TANDEM 3

Final Report

GLA Economics
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TANDEM 3

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1. Overview of TANDEM

1.1 Philosophy and Aim

1.1.1 It is important that policy makers understand the wider impacts of the transport changes they introduce. This is no simple task.

1.1.2 In developing the TANDEM model our aim has been threefold:

1. To think about the relationship between transport changes and the economy over the long term
2. To create a framework that is as simple to understand as possible
3. To be transparent about the inputs and assumptions which have been used and open to exploring their impact

1.1.3 This report describes the latest version of the TANDEM model in detail, discusses the issues raised during data collection and presents some preliminary outputs. One of the key lessons from the report is the importance of developing our understanding of how crowding is likely to impact upon economic growth in London.

1.1.4 Appendices following the main report give more technical details of the model, details of the sources used for the inputs, the elasticities, and some further results.

1.2 Building on TANDEM 2005

1.2.1 In October 2005 the first version of TANDEM was produced along with the report 'Investigating the Potential Impact of Transport Changes on the London Economy'. Since then we have been keen to improve upon the modelling we used. For this reason several substantial changes have been made including:

1. Increased number of zones modelled
2. The source of the elasticities
3. The addition of agglomeration bonuses in central London
4. The addition of crowding penalties in central London
5. The addition of exogenous employment growth

1.2.2 The main dynamic of the model and philosophy surrounding it remains unchanged.

2. Modelling Framework

2.1 The Simple Model

2.1.1 To start the investigation we proposed the following relationships between the demand for trips, generalised costs of trips and the levels of business and employment growth. This is illustrated in Figure 2.1.

2.1.2 Generalised cost is a measure of the total cost of a trip for the passenger. It includes monetary costs reflecting fares, parking costs and petrol costs, and time costs valuing the length of the journey, crowding on the route, and penalties for infrequent or unreliable routes. Economic output is measured in RGVA (Real Gross Value Added).

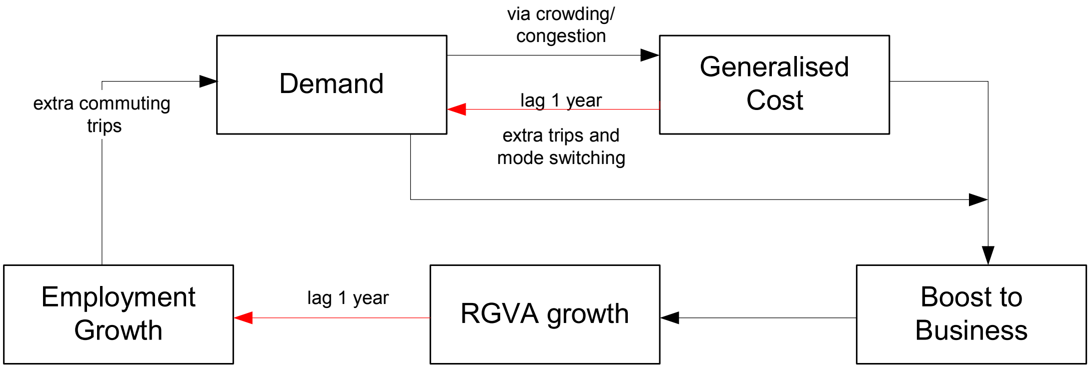


Figure 2.1: The Simple Model

2.1.3 The top two boxes - demand and generalised cost, both depend on each other. As the number of people travelling increases, the crowding and congestion within the system increase. This increases the generalised cost of trips made. As the generalised cost increases less people are willing to travel by that mode, and people either stop making the journey or change onto a different mode of transport, changing the level of demand. The full effects of this change take time to occur, since people are generally slow to change habits.

2.1.4 While these links have been widely explored in transport models, the lower loop in the diagram, which links through to employment, is more experimental. Firstly, the benefit to travellers of a change in generalised cost is calculated. This is given by:

Boost = previous passengers x absolute change in generalised cost

+

0.5 x new passengers x absolute change in generalised cost

2.1.5 The benefit reflects the surplus/loss to consumers based on their willingness to pay. This method of valuing the welfare effects of a price change is a standard technique in economics.

2.1.6 Secondly, we assume a proportion of this benefit/loss is absorbed by businesses. The 'Boost' referred to in the equation above is multiplied by the relevant proportion to give the 'Boost to Business'.

2.1.7 This boost contributes to output growth in the period and, after a year, to additional employment growth. This follows the strong link between the amount of cash in an employer's pocket and the number of people they wish to employ. Employment growth is then linked back up to the top box as it causes a growth in commuting trips, which completes the circle.

The Simple Model – Commuters

2.1.8 For commuting trips we need to add a few more links between the boxes to count up the full impacts on employment and RGVA.

2.1.9 The lower loop via the boost and output growth is unchanged from the simple model and captures the 'demand side' of the employment changes. Here employers use the cash they have saved to increase the number of employees they hire.

2.1.10 The additional part of the commuting model links the change in demand from generalised cost changes, in the top of the diagram, to additional employment and RGVA. This link reflects a 'supply side' effect as employees decide whether they are willing to travel or not.

2.1.11 The relationship between generalised cost and demand therefore affects employment levels in two distinct ways and both need to be counted. So when generalised cost changes commuting demand, we correspondingly expect changes in employment and RGVA.

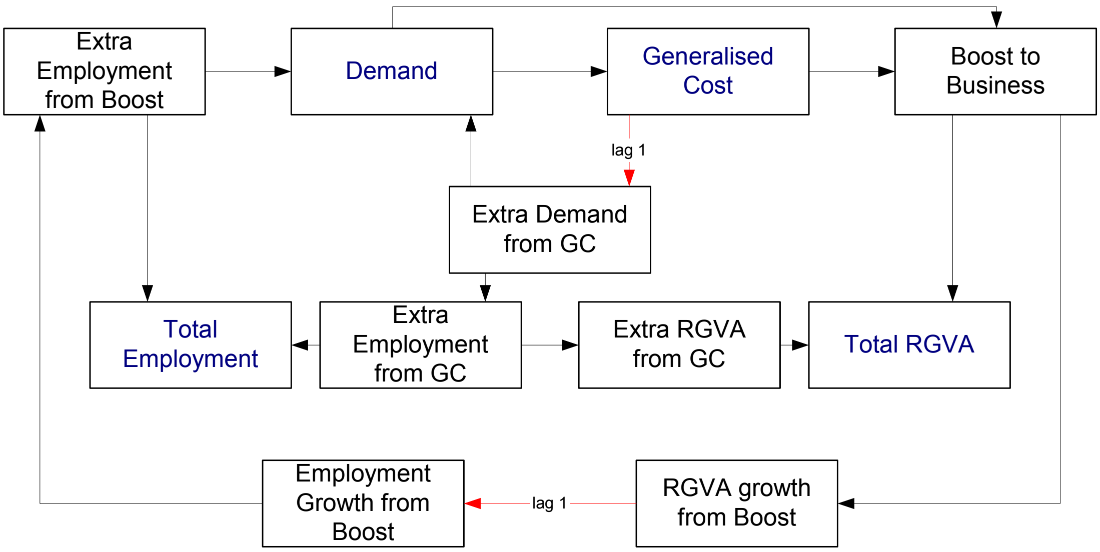


Figure 2.2: The Simple Model for Commuters

Exogenous Employment Growth

2.1.12 Employment in London is currently growing strongly. GLA forecasts expect 900,000 new jobs by 2026. This represents a growth of 20% overall and as high as 43% in Inner North East London. In order to build this growth in to the model we also add annual exogenous employment increases. These are accompanied by both increases in demand and increases in total RGVA. Demand increases for all journey purposes, commuting, other and business, since workers don't only commute and are often accompanied by families who travel to school or elsewhere.

Stability Conditions

2.1.13 Since the model is simple it is possible to analyse the conditions required for stable, and realistic, solutions. It is also possible to find which assumptions are key for driving the results.

2.1.14 We can expect that the boost to business from any transport change will never be a large proportion of total output since average earnings are much higher than average transport costs.

2.1.15 The critical links in the models are therefore those between demand and generalised cost which are represented as elasticities (ie the proportion by which demand changes with regard to a proportionate change in generalised cost and vice-versa). For these to be stable we need the product of the two elasticities to be between –1 and 0. In real terms, if the total number of people travelling jumps causing a rise in crowding levels then the number of people who stop travelling as a result must be less than the size of the initial jump.

2.1.16 For example if this condition were violated for buses this would lead to people flocking to the buses only to be put off by crowding and leave. The sight of the empty buses would then attract more people back than had originally left which would then cause an even greater crowding problem than existed previously. This process would continue getting more and more extreme which is unrealistic.

2.1.17 This then is a reflection of what happens in the real world and not an artificial construction of the model.

2.1.18 The additional commuting link from generalised cost directly to employment ends in the total employment and total RGVA boxes, as shown in figure 2.2. These convert between percentage growths and absolute growths but do not directly drive any changes. Therefore these should not cause instability.

High Density Considerations: Key Concerns In Central London

2.1.19 In many ways Central London is a special case. Employment density, productivity, and the enormous number of people transported every day are substantially higher here than elsewhere in Britain. Work that has sought to develop relationships between, say, employment density and accessibility has found evidence of significant non-linearity in the relationships.

2.1.20 We have therefore considered:

1. How the cost of crowding will rise in Central London
2. How productivity will respond to increased demand

High Density Considerations 1: Extreme Crowding

2.1.21 The scenarios we present below assess the impact of plans for London covering the next 25 years. In this time a major challenge is to ensure that the transport system is able to cope with the numbers of additional people who wish to travel into central London.

2.1.22 The elasticities that have been derived from the transport models LTS and SPAM imply that the costs due to overcrowding rise much more slowly than we would expect. This seems to be because the models:

1. Reflect people's response to crowding over the short term instead of the long term (in the short term people have to find another mode/route or put up with the crowding).
2. Are not capturing the non-linearity of costs as crowding stops being a nuisance and becomes a physical constraint.

2.1.23 Underestimating the costs of overcrowding is likely to lead to underinvestment in transport services in London, with large consequences for the economic and social welfare of the city's residents. It is therefore very important that further work looks into evidence for the likely response of Londoners to further increases in congestion and crowding.

2.1.24 In order to test what happens if costs do rise non-linearly, we have explored the impacts of adding an additional 'crowding penalty' for trips into central London. This is based on work undertaken by OEF which showed the costs to passengers as the demand for the transport system reaches, and exceeds, recommended capacity levels. We applied the OEF crowding factor to the generalised cost for the part of the journey which is likely to be in crowded conditions.

2.1.25 This has the impact of rapidly increasing costs as demand reaches capacity and therefore preventing demand from achieving unobtainable levels.

High Density Considerations 2: Agglomeration

2.1.26 There is strong evidence for the link between employment density and productivity. As density increases companies are able to work with more suppliers and customers, and are likely to benefit from improved labour markets causing their output to improve. In order to include the added output-per-head impact of facilitating more employment in central areas we have included an agglomeration elasticity of output per head with respect to employment.

2.1.27 This elasticity is only applied in Central London since this area benefits the most from agglomeration, due to its already high levels of employment.

2.2 The Big Picture – Pulling everyone together

2.2.1 There are a number of dimensions in which transport activity happens. What particular trips are people making? What mode of transport do they use? What is the purpose of the journey? While the types of journeys and reasons for travelling may be very distinct the travellers will interact with each other in a number of ways.

2.2.2 In order to think through the combined dynamic of transport in London, it is useful to think of a set of simple models running in parallel to each other. These models interact in 4 ways:

1. People can change mode
2. People making journeys for different purposes cause crowding for each other

3. The economic impacts to a zone depends on the impacts to all the people who travel to that zone, likewise new employment in a zone will impact on the number of trips made to it.
4. People making trips from different origins to different destinations can still end up causing crowding to one another.

2.2.3 For simplification in this work, we've only taken this into account for radial routes in to central London, where we can be very sure of the route people use and where crowding is currently a critical issue. For these trips passengers notice the total demand change on their route, rather than just the demand change of people making the same origin-destination journey.

2.2.4 Note that if the stability condition holds for a single model it will also hold when we take into account all of the different dimensions.

2.2.5 A technical description of the relationships in the model is supplied in Appendix B.

3. Model Inputs & Outputs

3.1.1 The most difficult step towards creating this model of London's economy and transport has been in collecting data on the appropriate elasticities to use. There are no agreed sets of elasticities for how people will change their behaviour following demand or cost changes. The main source of elasticities has been those implied by other transport models. In fact an important use for TANDEM has been as a tool for thinking through the implications of those elasticities.

3.1.2 Representing the link between demand and generalised cost as elasticities is, of course, a simplification. It does, however, have the benefit of allowing greater transparency to the results from the model. We calculated the changes in demand and generalised cost for each of the scenarios and then found our elasticities: the change in demand for each percentage change in generalised cost; and the change in time costs following percentage change in demand.

3.1.3 Further development is necessary to improve our estimation of the elasticities and we are keen to invite further discussion over the values and sources used in this work. The elasticities used are presented in Appendix E.

3.2 Elasticities – criteria and supplied data

3.2.1 The criteria for believable sets of elasticities are twofold:

1. The product of elasticities between demand and generalised cost and back again must be between -1 and 0 to ensure that the results don't spiral out of control
2. The product must be high enough to reflect long term responses to changes in the transport system.

3.2.2 Short term and long term responses to changes will be necessarily very different to each other. For the future of London's economy the key response will be that of commuters to continued (over)crowding. While commuters may be prepared to squeeze onto packed tubes in the short term, over years their choices of where to live and work are likely to be heavily influenced by their daily experience. Future migrants to the city are likely to have more hesitations and current workers are more likely to move away earlier. London Plan employment projections forecast a 21% increase in central London employment by 2026. Is this obtainable on the current transport network?

3.2.3 In the first version of TANDEM we used elasticities derived from SPAM (Strategic Policy Analysis Model). These elasticities were not usable in their entirety because they violated both the criteria in different places. We therefore used them as a guide while we estimated a complete and workable set.

3.2.4 For this version of TANDEM an expanded set of elasticities was required, to match the new 13 zones. After discussion with TfL we were provided with elasticities derived from the LTS transport model. This model is the largest policy model in use in London.

3.2.5 This is not an ideal source for elasticities since these models have a different focus than TANDEM. Firstly the elasticities reflect short-term choices and not long-term lifestyle changes. Secondly they assume that demand is more or less fixed so that people or firms will not simply relocate.

3.2.6 There were also some issues with the results provided to us. Our first issue was with matching between the modes and purposes provided and those used in our model. LTS holds a number of public transport trips and allows these to be multi-modal using both bus and train routes to complete a journey. Such a methodology would not be applicable in our simplified elasticity based model. It is not however clear how to translate between the results provided and inputs for our rail and bus journeys. On the purposes front we were only provided with results for work and business trips.

3.2.7 The bigger problems we encountered were with the results themselves however. These were raised with the LTS modellers and we understand that further analysis is being undertaken to understand these issues better. Roughly these issues include very large and very small elasticities and positive instead of negative elasticities for demand change with respect to generalised cost.

3.2.8 One of the main issues we understand is that LTS has a ‘redistribution’ function which is more sensitive than its mode choice function. One implication is that if you increase, say, fuel costs significantly then because people on long trips are likely to stop travelling, people are more likely to make short local road based trips on the now emptier roads. Effectively this means that the elasticities supplied to us are cross-elasticities for the different geographical areas and modes, and therefore would not show the own-price change for a particular cell following a change there.

3.2.9 This does not appear to be the only issue with the results supplied however. The magnitude of some of the elasticities is somewhat surprising. For example, for commuting trips by car the elasticities for demand with respect to generalised cost ranges between 1.24 and -20.33 for work. This implies that the percentage change in demand for every 10% increase in generalised cost varies between a 12.4% increase and 203% decrease in car trips!

3.3 Elasticities – estimated values

3.3.1 The set of elasticities for which we present results below has been guided by the LTS results where possible. The elasticity of generalised cost with respect to demand uses weighted averages of LTS results for the car mode. For other modes we used the same values as used previously. These previous elasticities were estimated using results from SPAM as a guide.

3.3.2 For elasticities for demand with respect to generalised cost we estimated values across the board in order to maintain the stability condition. The scale of the results was chosen to match the LTS values where possible.

3.3.3 We have tried to keep the pattern as simple and straightforward as possible. As discussed above we are keen to develop the elasticities used.

3.4 Redistribution factors

3.4.1 The other key inputs for the model that need to be estimated are the redistribution factors. Once the elasticities identify the number of people who want to change their journey in response to a cost change these factors show what proportion switch to each of the other modes and what proportion drop out entirely.

3.4.2 We have estimated values for the drop out rates and then derived the switch to other modes using current demand patterns. To do this we assume that current patterns are the best indication of the options available to people, and that if someone was switching from one mode the probability of choosing each of the other modes would be reflected in their current mode share.

3.4.3 An example of this follows. For a given trip we may have base data that of commuting trips 25% go by car, 25% bus and 50% rail. Say the dropout rate for rail trips is 40% and we know that 10 people switch away from rail. In this case 4 drop out and the remainder are split between car and bus according to the proportions (25% to 25%) so 3 to each of car and bus.

3.4.4 Small adjustments were made to the mode switch factors for central to central trips to add in the possibility of business trips going by bus. We also used the demand pattern for commute trips to derive mode shift likely for 'other' travellers.

3.4.5 Clearly this method is limited since it does not consider the state of each of the modes of transport at the time the decision is made, however it does offer some transparency over the implications of each change.

3.4.6 It should also be noted that the redistribution factors also work in reverse. That is when costs on a mode of transport fall, a number of people who would want to move onto the mode are calculated from elasticities and then the sources of where they are drawn from, either new trips or other modes, are found with the factors.

3.5 Outputs

3.5.1 We have considered results for three scenarios. For each we have employment growth following London Plan projections. In addition there are changes to the transport network of:

- Scenario 1: 15% deterioration of rail and tube services
- Scenario 2: Road pricing across London (priced by distance with higher prices centrally)
- Scenario 3: Package of rail improvements – PPP (2009), National Rail upgrades (2016) and Crossrail 1(2020) and 2 (2023).

3.5.2 The first key result output from the model is the level of London employment achieved between 2001 and 2026. This is shown for each scenario in Figure 3.1.

3.5.3 In Scenario 1, projected employment for 2026 falls 5% below the London Plan figure. This suggests that there is a significant impact on what employment level can be achieved due to the congestion in the network.

3.5.4 Only a slightly higher level of employment is achieved by 2026 in scenario 2, but the distribution of employment loss is weighted to more outer areas where car trips are more prevalent. The results reflect the increased options for switching to rail in the inner zones.

3.5.5 The results for Scenario 3 suggest that with the major schemes implemented employment narrowly overtakes the London Plan projection. This reflects the boost to employment levels from the significant transport improvements.

3.5.6 The disaggregation by zone shows that the missed employment opportunities are not likely to be spread evenly across zones. Part of the reason for this is the differing dependence of each area on available modes. Central London depends more on rail transport, while outer depends more on car trips, and bus supports mainly short journeys, and this is seen in bigger losses in central where rail is constrained, and in outer where car costs increase.

	2001	2026				% change 2001 to 2026			
		Forecast	Scen 1	Scen 2	Scen 3	Forecast	Scen 1	Scen 2	Scen 3
Central	1,321	1,598	1,462	1,512	1,610	21%	11%	14%	22%
Inner NE	484	692	661	686	700	43%	37%	42%	45%
Inner NW	426	592	572	589	598	39%	34%	38%	40%
Inner SE	233	291	289	293	296	25%	24%	26%	27%
Inner SW	133	184	182	185	187	38%	37%	39%	41%
Outer NE	406	420	419	415	422	3%	3%	2%	4%
Outer NW	883	970	960	956	970	10%	9%	8%	10%
Outer SE	426	438	435	431	439	3%	2%	1%	3%
Outer SW	235	264	268	267	271	13%	14%	14%	15%
Total	**4,547**	**5,450**	**5,247**	**5,334**	**5,494**	**20%**	**15%**	**17%**	**21%**

Figure 3.1: Employment by zone

3.5.7 Figure 3.2 presents the central area employment by year for each scenario. Here we can see how the employment changes feed through the years with changes taking some time to work through the system. Peaks in the Scenario 3 results are tied to the years when transport upgrades take place.

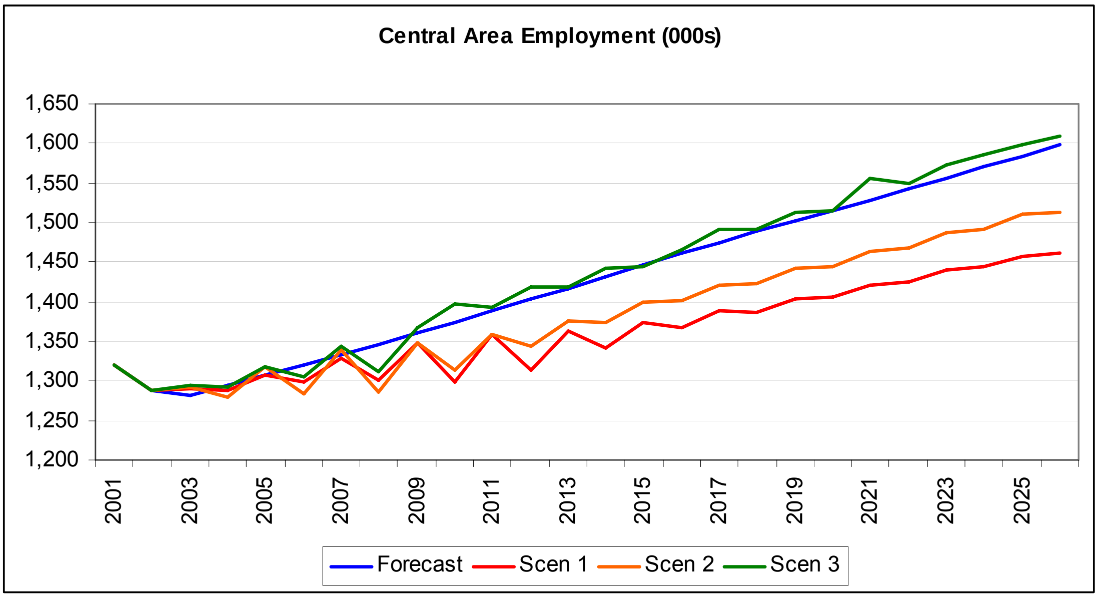


Figure 3.2: Central London Employment by Year

3.5.8 The following discounted RGVA figures give the difference between obtaining the forecast growth with no additional costs to passengers with the modelled constrained employment and higher cost scenarios. The overall difference in RGVA between Scenarios 1 and 3 - of roughly £70bn over a 25-year period is very large. It should be noted that the discounted value presented here only values the RGVA loss for years 2001 to 2026, and not for 60 years as is often the case in appraisals.

	Scen 1	Scen 2	Scen 3
Central	-40,814	-26,155	6,038
Inner NE	-8,506	-3,466	1,357
Inner NW	-5,001	-2,015	819
Inner SE	-1,580	-1,201	17
Inner SW	-931	-636	42
Outer NE	-834	-2,461	6
Outer NW	-1,988	-5,067	206
Outer SE	-814	-2,352	30
Outer SW	-731	-1,640	88
Total	-61,199	-44,992	8,272

Figure 3.3: Difference in RGVA due to transport changes (present value, 25 years)

3.5.9 These total employment and RGVA numbers mask much of the detail of what is happening to the transport demand which maintains those jobs.

3.5.10 Figure 3.4 first shows how total demand for different types of trips changes by the end of the period. For Scenario 1 the deterioration of rail service results in much higher car and bus use. Such a large increase in road use may be very optimistic. For Scenario 2, car use is cut with demand moving mainly to rail but also bus. The rail investment in Scenario 3 sees rail transport accounting for more trips than cars across London and also reduces the increase in bus trips.

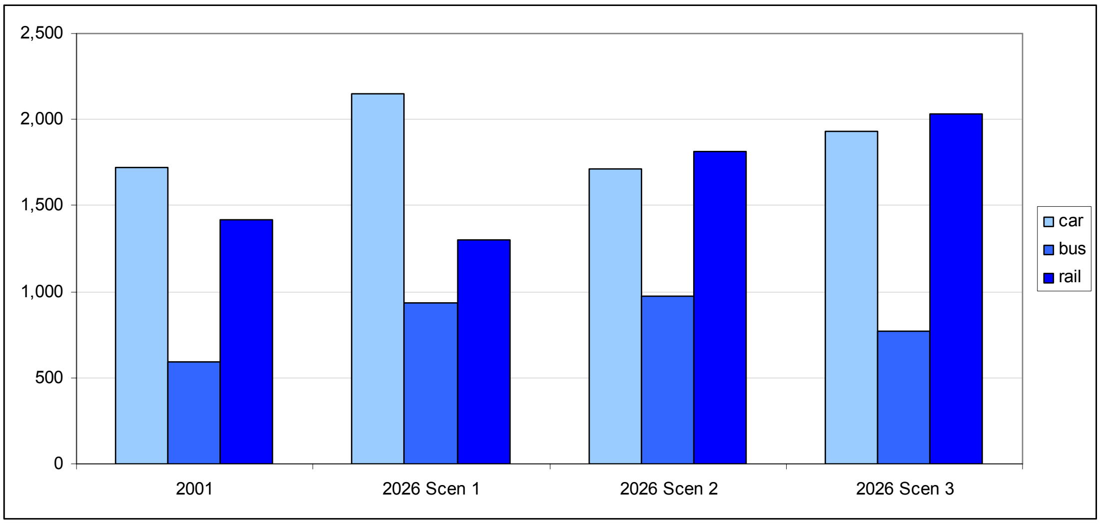


Figure 3.4: Demand by Mode

3.5.11 Demand change for the different journey purposes also shows considerable variation as demonstrated in Figure 3.5. IWT travellers stick to their journeys, with commuters and others being most likely to leave the system.

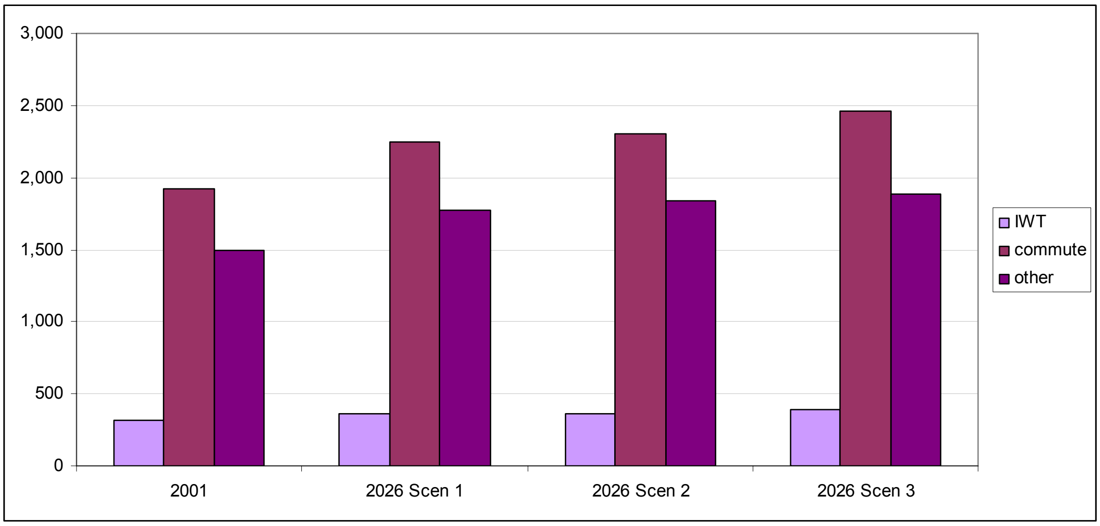


Figure 3.5: Demand by Purpose

3.6 Implications of the outputs and further developments

3.6.1 As discussed in more detail above, there has been considerable difficulty in gathering together appropriate elasticities for use in this model. Further work will be necessary to explore possible sources for these vital inputs, and to understand their implications for transport policy.

3.6.2 Results from models are always reflections of the inputs and assumptions that have been used. This is very clearly the case here. These results do however highlight some important issues for us to explore and address.

3.6.3 Firstly the importance of crowding and congestion on employment growth in London needs to be addressed further. There is clearly a practical limit to the number of people who can be transported daily through London and a much lower 'comfortable' limit. It may be the case that transport models are currently vastly underestimating the impact of overcrowding and therefore undervaluing projects which increase the available capacity. The results presented here include the crowding penalty for trips to central London, and yet still allow quite considerable growth to be achieved without significant further investment in the network. These results may be very optimistic.

3.6.4 Our Scenario 2 looks at the impact of raising money costs for car drivers by 50p/km in Central London, 20p/km in Inner London and 10p/mile in Outer London. The implications shown in our results are of reduced employment and lost RGVA. However there are likely to be benefits to charging which we have not counted here. These include higher driving speeds for those who value them enough to pay, increased bus speeds and revenue for investment in public transport. A further development of the model would be to incorporate some of these issues more appropriately.

4. Conclusions

4.1.1 This report presents the latest version of the TANDEM model. This version builds on earlier incarnations but includes more detailed zones, exogenous employment growth and a crowding penalty and agglomeration elasticity for central London.

4.1.2 The report discusses the issues around collecting suitable data to use, in particular the difficulty of sourcing appropriate elasticities. We are concerned that the transport models are underplaying the critical importance of overcrowding, and the possible constraint on employment growth that this may cause. We have presented results from the model, using a set of elasticities produced internally and discussed their implications.

4.1.3 The other major weakness of the models is that they do not redistribute growth according to transport infrastructure and/or policies. TANDEM is intended to provide a cheap and easily applicable mechanism for reviewing how alternative transport strategies would impact on the quantum and distribution of future growth.

4.1.4 The research clearly points to the need to develop our understanding of responses to crowding and in particular the constraints which exist on transport networks.

5. Appendices

Appendix A – Dimensions of the Model
Appendix B – Detail of links used
Appendix C – Data Sources Used
Appendix D – Summary of Additional Outputs
Appendix E – Elasticities

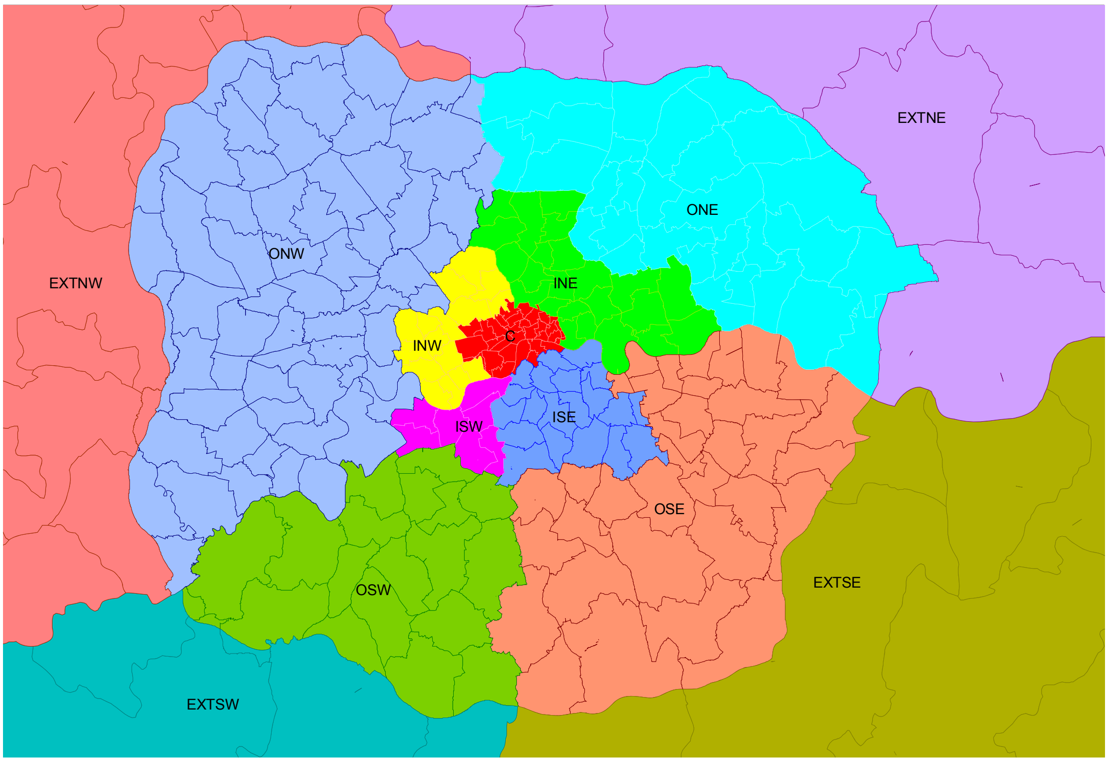
Appendix A: Dimensions of the Model

For the model to capture the main affects of transport policies we need it to include several journey purposes, modes of travel and origins and destinations with London. We tried to keep these groups as simple as possible while retaining enough information to be interesting to policy makers.

Since the original version of this model we have increased the number of zones that are modelled. The dimensions are now:

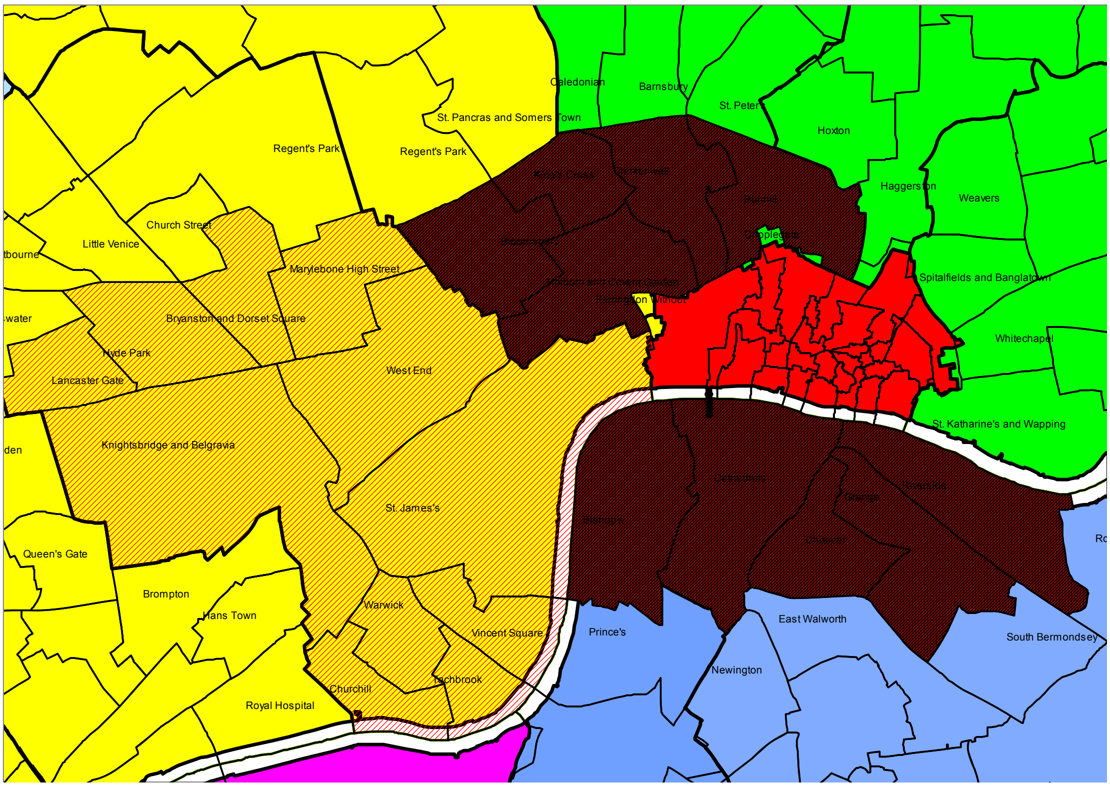
- **Purposes**: Commute; Business (trips during work hours paid for by company); and other.
- **Modes**: Car; Bus; and Rail (including Underground and Docklands Light Railway).
- **Zones**: Central, 4 Inner and 4 Outer London and 4 External as shown in Figure A1, with Central London as defined in Figure A2.

Figure A1: SPAM/TANDEM zones



The zones follow SPAM zones where possible. The Central Zone is defined to be roughly zone 1 in terms of transport costs and the City of London and all other central wards in zone 1, from an employment/output perspective. The wards we have attributed to Central London are shown in Figure A2.

Figure A2: Wards in Central London



The external zones are included to keep the contribution to total demand levels but we will not attempt to change employment in these zones at all.

Again to keep the model simple, we only consider am peak trips (07:00 to 10:00) on weekdays. We use annualisation factors to convert from am peak demand to annual demand in the business impacts equations. If we were to model other periods the split by mode and purpose of demand and the elasticities would be different.

Appendix B – Detail Of Links Used

Table B1 below lists the links within the model and the mechanism by which they work.

Table B1: Mechanisms for links and corresponding data sources

Link	**Mechanism**
Demand to Generalised Cost	
Demand → Generalised Cost	1) Elasticity to find change in time costs for each trip. For radial routes approaching Central London the change in the total demand along the route is considered – elsewhere the demand on that trip only. 2) Additional crowding penalty added for Rail trips in to central area 3) New time cost added to monetary costs divided by value of time by purpose to find new Generalised Cost.
Direct impacts of GC Change	
Generalised Cost → Extra Demand^G	1) Elasticity to find total change in demand for each trip 2) Redistribution factors are used to choose where this demand comes from – a proportion is created and proportions are taken from each of the other modes
Extra Demand^G → Extra Employment^G	One new job for each new commuting trip by destination (assumes that all the people who start commuting due to savings in cost are captured by this model and that people who do not commute in the morning peak are unaffected by transport changes).
Extra Employment^G → Extra RGVA^G	Multiplied by RGVA per job in Zone (assumes that those who loose a job drop out the London job market entirely)
Boost Loop	
Demand (D) and Generalised Cost (GC) → Boost	$Boost_t = (D_{t-1} + ½*(D_t-D_{t-1})) * A * (GC_t – GC_{t-1})* V * P$: 1) A =Annualisation factors by mode and purpose 2) V=Value of time by purpose 3) P=Proportion of benefit transferred to business by purpose Summed to give boost by trip destination
Boost →RGVA growth ^{B}	Boost converted to percentage of previous RGVA (for “Total Inner” and “Outer”)

Link	**Mechanism**
RGVA growth^B → Employment Growth^B	1) Linear coefficient to get total employment growth 2) RGVA "Total Inner" distributed to our "Central" and "Inner" zones by distribution of boost
Employment Growth^B → Extra Demand^B	Commute 1) Extra employment by zone converted to extra commute trips by ratio commuters/employment (assumes that those newly employed by businesses will have similar travel characteristics to current employees). 2) Distributed by previous distribution of trips for each destination (assumes people are still likely to live in the same areas despite transport changes) IWT and Other The initial ratio of commute trips to IWT and other trips is used to estimate additional IWT and other trips following increase in commuting from boost and exogenous employment
Exogenous Employment	
Extra Employment^E → Extra Demand^E	New exogenous employment all goes by train. Added in ratio previous ratio of demand origins to that employment location IWT and other trips added from each destination to maintain ratio of commute to IWT and other.
Extra Employment^E → Extra RGVA^E	Each new jobs is multiplied by the output per head in that zone to get new total output
Agglomeration	
RGVA per Head	Elasticity of productivity to employment density applied to the change in Employment. Additional output added to RGVA

A trip refers to a choice of mode, purpose, origin and destination. ^{B} is used to denote 'from boost' while ^{G} denotes 'directly from generalised cost change' and ^{E} denotes 'from exogenous employment growth'.

Appendix C: Data Sources

Collecting data for TANDEM has proved no easy task. This has been due to both the incredible complexity of the transport system in London and the level of abstraction at which the model operates.

Table C1 below summarises the inputs which have been used in the model. The source for each has been listed along with the dimensions of the data. We were unable to find data sources to match our requirements for a number of data, for these we were forced to estimate the data. A discussion of each of these data follows the table.

We are keen to improve the data sources used and would welcome feedback in to more appropriate basis for the data.

Table C1: Summary table of sources

Data	Dimensions	Source
Base Data		
Base Demand	z, z, m, p	SPAM (11/07/06)
Base Time Costs	z, z, m	SPAM (11/07/06)
Base Other Costs	z, z, m, p	SPAM (11/07/06)
Initial time in Crowded conditions	z, z, m, p	This has been set to a flat 25% for all journeys to central London – this is applied to the crowding penalty
Output	zone	Total London output 2001 – ONS Split using 2001 Earnings data from ASHE
Employment	zone	GLA structural employment estimates (includes self employed)
Elasticities and Redistribution Factors		
Elasticity of time costs wrt Demand	z, z, m	LTS/estimation*
Elasticity of Demand wrt Generalised cost	z, z, m, p	LTS/estimation*
Redistribution factors	z, z, m, p	Estimated using current levels of demand to guide, drop out rates estimated*
Elasticity of employment wrt output growth	constant	GLA productivity forecasts
Agglomeration elasticity	Central only	Estimated

Data	Dimensions	Source
Factors and parameters		
Crowding Curve Values of time Annualisation factors Daily commute trips per job Proportion of benefit from boost that goes to business	Central only p m, p constant p	OEF Estimated Estimated Estimated Estimated – we said 100% of business costs, 25% of commuting costs and 5% of leisure costs to business
Exogenous Changes		
Exogenous Employment	zone, year	GLA employment estimates (includes self employed)
Exogenous Generalised time Changes	z, z, m, year, scenario	Dependent on scenario
Capacity into central area	year, scenario	From RailPlan (scaled down by the ratio of demand in RailPlan to the SPAM demand)

m = mode, p=purpose, z=zone

Appendix D: Summary Of Further Outputs

In addition to the outputs contained in the report we have included the employment results of one other run which was carried out as part of the development of TANDEM Stage 3. The policy scenarios are as those as set out in the report but the crowding penalty has not been used.

D1 Results when the crowding penalty is excluded

	2001	2026			% change to 2026		
		Scen 1	**Scen 2**	**Scen 3**	**Scen 1**	**Scen 2**	**Scen 3**
Central	1,321	1,467	1,520	1,538	11%	15%	16%
Inner NE	484	628	647	660	30%	34%	36%
Inner NW	426	537	550	558	26%	29%	31%
Inner SE	233	280	283	287	20%	22%	23%
Inner SW	133	173	175	177	30%	32%	33%
Outer NE	406	415	410	418	2%	1%	3%
Outer NW	883	937	932	945	6%	6%	7%
Outer SE	426	434	429	437	2%	1%	3%
Outer SW	235	259	257	261	10%	9%	11%
Total	**4,547**	**5,130**	**5,204**	**5,281**	**13%**	**14%**	**16%**

Excluding the crowding penalty permits a much higher level of employment growth to occur in the central areas for Scenarios 1 and 2. The opposite is true for Scenario 3 since the increased capacity increases the attractiveness of travel.

Appendix E: Elasticities

This appendix shows the elasticities used in TANDEM 3. All other inputs are available on request.

Time Component of Generalised Cost with respect to Demand, car

E1 Elasticities of Time Component of Generalised Cost with respect to Demand, car

Car	Central	Inner NE	Inner NW	Inner SE	Inner SW	Outer NE	Outer NW	Outer SE	Outer SW	Ext NE	Ext NW	Ext SE	Ext SW
Central	0.38	0.42	0.42	0.42	0.42	0.44	0.44	0.44	0.44	0.39	0.39	0.39	0.39
Inner NE	0.42	0.50	0.50	0.50	0.50	0.39	0.39	0.39	0.39	0.37	0.37	0.37	0.37
Inner NW	0.42	0.50	0.50	0.50	0.50	0.39	0.39	0.39	0.39	0.37	0.37	0.37	0.37
Inner SE	0.42	0.50	0.50	0.50	0.50	0.39	0.39	0.39	0.39	0.37	0.37	0.37	0.37
Inner SW	0.42	0.50	0.50	0.50	0.50	0.39	0.39	0.39	0.39	0.37	0.37	0.37	0.37
Outer NE	0.55	0.65	0.65	0.65	0.65	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.43
Outer NW	0.55	0.65	0.65	0.65	0.65	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.43
Outer SE	0.55	0.65	0.65	0.65	0.65	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.43
Outer SW	0.55	0.65	0.65	0.65	0.65	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.43
Ext NE	0.61	0.64	0.64	0.64	0.64	0.60	0.60	0.60	0.60	0.10	0.10	0.10	0.10
Ext NW	0.61	0.64	0.64	0.64	0.64	0.60	0.60	0.60	0.60	0.10	0.10	0.10	0.10
Ext SE	0.61	0.64	0.64	0.64	0.64	0.60	0.60	0.60	0.60	0.10	0.10	0.10	0.10
Ext SW	0.61	0.64	0.64	0.64	0.64	0.60	0.60	0.60	0.60	0.10	0.10	0.10	0.10

E2 Elasticities of Time Component of Generalised Cost with respect to Demand, bus

Bus	Central	Inner NE	Inner NW	Inner SE	Inner SW	Outer NE	Outer NW	Outer SE	Outer SW	Ext NE	Ext NW	Ext SE	Ext SW
Central	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inner NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inner NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inner SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inner SW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outer NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outer NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outer SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outer SW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ext NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ext NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ext SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ext SW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*nb elasticities are zero to reflect ability of bus frequencies to be increased as demand grows

E3 Elasticities of Time Component of Generalised Cost with respect to Demand, rail

Rail	Central	Inner NE	Inner NW	Inner SE	Inner SW	Outer NE	Outer NW	Outer SE	Outer SW	Ext NE	Ext NW	Ext SE	Ext SW
Central	0.20	0.15	0.15	0.15	0.15	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05
Inner NE	0.15	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.07	0.03	0.03	0.03	0.03
Inner NW	0.15	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.07	0.03	0.03	0.03	0.03
Inner SE	0.15	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.07	0.03	0.03	0.03	0.03
Inner SW	0.15	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.07	0.03	0.03	0.03	0.03
Outer NE	0.10	0.07	0.07	0.07	0.07	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02
Outer NW	0.10	0.07	0.07	0.07	0.07	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02
Outer SE	0.10	0.07	0.07	0.07	0.07	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02
Outer SW	0.10	0.07	0.07	0.07	0.07	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02
Ext NE	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
Ext NW	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
Ext SE	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
Ext SW	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00

Elasticities of Demand with respect to Generalised Cost

E4 Elasticities of Demand with respect to Generalised Cost, car

Car	Central	Inner NE	Inner NW	Inner SE	Inner SW	Outer NE	Outer NW	Outer SE	Outer SW	Ext NE	Ext NW	Ext SE	Ext SW
Central	-0.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Inner NE	-0.50	-1.00	-1.00	-1.00	-1.00	-1.50	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00
Inner NW	-0.50	-1.00	-1.00	-1.00	-1.00	-1.50	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00
Inner SE	-0.50	-1.00	-1.00	-1.00	-1.00	-1.50	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00
Inner SW	-0.50	-1.00	-1.00	-1.00	-1.00	-1.50	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00
Outer NE	-1.50	-1.50	-1.50	-1.50	-1.50	-2.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00
Outer NW	-1.50	-1.50	-1.50	-1.50	-1.50	-2.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00
Outer SE	-1.50	-1.50	-1.50	-1.50	-1.50	-2.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00
Outer SW	-1.50	-1.50	-1.50	-1.50	-1.50	-2.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00
Ext NE	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Ext NW	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Ext SE	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Ext SW	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

E5 Elasticities of Demand with respect to Generalised Cost, bus

Bus	Central	Inner NE	Inner NW	Inner SE	Inner SW	Outer NE	Outer NW	Outer SE	Outer SW	Ext NE	Ext NW	Ext SE	Ext SW
Central	-2.40	-3.50	-3.50	-3.50	-3.50	-6.00	-6.00	-6.00	-6.00	0.00	0.00	0.00	0.00
Inner NE	-3.50	-3.50	-3.50	-3.50	-3.50	-5.00	-5.00	-5.00	-5.00	0.00	0.00	0.00	0.00
Inner NW	-3.50	-3.50	-3.50	-3.50	-3.50	-5.00	-5.00	-5.00	-5.00	0.00	0.00	0.00	0.00
Inner SE	-3.50	-3.50	-3.50	-3.50	-3.50	-5.00	-5.00	-5.00	-5.00	0.00	0.00	0.00	0.00
Inner SW	-3.50	-3.50	-3.50	-3.50	-3.50	-5.00	-5.00	-5.00	-5.00	0.00	0.00	0.00	0.00
Outer NE	-6.00	-5.00	-5.00	-5.00	-5.00	-3.50	-3.50	-3.50	-3.50	-10.00	-10.00	-10.00	-10.00
Outer NW	-6.00	-5.00	-5.00	-5.00	-5.00	-3.50	-3.50	-3.50	-3.50	-10.00	-10.00	-10.00	-10.00
Outer SE	-6.00	-5.00	-5.00	-5.00	-5.00	-3.50	-3.50	-3.50	-3.50	-10.00	-10.00	-10.00	-10.00
Outer SW	-6.00	-5.00	-5.00	-5.00	-5.00	-3.50	-3.50	-3.50	-3.50	-10.00	-10.00	-10.00	-10.00
Ext NE	0.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-5.00	-5.00	-5.00	-5.00
Ext NW	0.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-5.00	-5.00	-5.00	-5.00
Ext SE	0.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-5.00	-5.00	-5.00	-5.00
Ext SW	0.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-5.00	-5.00	-5.00	-5.00

E6 Elasticities of Demand with respect to Generalised Cost, rail

Rail	Central	Inner NE	Inner NW	Inner SE	Inner SW	Outer NE	Outer NW	Outer SE	Outer SW	Ext NE	Ext NW	Ext SE	Ext SW
Central	-2.26	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Inner NE	-1.64	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Inner NW	-1.64	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Inner SE	-1.64	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Inner SW	-1.64	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Outer NE	-0.46	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Outer NW	-0.46	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Outer SE	-0.46	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Outer SW	-0.46	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Ext NE	-0.43	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Ext NW	-0.43	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Ext SE	-0.43	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
Ext SW	-0.43	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00