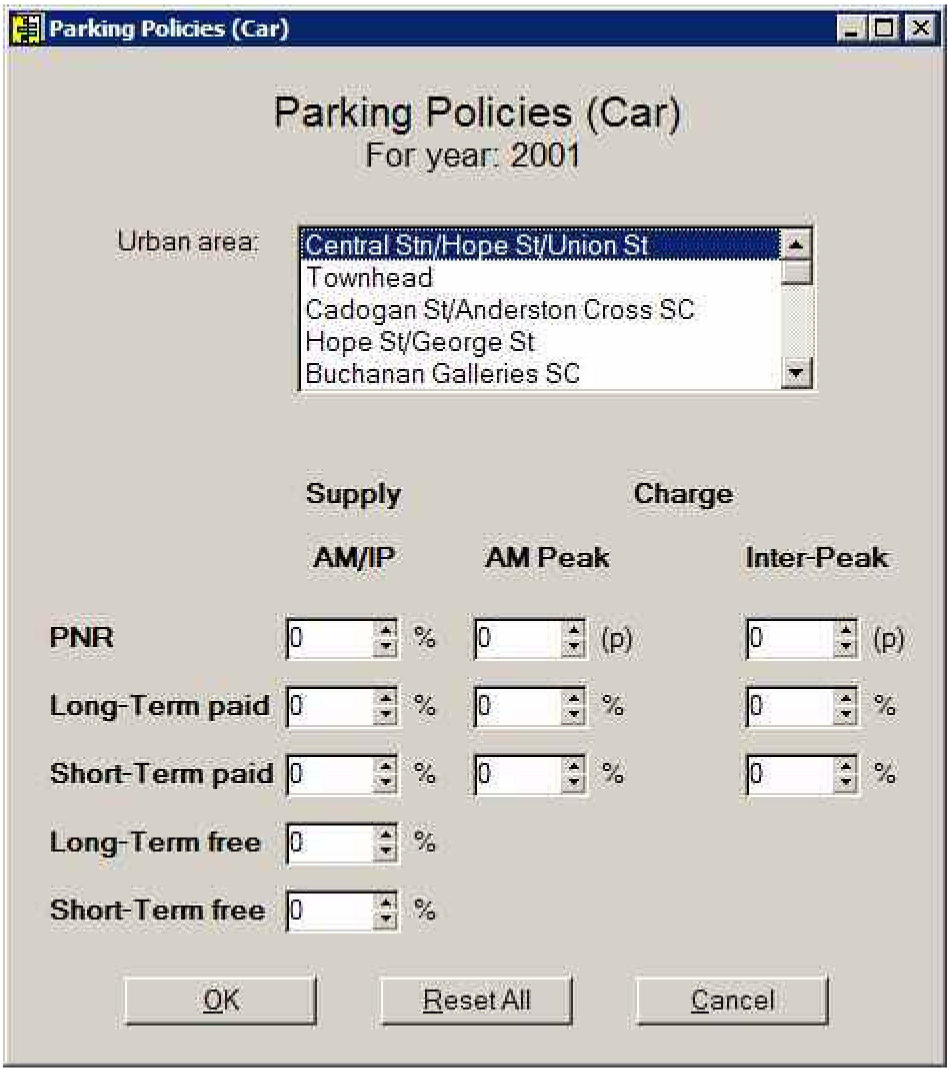

Figure 8.1: Parking policy input screen in the GUI.

At present we are limited to these features as the mode chain policies.

8.7 Mode chain model outputs

The Platform STM provides general outputs of the following types:

- Flows of person (by purpose, mode, etc) between zones.
- Travel times between zones.
- Parking levels in parking zones.
- Crowding information for public transport
- Vehicle emissions

The flows of person are conveniently analysed into trip attractions and trip starts i.e. the numbers of person trips destinating or starting in a zone or group of zones (called a region in STM-speak). These can be displayed on the map display of the STM GUI. Where large matrices are required (e.g. trip matrices) then these would be written to files.

The development of GUI facilities is fairly time consuming so we have not extended the GUI output windows to accommodate the mode chaining feature. The impacts of mode chaining on the above variables can however be displayed. The main outputs which show the operation of mode chain model are written in tabular form to files; this is much easier to implement than a GUI feature.

8.8 Example runs

8.8.1 Preliminary remarks

The following calculations make use of the STM platform described in Section 6. We have not endeavoured to produce a highly polished STM (given the time restraints) and so the results given here should be regarded as only illustrative. In order to assist interpretation of results we have also switched off the crowding mechanisms for public transport so that use of rail, underground and bus are not constrained by capacity.

The model has used a limited number of 'Central zones' to test the model – these were selected as been prominent centres of employment within the centre of Glasgow. The model can of course function with rather more Central Zones (but at the expense of longer run times). At present there is a wired in limit of 20 parking zones which limited the number of central zones once the Subways had been taken into account. We decided not to increase this number (it requires some reworking of the software) in favour of concentrating on model development and testing.

Because of the experimental nature of the model we have not attempted to model realistic policies as yet and have, for example, chosen car park sizes and locations for illustrative purposes only.

8.8.2 Base situation data

The model has been set up by defining the following inputs:

- Demographic/employment files for notional years. Because the aim is to demonstrate the model we have created artificial scenarios for population and jobs.
- Base parking data for the Subways and 'Central' zones plus Kilmarnock.

The base parking data are for the zones listed in Table 8.1 below.

Parking zone name	Zone	Type
Central Stn/Hope St/Union St	5	Central
Townhead	7	
Cadogan St/Anderston Cross SC	12	
Hope St/George St	13	
Buchanan Galleries SC	20	
Buchanan St Subway Stn	14	Subways
Cowcaddens Subway Stn	18	
St Georges Cross Subway Stn	49	
Kelvinbridge Subway Stn	47	
Hillhead Subway Stn	48	
Kelvinhall Subway Stn	59	
Partick Subway Stn	60	
Govan Subway Stn	38	
Ibrox Subway Stn	37	
Cessnock Subway Stn	36	
Kinning Park Subway Stn	40	
West St/Shields Rd Subway Stn	33	
Bridge St Subway Stn	28	
St Enoch Subway Stn	3	

Table 8.1 of Parking Zones and Zone numbers (see Figure 8.2b)

The basic data are for tariffs, spaces and utilisations. The parking model determines the spaces for by type from user input utilisations and the demand calculated within the model. The base subway spaces are specified by the user as well as utilisations (initial values). A Subway Base Demand algorithm determines the demand levels for each Subway such that the target occupancies are achieved given the spaces and the utilisations. A more general algorithm (applied to all parking zones) converts utilisation and demand levels to spaces. When Subways are being considered this algorithm receives the demand from the Subway Base Demand model and the utilisation. This generates (for the general parking model) the spaces originally input into Subway Base Demand model and allows Subway zones to be treated on the same footing as a general parking zone. It should be noted that in some cases the initial utilisation value has to be adjusted if the model generated demand level is insufficient to achieve the target.

The base am peak utilisations for pnr, long pay, short pay, long free, short free the ‘Central’ parking zones were as follows. The values were not based in data but are reasonable assumptions (typically close to 1.0).

Parking zone name	PNR	LP	SP	LF	SF
CentralStn/Hope St/Union St	0.8	0.8	0.86	x	1.0
Townhead	0.8	0.8	0.77	x	1.0
CadoganSt/Anderston Cross	0.81	0.81	1.0	x	1.0
Hope St/George St	0.8	0.8	1.0	x	1.0
Buchanan Galleries SC	0.8	0.8	0.7	x	1.0

x = not applicable

Table 8.2 of Central Parking Zones Utilisations (am peak)

The tariffs for long pay and short pay were assumed to 440p and 90p respectively. For the Subways, we have taken values of supply for Shields Rd / West St, Bridge St, and Kelvinbridge based on actual values. For all other subways (which do not have park-and-ride car parks) we have assumed, as a demonstration exercise, 200 places. The utilisations in the base are in the table below. We have treated Subway parking as if there are long pay and short pay to show the flexibility of the model. This assumes to categories of parking place – in practice places may be open to both short and long term parkers who simply pay the appropriate fee.

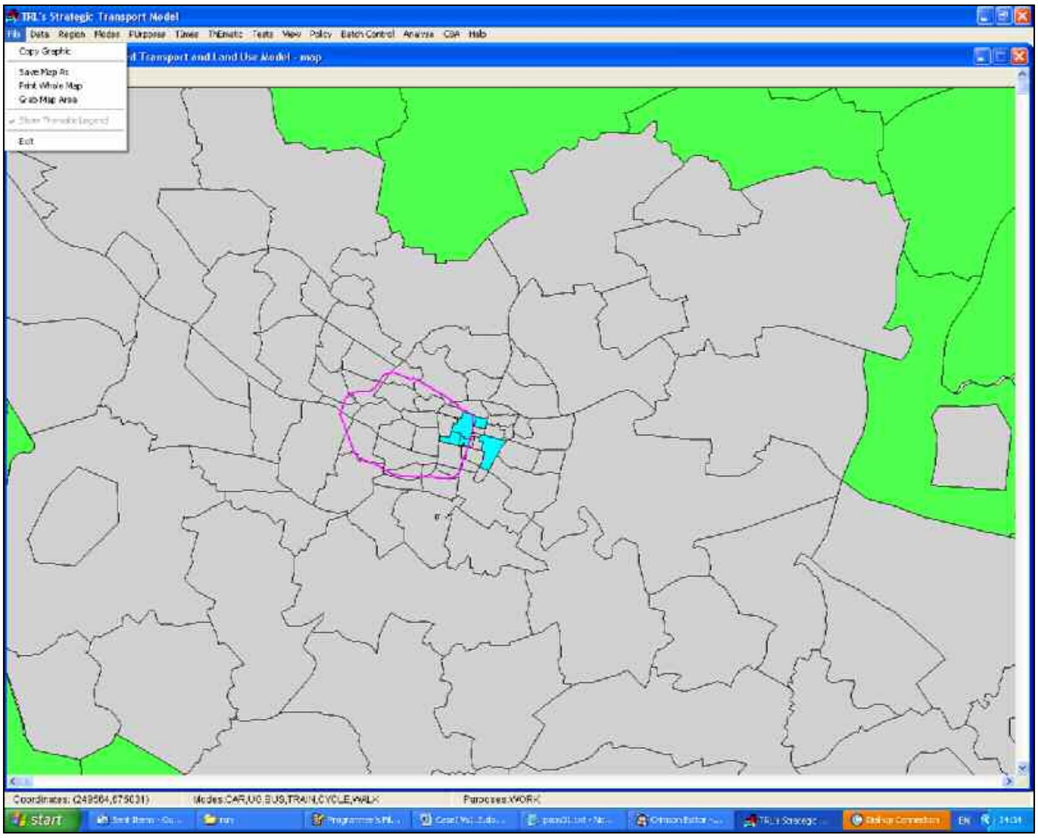

Figure 8.2a: STM map showing location of the 'Central Zones'. The Subway circuit is also shown.

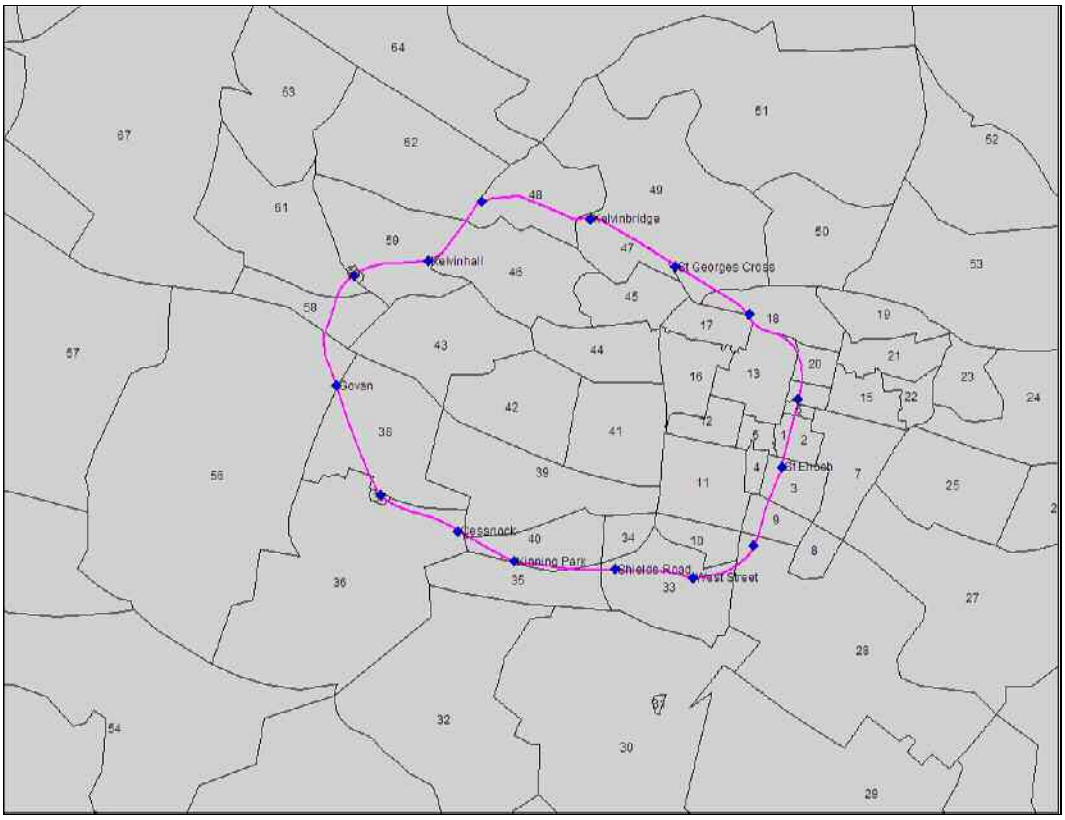

Figure 8.2b: Map of the central area of Glasgow showing the Subway system

Parking zone name	LP	SP
Buchanan St Subway Stn	0.8	0.8
Cowcaddens Subway Stn	0.8	0.8
St Georges Cross Subway Stn	0.8	0.8
Kelvinbridge Subway Stn	0.8	0.8
Hillhead Subway Stn	0.62	0.25
Kelvinhall Subway Stn	0.8	0.58
Partick Subway Stn	0.8	0.8
Govan Subway Stn	0.8	0.8
Ibrox Subway Stn	0.8	0.8
Cessnock Subway Stn	0.8	0.8
Kinning Park Subway Stn	0.8	0.8
West St/Shields Rd Subway Stn	0.73	0.8
Bridge St Subway Stn	0.80	0.8
St Enoch Subway Stn	0.80	0.8

Table 8.3 of Subway Parking Zones Utilisations (am peak)

These figures were generated by the algorithms starting from initial values. In the case of LP these have mainly been realised but SP are quite low. These figures are for demonstration purposes only and should not be treated as accurate.

The numbers of places that the model uses for Subways are as follows:

Parking zone name	LP	SP
Buchanan St Subway Stn	200	20
Cowcaddens Subway Stn	200	20
St Georges Cross Subway Stn	200	20
Kelvinbridge Subway Stn	100	20
Hillhead Subway Stn	200	20
Kelvinhall Subway Stn	200	20
Partick Subway Stn	200	20
Govan Subway Stn	200	20
Ibrox Subway Stn	200	20
Cessnock Subway Stn	200	20
Kinning Park Subway Stn	200	20
West St/Shields Rd Subway Stn	600	20
Bridge St Subway Stn	200	20
St Enoch Subway Stn	200	20

Table 8.4 of Subway Parking Zones Places

8.8.3 Scenario 1: Increase of jobs in Central Zones

The first test to be carried out was to demonstrate the functioning of the model in response to a change in demand. This was achieved by increasing the number of jobs in the four of the five central zones by 50%. The approximate figures for the numbers of jobs assumed in the model are given in the Table 8.5 below. The utilisations for the central zones are given in Table 8.7 for the Scenario (the ‘after’ case). These can be compared with Table 8.2 in Section 8.8.1. It can be seen that the PNR and LP has all filled but there has been little impact on short stay (commuters cannot park in short stay).

Parking zone name	Base	Scen 1
CentralStn/Hope St/Union St	2700	4000
Townhead	9300	14000
CadoganSt/Anderston Cross	7200	7200
Hope St/George St	17500	26000
Buchanan Galleries SC	2800	4200

Table 8.5 of jobs in the base and scenario 1

Table 8.6 shows car person trips (all purposes) and total work trips in the central zones arising from the base and scenario 1 situations. Work trips to the four zones with jobs increases have raised by about 50%. Increases in car trips are less; in three zones the rise in car trips is about 30%. In the ’Buchanan Galleries Zone’ the increase was somewhat less at about 15%. If the car person trip are divided by 1.25 this will give an estimate of the corresponding flow of cars.

Parking zone name	Base carpers	Scen 1 carpers	% diff	Base work	Scen 1 work	% diff
CentralStn/HopeSt/Union St	98	129	+32	324	484	+49
Townhead	561	729	+30	1864	2780	+49
CadoganSt/Anderston Cross	398	374	-6	1439	1433	0
Hope St/George St	1005	1345	+34	3500	5248	+50
Buchanan Galleries SC	214	247	+15	564	840	+49

Table 8.6 of car person trips (all purposes) and work trips (all modes) per hour in am peak

The outparkers for these (top of table downwards) were 61, 173, 0.0, 409 and 0.0 cars per hour.

Parking zone name	PNR	LP	SP	LF	SF
CentralStn/Hope St/Union St	1.0	1.0	0.89	x	1.0
Townhead	1.0	1.0	0.77	x	1.0
CadoganSt/Anderston Cross	1.0	1.0	0.99	x	1.0
Hope St/George St	1.0	1.0	1.0	x	1.0
Buchanan Galleries SC	1.0	1.0	0.7	x	1.0

x = not applicable

Table 8.7 of Predicted Central Parking Zones Utilisations (am peak) for Scenario 1

Parking zone name	Base			Scen 1		
	work	other	outpk	Work	other	outpk
Buchanan St	53	8.0	0.0	71	8.0	24
Cowcaddens	53	8.0	0.0	71	8.0	25
St Georges Cross	53	8.0	0.0	71	8.0	25
Kelvinbridge	27	8.0	0.0	35	8.0	5
Hillhead	42	2.6	0.0	55	2.6	0
Kelvinhall	53	6.0	0.0	68	6	4
Partick	53	8	0.0	68	8	7
Govan	53	8	0.0	68	8	7
Ibrox	53	8	0.0	68	8	7.5
Cessnock	53	8	0.0	67	8	7
Kinning Park Stn	53	8	0.0	68	8	6
WestSt/Shields Rd	146	8	0.0	181	8	0
Bridge St	27	8	0.0	35	8	5
St Enoch	53	8	0.0	69	8	19

Table 8.8 of Subway Car Flows (per hour) into car park by purpose in am peak

Table 8.8 shows the Subway park-and-ride flows in the base and in Scenario 1 resulting from the increases in jobs. The level of outparking is fairly high in Scenario 1. These would be assumed simply to have been absorbed within study area (possibly as illegal parkers) outside the designated car parks. The level of outparking is dependent on the penalty outparkers incur – this then pushes down the level of car travel. High figures for outparking may be indicative that the penalty needs to be increased (this can have undesirable effects if it s made tool large). Table 8.9 gives the corresponding utilisations, which show that most long pay car parking has saturated. Hillhead and West St /Shields Rd were below saturation (and hence no outparkers).

Parking zone name	LP(before)	LP(after)	SP(before)	SP(after)
Buchanan St Subway Stn	0.8	1.0	0.8	0.8
Cowcaddens Subway Stn	0.8	1.0	0.8	0.8
St Georges Cross Subway Stn	0.8	1.0	0.8	0.8
Kelvinbridge Subway Stn	0.8	1.0	0.8	0.8
Hillhead Subway Stn	0.62	0.87	0.25	0.25
Kelvinhall Subway Stn	0.8	1.0	0.58	0.58
Partick Subway Stn	0.8	1.0	0.8	0.8
Govan Subway Stn	0.8	1.0	0.8	0.8
Ibrox Subway Stn	0.8	1.0	0.8	0.8
Cessnock Subway Stn	0.8	1.0	0.8	0.81
Kinning Park Subway Stn	0.8	1.0	0.8	0.8
West St/Shields Rd Subway Stn	0.73	0.94	0.8	0.82
Bridge St Subway Stn	0.80	1.0	0.8	0.8
St Enoch Subway Stn	0.80	1.0	0.8	0.8

Table 8.9 of Subway Parking Zones Utilisations (am peak)

Figure 8.3 shows the overall percentage increase in trip ends for different mode between the base and Scenario 1 (nominally 2015) in the am peak. The value for the subway (underground) has increased by 16%. This figure is the approximate overall increase for entire Subway (the figures are for outward trips – a small proportion of return trips could be added). Figure 8.4 shows as a blue shaded area the definition of the 'catchment' for subway as employed in Figure 8.3.

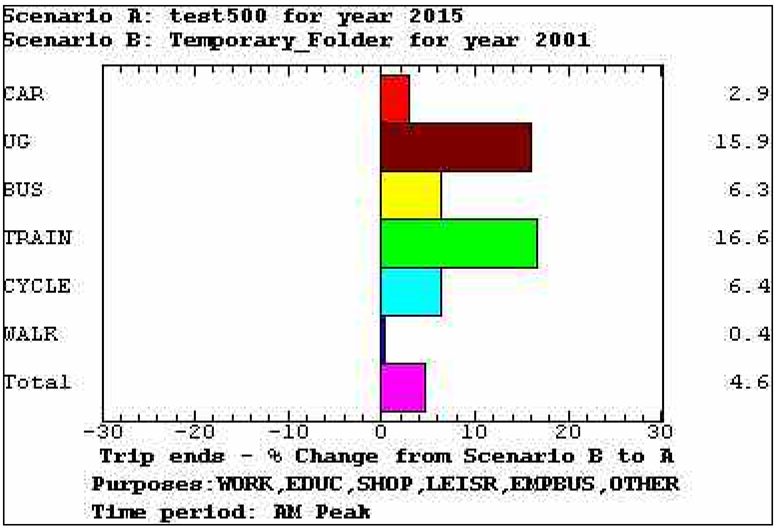

Figure 8.3: Increases in modes within the Subway Catchment Region

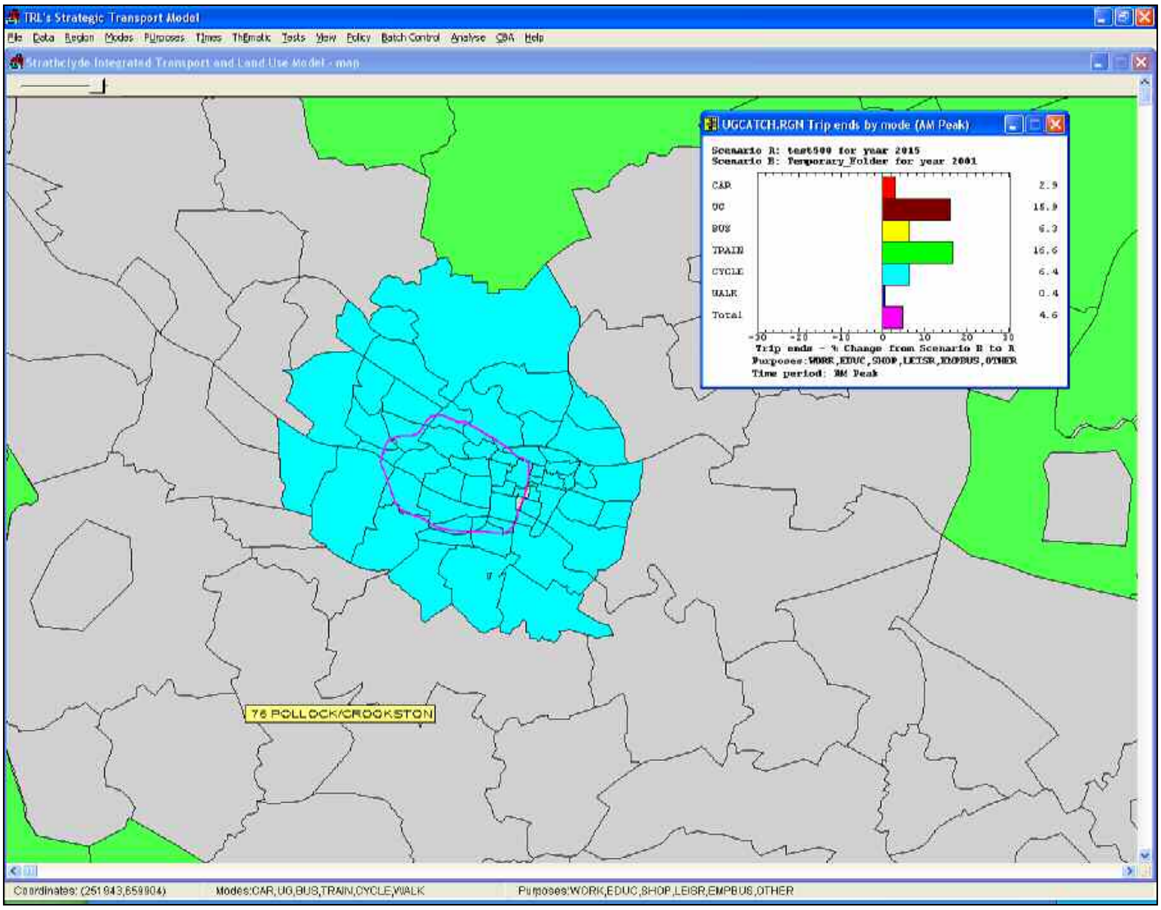

Figure 8.4: Subway Catchment Region

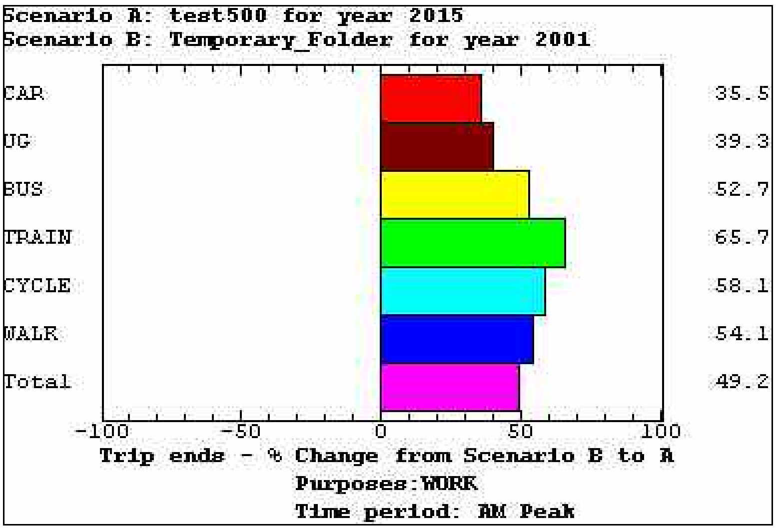

Figure 8.5: Relative Changes in trip ends (work purposes only) in am peak to Central Zones with 50% jobs increase.

In Figure 8.5 we show the increase in work trip ends across all modes to the Central zones to which the jobs increase was applied. It is evident that some switching to heavy rail and slow modes has taken place. Subway use has also increased by about 39% for travel to these zones.

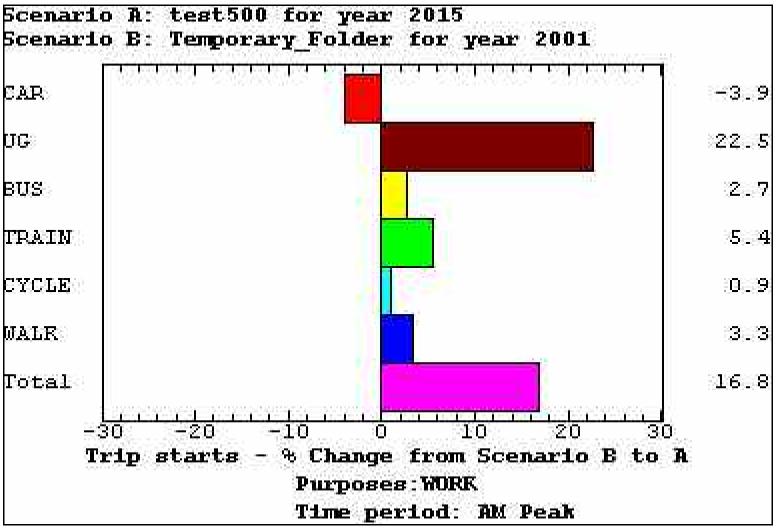

Figure 8.6: work trip starts from the West St/Shields Rd Subway zone – the increase in underground is mainly due the increase commute to the 'Central zones'.

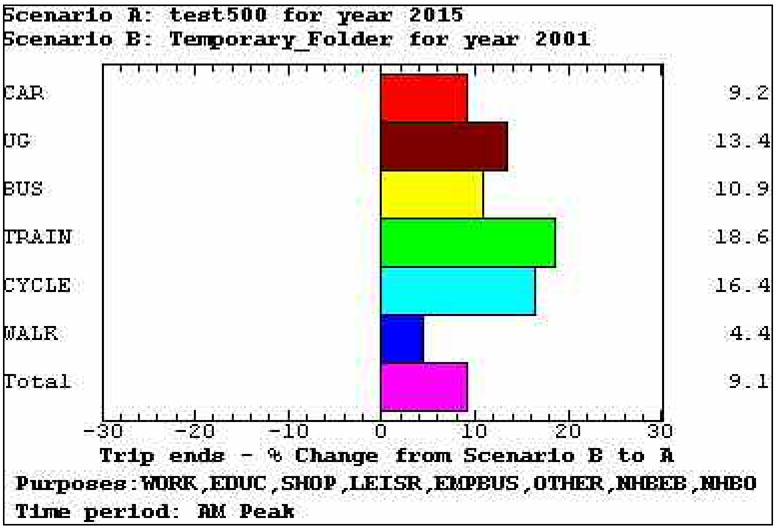

Figure 8.7: Percentage change in trip ends (all purposes) to West St/Shields Rd zone showing increase in car trips (by about 9%).

Figure 8.6 and 8.7 shows the Percentage change in trip starts and trip ends (all purposes) to West St/Shields Rd zone showing increase in underground from the zone and car trips to the zone (by about 9%) for the zone as a whole. This is due mainly to attracted park-and-ride users at the Subway stations.

8.8.4 Scenario 2: Increase in tariffs at the Subway stations

In the base the tariffs on the long pay places have been set to 100p. In this scenario we have increased the tariffs by 300% (i.e. to 400p). Tariffs in the Central Zones have been held fixed. The calculation is otherwise identical to 2001 base run. In following we limit ourselves to summary results.

Parking zone name	LP(before)	LP(after)
Buchanan St Subway Stn	0.8	0.66
Cowcaddens Subway Stn	0.8	0.66
St Georges Cross Subway Stn	0.8	0.66
Kelvinbridge Subway Stn	0.8	0.66
Hillhead Subway Stn	0.62	0.41
Kelvinhall Subway Stn	0.8	0.57
Partick Subway Stn	0.8	0.58
Govan Subway Stn	0.8	0.59
Ibrox Subway Stn	0.8	0.59
Cessnock Subway Stn	0.8	0.54
Kinning Park Subway Stn	0.8	0.57
West St/Shields Rd Subway Stn	0.73	0.42
Bridge St Subway Stn	0.80	0.56
St Enoch Subway Stn	0.80	0.64

Table 8.10 of Subway Parking Zones Utilisations (am peak)

Table 8.10 shows that occupancy of the Subways is reduced by a factor of 0.57-0.83 (mid value 0.70). Figures 8.8 and 8.9 illustrate the impact on Subway trips from the increase in tariff for Shields Rd.

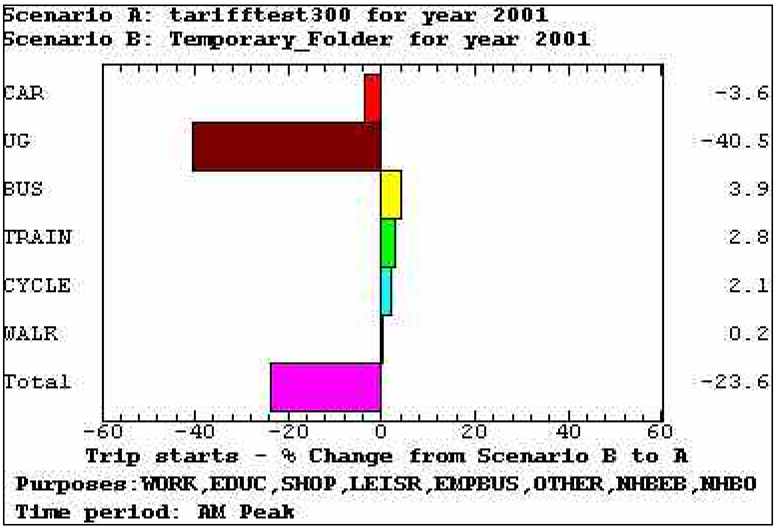

Figure 8.8: Trips starts from West St/Shields Rd showing reduction in Subway.

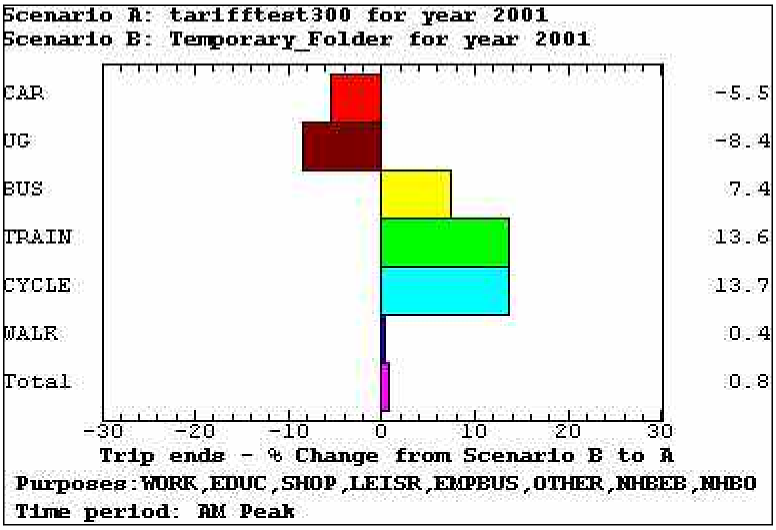

Figure 8.9: Trip ends to the Subway Catchment area showing the overall reduction in trip levels for the Subway system.

At present there are a number of calibration and 'side effect' issues to be investigated when tariff charge policies are applied. The results should therefore be seen only as illustrative.

9 Conclusions and Summary

The case study has succeeded in creating a mode chain model within a Strathclyde STM based on park-and-ride from stations of the Subway system. The model was developed in response to SPT interest in such a model for testing park-and-ride related policies in the centre of the Glasgow conurbation.

The development of this model required considerable work on the platform model. In order to more faithfully represent the spatial detail of the Subway system and its stations and the centre of Glasgow it was necessary to expand the zonal system from 173 zones to 233 zones (most of the new zones obtained by splitting central zones in Glasgow- the split zones being based on those in the 1000 zone SITM4 network model). This work required reconstructing the base trip and cost matrices for the new zonal system. The work also required a fair amount of routine recoding to allow the STM to easily handle the larger number of zones.

The park-and-ride model can be summarised by the following points (critical observations are italicised):

- Zones were identified with Subway stations – in most cases each Subway station had its own zone (Shields Rd and West St were the exception and were treated as a composite).
- In some cases zones containing the Subway stations were also rather too large. This is not desirable and in a future model each station should be represented by its own 'micro zone'
- Each Subway zone (as defined above) was formally designated as a 'parking zone', i.e. as an STM in which parking supply and demand would be modelled using the standard STM parking model. For such zones parking supply and demand would refer only to the Subway – all other parking would be treated more simply as a tariff (ignoring capacity effects). The use of STM parking zones in this way has the advantage that the policy input and results output features of STM could be applied directly to the Subway stations.
- This is not ideal and requires a careful integration of park-and-ride parkers and other parkers or the use of micro zones.
- Park-and-ride at Subway stations was in competition with zones in the Centre of Glasgow. There was also an overall competition with alternative modes (public transport and slow modes).
- The model allows changes in policies in which parking tariffs can be adjusted and parking capacities changed. Long and short pay parking is allowed.
- The system of tariffs can be more complicated in practice (e.g. fare including parking , the use of multijourney tickets etc). More attention might be paid to this.
- The model uses an overflow mechanism whereby cars unable to park in one zone can be accommodated in designated nearby zones. In the present model Subway parkers are allowed, by this mechanism, to overflow into other Subway car parks

and, quite separately, parkers travelling to the centre overflow to other central zones.

- There is no or little data on the patterns of travel to the Subway stations by current park-and-riders. To circumvent this problem the model was designed to synthesise a base pattern of car travel to Subway stations and constrain thru total base usage of the car parks to target utilisation values.

- A current weakness of the model is its inability to model new Subway car parks or the effect on demand when there are capacity increase ceteris paribus. Some attempts were made to do this using a 'capacity increase' model (Section 8.5.3) but were unsatisfactory. An approach using non-incremental demand models may be necessary here – but more thought on this is required.

- In spite of the last comment it is possible to estimate the impact of new Subway car parks provided an assumption is made about a hypothetical base utilisation. The model could then be run using the base synthesis technique to introduce new Subway car parks and then updated to a forecast year. The outputs could then be compared with a corresponding run without the new car parks. This could be used to explore the likely impact of Subway based park-and-ride strategy.

The model has been used to provide some demonstration runs (Section 8.8) based on a hypothetical base case (the main feature is that we have allowed all Subway stations to have parking spaces; see Section 8.8.2). In the first run, demand for travel into certain central zones was raised by increasing the number of jobs in those by 50%. This allowed the capacity restraints of the model to be studied. In a second run, a change in the Subway parking tariffs by 300% ((£1.00 to £4.00) was used to study the cost sensitivity of the model. In both cases it was possible to obtain changes in demand for the individual Subway zones and for the Subway system as a whole.

10 References

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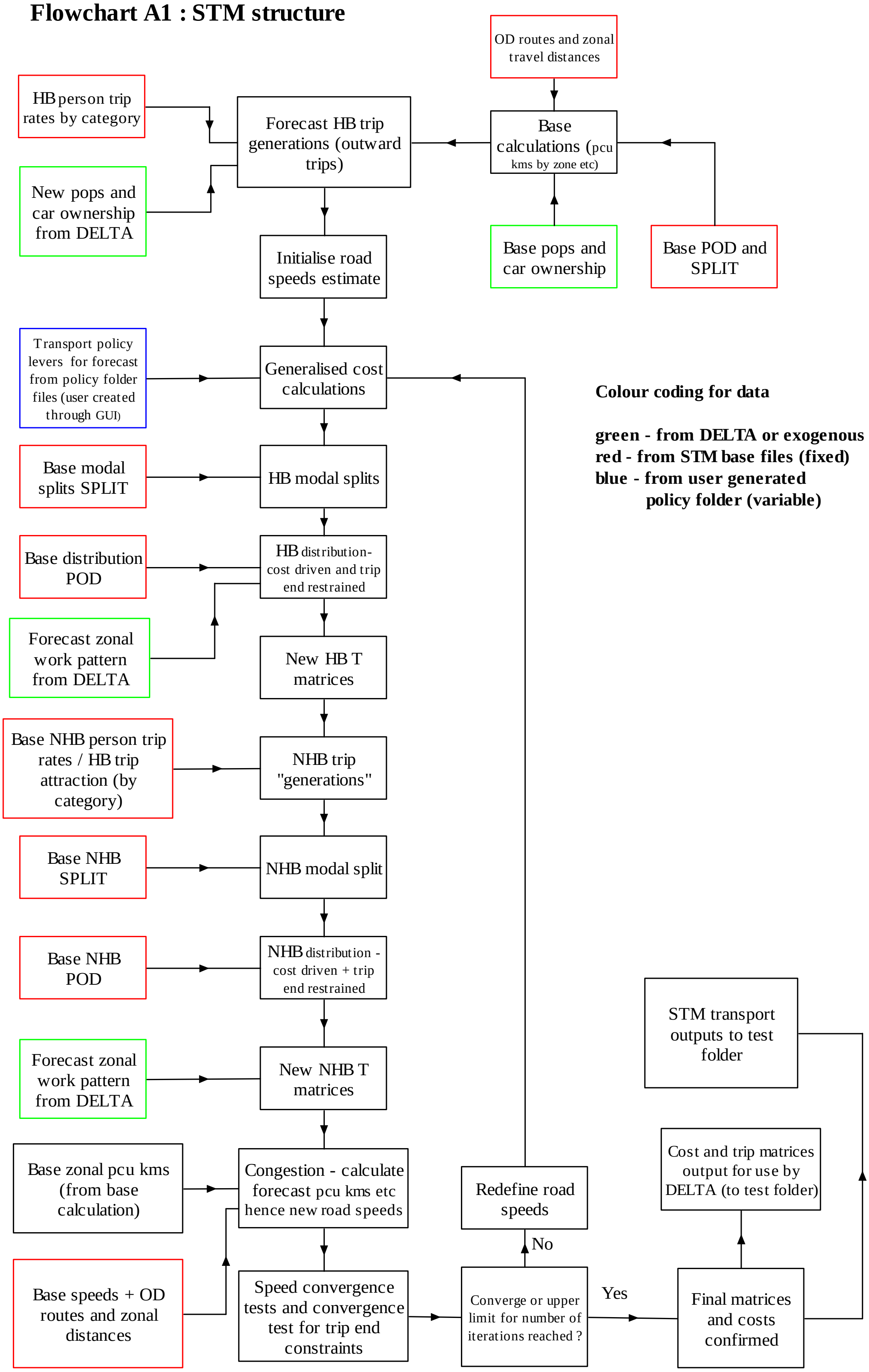
Appendix A: Model Flowcharts

Flowchart A1 : STM structure



Flowchart A2: Park and Ride model structure