

Congestion pricing model tests in Dublin

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ABSTRACT

Traffic demand management for Dublin's congested streets is part of the package of measures currently being implemented to offset the imbalance between transport demand and supply. The aim of the research project on which this paper reports is to evaluate the impacts of a series of cordon road use pricing scenarios using a newly developed parallelised version of the traffic network analysis model, SATURN, running on the IBM SP2 supercomputer.

The analysis will evaluate both the city-wide and local impacts of applying such cordon schemes to the Dublin transportation network. Variables to be examined include queue lengths, queue dissipation, travel time and distance, and reductions in the demand for trips. The sensitivity of the model to elasticity levels, which are based on international experience, will be assessed using a series of model tests.

The output of the research draws conclusions from the results of a series of model runs for the evaluation of road use pricing in Dublin. Overall, it is found that the greater Dublin area would be far less congested as a result of the cordon application, with approximately a 30% reduction in trip demand and a 20% reduction in the distance travelled over the network. The analysis also shows that charging would help reduce delays in the outer area of the city more so than within the central area. There is also evidence to suggest the occurrence of peak spreading causing congestion in the shoulder of peak periods.

INTRODUCTION

A package of measures has been outlined by the Dublin Transportation Office (DTO) to offset the current imbalance between transport demand and supply on the typically heavily congested roads of the greater Dublin area (GDA) transport network, see FIGURE 1. As part of this package, traffic demand management is proposed as an important method for the control of traffic congestion.

Demand management seeks to reduce the growth in travel while maintaining economic progress and is designed to encourage a transfer of trips, especially during peak periods, from the private car to sustainable modes of transport (*1*). Road user pricing is an important tool for demand management. There are a number of established forms of road user pricing including cordon charging, area licensing, screen-line tolling and pricing by time or distance. This paper reports on the impact of a series of cordon road use pricing scenarios using a newly developed parallelised version of SATURN, running on the IBM SP2 supercomputer, which allows faster processing of tests while retaining accurate modelling behaviour. SATURN is a combined traffic simulation and assignment model for the analysis of traffic management systems, see Van Vliet (*2, 3*).

The paper is laid out in six sections. Section two describes the developments that have led to the present situation in the GDA. Section three describes the methodologies used to assess the different cordon road use pricing scenarios. Section four looks at the tests that have been completed and discusses the results from these tests while section five describes the conclusions.

BACKGROUND

The Dublin Transportation Office (DTO) produced the Transportation Review and Short-Term Action Plan (TRSAP) in 1998 (*4*). This Plan represented an update of the Dublin Transportation Initiative (*5*), published three years earlier, and a radical transportation strategy for the GDA. Shortly after the DTI began, the implementation of its strategy failed to match the increasing demand for transport in the GDA. This was due, mainly, to increased economic activity. TRSAP assessed the remaining period of the Operational Programme for Transport (1994-1999) in the Dublin region and progress on implementation of the DTI Strategy. It also laid out short-term plans to address the deterioration in travel conditions found through the assessment.

In September 2000, the DTO published a further transportation strategy for the GDA, consisting of two main elements, infrastructure and service improvements and demand management. The proposed infrastructure and service improvements have been well documented, see, 'A Platform for Change' (*1*), but as this document states, they will not be enough to cope with the predicted demand for transport in the future without some form of additional demand management strategy.

Any increase in person-trips by car over that predicted by the DTI is defined as a transportation deficit (*4*). Two main problems exist as the cause of Dublin's transportation deficit. The first is that there has been considerable 'slippage' in the implementation of the DTI Strategy, although with the emergence of the DTO to oversee its implementation, progress has been made. The second is that there has been enormous growth in the economy resulting in very large increases in the level of traffic and increased congestion. This economic growth was not predicted in the DTI Strategy. Demographic and economic indicators for the GDA are presented in Table 1.

The high rate of economic growth has resulted in a large increase in the demand for travel. Peak hour trips between 1991 and 1997 have grown by 45 percent or 78,000, 71,000 of which are due to private car commuting. The average journey time has increased from 31 minutes to 43 minutes over the same period with 72 percent of peak hour trips being accounted for by the private car.

The Dublin Transportation Network Model (DTNM) was produced as part of the DTI to make transportation forecasts. The DTO have developed this model further to produce new forecasts for the GDA (1). A percentage growth factor per year to predict future year trip matrices is not used. Instead, land-use planning and employment information on a zone by zone basis is used to predict the growth for each zone within the GDA.

The forecast produced by the DTO for 2016 predicts an even worse outlook with a 95 percent increase in the total peak hour trips over and above the predicted demand in 1997, while the off peak demand for trips in 2016 will also exceed the peak period demand in 1997. If, however, other strategies of transportation management were to be used, such as demand management e.g. road use pricing, this situation could potentially be improved.

The Greater Oslo Area is a metropolitan region of a comparable size to that of the Greater Dublin Area (GDA), with a population of 989,964 in 2001 and a workforce of 572,000. This workforce represents a net growth of over 85,000 from 1996 to 2001, compared with an increase for the GDA of 53,000 between 1996 and 1999. The average unemployment rate in 2001 was 2.2 percent. Oslo has a good transportation system, which includes tolling for access to the inner city as well as metro, light rail and bus services. Congestion charging is currently being investigated as an additional feature to add to the tolling scheme that exists there at the moment. The strategic plan for 2016 is for public transportation services to take the burden of the predicted 60 percent growth in passenger transport (6), while the main challenge is to improve public transportation sufficiently so that growth in the number of trips made on the road network is significantly reduced (7).

The situation in London, where congestion charging has been implemented, is very important to the people of the London Metropolitan Region, with 60 percent citing congestion delays and related issues as London's biggest problem on a questionnaire investigating public opinion (8). This is unsurprising considering that the average traffic speed in Central London is around 16km/hr during the working day with trip demand apparently still on the increase (8).

METHODOLOGY

Previous studies of road use pricing in the greater Dublin area

'A Study of Road Pricing in Dublin' was produced by Oscar Faber et al in 1998 (9). This is the only report that has been produced to assess road use pricing in the GDA and in essence was a feasibility study. It examined a small number of testing scenarios to try to assess the feasibility of road use pricing and other fiscal instruments, such as parking charges, for the management of transportation and traffic demand in the GDA. The study also looked at the different forms of road use pricing and their implementation and went on to confirm the potential of road use pricing in contributing to the management of traffic in the GDA. The study was undertaken strictly as a preliminary study to assess the potential of road user pricing and it was assumed that further information and detail would be required to fully evaluate road use pricing in the GDA. Based on the positive preliminary findings of the study the report recommends that further work

should be undertaken to investigate the feasibility of introducing a road use pricing scheme, and in particular a cordon pricing scheme, to the GDA network.

Factors and constraints

There are a number of factors and constraints that must be considered for the road use pricing tests examined in this paper. There are two sets of data to be used as input to the model. The first data set describes the road network, including the infrastructure, traffic signals, geographic layout, etc., with over 2500 links, 4500 simulated turns and 320 traffic signals. The data describing the network has been provided by the DTO and was initially produced for the DTI, see the DTI Final Report (5) for more detail. This data was then edited to incorporate the cordon. The second data set is the trip matrix (367*367, each element of the matrix being the equivalent of the number of trips either originating or destined in a certain zone, of which there are 367 that make up the study area), which was also provided by the DTO and was produced using a number of surveying and interviewing techniques and census data (5). The main factors and constraints include the charge associated with the cordon or screen-line, the elasticity of user response to this level of charge and the demand equation used to calculate the new trip demand resulting from the implementation of the user pricing scheme.

Charge levels

Road user charges should be linked as closely as possible to marginal external costs (10). A study of transport externalities in Dublin found that a charge of approximately €6.86 (\$7.88¹) would be representative of the externalities associated with trips in the GDA (11). In London, consultants Halcrow Fox (12), have found that between €8.20 – €16.39 (\$9.42-\$18.82) could be charged to enter central London, while £3,000 sterling (\$4,879) per annum could be levied on work related parking within the central cordoned area (13). In Singapore, where they use a system with restricted zones and toll charges on the major expressways entering the city centre, the charges range from between €2.09 – €3.48 (\$3.00 and \$5.00) (\$2.4 and \$3.99) during peak periods (14). In 1999, Oscar Faber et al (9) suggests charges varying from €0.79 – €3.81 (\$0.9 - \$4.37), but this report was based on the 1997 transportation network for the GDA. Further testing has been carried out for Cambridge using charges between €0.98 – €8.20 (\$1.12 - \$94.2) for congestion charging (15).

Tolling, which is used primarily for raising revenue, has been implemented in Scandinavia, including Bergen (in 1986), Oslo (in 1990) and Trondheim (in 1991), while experiments have been undertaken in Stuttgart (1994-95) and in Stockholm. Also, single facility schemes such as toll roads have been implemented in France, California, San Diego and other places in the US (16). The charges used for these toll schemes are much lower so as to raise revenue but not to dissuade drivers from using of the roads.

On the basis of the summary above, a wide range of charges will be used for this research to reflect international experience. Cordon charges of between €3.81 – €10.16 (\$4.38 - \$11.67) will be used for a single peak hour, with a representative value of €5.72 (\$6.57) being examined for the purposes of this paper over a range of elasticity levels. Other charges in addition to €5.72 were examined and presented elsewhere but because a range of elasticities were also examined for the purposes to reduce the complexities of presentation only one charge level is examined. (17). This charge level lies within the range that other studies have used as mentioned above.

¹ Conversion rate used 1 EUR = 1.14875 USD, 29/07/03

The results found for the other charge levels are currently forming the basis of further research and will be published at a later date.

Elasticity

At this stage it is not possible to assign specific elasticities to represent user response to road use pricing scenarios in the GDA. Instead, a number of different elasticities will be used based on international experience. A large body of literature exists on the estimation of demand elasticities, and a number of literature reviews have been published which summarise this literature very well. These reviews include Oum, Waters and Yong (18) and Goodwin (19). It is suggested in Oscar Faber et al. (9) that a peak demand elasticity value of between -0.1 and -0.5 should be used for the GDA. For other examples and studies of road user pricing, elasticity estimates vary from -0.1 to -1.2, see Cole (20), Oldfield (21) and Halcrow Fox (12). Based on these studies, elasticities varying from between -0.1 and -0.7 will be used to represent trip makers reactions to charges during peak periods.

These elasticities are directly related to the overall generalised costs through the elasticity demand function described in the next section. During peak periods elasticities are lower because work related commuting trips, which make up 67 percent of trips during this period (4), have to be made through one mode or another (21). 19 percent of trips are school or college related while other trips make up the remaining 14 percent (4). For a journey to work, there is little chance of a change in destination or abandonment of the trip, which suggests that the elasticity of demand for commuting with respect to changes in generalised cost may be relatively low (9). As such, disincentives, like a road user charge, are likely to have less effect on these high priority trips.

Elasticity demand function

The elasticity demand function used for the research is the same as that used in Oscar Faber et al (9). The elastic exponential, or semi-log function, referred to below is one of four demand response functions available as part of an elastic assignment algorithm in the SATURN suite, see Van Vliet (2) and Hall et al. (22).

The methodology used in the UK Engineering and Physical Sciences Research Council (EPSRC) study, that led Oscar Faber et al (9) to use this function, involved building an independent relationship from a set of stated preference (SP) data via traditional logit-based approaches and then attempting to fit one of the four SATURN elastic assignment options to it. In the study, the semi-log function, described below, came out as a best fit. In a subsequent, more complex project where SP data was collected in Cambridge, Norwich & York, the best fit was found to be a simple exponential function, e.g., $y = a + b \ln(x)$.

However, according to Oscar Faber et al (9), the function below is more consistent with what might be expected in the case of the GDA and this is assumed to be the case for this research. The exponential aspect of the demand function also takes into account the fact that work, or priority, trips make up approximately 67 percent of the trips being made in the peak hour period (4). The function does this by dampening the effect an increase in the elasticity of user response has on the trip demand to give a more realistic, or elastic, response to a cordon charge over a peak hour charging period.

$$T_{\text{new}} = T_{\text{base}} \text{EXP} (\text{EL} \cdot ((CH + C_{\text{base}}) / C_{\text{base}} - 1))$$

where T_{new} = trip demand after charging has been applied

- T_{base} = trip demand in the base year per route
 CH = road user charge at the cordon
 C_{base} = total generalised cost in the base year for each trip and
 $El.$ = a constant power coefficient that regulates the shape of the function, i.e., the elasticity.

Generalised cost

It is assumed that journeys are made for the utility (value) taken from activities that are performed at their destination. However, when making such a journey the traveller incurs the disutility of expense, time spent travelling, etc. Generalised cost represents this disutility. The zone to zone generalised cost used by the DTI is given by the two formulae (5):

$$GC_{car} = a_1IVT + a_2WK + a_3EX + a_4VOC + a_5PK + a_6$$

$$GC_{pt} = a^1_1IVT + a^1_2WK + a^1_3WT + a^1_4FARE + a^1_6$$

Where; IVT is the in-vehicle travel time, WK is the walk time, WT is the waiting time for public transport, EX is the excess time while finding parking, VOC are the vehicle operating costs, FARE are the public transport fares, PK refers to the parking charges for the private car, and, a_1 to a_6 are parameters used as both conversion factors and weights to express generalised costs in common units.

The generalised cost can be expressed in monetary or time units. If the generalised cost is measured in monetary terms ' a_1 ' can be interpreted as the perceived value of IVT. Usually ' a_2 ' and ' a_3 ' are approximately twice that of ' a_1 ', making the perceived value of walking and waiting times twice that of IVT. Parameters ' a_4 ' and ' a_5 ' convert values of fare into their equivalent values in time while ' a_6 ' is the mode specific constant representing the inherent costs of a mode.

CORDON TESTS

The GDA transport network is made up of two networks, which are better known as the simulation network, covering the Central Business District (CBD) and the buffer network (area outside CBD). The simulation network encapsulates the inner city and suburbs and is programmed in more detail than that of the buffer network, see FIGURE 1 for the simulation boundary location. The buffer network represents the greater part of the GDA (other than the simulation area) and also incorporates traffic entering the area along major routes from the rest of the country. The simulation and buffer networks combined give the complete network, as used in the Dublin Transportation Network Model (DTNM). The initial cordon location for testing is based on that described in the Oscar Faber et al. report (9), see FIGURE 1. The trip matrix and network files developed by the DTO were used for initial testing. The base year for these files is 1997. The files were then factored up by the DTO to represent trip demand on the network for 2000 and 2006.

A number of changes have been made to the network file for the 2006 version of the GDA network. The changes have been made to represent the completion of planned and confirmed infrastructural projects that are to be put in place in the intervening years. These changes include, amongst others, the completion of arterial and radial quality bus corridors (QBCs), improvements to suburban rail, completion of a cycle network and completion of two lines of the new light rail implementation that is already under construction. The DTO assumed

that the growth for 2006 is 60% of the growth that occurs from 1997 to 2016. The 2016 values are based on projections, on a zone-by-zone basis, in local authority areas and are capped at the Strategic Planning Guidelines totals (22).

The testing procedure involves adapting both the network and trip matrix files to accurately represent the different road use pricing scenarios on the GDA network. The network file is edited to incorporate the cordon by applying a charge to links defining the cordon boundary. The trip matrix file is edited by applying the demand function defined in the previous section to the standard trip matrix provided by the DTO, for the year being tested, to produce the new trip matrix of demand for the cordoned network. All testing has been iterated to convergence and was carried out at a number of different elasticity levels, as described in the next section. The monetary road user charge is converted to an equivalent value of time so that all of the generalised cost equation parameters in the model are presented in the same way, in units of time.

Test scenarios

- 1 Baseline 2006 network file and trip matrix file, as provided by the DTO.
- 2 Cordoned network file using €5.72 (\$6.52) charge. New trip matrix file using a €5.72 charge, which at €0.076 per minute gives an equivalent charge in seconds (CH) of 4500. Elasticity of -0.1 ($El = -0.1$).
- 3 Cordoned network file using €5.72 charge. New trip matrix file using CH = 4500 seconds, and $El = -0.3$.
- 4 Cordoned network file using €5.72 charge. New trip matrix file using CH = 4500 seconds, and $El = -0.5$.
- 5 Cordoned network file using €5.72 charge. New trip matrix file using CH = 4500 seconds, and $El = -0.7$.

Results and discussion

The road user pricing scenarios will be assessed and discussed using a number of variables described here. Transient queues record the time spent by vehicles in queues which, in the case of traffic signals, clear during a single cycle. Over-capacity queues record the extra time spent in queues at over-capacity junctions waiting for the cycle in which the vehicle exits. Free-flow time is the time which would be spent travelling on links operating at their free-flow speeds to which must be added, delays, the flow-specific extra travel time on those links with link speed-flow curves. The link cruise time is the sum of the previous two link times. The total travel time is the sum of both link and junction times. The travel distance is the vehicle or pcu.kms on simulation links and the overall average speed is defined by distance/time.

The simulation time period is one hour in duration. However, the model continues to run until over-capacity queues at intersections dissipate completely, i.e., that the traffic is running at its optimum level of capacity. In the discussion below there are two time periods being referred to, the charged period (during which time the charge is applied), and the total time period modeled, which is the charged period plus the time taken for over-capacity queues to dissipate.

FIGURE 2 shows the results from the simulation network for the charged period, one hour in this case, using a cordon charge of €5.72. It can be seen from FIGURE 2 that the elasticity demand function is reducing the effect of higher elasticities to give a more realistic reaction to the charge during the morning peak period. Part one of this FIGURE shows that transient queues remain at relatively the same level irrespective of increasing elasticity through Test Scenarios 1 to 5. This trend remains unchanged for the complete network, see FIGURE 3,

where the time spent by vehicles in transient queues throughout the total time period modeled decreases by only a small margin through Test Scenarios 2 to 5.

Returning to FIGURE 2 but concentrating on over-capacity queue totals, it can be noted that there is a sharp drop in the number of pcu.hrs between Test Scenario 1 and 2. This is as a result of the reduction in trip demand due to the application of the cordon charge to the inner city with an elasticity of user response -0.1 in Test Scenario 2. It can be seen that the rate of reduction of the over-capacity queue totals reduces when proceeding through Test Scenarios 2 to 5. In FIGURE 3, for the total time period modelled and for the complete network, there is a small but relatively constant reduction through Test Scenarios 1 to 5. This suggests that there are a large number of permanent queues on the complete network close to their origins that only dissipate after the cordon charged period.

Analysing the link cruise times in FIGURE 2, there is very little change between Test Scenarios 1 through 5 on the simulation network. For the complete network, presented in FIGURE 3, there is a sharp drop in the pcu.hrs in Test Scenario 2 compared with Test Scenario 1 followed by a smaller, but consistent, drop as the elasticity is increased, proceeding from Test Scenario 2 through to 5. This suggests that although the link cruise times are decreasing throughout the complete network, the simulation network is remaining congested due to demand, while the buffer network is becoming the beneficiary of a decrease in delays.

The last variable shown in FIGURES 2 and 3 is the total travel time. Over the simulation network, presented in FIGURE 2, a very similar pattern to that which occurs for link cruise times is found. This suggests that the cordon has little effect on junction times during a busy peak period. In FIGURE 3, for the complete network, the total travel time drops markedly when the cordon is introduced. In Test Scenarios 2 to 5 there appears to be some degree of fluctuation in the results for the complete network and further tests will need to be carried out to assess why this is but for the purposes of this paper the results are of similar order.

FIGURE 5 shows a graph of elasticity versus travelled distance for the charged period for both the simulation and complete networks. The travelled distance over the complete network drops sharply as the cordon is introduced whereas the drop in the simulated network is relatively small in comparison. This appears to be due to less trip makers making a trip to the city centre by car, resulting in reduced congestion in the buffer network. However, the travelled distance remains high in the simulation network. From FIGURE 1 it is noted that the simulation network is substantially larger than the cordoned area. It is possible, therefore, that trip makers wishing to avoid the charge at the cordon location are re-routing around the cordon but remaining inside the simulation network leading to relatively unchanged levels of distance travelled.

The simulation network has approximately an 8 percent reduction in the kilometres travelled through Test Scenarios 1 to 5. This implies an even higher reduction inside the cordon boundary. During the charged period there is also a 15 to 16 percent reduction in the total travel time in the simulation network. This compares favourably to results obtained in London where congestion charging is predicted to cut traffic levels inside the charging zone, in kilometres travelled, by 10-15 percent and congestion, measured in 'vehicle delays', by 20-30 percent (24). Overall, although the simulation network remains relatively congested, there is a considerable reduction in congestion, signified by a 30 percent reduction in the distance travelled on the complete network, see FIGURE 4.

Similar results have been found in London where the effects of a congestion charging, city centre, cordon application are predicted to have a larger effect outside of the charged area than inside it. It is predicted that drivers will save 2 to 3 million hours within the charged zone

while a further 4 to 7 million hours will be saved on roads outside of the charged area but within the metropolitan region (23).

FIGURE 5 shows the average speed on the simulation network for the charged period and for the total time period modelled. During the charged period the average speed rises as expected. This implies that even though the travelled distance on the simulation network does not reduce dramatically, the traffic is moving more efficiently. When the average speed for the total time period is analysed, i.e., where over-capacity queues have been allowed to dissipate, it can be seen that there is an initial drop in speed followed by a slow but gradual recovery. This may demonstrate the number of trips that are stuck in permanent queues close to their origin causing delays to their journeys and congesting the network after the cordoned, or charged, period has expired. These delays are most likely due to the increased travel inside the simulation network but outside the cordoned area where drivers are attempting to avoid the cordon charge by circumnavigating the cordoned area. This suggests that perhaps screen-lines along radial routes may be necessary to discourage such behaviour. It also suggests that perhaps a spreading of charges to the shoulders of the peak period would have a positive effect on congestion in the simulation and complete networks by removing the possibility of avoiding a charge. The gradual improvement in average speed after the initial drop reflects the reduced number of trip makers on the network due to the increased elasticity of user response.

Though it is difficult to suggest a single most accurate test scenario for the GDA, from Goodwin's (18) assertion that around -0.4 is a good long-run elasticity with respect to increases in petrol prices, test scenario 3, with a conservative elasticity estimate of -0.3 , is assumed here.

CONCLUSIONS

- Based on the results of this research it is suggested that demand management could constitute an important part of an integrated solution for the congestion difficulties in the greater Dublin area (GDA). This is reinforced by the results of the tests discussed in this paper and by the DTO 2000-2016 Strategy laid out in 'A Platform for Change' (1).
- There is a reduction in the number of trips entering the simulation network, as expected. However, because transient queue levels drop off slowly it is evident that trip demand within the GDA is remaining high. Considering that peak periods are being modelled this is as expected.
- There is a reduction of congestion delays on the simulation network during the charged period. This is demonstrated by the reduction in over-capacity queues on the simulation network.
- There are a substantial number of trip makers that are circumnavigating the cordon to avoid the charge. This is implied from the slight reduction of over-capacity queues of 5 percent and the effects on average speed. Some form of radial screen-lines from the city centre cordon outwards or an additional loop cordon application situated further out from the inner city may counteract these effects.
- A reduction of travellers is felt more quickly on the buffer network than on the more congested simulation network where there is an increase in the travelled distance between the cordon and simulation network boundaries.

- The travelled distance, which also reduces slowly after an initial drop, demonstrates that people are travelling out of their way to avoid the cordon charge. However, because of the effects within the cordoned area, traffic inside the simulation area as a whole is moving more efficiently during the charged period as is demonstrated by the increase in the average speed from 18.4 to 19.5km/hr.
- The buffer network appears to gain a lot of benefit from the inner city cordon and during the charged period the region inside the cordon also benefits greatly even though demand remains high. While there is a reduction of 8 percent in the travelled distance in the simulation network there is a 24 percent reduction across the complete network.
- Overall the GDA is less congested by up to 30 percent with only a 20 percent reduction in the distance travelled. The 10 percent shortfall in the distance travelled is due to trip makers choosing new, longer, routes so as to avoid the cordon charge. There is an 8 percent reduction in kilometres travelled on the simulation network as well as a 15 to 16 percent reduction in the total travel time in the simulation area. These statistics show that travellers are re-routing to avoid the cordon and are predominantly doing so within the simulation area.

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REFERENCES

- 1 Dublin Transportation Office (DTO). *A Platform for Change*. Dublin Transportation Office, Dublin, Ireland, 2000.
- 2 Van Vliet, D. SATURN: A Modern Assignment Model. *Traffic Engineering and Control*, Vol. 23, 1982, pp. 575-581.
- 3 Van Vliet, D. and M. Hall. *SATURN User Manual*. W. S. Atkins, UK, 2001.
- 4 Dublin Transportation Office (DTO). *Transportation Review and Short-Term Action Plan*. DTO, Dublin, Ireland, 1998.
- 5 Dublin Transportation Initiative (DTI). *Final Report*. Steer Davis Gleave in association with McHugh Consultants, Government Stationary Office, Dublin, Ireland, 1994.
- 6 AS Oslo Sporveier.
<http://www.sporveien.no>
Accessed November 2002.
- 7 Oslopakke 2 (Financial Plan).
<http://www.oslopakke2.no>
Accessed February 2003.
- 8 Government Office for London (GOL) in association with the Greater London Authority (GLA). *Road Charging Options for London: A Technical Assessment*. GOL, London, England, 2000.
- 9 Oscar Faber, Goodbody Economic Consultants, TSRG and TORG. *A Study of Road Pricing in Dublin*. Department of the Environment and Local Government, Dublin, Ireland, 1998.
- 10 Boot, J., Boot, P. and E. T. Verhoef. *The long road towards the implementation of road pricing: the Dutch experience*. ECMT/OECD Workshop, Dublin, Ireland, 1999.
- 11 Gibbons, E. *Application of an Economics Model to Transport Externalities in Dublin*. MSc Dissertation, Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin, Ireland, 1998.
- 12 Halcrow Fox. *London congestion charging review and specification of model elasticities*. Accent Market Research, University of Leeds, UK, 1993.
- 13 Williams, D. *Road pricing 'will cripple trains and Tube'*. Motoring Correspondent, Associated Newspapers Ltd., London, 1999.
- 14 Willoughby, C. *Singapore's Experience in Managing Motorization and its Relevance to other Countries*. Discussion Paper, World Bank, Washington D. C., USA, 2000.
- 15 May, A. D. and D. S. Milne. Effects of alternative road pricing systems on network performance, *Transportation Research Part A*, Vol. 34, 2000, pp. 407-436.
- 16 Button, K. J. and E. T. Verhoef. *Road pricing, traffic congestion and the environment: issues of efficiency and social feasibility*. Edward Elgar Publishers, Cheltenham, UK, 1998.
- 17 O'Cearbhaill, E. (2003). The use of high performance computing in assessing congestion charging in Dublin'. To be submitted as PhD to University of Dublin, Trinity College, November 2003.
- 18 Oum, T. H., Waters II, W. G and J. Yong. Concepts of price elasticities of transport demand and recent empirical estimates. *Journal of Transport Economics and Policy*, Vol. 26, 1992, pp. 139-154.
- 19 Goodwin, P. B. A review of new demand elasticities with special reference to short and long run effects of price changes, *Journal of Transport Economics and Policy*, Vol. 26, 1992, pp. 155-169.

- 20 Cole, S. *Applied Transport Economics: Policy, Management and Decision Making*, 2nd edition. Kogan Page Ltd., London, 1998.
- 21 Oldfield, R. H. and Tyler. *The elasticity of medium distance rail travel*, Report LR 993. Transport Research Laboratory, Crowthorne, Berkshire, UK, 1981.
- 22 Hall, M.D., Fashole-Luke, T., Van Vliet, D. and D.P. Watling. *Demand response assignment in SATURN*. PTRC European Transport, Highways and Planning 20th Summer Annual Meeting, Proceedings of Seminar E - Transportation Planning Methods, WS Atkins Planning Consultants and University of Leeds, UK, 1992, pp. 25-39.
- 23 Brady Shipman Martin, Kirk McClure Morton, Fitzpatrick Associates and Colin Buchanan and Partners. *Strategic Planning Guidelines for the Greater Dublin Area*. Department of the Environment and Local Government, Dublin, Ireland, 1999.
- 24 Transport for London: congestion charging.
http://www.tfl.gov.uk/tfl/cc_fact_sheet_key_stats.shtml
Accessed March 2003.

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- 3 Results for the simulation network for the total time simulated during testing. Results from the complete network over the total time period modeled (charged period plus the time taken for over-capacity queues to dissipate).
- 4 The effect of elasticity on the distance travelled during the charged period for the simulation network and for the complete network.
- 5 The effect of elasticity on the average speed over the simulation network for the charged period and for the total time period modelled.

TABLE 1. Factors Influencing Traffic Growth (I)

<i>Greater Dublin Area</i>	1991	1996	1999	2016
Population (million)	1.35	1.41	1.46	1.75
Households ('000)	402	446	521	675
Employment ('000)	452	549	602	878
Unemployment rate	16%	12%	6%	5%
Car ownership (per 1000 population)	247	292	342	480
% growth in GDP since 1991	-	42%	79%	260%



FIGURE 1. Basic map of the greater Dublin area showing the metropolitan area, the simulation area boundary and the inner city cordon.

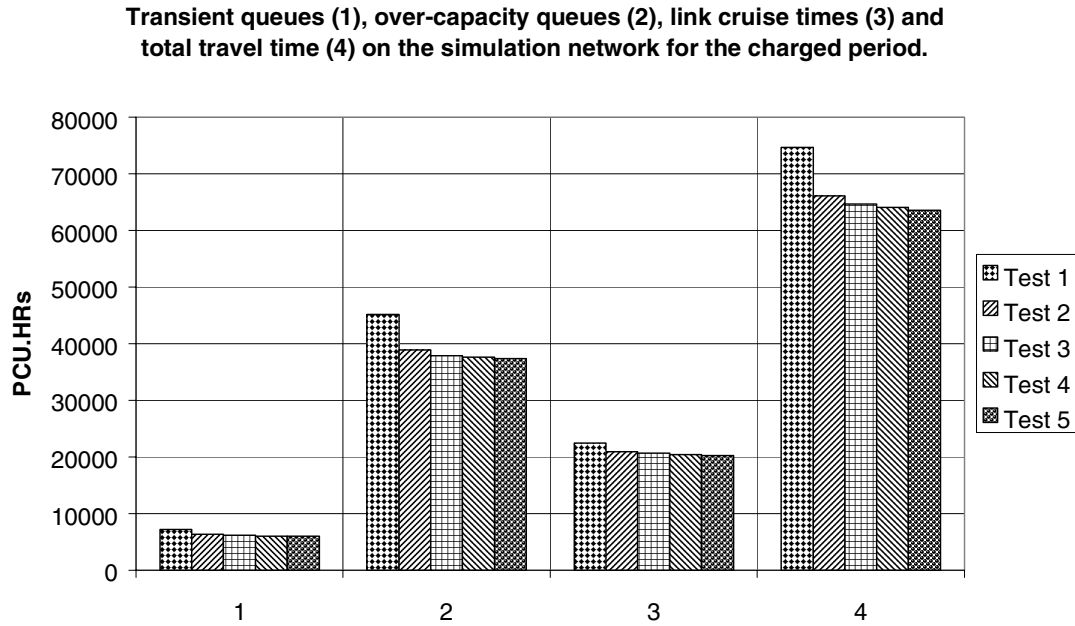


FIGURE 2. Results from the simulation network over the charged period, one hour in this case.

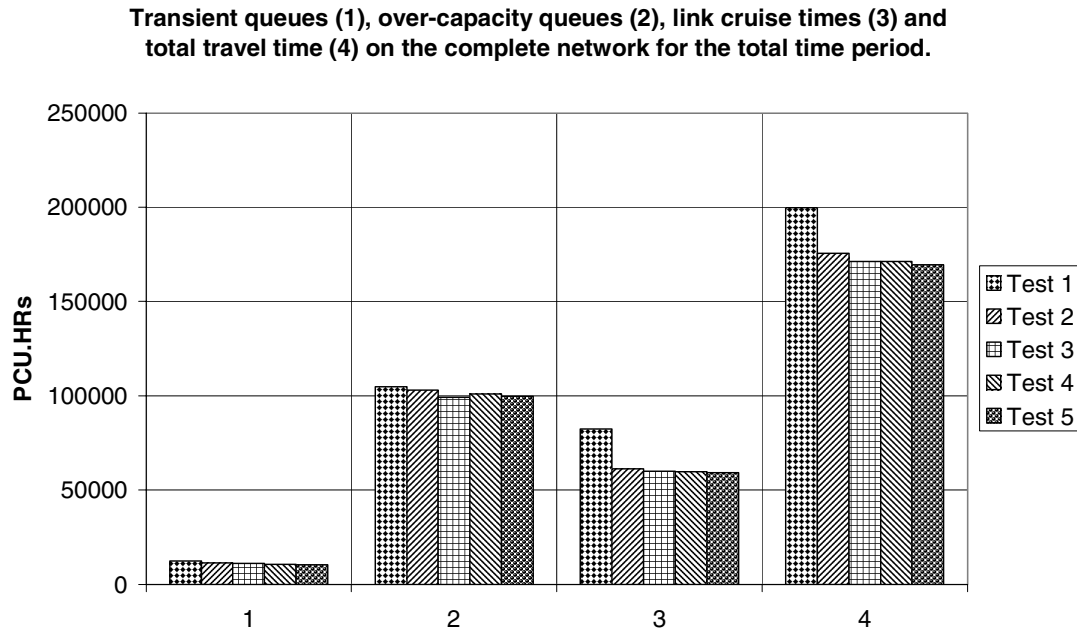


FIGURE 3. Results for the simulation network for the total time simulated during testing. Results from the complete network over the total time period modeled (charged period plus the time taken for over-capacity queues to dissipate).

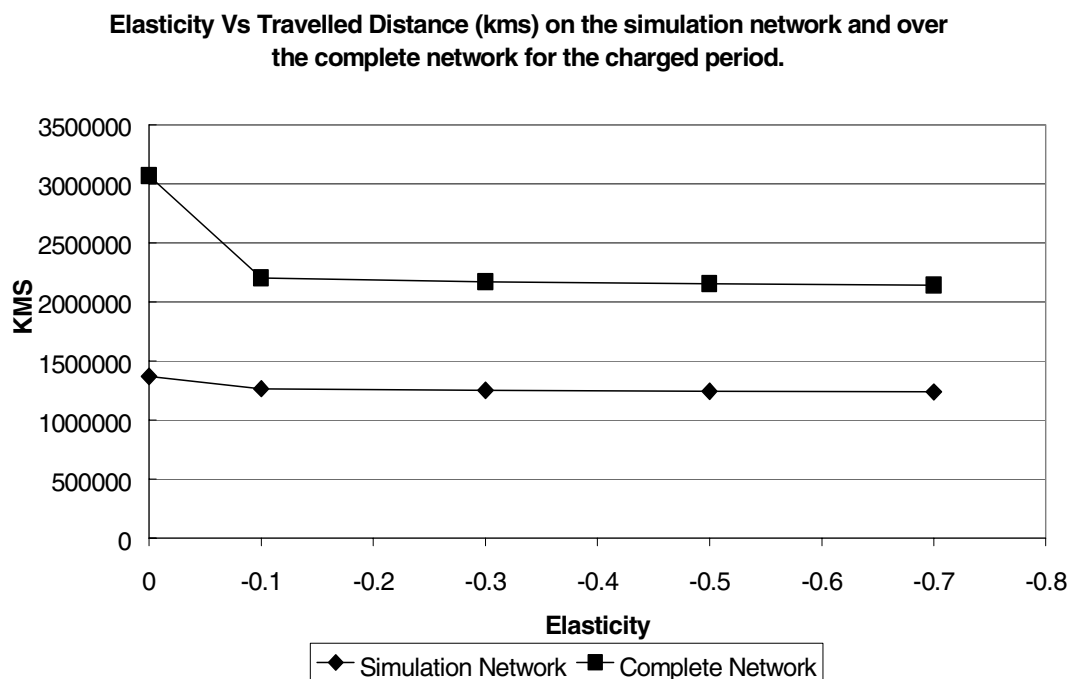


FIGURE 4. The effect of elasticity on the distance travelled during the charged period for the simulation network and for the complete network.

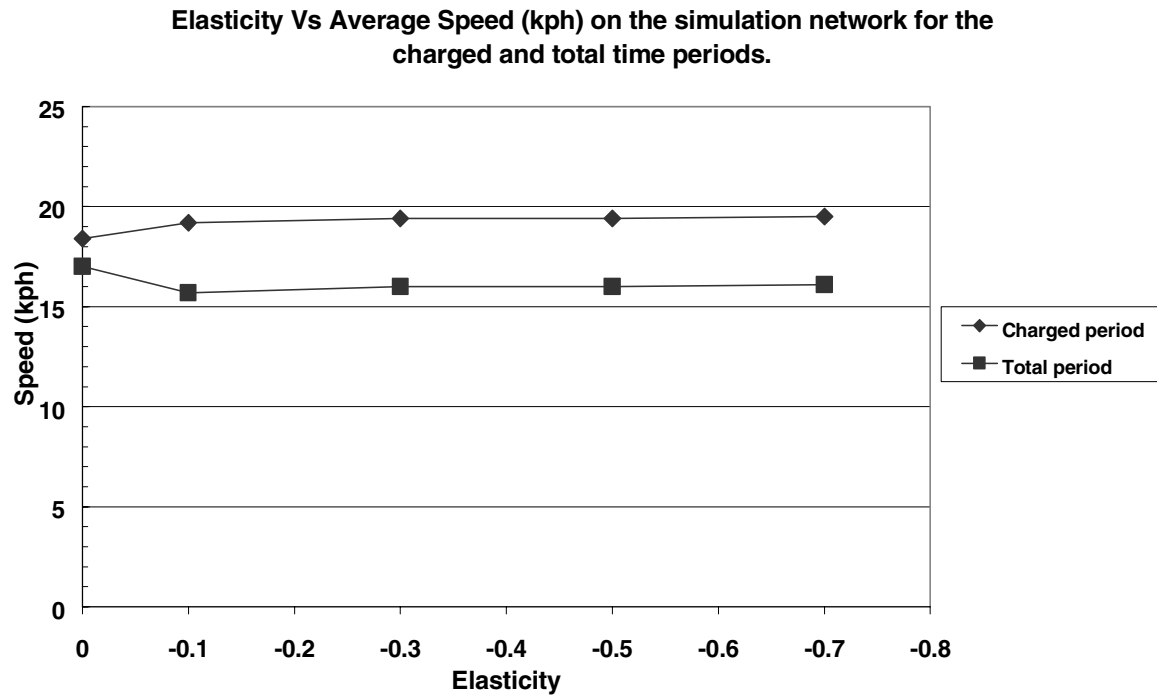


FIGURE 5. The effect of elasticity on the average speed over the simulation network for the charged period and for the total time period modelled.