Road use pricing for 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 parallelized version of the traffic network analysis model, SATURN, that runs on parallel processors.

The analysis evaluates both the citywide and local impacts of inserting such cordons onto the network. Variables to be examined include travel time, travel distance, queue lengths and transfer to other modes. The sensitivity of the model to changing elasticity levels will also be evaluated using a series of model tests. The elasticity levels used are based on previous international experience.

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. It is found that as a result of the cordon application there is approximately 30% less traffic in the area and a reduction in the distance traveled throughout the area of approximately 20%.

However, the area within the cordon, the inner city, appears to remain relatively congested. This leads to the conclusion that most of the benefits of the cordon are felt outside of the cordoned area as a result of trip makers switching to other modes of travel to get to their respective destinations.

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. As part of this package, traffic demand management is proposed as an important method for the control of traffic and traffic congestion.

Demand management seeks to reduce the growth in travel demand while maintaining a progressive economic environment and is designed to encourage a transfer of trips, especially during peak periods, from the private car to more sustainable modes of transport such as public transport, cycling and walking (*1*). There are a number of well-established forms of road user pricing including cordon charging, area licensing, screen-line tolling and pricing by time or distance. This paper evaluates the impact of a series of cordon road use pricing scenarios on the GDA using a newly developed parallelized version of SATURN that runs across parallel processors (see FIGURE 1 for an outline of the main arterial ad orbital routes of the GDA). SATURN is a suite of traffic network analysis programs with five basic functions. Its main function however, is as a combined traffic simulation and assignment model for the analysis of traffic management systems (*2*)

The paper is laid out in six sections. Section two describes the developments over the past fifteen years or so that have led to the present transportation situation in the GDA. Section three describes the methodologies used to assess the different cordon road use pricing scenarios. Section four describes the tests that have been carried out and discusses the results from these tests. Sections five and six look at the conclusions that have been drawn from the discussion and describe potential future research respectively.

The analysis will evaluate the local and citywide impact of cordon road use pricing scenarios on the GDA road network. Variables to be examined include travel distance, travel time, average speeds on the network, queue lengths and the transfer to other modes. The conclusion of this research will give a comprehensive set of results for a series of model runs evaluating cordon applications in the GDA.

BACKGROUND

The Dublin Transportation Initiative (DTI) was initiated in 1988 when the Minister for the Environment commissioned a review of transport planning in the GDA. As such, the DTI heralded a fresh, new approach to transport planning in the GDA.

In 1992, Phase Two of the DTI began the most important objectives of which was the drafting of a short and long term transportation strategy and the organisation and structuring of a continuous planning process. In 1994, two years later, after intensive negotiations and consultation between all of the interested groups, the DTI Final Report was published laying out a strategy for transportation planning in the GDA (*3*).

In the year following the publication of the DTI Final Report its implementation was already beginning to fall behind schedule. This led to the emergence of the Dublin Transportation Office (DTO) in 1995. The DTO's mandate was to strategically monitor the transportation planning process. In September 1998 the DTO published a report entitled 'Transportation Review and Short-Term Action Plan' (*4*). This assessed the remaining period of the Operational Programme for Transport (1994-1999) set out in the DTI for the GDA and progress on the implementation of the DTI. It was found that there had been considerable

'slippage' in this implementation. The report went on to produce short term plans to address the deterioration in travel conditions, especially during peak periods, within the GDA.

In September 2000, the DTO published a further transportation strategy for the GDA, entitled 'A Platform for Change' (*1*), planning the development of infrastructure, services and potential management approaches for the period between 2000 and 2016. The aims of this strategy are to develop a more efficient transport system by increasing the overall capacity of the transport network and by reducing the demand for trips through demand management and traffic calming measures.

The DTO 2000-2016 Strategy has two elements of approach, 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 the DTO 2000-2016 Strategy states, the proposed infrastructure and service improvements will not be enough to cope with the predicted demand for transport in the near future without some form of additional demand management strategy.

There are two main reasons that exist as the cause of the transportation deficit in the GDA. The first reason is that there has been considerable 'slippage' in the implementation of the DTI, although with the emergence of the DTO more efficient progress has been made. The second reason is that there has been unprecedented growth in the Irish economy resulting in very large increases in the levels of traffic on the roads and increased congestion. At the time the DTI was produced this economic growth could not have been predicted accurately.

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% 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% of peak hour trips being accounted for by the private car. The forecast for 2016 looks even worse with a 95% 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(*1*). 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.

METHODOLOGY

Previous studies of road use pricing in the greater Dublin area

'A Study of Road Pricing in Dublin' was produced by Oscar Faber Consultants, Goodbody Economic Consultants, TORG – University of Newcastle and TSRG, Trinity College Dublin (*5*) and published in 1998. This is the only report that has been produced to assess road use pricing in the GDA and in essence was a feasibility study.

The study examined a small number of testing scenarios to try to assess the feasibility of road use pricing and other economic 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 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 were 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. The data describing the network has been provided by the DTO. This data was then edited to incorporate the cordon. The second data set is the trip matrix, which was also provided by the DTO. There are three main factors to consider when editing the trip matrix to represent the reaction of trip makers to the cordon. These include the charge applied at the cordon, 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 road use pricing scenario.

Charge levels

Road use charges should be linked as closely as possible to marginal external costs (*6*). A study of transport externalities was undertaken in the GDA in 1998. The study found that a charge of approximately EURO 6.86 (US$5.55) would be representative of the externalities associated with the average trip in the GDA (*7*). This means that for the average trip approximately EURO 6.86 (US$5.55) would have to be levied from the trip maker to cover the cost of making the trip in 1998.

Consultants Halcrow Fox and Associates have found that between EURO 8.20 and 16.39 (US$7.10 – 14.20) could be charged to enter London's central district, while EURO 4917 (US$4260) could be levied on all work related long term parking within the central cordoned area (*8*). In Singapore, where they have used a system that combines using toll charges on the major expressways entering the city centre with a restricted zones network, charges range from between S$3.00 and S$5.00 (US$ 1.65 – 2.75) during peak periods (*9*). The exchange rate in 1999 was 1.69 Singapore Dollars to one American Dollar (*9*). In 1999, the Oscar Faber et al report looking at Dublin (*5*) suggested that charges varying from between EURO 0.79 and 3.81 (US$ 1.11 – 3.33) should be used. However, this report is based on an aggregated transportation network produced by the DTO for the GDA in 1997. Further testing has been carried out in Cambridge to investigate the effects of congestion charging (*10*). Charges of between EURO 0.98 and 8.20 (US$ 0.85 – 7.10) were used for the testing.

Another form of road use pricing is toll charging. In Europe, toll charging tends to be used for raising revenue. Toll charging schemes have been implemented predominantly in Scandinavia, including Bergen (1986), Oslo (1990) and Trondheim (1991), while more limited experiments have taken place in Stuttgart (1994-95) and in Stockholm. Single facility schemes such as toll roads have also been implemented around the world, including France, California, San Diego and other places in the US (*11*). Two such schemes also exist in the GDA and while they have had little effect on the levels of transport demand, they have been successful as revenue collectors. The charges used for these toll schemes are much lower so as to raise revenue and not, predominantly, to dissuade too many travellers from using the tolled facilities.

To reflect the range of charges associated with the different types of road use pricing that have been implemented around the world, a wide range of charges will be used for this research. Cordon charges of between EURO 3.81 and 10.16 (US$3.33 – 8.88) will be used.

Elasticity

At this stage it is not possible to assign specific elasticities to represent user response to road use pricing scenarios in the GDA. As a result, a range of different elasticities is used to try to reflect

international experience. Estimating elasticities is a difficult task due to the number of factors that need to be taken into account. There is a large body of literature that has been produced on the estimation of demand elasticities and a number of good literature reviews have been published which summarise the literature well. These reviews include Oum, Waters & Yong (*12*) and Goodwin (*13*). The only information on elasticities in the GDA is provided by the Oscar Faber et al report (*5*), which suggests that a peak demand elasticity value of between –0.1 and –0.5 be used for the GDA during the morning peak period.

Other studies of, and research using, road use pricing elasticity estimates suggest values varying from between –0.1 to –1.2, see Cole (*14*), Oldfield (*15*) and Halcrow Fox (*16*). During peak periods elasticity values tend to be lower. This is because work related commuting trips are considered to be more of a necessity for trip makers. As a result, their user response to an extra charge on the way to work is offset by their necessity to get to work. Based on available literature, elasticities varying from between –0.1 and –0.7 are used to represent trip maker's user response to charges during peak periods.

Elasticity demand function

The elasticity demand function used for the research is the same as that used in the Oscar Faber et al study in 1998 (*5*). 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.

The methodology used in the UK Engineering and Physical Sciences Research Council (EPSRC) study, that led Oscar Faber 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, in the case of the GDA the function below is more consistent with what might be expected (*5*).

$$\mathbf{T_{new} = T_{base} \ EXP \ (El. \ (\ (\ CH + C_{base}) \ / \ C_{base} - 1) \ )}$$

where T_{new} = trip demand after road use charge has been applied to the trip cost
T_{base} = trip demand in the base year over each route for each origin/destination pair
CH = road user charge applied 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 estimate.

TESTING

The GDA network is split into a simulation network and a buffer network. The simulation network encapsulates the inner city and suburbs while the buffer network represents the greater part of the GDA as well as traffic entering the GDA along major routes from the rest of the country. Below, the simulation and buffer networks combined are referred to as the complete network. The initial cordon location for testing is based on that described in the Oscar Faber et al report (*5*). For initial testing the trip matrix and network files used were developed by the DTO.

The base year for these files is 1997, i.e., the files have been produced based on data collected from surveys that took place in 1997. The 1997 base year trip matrix has been factored up by the DTO to represent regular trip demand on the network for 2000 and 2006.

Testing has been carried out on the GDA network for 1997, 2000 and 2006. However, this paper will concentrate on results from testing carried out on the GDA network for 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 the file to represent the completion of planned and confirmed infrastructural projects that should 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 (*1*).

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. Five testing scenarios are described in the next section below.

Test scenarios

1   Baseline 2006 network file and trip matrix file, as provided by the DTO.
2   Cordoned network file using EURO 3.81 (US$3.33) charge. New trip matrix file using a EURO 3.81 (US$3.33) charge (which, at EURO 0.0762 (US$0.066) per minute gives a charge (CH) of 3000 seconds), and an elasticity of –0.1 (El = –0.1).
3   Cordoned network file using EURO 3.81 (US$3.33) charge. New trip matrix file using CH = 3000 seconds, and El. = -0.3.
4   Cordoned network file using EURO 3.81 (US$3.33) charge. New trip matrix file using CH = 3000 seconds, and El. = -0.5.
5   Cordoned network file using EURO 3.81 (US$3.33) charge. New trip matrix file using CH = 3000 seconds, and El. = -0.7.

Test results and discussion

The road use pricing scenarios will be assessed and discussed using a number of variables described as follows: -
- Transient queue measurement records the time spent by vehicles in queues which, in the case of signals, clear during a single cycle.
- Over capacity queue measurement records 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 (passenger car unit), kilometres on simulation links.
- The overall average speed is defined by (distance)/ (time).

These variables are given for both travel in the time period simulated and for extra travel time and distance in later periods because of the impact of vehicles queued at over capacity intersections and because of the time it takes for those queues to dissipate. In FIGURES 2 to 7 there is a distinction made between the first time period simulated, one hour in this case, and the total time simulated (the first time period plus the next time period, i.e. total of two hours) over the test runs. The reason why an extra time period is examined is because of the over capacity queuing at intersections where the traffic congestion has not yet dissipated.

FIGURE 2 shows the results from the simulation network for the first time period simulated, one hour in this case, for a cordon charge of EURO 3.81 (US$3.33). Section one of this figure shows that transient queues remain at relatively the same level irrespective of an increasing elasticity with respect to the charge of EURO 3.81 (US$3.33) through Tests 1 to 5. In FIGURE 3 where similar information is displayed but for the total time period of two hours, it can be seen that over the total time simulated, the levels of transient queue remain similar. There is a slight reduction in these levels as the elasticity is increased. This trend is reflected in FIGURES 4 and 5 for the complete network. The time spent by vehicles in transient queues throughout the total simulated time for each test remains at approximately the same level for both the simulation network and the complete network.

Returning to FIGURE 2 but concentrating on over-capacity queue totals it is noted that there is a sharp drop in the number of pcu.hrs between Test 1 and 2. This is due to the application of the cordon charge to the GDA with an elasticity of user response of –0.1 in Test 2. Overall it can be seen that the rate of reduction of the over-capacity queue totals appears to reduce when proceeding through Tests 2 to 5 irrespective of the increases in elasticity. In FIGURE 3, for the total time simulated, the over-capacity queue totals actually increase between Test 1 and 2 in the simulation network before dropping off slowly as one proceeds from Test 2 to 5. This means that over-capacity queuing is worse in the period immediately after the initial charged one-hour period. Over the complete network, in FIGURES 4 and 5, more predictable results were found. For the first time period simulated the complete network mirrors the reaction of the simulation network to the cordon in FIGURE 2. For the total time simulated, FIGURE 5, there is a small but relatively constant reduction through Tests 1 to 5 over the complete network.

Link cruise times are made up of free flow times on links plus the delays on those links. Analysing the link cruise times in FIGURES 2 and 3, there is very little change running through from that of the initial level output for the base test, Test 1, and levels output after the cordon has been applied in Tests 2 through 5. This is found for all of the test runs within the simulation network (see FIGURE 3 where results for the total time simulated are graphed). For the complete network, presented in FIGURES 4 and 5, there is a sharp drop in the pcu.hrs followed by a smaller, but consistent, drop as the elasticity is increased, proceeding from Test 2 to 5. This suggests that although the over capacity queues 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 to 5 is the total travel time. Over the simulation network, presented in FIGURES 2 and 3, 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 FIGURES 4 and 5, for the complete network, the total travel time drops markedly when the cordon is introduced. It also appears that as the elasticity increases the rate of reduction in travel times is decreasing rapidly. This demonstrates that for a particular cordon charge there appears to be only a certain number of travellers who will respond to it.

FIGURE 6 shows a graph of elasticity versus travelled distance for the total time simulated. 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, trip demand remains high in the congested simulation network. The simulation network remains congested with the kilometres traveled reducing only slightly through the tests. This brings the strategic aims of applying an inner city cordon into question. The question is whether the cordon should reduce the levels of congestion in the inner city more dramatically or should it be used as a tool to reduce the overall traffic demand of the GDA. This reduction in demand within the GDA as a whole is demonstrated by the large initial reduction in the kilometres traveled on the complete network.

FIGURE 8 shows the response of the average speed levels to the change in the elasticity for the simulation network and for the complete network over the first and total time periods. When FIGURE 8 is examined it is noted that the speed on both the simulation and complete networks have slowed down in Test 2 and then recovered when proceeding through the tests as the elasticity is increased. This is due to the test setup where the cost of passing through the cordon is used in the model in units of seconds. Therefore, the time for making a trip into the cordoned area, i.e. the inner city, is increased by the charge (in seconds) but fewer trips are being made, giving a reduction in the distance travelled over the network.

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*). Irrespective of the increase in capacity due to the present and future developments in infrastructure and services (*1*), the transportation deficit will continue to grow unless one or more forms of demand management are utilised (*5*).

This paper has examined one form of demand management, road use pricing, with a view to assessing the effects of an inner city cordon scheme on transportation in the GDA. The effects of a charge of EURO 3.81 (US$3.33) were examined over a range of user elasticities ranging from –0.1 to –0.7.

Transient queues decreased slightly as the elasticity was increased up to –0.7. This shows a reduction in the numbers of trips entering the simulation area, as expected. However, because the levels of transient queue drop off as the elasticity level is increased it is evident that the GDA network is remaining relatively congested, even with high response rates to the cordon application, i.e., an elasticity of –0.7. A reduction in over-capacity queues is noted in the simulation network during the first hour of the model run for elasticities up to –0.7. This demonstrates a reduction of congestion delays during this period. However, over the course of the total time period examined i.e. two hours the cordon is having less effect on the over-capacity queues in the GDA. This may be due to peak spreading.

The analysis of the link cruise times suggests that the cordon helps to reduce delays on the buffer network more than on the simulation network. This point seems to be reinforced further by the total travel distance recorded, which also levels off after an initial sharp reduction from Test 1 to 2, although there is a relatively constant decrease in the traveled distance from an elasticity of –0.1 to that of –0.7. Perhaps an increased charge would be more appropriate to reduce inner city congestion more effectively. The test results also demonstrate a possible need

to widen the charging period to obtain a more efficient system. Further research will examine these possibilities.

Overall it is apparent that the complete network, representing the GDA, is far less congested as a result of the cordon application with approximately 30% less traffic on the network and a reduction in the distance traveled of approximately 20%. The simulation network remains relatively congested due to very high initial over capacity queues that are unable to dissipate efficiently. This leads to the conclusion that most of the benefits of the cordon are felt in the buffer network as a result of trip makers, that travel from the buffer network, switching to other modes of travel to get to their respective destinations.

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TABLES AND FIGURES

TABLES

1 Factors Influencing Traffic Growth (*1*)

FIGURES

1 Basic map of the greater Dublin area showing major arterial and orbital routes in the region.
2 Results from the simulation network for the first time period simulated, one hour in this case.
3 Results for the simulation network for the total time simulated during testing.
4 Results from the complete network for the first time period simulated, one hour in this case.
5 Results for the complete network for the total time simulated during testing.
6 The effects of elasticity on the distance traveled during the total time simulated for the simulation network and for the complete network.
7 The effects of elasticity on the average speed during the total time simulated for the simulation network and for the complete network.

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TABLE 1 Factors Influencing Traffic Growth (*1*)

Greater Dublin Area	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%
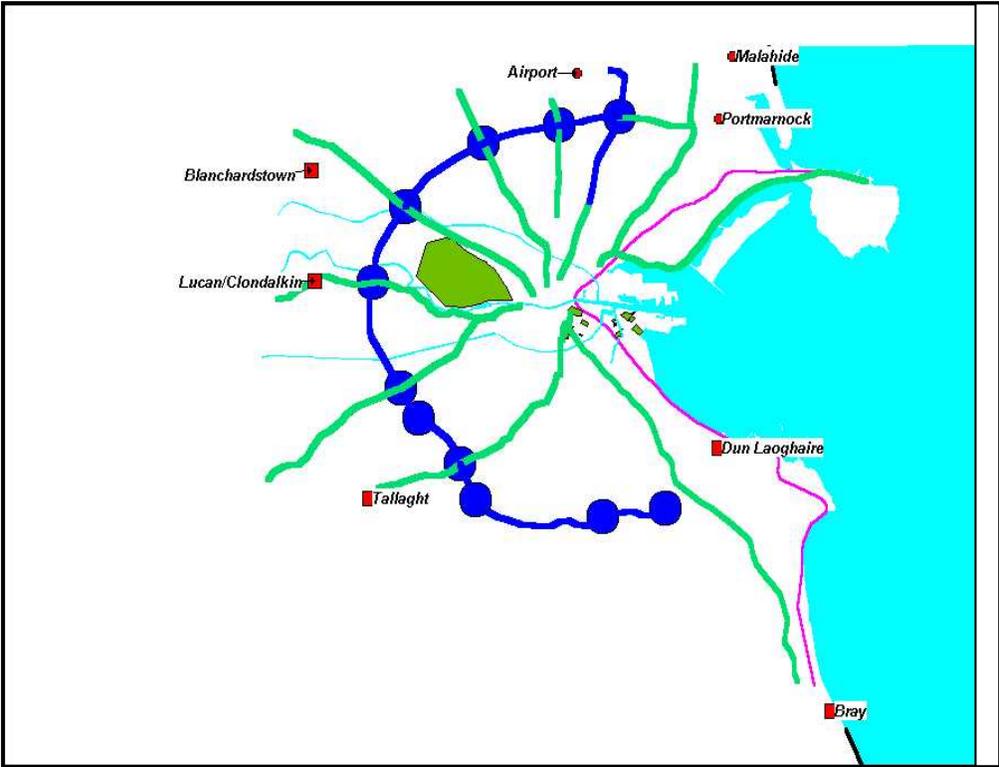
FIGURE 1 Basic map of the greater Dublin area showing major arterial and orbital routes in the region.
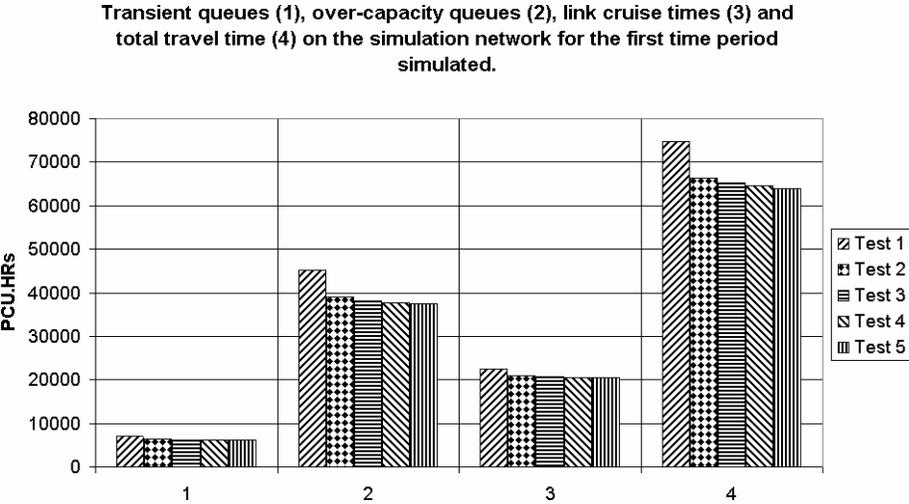
Transient queues (1), over-capacity queues (2), link cruise times (3) and
total travel time (4) on the simulation network for the first time period
simulated.

**FIGURE 2 Results from the simulation network for the first time period
simulated, one hour in this case.**

Transient queues (1), over-capacity queues (2), link cruise times (3) and total travel time (4) on the simulation network for the total time simulated.
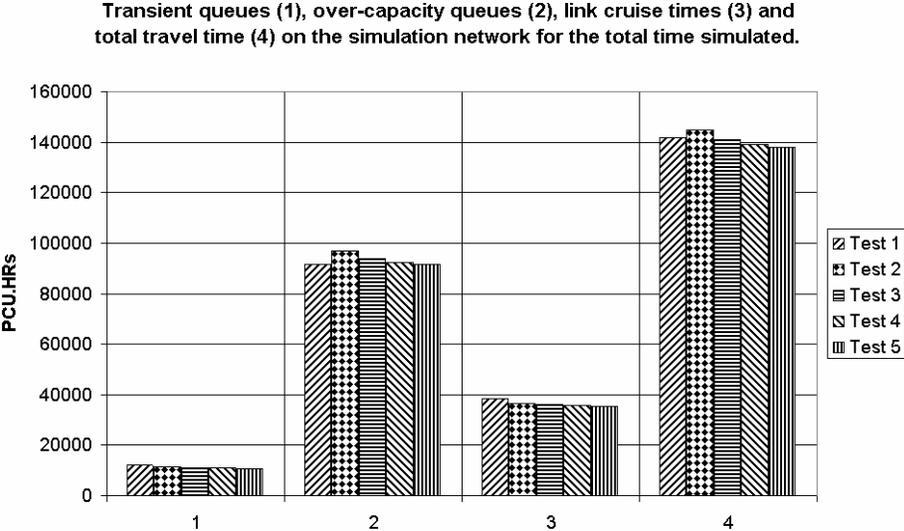
FIGURE 3 Results for the simulation network for the total time simulated during testing.

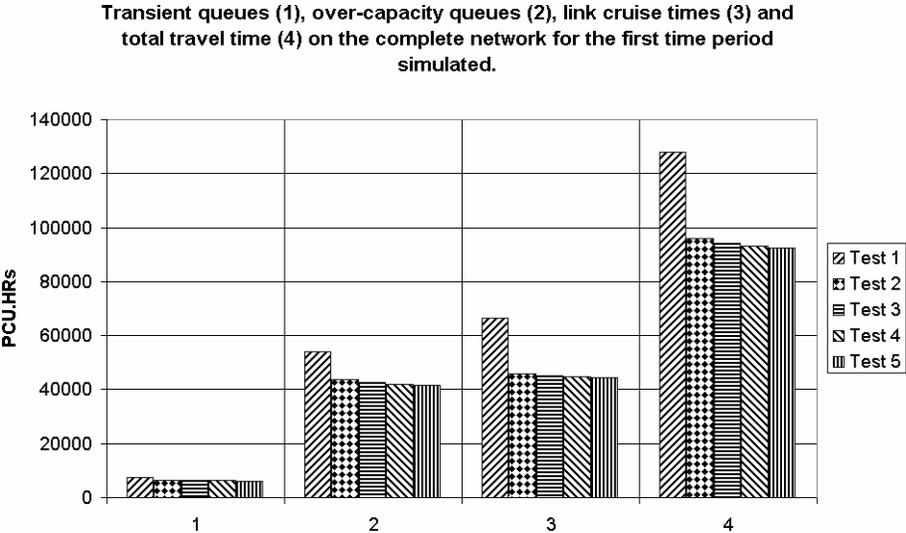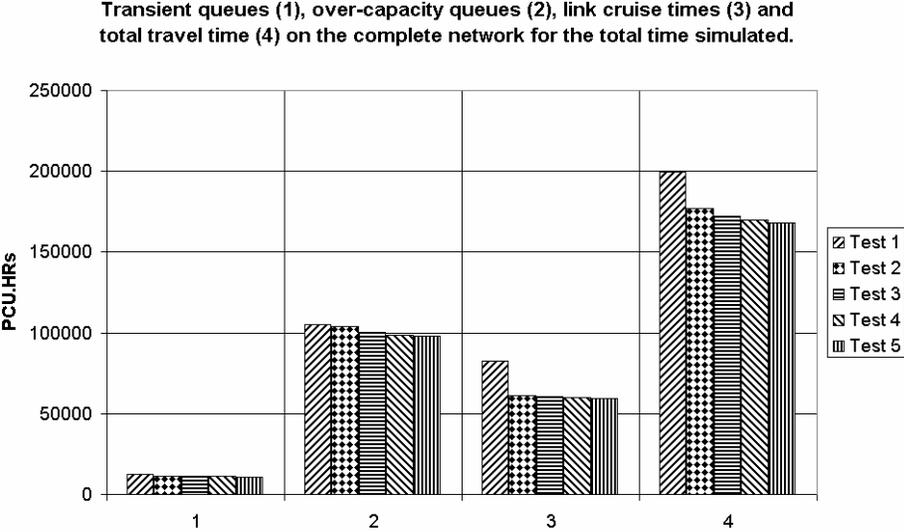**FIGURE 4 Results from the complete network for the first time period simulated, one hour in this case.**

Transient queues (1), over-capacity queues (2), link cruise times (3) and
total travel time (4) on the complete network for the total time simulated.

**FIGURE 5 Results for the complete network for the total time simulated
during testing.**

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Elasticity Vs Average Speed (kph) on the simulation network and over the complete network for the total time simulated.
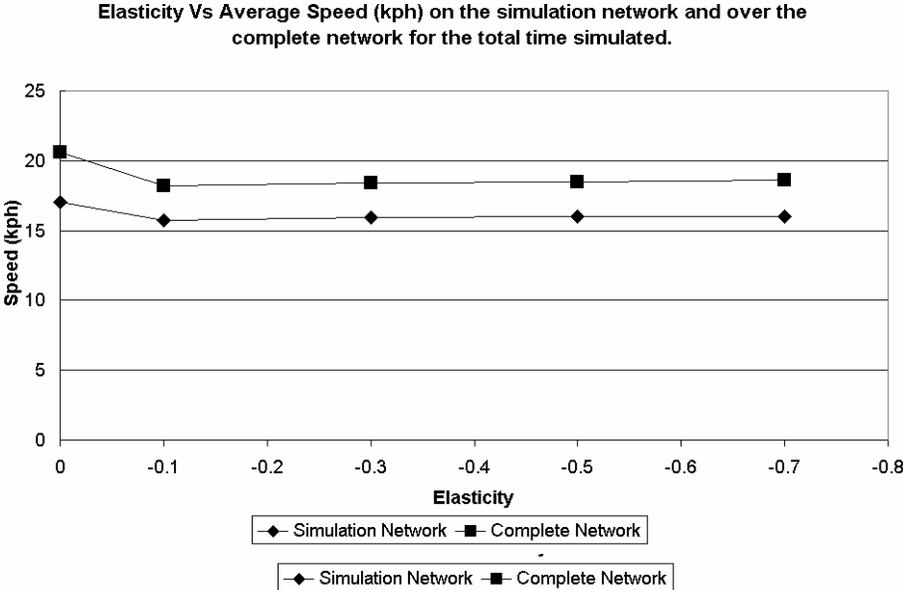
FIGURE 6 The effects of elasticity on the distance traveled during the total time simulated for the simulation network and for the complete network.