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FORECASTING THE IMPACT OF DEMAND MANAGEMENT STRATEGIES: RESULTS FROM SATURN MODEL TESTS (PART 1)

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1. INTRODUCTION

This report provides a summary of the network modelling which has been undertaken as part of the "Transport Demand Management in Historic Cities" research project. This report describes the development of techniques which enable the strategies of the project, as described in the document "Proposed Strategy Measures - Consultation Document,"[1] to be modelled. The results presented within this report should not be taken as the final results for the project. However, the results can be read as a first round of results indicating that the model is capable of forecasting the impacts of the strategies. Furthermore, these results provide an indication of the possible impacts of the strategies and should be used as the basis of discussion with regard to the implications of introduction of such strategies and the manner in which the strategies could be combined.

2. THE BASE MODELS

Please refer to Figure 1 to Figure 6 whilst reading this section.

This section provides some background information on the three models being used within this project. This information should be referred to during the consideration of the results as the structure of the model can often have an impact on the behaviour observed within that model. Figure 1 to Figure 6, attached in Appendix A are network plots of each model showing the extent of the network and the location of the inner and outer orbital routes. Table 1 indicates the basic statistics of the models.

	Cambridge	Norwich	York
Road Length (km)	810	423	218
Zones	141	182	179
PCU Trips	42216	40032	31481

Table 1 Model Summary

As Table 1 clearly represents, the models are different in scale. The Cambridge model includes several long distance links. This has given Cambridge 1 kilometre for every 0.52 kilometres in the Norwich model and 0.27 kilometres in the York model. Table 2 below shows the implications of these links once loaded with trips.

Network	Total Delay (Hours)	Total Travel Time (Hours)	Total Travel Distance (km)	Average Speed (km/h)	Delay / TTT
Cambridge	1554	18755	1240556	66.14	0.08
Norwich	2633	10519	371697	35.33	0.25
York	1845	4795	192597	40.17	0.38

Table 2 Overall Network Results

As Table 2 shows, the base situation in each network is noticeably different from one another. The long links of the Cambridge model are also heavily trafficked which produces the very large figure for total travel distance. Additionally, many of these links have been coded as 'buffer' links. Within

[1] This document is an internal project document that has been circulated amongst the collaborating partners. The descriptions of the strategies within this report are the same as those of the consultation document.

the model, buffer links are crudely modelled in terms of the interaction between flow and speed. This leads to, perhaps artificially, low levels of delay in this part of the network. Using a crude measure for density of traffic movement, total travel distance divided by the road length, the Norwich and York models return results of 878 and 883 travelled kilometres per kilometre respectively, whereas the Cambridge figure is 1531 travelled kilometres per kilometre suggesting that the network is much more trafficked.

To ameliorate this effect, the network indicator results, except those relating to the matrices, considered in this report relate to the city as far as and including the outer orbital. By limiting the investigation to the area of the city, the base results change to become more similar.

Network	Total Delay (Hours)	Total Travel Time (Hours)	Total Travel Distance (km)	Average Speed (km/h)	Delay / TTT
Cambridge	1341	4105	166556	40.57	0.33
Norwich	1587	4261	93597	21.97	0.37
York	1798	4457	164837	36.98	0.40

Table 3 City Network Results

As Table 3 shows, the cities as defined within this project, are more similar to each other than the network models would suggest. The York figures are only marginally less than those presented above. This reflects the scale of the model in that the modelled area extends little beyond the outer orbital. The Norwich figures reflect the choice of outer orbital, being closer to the city centre than the other cities and shorter in length. The implication of this is that there is physically less space enclosed and hence a much smaller amount of road length. A further complication of the Norwich model is that the outer orbital is incomplete in the south west corner. The will have implications in the discussion of results. The Cambridge outer orbital is well defined on the west and north sides of the city, and of motorway standard in places, but becomes more arbitrary on the east and south sides.

Another measure of the differences between the models is to consider the distribution of trip ends. Below is a simple three by three matrix which indicates the distribution of trip ends for each city. The rows within the matrices are the origins and the columns are the destinations - e.g. 3.5% of trips within the Cambridge model are from the centre of Cambridge to the [Rest of the] City and a total of 6.7% of trips within the model start from the city centre.

Cambridge Base Matrix	Centre	City	External	Total
Centre	1.6%	3.5%	1.6%	6.7%
City	5.4%	18.8%	9.3%	33.6%
External	6.7%	25.5%	27.5%	59.7%
Total	13.8%	47.8%	38.4%	100.0%
Norwich Base Matrix	Centre	City	External	Total
Centre	1.4%	2.0%	1.9%	5.3%
City	4.9%	13.9%	15.0%	33.8%
External	8.0%	27.7%	25.1%	60.9%
Total	14.4%	43.6%	42.0%	100.0%
York Base Matrix	Centre	City	External	Total
Centre	0.3%	3.9%	1.5%	5.7%
City	8.6%	37.0%	13.9%	59.5%
External	3.9%	23.0%	7.9%	34.8%
Total	12.7%	63.9%	23.3%	100.0%

Table 4 Trip Distributions of the Three Cities

As Table 4 indicates, the York model concentrates on trips which are mainly contained within the city. Only 7.9% of the York matrix does not have a trip end within the city, whereas, both Cambridge and Norwich have more than 25% of their modelled trips without a city based trip end. The implication of this is that more traffic will be affected directly by the strategies in York than in the other cities. However, each of the cities has about 13 per cent of traffic with a city centre destination. As the focus of the strategies is at the city centre, there is merit in comparing the changes to the levels of this traffic.

3. MODELLING THE STRATEGIES

3.1 General

3.1.1 The SATURN Model

The modelling work has used the network model SATURN, which has been developed and continues to evolve at the ITS. The work has been undertaken using various versions of SATURN ranging between 9.3.15 to 9.4.6. SATURN is, first and foremost, a route choice model, using the concept of generalised costs to allocate trips to routes. The distribution of trips is determined on the premise that no one trip can reduce its generalised cost by choosing an alternative route. The base unit within SATURN is generalised seconds which is derived from the following relationship:

$$GTIME = T + (D \times VOD) + \frac{OP}{VOT}$$

Where:

GTIME =	Generalised Time
T =	Time in seconds
D =	Kilometres
VOD =	Value of Distance
OP =	Out of Pocket Expenses
VOT =	Value of Time

The modelling process within the project has called for the application of new techniques and some modifications to the SATURN files themselves. These will be outlined described below.

3.1.2 Elastic Assignment

The results presented in this report are all taken from elastic assignment runs of SATURN. The assumption of elastic assignment is that if the cost of a movement between an origin and destination increases, then the demand for that movement will fall. The opposite is also assumed to hold true, when a movement becomes less expensive the demand for that movement will increase. As each of the strategies aims to impact upon an element within the generalised cost of trips, it is only prudent to allow demand to change to reflect this.

An elasticity value -0.5 has been used throughout the modelling exercise. The value was adopted after conducting a review of work by Goodwin (1992), Fowkes et al. (1991), Milne and Van Vliet (1993), Halcrow Fox and Associates et al (1993) and Toner (1993). This figure suggests that for a one per cent change in the cost of travel, demand will change by half a per cent in the opposite direction. The only other elasticity value employed was 0, which fixes the trips. As the elasticity value plays an important role in determining the magnitude of response to changes in the travel conditions within this project it will become the focus of more detailed work as this task and the stated preference work progresses.

3.2 Location of Strategy Implementation

As the strategies aim to reduce the amount of traffic in the city centre the city centre has to be defined. In each city a series of links which form an orbital was identified in the model and these were taken as the city centre boundary. A second series of links, further from the city centre were identified to form an outer orbital, effectively placing an outer boundary on the extent of the strategy target area and the "city." Figure 1 to Figure 3, attached in Appendix A, show the inner and outer orbital for each city[1].

3.3 Physical Restraint

This strategy is the most similar to usual applications of SATURN of all the strategies. Basically the modelling work concentrated on modifying the network description files for each city. The stated aim of this strategy was to increase inbound travel times by up to 20 minutes. However, as travel times are an output of the model rather than an input they are very difficult to control. The aim of inducing extra travel time is to reduce the number of vehicles within the city centre by discouraging travel en route to the centre.

There are several methods that can be employed as a means of changing the performance of links and junctions within the SATURN model. The work within this project concentrated on reducing the number of lanes entering junctions on the inbound radials. The radials that were focussed upon were those which directly connected the outer orbital and the inner orbital. The routes are highlighted in Figure 1 to Figure 3. This measure reduces the effective capacity of these junctions which in turn will have the effect of producing extra queuing as vehicles fail to clear the junction.

[1] It should be noted that the outer orbital for Norwich is within the built up. The choice of route was taken after discussion with Norfolk County Council.

3.4 Permit Restraint

The first step involved with implementing this strategy was to divide the base trip matrix into two user classes. The classes are based on whether the modelled trip terminates at the city centre. The modelling then took place in three stages;

- banning through traffic and allowing all city centre trips,
- banning through traffic and allowing 75% of city centre trips and;
- banning through traffic and allowing 50% of city centre trips.

The class of trip maker not terminating at the city centre was then banned from using the links from the inner orbital into the city centre. The reduction of the allocation of permits from 100 per cent of terminating trips to 75 per cent and then 50 per cent was effected by reducing the city centre terminating matrix accordingly.

3.5 Parking Charges

The manner by which parking charges were applied within the model has drawn heavily on the methods described by Milne and Van Vliet (1993). Essentially a penalty in seconds of the equivalent to the financial charge, calculated by converting using the relevant value of time[1], is applied to a specific link. In the case of parking charges the link is the zone centroid connector. This places an extra cost on all traffic using that particular zone, without having any impact of the traffic using the real links in the network. For the modelling within this project a flat penalty was applied to each city centre zone the rates being £2.00, £4.00, £6.00 and £10.00. The main reason for adopting this method was linked to the available information about parking in each city. As there was little information available on the numbers of trips paying for parking at the city centre in the morning peak. Additionally, where the data was available it transpired the weighted average fee paid was less than the charges being considered.

3.6 Road Use Charging

Again the work of Milne and Van Vliet (1993) was adapted for modelling this strategy. Charges were specified for road links in the network at both the outer and inner cordon. The charges applied, as time penalties calculated using the above method, at the outer cordon were double those of the inner cordon. This strategy imposes a greater penalty on trips from outside the city than on movements wholly within the city. The levels of toll considered were those given in Table 5 below:

	Level 1	Level 2	Level 3	Level 4
Inner Cordon	50p	100p	150p	200p
Outer Cordon	100p	200p	300p	400p

Table 5 Cordon Charge Levels

[1] The Value of Time in each model was assumed to be 7.63 pence per minute.

3.7 Combination Strategies

At this stage in the project the above strategies have all been tested in isolation from one another. However, the purpose of modelling these strategies is to identify the most suitable candidates for further modelling work. These will include some of the above strategies, changes to the above levels examined and combinations of the above.

4. PRESENTATION OF RESULTS

4.1 Network Performance

The following network performance indicators have been considered for presentation.

- Matrix changes, indicating the pattern of demand between different spatial areas of the model,
- Total time spent travelling by all vehicles, measured in hours,
- Total travelled distance, measured in kilometres,

The tables presented within this report show indexed values to a base of 100. Although this masks the contribution to each indicator that each road class, defined below, makes it does give a ready indication of changes on those road classes between strategies.

4.2 Other Indicators

4.2.1 Environmental Indicators

Fuel Consumption, Carbon Monoxide, Carbon Dioxide, Hydro-carbons, Oxides of Nitrogen and Lead. These indicators will be taken directly from the model output. The discussion of these indicators will be limited to one test in each strategy for each city which will show an indexed result to the base. The reason for the limited discussion is that the emission model within SATURN is due to be updated as part of this project. The model presently in use uses emissions for the average car in the vehicle stock in 1981. As this precedes most of the European Union legislation on vehicle emissions it brings the figures produced into doubt. Therefore, by showing an index value it is hoped that the figures are taken as an indication of the magnitude and direction of change rather than an indicator of the actual quantity of the pollutant being emitted.

4.2.2 Revenues

Where applicable, the revenues for the strategies have been estimated. These are described in pounds per day. The calculation of these is simply the product of the number of vehicles parking or crossing the toll cordon and the relevant fee rate.

4.3 Road Classification

To allow for an investigation of the impact of the strategies on different roads and in different areas of the city, the links have been classified in each of the cities and figures for flows into the city and the city centres have been taken from the model output. The classification is as follows:

City centre	implying those links wholly within the inner orbital
Inner Orbital	the links which make up the inner orbital

Rest of City	the links within the outer orbital, but beyond the inner orbital, including all radial routes
Outer Orbital	the links of the outer orbital route.

5. NETWORK PERFORMANCE

As the SATURN model produces copious amounts of figures there has to be an element of selection about the results presented and discussed. This section includes trip matrices from the harhest of each strategy and indexed time and distance results. However, there are more detailed trip matrices, and time and distance results for each city in Appendix B.

5.1 Physical Restraint

The impact upon the distribution of demand for travel within the matrices of each city is shown in Table 6 below.

Cambridge	Centre	City	External	TOTAL
Centre	102	103	101	102
City	98	97	100	98
External	96	96	99	97
TOTAL	97	97	99	98
Norwich	Centre	City	External	TOTAL
Centre	100	100	100	100
City	99	100	100	100
External	99	100	98	99
TOTAL	99	100	99	99
York	Centre	City	External	TOTAL
Centre	101	103	101	102
City	93	98	100	98
External	95	98	100	98
TOTAL	94	98	100	98

Table 6 Physical Restraint: Impact on Trip Matrices

As Table 6 clearly indicates the strategy tested had little effect on the overall demand for travel in each of the cities, as the total number of trips made only fell by one or two per cent. There are individual movements which did lose traffic, most notably all travel to the York city centre and travel to Cambridge city centre from the rest of the city and external zones. There were also movements which gained traffic, with trips originating in the city centre of Cambridge and of York rising by two per cent. The changes in the demand for travel reflect the manner in which the costs, time and distance cost of using links has changed. Table 7 gives the cost change details.

Physical - Distance	Cambridge	Norwich	York
City Centre	91	96	92
Inner Orbital	95	95	98
Rest of City	92	100	96
Outer Orbital	102	100	106

Table 7

Physical - Time	Cambridge	Norwich	York
City Centre	82	96	88
Inner Orbital	84	95	94
Rest of City	112	103	104
Outer Orbital	106	100	106

Physical - Distance	Cambridge	Norwich	York
City Centre	91	96	92
Inner Orbital	95	95	98
Rest of City	92	100	96
Outer Orbital	102	100	106

Table 7 Physical Restraint: Changes in travelled time and distance

As described above, the indicators of travel in each city centre and each inner orbital have fallen. Cambridge experiences the greatest decrease in travel with travelled time reduced by 18 per cent and distance by 9 per cent within the city centre. These results reflect the inability of traffic to get to the city centre. As the rest of the city links indicate there is 12 per cent more time spent, but 8 per cent less distance covered on these links. This translates to a reduction in travel speed of 19 per cent. Overall, the scheme is fulfilling the objective of reducing traffic in the city centre.

Within Norwich and York, the city centre results are similar but not as large as those of Cambridge. The changes to the radial routes have increased the time spent within the rest of the city. The Norwich model has no increase in travel on the outer orbital, unlike the other two cities, which indicates that this is not used much as a diversionary route. As described above, the outer orbital is within the urban area, with a comprehensive road network outside. As traffic can therefore reroute elsewhere the identified outer orbital will not show this.

5.2 Permit Control

The trip matrices presented in Table 8 below are taken from the "No Through Traffic and 50% Reduction in Terminating Trips" strategy.

Cambridge	Centre	City	External	TOTAL
Centre	50	105	101	90
City	50	100	100	92
External	50	100	99	94
TOTAL	50	100	99	93
Norwich	Centre	City	External	TOTAL
Centre	50	101	101	88
City	50	101	100	93
External	50	101	99	93
TOTAL	50	101	99	93
York	Centre	City	External	TOTAL
Centre	50	103	101	100
City	50	102	101	94
External	50	101	101	95
TOTAL	50	102	101	95

Table 8 Permit Control: Impact on Trip Matrices

The first column, trips to the city centre is the focus of the strategy and has been capped at 50 per cent of the base. By removing trips to the city centre in each of the subject cities there has been an

increase in other traffic, most notably from the city centre to the city and for city to city movements. This suggests that there the reduction of trips to the city centres has reduced the cost of travel elsewhere in the network to encourage additional trips. Table 9 below reveals the changes to the travel costs in the networks.

Permit Control	No Through Traffic			NTT + 25% Reduction in Terminating			NTT + 50% Reduction in Terminating		
Time	Cambridge	Norwich	York	Cambridge	Norwich	York	Cambridge	Norwich	York
City Centre	67	71	90	54	58	72	43	45	56
Inner Orbital	125	112	104	121	126	94	117	113	87
Rest of City	93	99	100	88	94	96	83	91	91
Outer Orbital	107	103	100	104	100	97	102	104	94

Permit Control	No Through Traffic			NTT + 25% Reduction in Terminating			NTT + 50% Reduction in Terminating		
Distance	Cambridge	Norwich	York	Cambridge	Norwich	York	Cambridge	Norwich	York
City Centre	74	76	87	61	64	74	49	49	59
Inner Orbital	109	110	100	108	110	100	107	111	100
Rest of City	98	97	99	95	95	97	93	92	95
Outer Orbital	103	103	100	102	102	98	101	100	96

Table 9 Permit Control: Changes in Travelled Time and Distance

Banning through traffic alone reduces the time spent travelling in the city centre by 33 per cent and the distance travelled 18 per cent for Cambridge, by 29 per cent and 24 per cent respectively for Norwich and by 10 and 13 per cent respectively for York. These results indicate that a sizeable proportion of traffic in the base uses the city centre links as through routes, especially in Cambridge and Norwich. As the amount of terminating traffic reduces, the travel indicators for the city centre continue to improve, with reductions for both indicators of up to an additional 26 per cent for the removal of 50 per cent of terminating traffic.

In all the cities, the inner orbital route bears the brunt of the diversion of through traffic with additional time, indicated by an increase in time and distance expended on this class of road. This is the case in all the tested options, even once city centre terminating traffic is removed.

The outer orbital also carries additional traffic as increases in travelled time and distance are recorded for the "No Through Traffic" option. Once the numbers of trips are reduced the outer orbital returns to, approximately, base conditions.

5.3 Parking Pricing

As a fiscal tool parking can be expected to demonstrate noticeably different results in comparison to the previous tools. Table 10 below shows the impact of trips for the highest level of parking charge, that of £10.00 per day.

Cambridge	Centre	City	External	TOTAL
Centre	16	101	101	80
City	24	103	101	90
External	50	102	99	95
TOTAL	36	102	99	92
Norwich	Centre	City	External	TOTAL
Centre	20	102	101	80
City	27	103	101	91
External	41	102	99	93
TOTAL	34	102	100	91
York	Centre	City	External	TOTAL
Centre	17	103	101	98
City	34	105	102	94
External	41	103	101	95
TOTAL	36	104	101	95

Table 10 Parking Charges: Impact on Trip Matrices

As Table 10 shows, the impact of the parking charges is felt most by the trips destined to the city centres since the charges are only applied in these zones. However, the magnitude of the change is important to note. In each of the cities the number of city centre to city centre trips falls by almost 85 per cent and all trips to the city centre by about two thirds. The charge has given rise to a more substantial decline in trips than the removal of 50 per cent of the city centre trips in the permit strategy.

The results also indicated that there si an element of trip replacement. Trips to other destinations in the city have increased by up to 4 per cent and trips to external zones are also up from city centre and city origins. Therefore, the overall impact is about the same as the enforced removal of trips from the matrix. The generation of trips, in those cells with a figure of more than 100, indicates a reduction of the travel cost between and within some areas of the network. Table 11 shows how the parking strategy affects the network conditions for each of the cities.

Parking Charges	£2.00			£4.00			£6.00			£10.00		
Time	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor
City Centre	82	79	75	79	74	70	76	69	68	73	65	65
Inner Orbital	89	95	90	87	92	90	85	99	83	85	97	80
Rest of City	93	96	93	91	94	91	90	93	91	88	93	89
Outer Orbital	95	96	96	93	95	95	93	93	94	92	92	93

Parking Charges	£2.00			£4.00			£6.00			£10.00		
Time	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor
City Centre	92	81	81	90	76	75	88	73	71	85	69	68
Inner Orbital	95	100	99	95	100	99	94	99	99	94	99	98
Rest of City	97	99	97	97	98	96	96	97	96	95	97	95
Outer Orbital	98	98	97	97	97	96	97	96	95	96	96	94

Table 11 Parking Charges: Changes in Time and Distance

Table 11 demonstrates a level of consistency with the changes in trip patterns, in that there are reductions in the travelled time and distance expended in the city centre networks. However, these fall short of the magnitude of change in the number of trips which terminate at the city centre. This leads to the conclusion that there is an increase in the level of through traffic. This conclusion is corroborated by the results from the other road classes in each network.

5.4 Road Use Charging

Road use charging, as defined for this strategy, employs a cordon at the outer and inner orbitals. The matrices presented Table 12 below are the results from the highest levels of charge, that of £4.00 per crossing at the outer cordon and £2.00 per crossing of the inner cordon.

Cambridge	Centre	City	External	TOTAL
Centre	92	106	101	102
City	67	91	101	90
External	62	74	99	84
TOTAL	68	83	99	87
Norwich	Centre	City	External	TOTAL
Centre	104	103	102	103
City	50	88	101	88
External	50	67	98	78
TOTAL	55	75	99	83
York	Centre	City	External	TOTAL
Centre	63	101	101	99
City	66	97	102	94
External	47	44	97	56
TOTAL	60	78	100	81

Table 12 Road Use Charging: Impact on Trip Matrices

The figures in Table 12 suggest that road use charging has an impact throughout the trip matrix in each of the cities. The most notable result is the fall in trips to the city centre, which in each city falls between 30 per cent and 40 per cent. The rest of the city also experiences a decline in the number of terminating trips of about 20-25 per cent for each city. This relates to the cost of crossing from the outer orbital into this area and is especially marked for cell of the matrix which reports external to city trips.

There are cells which demonstrate an increased number of trips. These are the outbound trips, such as the city centre to other city or external cells and the other city to external cell. The implication of this is that as the inbound traffic recedes the travel conditions for outbound traffic improve. This can be manifested as a reduction of opposing crossing movements at junctions, which over a trip involving several junctions can add up to a significant time saving. As conditions improve the number of trips increases. The implications of the changes in trip patterns are shown in Table 13 below.

Road Use Charging	50p / 100p			100p / 200p			150p / 300p			200p / 400p		
Time	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor
City Centre	51	57	67	42	51	63	40	47	60	38	45	57
Inner Orbital	129	86	106	129	76	101	119	70	97	115	65	94
Rest of City	77	78	96	72	72	92	69	69	88	68	67	86
Outer Orbital	104	108	76	103	106	71	100	105	68	99	105	66

Road Use Charging	50p / 100p			100p / 200p			150p / 300p			200p / 400p		
Distance	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor	Cam	Nor	Yor
City Centre	55	64	72	46	58	66	44	54	63	42	51	60
Inner Orbital	110	94	105	110	90	104	108	88	103	107	85	103
Rest of City	85	81	91	81	76	88	78	73	86	77	71	84
Outer Orbital	104	107	82	103	106	76	102	106	74	102	105	71

Table 13 Road User Charging: Changes in Travelled Time and Distance

The most notable results shown in Table 13 are the fall in travelled time and distance in the city centres of each city. The most dramatic falls are in Cambridge, which experiences declines of up to 60 per cent from both of these measures. Although neither of the other cities quite match these figures there are considerable changes from the base, up to 55 per cent less time spent in the city centre networks and 50 per cent less distance travelled.

Elsewhere in the networks there is an increase in the travel on the inner and outer orbital routes, of Cambridge and York and the outer orbital for Norwich. This reflects the use of these routes as traffic attempts to avoid crossing the cordons. The Norwich results suggest that Norwich traffic is more inclined to use the outer orbital, which in the light of the proximity to one another of these routes, seems a reasonable result.

The rest of the city links are benefitting from the diversion of traffic around the outer orbital as seen from the fall in travelled time and distance, especially for Cambridge and Norwich. York shows a much smaller benefit, reflecting the model description, which as discussed above, is more focussed on city traffic and less on area wide traffic.

6. Other Indicators of Performance

6.1 Environmental Indicators

6.1.1 Physical Restraint

The figures given in Table 14 below are results from the physical restraint tests in each city.

Physical	Cambridge						Norwich						York					
Radials	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb
City Centre	83	82	82	87	82	86	96	96	96	96	96	95	88	88	88	89	88	80
Inner Orbital	86	84	86	91	85	88	96	97	97	95	97	95	95	95	95	97	95	94
Rest of City	100	103	99	94	102	99	103	103	103	101	103	103	100	101	100	96	100	99
Outer Orbital	104	107	105	100	107	106	99	100	99	99	100	100	106	106	106	106	106	108

Table 14 Pollutants Emitted - Physical

The results in Table 14 above suggest that physical restraint reduces fuel consumed and emissions within the city centres and on the inner orbitals of each city. There is little change elsewhere in the city, except for NOx which falls slightly for each city, indicating slower moving traffic. It is also apparent from the figures that the additional travel on the outer orbital is producing additional pollution and consumption of fuel. This is consistent with the patterns of travel forecast and discussed above.

6.1.2 Permit Control

Table 15 gives details of the pollutants emitted in the scenario with all through traffic banned and city centre trips reduced to 50 per cent of the base.

Permit	Cambridge						Norwich						York					
	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb
City Centre	41	44	42	48	44	43	64	66	65	65	66	67	60	56	60	54	56	60
Inner Orbital	109	109	109	104	109	112	96	97	97	98	97	96	92	91	92	97	91	94
Rest of City	88	86	88	90	86	89	91	92	92	93	92	96	93	92	93	94	92	92
Outer Orbital	100	100	100	98	100	100	95	95	95	97	95	94	95	94	95	94	94	96

Table 15 Pollutants Emitted - Permit Control

As the figures of Table 15 show, the strategy is effective in reducing the emissions within the city centre and for the rest of the city. However, the enforced diversion around the city centre has caused an increase on the inner orbital for Cambridge. As there is little through traffic in York the impact in not as marked on the inner orbital. Interestingly, the NOx figures change very little from the base suggesting that speeds are relatively stable.

6.1.3 Parking Pricing

The pollution figures are taken from the model run imposing the greatest parking charge in each city, that of £10.00 per day.

Parking	Cambridge						Norwich						York					
	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb
City Centre	79	74	79	77	75	79	65	66	66	67	66	68	67	64	67	63	64	60
Inner Orbital	88	87	88	92	87	94	94	95	94	95	95	95	87	85	86	94	86	88
Rest of City	92	89	90	94	89	92	93	93	93	95	93	100	93	91	93	94	92	94
Outer Orbital	90	87	90	94	88	88	93	93	93	95	93	94	94	92	94	92	92	92

Table 16 Pollutants Emitted - Parking

The results reported in Table 16 above suggest that the city centres are receiving some benefit in terms of reduced emissions but these are not as great as those of the permit control strategy. However, as the strategy has reduced travel on the inner orbital this route also experiences improved levels of emissions, with NOx lagging behind the other pollutants suggesting that the speeds are again relatively stable. The other two classes of road also suggest that the parking strategy will produce a reduction in the levels of all the environmental indicators suggesting that the scheme would be beneficial beyond the focal city centre.

6.1.4 Road Use Charging

The figures in Table 17 are taken from the highest charge regime, that of £4.00 at the outer cordon and £2.00 at the inner cordon.

Road Use	Cambridge						Norwich						York					
	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb	Fuel	CO	CO2	NOx	HC	Pb
City Centre	35	39	36	43	39	43	43	45	44	48	45	45	60	57	60	54	56	60
Inner Orbital	109	108	108	105	108	112	68	67	68	76	68	71	97	97	97	102	97	100
Rest of City	72	71	73	74	71	72	67	67	67	69	67	69	85	86	85	85	86	86
Outer Orbital	96	92	95	99	93	94	103	105	104	105	105	106	70	66	71	66	66	64

Table 17 Pollutants Emitted - Road Use Charging

Again the environmental indicator results of the road use charging tests follow the patterns of travel movements and demand. The benefits are greatest at the city centre and are notable for the resot of the city for each model. This is linked to reduced amount of traffic moving with less congestion. The inner orbitals, especially that of Cambrige, demonstrate that the emission benefits of this strategy, with its definite boundaries, can be localised. The resutls for the York outer orbital suggest

that the strategy would have great benefits for this class of road. However, given this result is probably over optimistic as the manner in which external trips are considered.

6.2 Revenue

6.2.1 Parking Revenues

The potential revenues from the cordon charges at each level are presented inTable 18 below.

Revenues	£2 pd	£4 pd	£6 pd	£10 pd
Cambridge	£7,090	£11,578	£15,152	£20,920
Norwich	£7,056	£11,228	£14,424	£19,426
York	£5,056	£8,068	£10,432	£14,258

Table 18 Forecast Parking Revenues

As a fiscal measure parking produces an income for whoever is controlling the spaces. As this strategy sets out to allow the local authority or its agents to collect the charged fee from those trips choosing to park in the city centre it is only reasonable to indicate the revenues one may expect from this strategy. Table 18 above gives an indication of the daily morning peak hour income from the scenarios modelled. The figures indicate that although the higher levels of charge reduce the number of terminating trips in the city centre the income continues to increase.

6.2.2 Road Use Charging

The potential revenues from the cordon charges at each level are presented in Table 19.

Revenues	50p / 100p	100p / 200p	150p / 300p	200p / 400p
Cambridge	£11,727	£20,465	£28,037	£34,686
Norwich	£12,864	£21,838	£29,139	£35,414
York	£7,763	£12,817	£16,841	£20,228

Table 19 Forecast Cordon Charging Revenues

The potential income from road use charging, shown in Table 19 above, is much greater than that of parking as there is a much larger number of paying trips. As can be seen, the second level of charge tested, £1.00 and £2.00, is producing revenues similar to £10.00 per day parking charges.

7. SUMMARY

The results presented above are the first round of results of the modelling Task for this project. These are not the final results but should be used to stimulate discussion about the manner in which the strategies should be progressed and / or combined. In summary, this report has suggested the following about each of the strategies:

- Physical

  The introduction of capacity restraint on the inbound radial routes brought some benefits to the city centre and the inner orbital as traffic queues were relocated. However, conditions in the rest of the city and the outer orbital deteriorated because of this relocation and a degree of rerouting. The overall pattern of demand for travel changed little in any of the subject cities. The environmental indicators suggest that the pattern of emissions follows that of traffic movements.

- Permits

  The introduction of a permit system which partially removed traffic in the city centre brought benefits to the city centre, with little impact elsewhere in the city. However, the orbital routes experienced some additional travel as traffic was forced to use routes avoiding the city centre. The emission of pollutants increased on the inner orbital routes in each city, but the levels of the city centre reduced as traffic levels declined.

- Parking

  The parking strategy encouraged additional through traffic within the city centre as trips to city centre destinations declined. However, this pattern of travel did improve conditions throughout the considered network. This produced reductions in the emissions forecast on all classes of road. In addition to these benefits there are forecast revenues of up to £20,000 per morning peak hour.

- Road Use Charging

  The results of this strategy suggested that additional travel time would be expended on the inner and outer orbitals, which are effectively the boundary routes for the cordons. However, the overall reduction in the amount of traffic lead to reductions in travelled time and distance in the networks as a whole and complementary reductions in the emissions considered. Additionally this strategy produced up to £30,000 per morning peak hour in revenue.

8. FURTHER WORK

The modelling work conducted to date has seen the development of techniques to allow SATURN to replicate the impact of each strategy, notably:

- mixing elastic and inelastic assignment within one model run, to consider the impacts of fixing one class of trips whilst allowing other traffic to respond in an elastic manner for permit control;
- the introduction of penalties specifically aimed at trips leaving the network, including some tests which considered differential application of this charge for parking charges; and
- application of different levels of road use charge for use of different sections of the network.

The work to date has thus demonstrated that the SATURN suite is sophisticated enough to be able to replicate the intricacies of all the strategies.

There are three areas in which the modelling task will progress over the remainder of the project:

- improvements to the base models, reflecting all the base costs not just the network costs of time and distance;
- changes to elasticity value used within the elastic assignment to those which are derived specifically from the subject cities. The manner in which elasticities are used by SATURN is an area which is receiving research interest at present which offers scope for additional tests to be performed within this project;
- improvements to the emissions model that forms part of the SATURN suite, incorporating changes to the pollutants considered, the rates at which these pollutants are produced and the method by which the results are presented.

As stated in the introduction, the modelling work of this project falls into two areas. The former is development of the model to allow the strategies as defined to be tested. The latter involves refining these tests to incorporate the findings of the stated preference surveys. At this stage in the project the former task has now been completed.

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APPENDIX A - MISSING

Appendix A includes SATURN plots from each of the cities. Figures 1 to 3 show the full network considered in each model. Figures 4 to 6 show the city network for each city with the city centre, inner orbital, radial routes and outer orbital links highlighted.

Figure 1 The Cambridge Network

APPENDIX B - TABLES OF RESULTS

Appendix B gives more detailed results of each of the model tests discussed in summary above. Before reading these tables please read the following notes:

- the base results are presented as actuals,
- all other results are expressed as indexed to the base, assuming a figure of 100 for the base
- the results for time and distance are presented by road class, defined as follows:

  100 City centre links, defined as within the inner orbital

  200 The inner orbital or ring road

  300 Inbound Radials, which connect the outer and inner orbital routes

  350 Outbound Radials

  500 Other city roads, within the outer orbital, outside the inner orbital, but not the inner orbital or on radial routes

  900 The outer orbital

- trip matrices are indexed to the base matrices. The coding of the matrices is as follows:

  first character is the city (C - Cambridge, N - Norwich, Y - York), the E stands for elastic assignement and the 2 indicates that two user classes are being considered. The characters after these indicate the proportion of city centre terminating traffic still in the matrix (100 - 100% of the base, 075 - 75% of the base and 050 - 50% of the base), level of parking fee (£2, £4, £6 and £10) or the level of cordon charge (510 - 50p and 100p, 1020 - 100p and 200p, 1530 - 150p and 300p and 2040 - 200p and 400p).

CAMBRIDGE RESULTS.

Time and Distance

Time	Base	Phys	No Through Traffic	25% Reduction	50% Reduction	£2.00 per day	£4.00 per day	£6.00 per day	£10.00 per day	50p and 100p	100p and 200p	150p and 300p	200p and 400p
100	422	82	67	54	43	82	79	76	73	51	42	40	38
200	542	84	125	121	117	89	87	85	85	129	129	119	115
300	928	154	90	81	72	85	84	82	79	72	62	57	54
350	363	87	92	92	92	108	107	111	108	84	82	83	84
500	530	95	98	91	85	86	82	78	78	76	71	69	67
900	1196	106	107	104	102	95	93	93	92	104	103	[illegible]	99
Total	3981	108	99	93	88	90	89	87	85	89	84	81	79
Dist	Base	Physical	No Through Traffic	25% Reduction	50% Reduction	£2.00 per day	£4.00 per day	£6.00 per day	£10.00 per day	50p and 100p	100p and 200p	150p and 300p	200p and 400p
100	8331	91	74	61	49	92	90	88	85	55	46	44	42
200	12270	95	109	108	107	95	95	94	94	110	110	108	107
300	28860	91	97	90	83	94	93	91	89	83	75	70	66
350	13840	94	96	97	98	105	108	108	109	91	90	91	91
500	14310	92	102	99	96	93	91	90	88	81	78	75	73
900	88190	102	103	102	101	98	97	97	96	104	103	102	102
Total	165801	97	100	98	95	97	96	96	95	95	93	91	89

Table 20 Cambridge Time and Distance Results

Trip Matrices

Base	Centre	City	External	TOTAL
Centre	688	1476	662	2826
City	2298	7948	3922	14168
External	2842	10764	11616	25222
TOTAL	5828	20188	16200	42216

Table 21 Cambridge Base Trip Matrix

Physical	Centre	City	External	TOTAL
Centre	102	103	101	102
City	98	97	100	98
External	96	96	99	97
TOTAL	97	97	99	98

Table 22 Cambridge Trip Matrix - Physical Restraint

CE2U100	Centre	City	External	TOTAL
Centre	99	104	100	102
City	100	98	100	99
External	100	99	99	99
TOTAL	100	99	99	99

CE2U075	Centre	City	External	TOTAL
Centre	74	104	101	96
City	75	99	100	95
External	75	100	99	96
TOTAL	75	100	99	96

CE2U050	Centre	City	External	TOTAL
Centre	50	105	101	90
City	50	100	100	92
External	50	100	99	94
TOTAL	50	100	99	93

Table 23 Cambridge Trip Matrix - Permit Control

CE2U£2	Centre	City	External	TOTAL
Centre	34	101	100	84
City	48	102	100	93
External	78	101	99	97
TOTAL	61	101	99	95

CE2U£4	Centre	City	External	TOTAL
Centre	25	101	101	82
City	36	102	101	91
External	66	101	99	96
TOTAL	50	102	99	94

CE2U£6	Centre	City	External	TOTAL
Centre	21	101	101	81
City	31	103	101	90
External	59	102	99	96
TOTAL	43	102	99	93

CE2U£10	Centre	City	External	TOTAL
Centre	16	101	101	80
City	24	103	101	90
External	50	102	99	95
TOTAL	36	102	99	92

Table 24 Cambridge Trip Matrices - Parking Charges

CE2U510	Centre	City	External	TOTAL
Centre	98	105	101	102
City	82	93	100	93
External	84	88	99	93
TOTAL	85	91	99	93

CE2U1020	Centre	City	External	TOTAL
Centre	95	106	101	102
City	74	92	100	91
External	74	82	99	89
TOTAL	77	88	99	91

CE2U1530	Centre	City	External	TOTAL
Centre	93	105	101	101
City	70	92	101	91
External	67	78	99	86
TOTAL	71	85	99	89

CE2U2040	Centre	City	External	TOTAL
Centre	92	106	101	102
City	67	91	101	90
External	62	74	99	84
TOTAL	68	83	99	87

Table 25 Cambridge Trip Matrices - Road Use Charging

NORWICH RESULTS

Time and Distance

Time	Base	Phys	No Through Traffic	25% Reduction	50% Reduction	£2.00 per day	£4.00 per day	£6.00 per day	£10.00 per day	50p and 100p	100p and 200p	150p and 300p	200p and 400p
100	646	96	71	58	45	79	74	69	65	57	51	47	45
200	678	95	112	126	113	95	92	99	97	86	76	70	65
300	689	110	99	90	81	91	86	85	82	67	58	54	50
350	295	100	95	98	100	106	108	109	110	88	88	88	88
500	1065	99	103	94	93	90	88	87	86	78	71	65	62
900	999	100	103	100	104	96	95	93	92	108	106	[illegible]	105
Total	4372	100	98	94	90	92	89	89	87	82	76	72	70
Distance	Base	Phys	No Through Traffic	25% Reduction	50% Reduction	£2.00 per day	£4.00 per day	£6.00 per day	£10.00 per day	50p and 100p	100p and 200p	150p and 300p	200p and 400p
100	10100	96	76	64	49	81	76	73	69	64	58	54	51
200	11780	95	110	110	111	100	100	99	99	94	90	88	85
300	15200	98	97	92	85	94	91	90	88	72	63	58	54
350	8251	99	95	98	100	106	108	109	110	88	88	88	88
500	22510	101	98	95	92	95	94	93	92	84	78	73	70
900	26220	100	103	102	100	98	97	96	96	107	106	106	105
Total	94061	99	98	95	92	96	94	93	92	88	84	81	79

Table 26 Norwich Time and Distance Results

Trip Matrices

Base	Centre	City	External	TOTAL
Centre	564	818	759	2141
City	1976	5562	5993	13531
External	3212	11092	10056	24360
TOTAL	5752	17472	16808	40032

Table 27 Norwich Base Trip Matrix

Physical	Centre	City	External	TOTAL
Centre	100	100	100	100
City	99	100	100	100
External	99	100	98	99
TOTAL	99	100	99	99

Table 28 Norwich Trip Matrix - Physical Restraint

NE2U100	Centre	City	External	TOTAL						
Centre	100	101	100	100						
City	100	99	100	99						
External	100	99	98	99						
TOTAL	100	99	99	99						
NE2U075	Centre	City	External	TOTAL		NE2U050	Centre	City	External	TOTAL
Centre	75	101	100	94		Centre	50	102	101	88
City	75	100	100	96		City	50	101	100	93
External	75	100	98	96		External	50	101	99	93
TOTAL	75	100	99	96		TOTAL	50	101	99	93

Table 29 Norwich Trip Matrix - Permit Control

NE2U£2	Centre	City	External	TOTAL		NE2U£6	Centre	City	External	TOTAL
Centre	41	101	101	85		Centre	25	102	101	81
City	53	102	101	94		City	34	103	101	92
External	71	101	99	96		External	50	102	99	94
TOTAL	62	101	99	95		TOTAL	42	102	100	92
NE2U£4	Centre	City	External	TOTAL		NE2U£10	Centre	City	External	TOTAL
Centre	31	102	101	83		Centre	20	102	101	80
City	40	102	101	93		City	27	103	101	91
External	58	102	99	95		External	41	102	99	93
TOTAL	49	102	100	93		TOTAL	34	102	100	91

Table 30 Norwich Trip Matrices - Parking Charges

NE2U510	Centre	City	External	TOTAL		NE2U1530	Centre	City	External	TOTAL
Centre	104	103	102	103		Centre	104	103	102	103
City	76	93	100	94		City	56	89	101	89
External	76	84	98	89		External	56	71	98	80
TOTAL	79	88	99	91		TOTAL	60	78	99	84
NE2U1020	Centre	City	External	TOTAL		NE2U2040	Centre	City	External	TOTAL
Centre	104	103	102	103		Centre	104	103	102	103
City	64	91	101	91		City	50	88	101	88
External	64	76	98	84		External	50	67	98	78
TOTAL	68	82	99	87		TOTAL	55	75	99	83

Table 31 Norwich Trip Matrices- Road Use Charging

YORK RESULTS

Time and Distance

Time	Base	Physical	No Through Traffic	25% Reduction	50% Reduction	£2.00 per day	£4.00 per day	£6.00 per day	£10.00 per day	50p and 100p	100p and 200p	150p and 300p	200p and 400p
100	140	88	90	72	56	75	70	68	65	67	63	60	57
200	609	94	104	94	87	90	90	83	80	106	101	97	94
300	1090	106	101	95	85	90	86	86	83	88	80	72	68
350	467	100	100	100	101	100	101	102	102	96	97	99	99
500	1468	107	99	92	86	90	86	86	84	104	99	94	92
900	740	106	100	97	94	96	95	94	93	76	71	68	66
Total	4514	103	100	94	88	92	89	88	86	94	89	84	82
Distance	Base	Physical	No Through Traffic	25% Reduction	50% Reduction	£2.00 per day	£4.00 per day	£6.00 per day	£10.00 per day	50p and 100p	100p and 200p	150p and 300p	200p and 400p
100	2288	92	87	74	59	81	75	71	68	72	66	63	60
200	8369	98	100	100	100	99	99	99	98	105	104	103	103
300	32360	90	99	95	91	95	93	92	91	80	73	68	65
350	18500	98	100	101	102	102	102	103	103	94	95	95	96
500	39590	101	100	96	93	96	94	93	92	98	95	93	91
900	64270	106	100	98	96	97	96	95	94	82	76	74	71
Total	165377	100	99	97	94	97	95	94	94	88	84	81	79

Table 32 York Time and Distance Results

Trip Matrices

Base	Centre	City	External	TOTAL
Centre	92	1236	470	1798
City	2693	11662	4372	18727
External	1228	7228	2501	10956
TOTAL	4012	20125	7343	31481

Table 33 York Base Trip Matrix

Physical	Centre	City	External	TOTAL
Centre	101	103	101	102
City	93	98	100	98
External	95	98	100	98
TOTAL	94	98	100	98

Table 34 York Trip Matrix - Physical

YE2U100	Centre	City	External	TOTAL						
Centre	100	101	101	101						
City	100	99	100	99						
External	100	99	100	99						
TOTAL	100	99	100	100						
YE2U075	Centre	City	External	TOTAL		YE2U050	Centre	City	External	TOTAL
Centre	75	102	101	100		Centre	50	103	101	100
City	75	101	101	97		City	50	102	101	94
External	75	100	101	97		External	50	101	101	95
TOTAL	75	101	101	97		TOTAL	50	102	101	95

Table 35 York Trip Matrix - Permit

YE2U£2	Centre	City	External	TOTAL		YE2U£6	Centre	City	External	TOTAL
Centre	34	102	101	98		Centre	21	102	101	98
City	61	103	101	96		City	41	104	101	95
External	69	101	101	98		External	49	102	101	96
TOTAL	63	102	101	97		TOTAL	43	103	101	95
YE2U£4	Centre	City	External	TOTAL		YE2U£10	Centre	City	External	TOTAL
Centre	25	102	101	98		Centre	17	103	101	98
City	48	104	101	95		City	34	105	102	94
External	56	102	101	97		External	41	103	101	95
TOTAL	50	103	101	96		TOTAL	36	104	101	95

Table 36 York Trip Matrices - Parking

YE2U510	Centre	City	External	TOTAL		YE2U1530	Centre	City	External	TOTAL
Centre	79	100	101	99		Centre	66	101	101	99
City	84	96	101	95		City	70	97	102	94
External	73	68	100	76		External	52	49	98	60
TOTAL	80	86	101	89		TOTAL	64	80	100	83
YE2U1020	Centre	City	External	TOTAL		YE2U2040	Centre	City	External	TOTAL
Centre	71	101	101	99		Centre	63	101	101	99
City	76	96	101	94		City	66	97	102	94
External	60	56	99	66		External	47	44	97	56
TOTAL	71	82	100	85		TOTAL	60	78	100	81

Table 37 York Trip Matrices - Road Use Charging