TRANSPORT RESEARCH LABORATORY

Motorway tolling — modelling some congestion effects of diversion

Prepared for Tolling and Private Finance Division, Department of the Environment, Transport and the Regions

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CONTENTS

Executive Summary

This report describes work carried out by the Transport Research Laboratory on behalf of the Tolling and Private Finance Division of the Department of Transport (now the Department of the Environment, Transport and the Regions).

The introduction of tolling on motorways would be expected to cause some movement of traffic away from motorways, which could change the levels of queueing and vehicle delay in the vicinity of motorways. This report describes an investigation into the extent of such changes, undertaken using the MCONTRM model to estimate the effects which different toll rates, and hence different levels of traffic diversion, would have on congestion. The study used models of the motorway box surrounding Birmingham and the motorway corridor formed by the M20 and the M2 in Kent.

The study showed that the model of the Birmingham box was insufficiently detailed, with respect to all-purpose roads, to allow strong confidence in the levels of congestion predicted. Delays and queues increased as expected on the all-purpose roads, but queues unexpectedly increased on the motorways. The increase in motorway queues was on the off ramps, as traffic attempting to leave the motorway was hampered by the increased traffic using the all-purpose roads at the intersection. The effect was exaggerated in the Birmingham model by the limited number of all-purpose roads modelled. The same effects were predicted for the Kent corridor, but with much smaller queues on the motorways.

The report recommends the construction of more detailed models allowing more freedom for displaced traffic if better estimates of traffic associated parameters are required.

1 Introduction

TRL are undertaking a research project concerned with motorway tolling for the Tolling and Private Finance Division of DOT (now DETR). Previous reports in this context have studied the likely effects of tolling on accident risk and the effects on road usage.

One possible consequence of the introduction of motorway tolls is the diversion of some motorway traffic from tolled roads on to the adjacent road network. This will occur as a proportion of drivers choose to reduce their perceived travel costs by avoiding tolled roads. The resulting change in traffic patterns may well lead to changes in the distribution of congestion, and in the absolute levels of congestion.

This report describes the use of the MCONTRM model to examine congestion in traffic networks combining motorways and all-purpose roads, and to assess the likely changes resulting from varying levels of traffic diversion from motorways as toll rates increase.

The areas modelled, and the methods of estimating the changes in queues and delays are described in section 2, and the results are given in section 3.

2 Methodology

The methods used for modelling the networks and tolling levels, and the operation of MCONTRM in the current context, are based on those described in a previous report on the impact of diversion, with necessary modifications as indicated in the following sections.

The term ‘congestion’ is difficult to define precisely, but a road is usually considered to be more congested if the queues and delays to traffic are increased. In this report the delay to traffic, in vehicle hours, and the number of vehicles queueing are used as indicators of congestion. The number of vehicles queueing is measured by counting the size of the queues in the network at the end of each modelling time period. It is thus the result of a sampling procedure, and though the results can be used for comparative purposes within one network, the numbers should not be used for comparison between networks unless the number and duration of time periods are identical - and even then extreme caution should be used.

2.1 Area 1

This project required the motorway envelope around Birmingham to be examined to assess the changes in congestion. TRL possesses an MCONTRM model of the motorway box surrounding Birmingham which was constructed for tests on the MOLA system for motorway control by VMS. The MCONTRM link diagram for the network is shown in Figure 1. The network was designed to model the movement of traffic on the motorways. It does not include a full model of the all-purpose roads and only the major through routes were represented, by a set of approximate equivalent links. The demand is derived from an extensive Origin-Destination survey carried out for the West Midlands Regional Office. The demand flows are modelled in 60 time slices each of 15 minutes, from 6.00 am to 9.00 pm. The total area covered is a little under 30 kilometres square, and 605 kilometres of links are modelled.

An inspection of the links was made with reference to the corresponding Ordnance Survey road maps, and each link was classified as ‘motorway’ or ‘urban’, with a small number of unclassified links (not shown in the Figure) used by MCONTRM to allocate flows to the central region.

2.2 Procedure

Although MCONTRM produces predictions of queues and delays on each link for each time slice, different types of link are not distinguished. It was therefore necessary to write analysis programs which extracted the relevant data from the huge output from MCONTRM and assigned values according to the class of the links.

A baseline run of MCONTRM was performed with no tolling costs applied to provide a ‘normal’ situation as a basis for comparison when tolling was introduced on the motorways. A set of modelling runs with various levels of tolls were then made to assess the effects on queues and delays.

2.2.1 Network modelling problems

It immediately became apparent that there were deficiencies in the network model. The problems were all connected with the access and exit lanes at motorway junctions, and the traffic circulating on the grade separated roundabouts at these junctions. These areas had not been modelled in complete detail for the MOLA study, as that had concentrated on traffic on the motorways only, and had considered movements of traffic joining and leaving the motorway only in a limited way. A number of small modifications were made to the modelling of several roundabouts to bring them closer to the actual layout.

As soon as any toll costs were applied to the motorway, the problems became much more acute. The diversion of some of the motorway traffic resulted in much heavier stress being placed on the entry and exit points of the network. Traffic which normally would travel to a destination outside the motorway box by motorway, was now using the all-purpose roads, and putting a strong pressure on the grade separated roundabouts on the borders of the area. The congestion resulting from this pressure caused queues to form on the off ramps of the motorway at those junctions, and these queues backed onto the motorway itself and caused heavy delays. The apparent effect of introducing a toll on the motorway was thus to cause a considerable increase in the queues on the motorway. The identification of the source of this problem, and its correction, occupied a considerable portion of the time allocated for the whole study.

2.3 Area 2

Although it was clear that much of the problem resulted from approximate values for link capacities at roundabouts, it was also possible that the effect was real. This was difficult to assess on the available Birmingham box network, because, as has been explained, most of the all-purpose road links were not modelled, and it was

Figure 1 Birmingham network link diagram

possible that in reality the all-purpose links would be sufficiently numerous to absorb the traffic displaced from the motorway. However there was no certainty of this, as the area is already heavily loaded. It was therefore decided to make comparable tests on another network, namely the Kent corridor network. The Kent network (Figure 2) is much more complete in its modelling of the all-purpose roads closely associated with the motorways. The network covers an area of about 85 by 40 kilometres, modelling about 1285 kilometres of links. The period modelled covered from 6.00 am to 10.00pm, in 48 time slices, each of 20 minutes. The tests on the Kent network, described more fully in section 3.2, indicated that there could be a small effect on motorway exit ramps, and it is believed that in some networks this could be a factor which should not be ignored.

A similar set of runs was made with the Kent network as had been performed with the Birmingham network. The results of all the tests are described in the next section.

3 Results

3.1 Birmingham network

After setting up a base run with no tolling, for comparisons, a set of four runs of MCONTRM were made with tolls set at 1, 2, 3 and 4 pence per kilometre. The resulting percentage changes in the amount of travel (veh-hrs) on motorways and the remaining urban roads are shown in Figure 3. This figure corresponds to the similar figure for the Kent network in a report on road usage, which is reproduced here in Figure 5. It can be seen that a larger toll is required in Birmingham to achieve the same levels of diversion from the motorway. This is not surprising considering that the criteria for route choice is heavily influenced by journey time. In the Birmingham network, all the alternative routes to the motorway are heavily trafficked urban roads, whereas in the Kent corridor the alternative routes are mostly good quality rural roads with sufficient spare capacity to absorb diverted traffic without

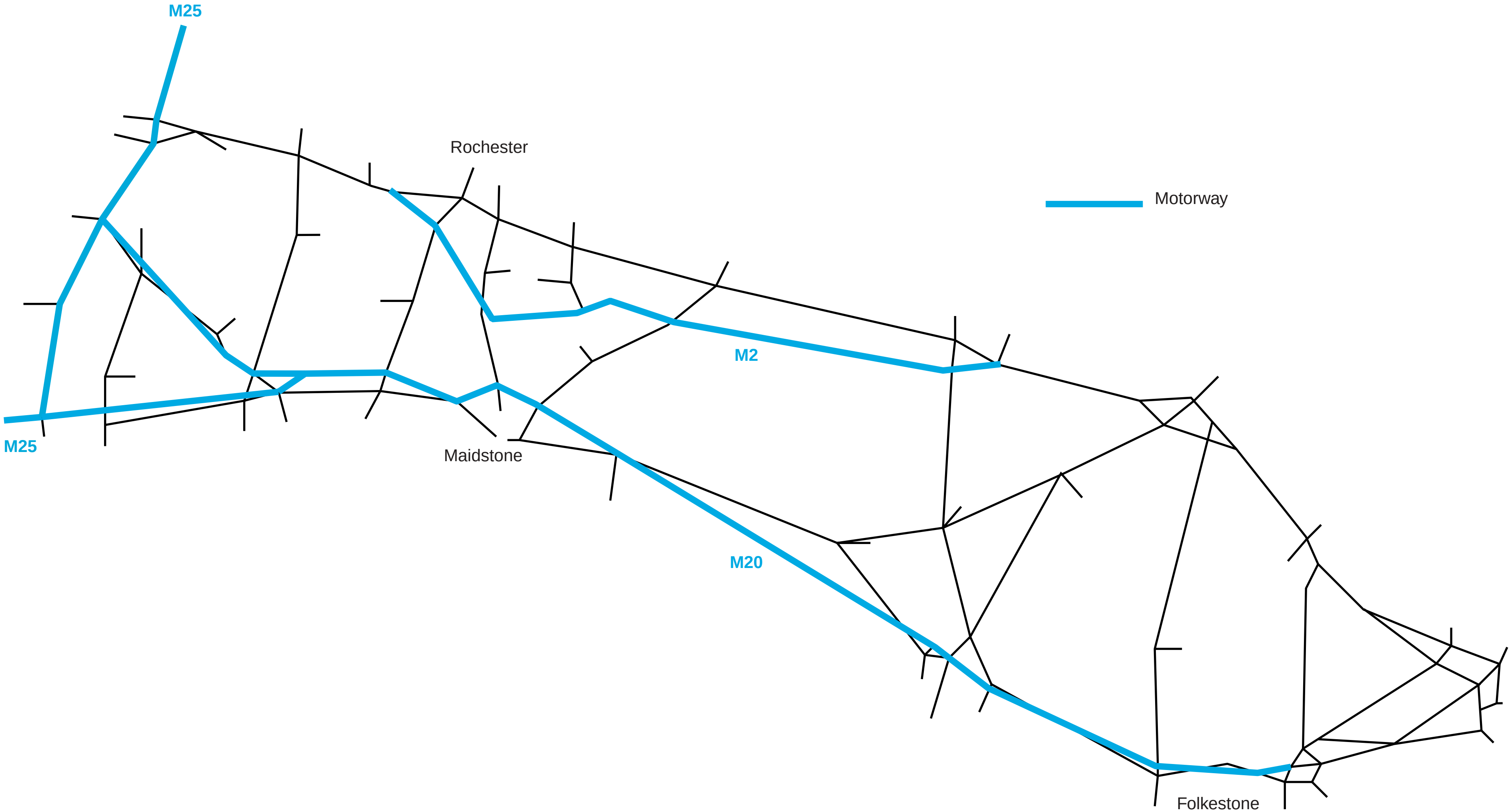

Figure 2 Kent corridor link diagram

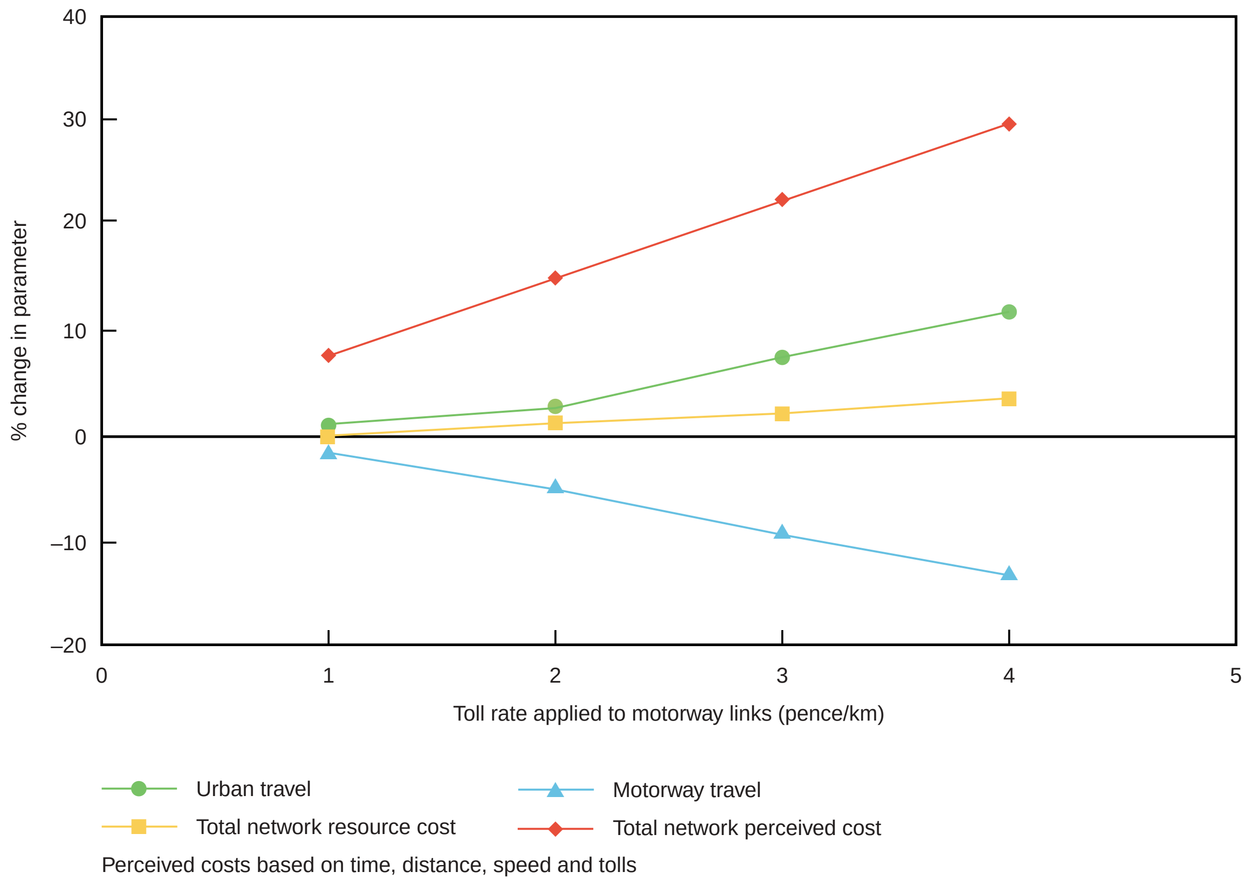

Figure 3 Birmingham network: change in results against motorway toll rate

suffering significant increases in journey time. This is confirmed in Kent by the much greater increase in traffic on the rural roads than on urban roads, whereas in Birmingham there are no rural roads available. The figures relating to the Birmingham box are given in Table 1. (Urban and motorway travel are given in vehicle-Megametres, TNJT is Total Network Journey Time, TNRC and TNPC are Total Network Resource and Perceived Costs.)

The delays and queues for motorways and urban roads in the Birmingham box are shown in Figure 4. It can be seen that the motorway delays (veh-hrs) decrease steadily as tolls and diversions increase. The urban (A-road) delay increases markedly over the same range of tolls, as do the queues on A-roads.

The situation with the motorway queues is less satisfactory, and more complex to explain. In the Birmingham box there are six motorway-to-motorway junctions, and with the heavy traffic experienced in the area, there is queueing during peak periods on the interchange ramps, which are classed as motorway. There are therefore many more vehicles queuing on the motorway than would usually be expected for the total length of motorway modelled. The reduction in motorway flow reduces the queueing on the interchange ramps, but the increase in diverted flow on the roundabouts causes increased queues on the off ramps at the motorway/surface street junctions. In the case of Birmingham this seems to result in a net increase in vehicles queuing. In addition, the reduction in motorway flow on the major entry and exit motorways (at the four ‘corners’) is virtually nonexistent as a result of tolling, because there are no alternative routes. This is a consequence of the model rather than of the actual road layout. The result is that the imposition of tolls does not produce the overall reduction in queueing on the motorway which had been expected. The values relating to Figure 4 are shown in Table 2.

Table 1 Parameter variation with Toll Rate - Birmingham

	Tolls (p/km)				
Parameter	*0*	*1.0*	*2.0*	*3.0*	*4.0*
Urban (veh Mm)	99.3	100.1	101.8	106.7	110.9
Mway (veh Mm)	7958.5	7824.6	7554.8	7212.3	6889.1
TNJT (veh hrs)	100253.1	100915.6	102091.8	104154.5	106717.6
TNRC (£)	1129451.1	1131941.9	1138194.9	1150778.8	1167805.5
TNPC (£)	1129451.1	1214101.5	1297086.5	1379171.6	1459528.0

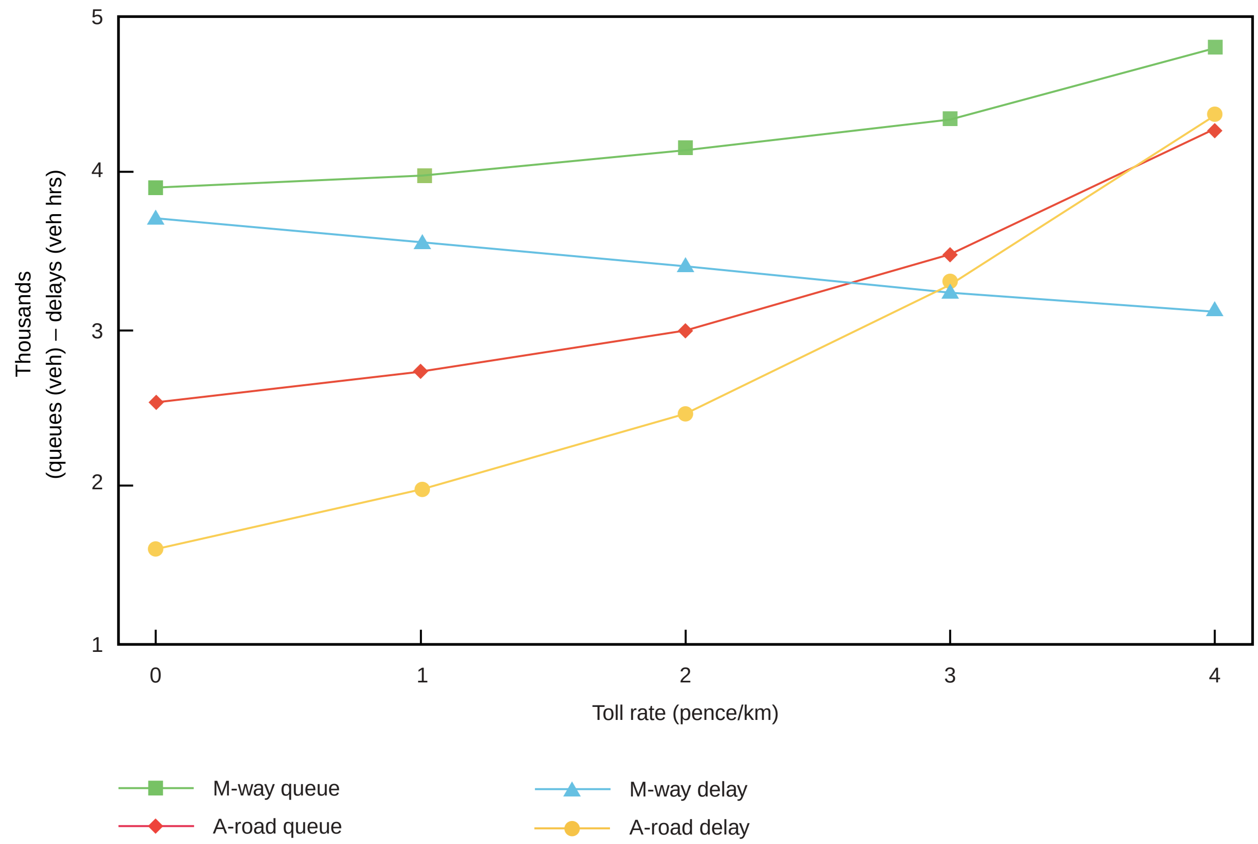

Figure 4 Birmingham network: queues and delays

Table 2 Birmingham: Queue and delay variation with Toll Rate and percentage diversion

	Tolls (p/km) (Motorway percentage diversion)				
Parameter	*0 (0.0)*	*1.0 (-1.7)*	*2.0 (-5.1)*	*3.0 (-9.4)*	*4.0 (-13.4)*
Mway queues (veh)	3885.8	3961.0	4132.8	4328.9	4813.4
Mway delays (veh hrs)	3699.0	3543.4	3387.8	3232.4	3118.6
A road queues (veh)	2536.2	2725.3	3001.5	3479.3	4304.8
A road delays (veh hrs)	1589.9	1978.1	2501.9	3285.2	4384.4

Table 3 Kent network: Queue and delay variation with Toll Rate and percentage diversion

	Tolls (p/km) (Motorway percentage diversion)				
Parameter	*0*	*1.0 (-4.0)*	*2.0 (-12.7)*	*3.0 (-22.5)*	*4.0 (-26.8)*
Mway queues (veh)	41.0	5.2	8.9	80.2	244.1
Mway delays (veh hrs)	4257.9	4020.3	3589.9	3227.9	3034.0
A road queues (veh)	14745.6	15822.8	19180.8	21869.4	26686.5
A road delays (veh hrs)	14524.0	16128.7	19666.2	23570.9	27901.3

3.2 Kent network

As with the Birmingham network, a base run with no tolls was made, and then runs with tolls of 1, 2, 3 and 4 pence per kilometre. The percentage changes in motorway and other traffic are shown in Figure 5.

The behaviour of the queues and delays are shown in Figure 6. Two factors are immediately apparent. Firstly, because the Kent network includes many more kilometres of all-purpose roadway the actual levels of total delay and queues are mostly higher. Secondly, the motorway queues are very much smaller. The A-road queues and delays increase substantially, very much as in Birmingham. Table 3 shows the values used in Figure 6.

In both networks the motorway queues increase as tolls increase, and in both cases this is because of queueing on the off ramps at roundabouts which have become more congested as some traffic moves away from the motorway.

The increase in Kent is much less marked that in Birmingham, but appears to be a genuine effect.

4 Conclusions

The most surprising factor arising from this study is the increase in motorway queueing as tolls are increased. In the Birmingham network this effect has been increased by the limitations of the model available, but the effect is apparent also in the Kent network. The extra queues are concentrated on off ramps, so the motorway carriageways are not affected. The changes in delays on the motorways, and the queues and delays on the all-purpose roads are much as expected, showing a steady increase as tolls are increased and more traffic diverts away from tolled roads.

However, a serious factor is the inadequacy of the

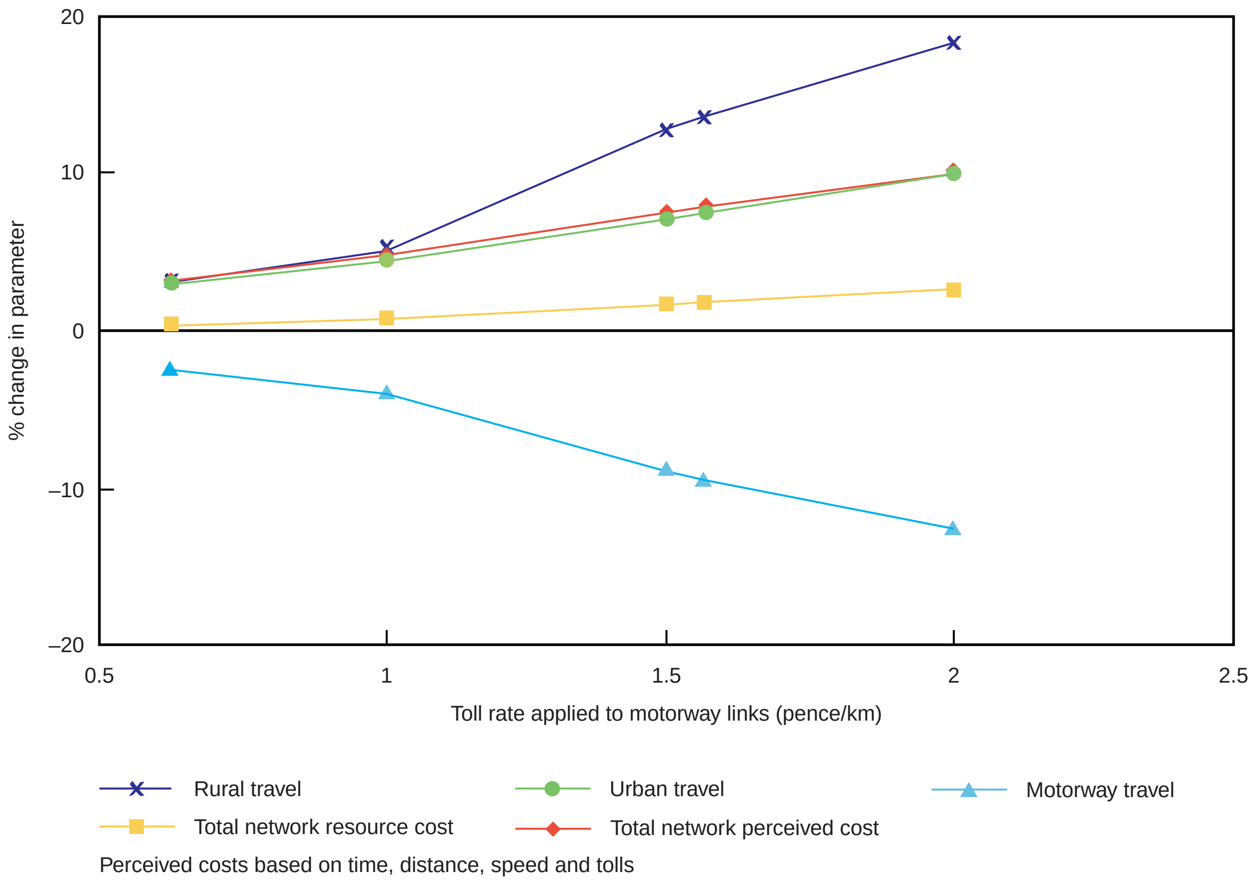

Figure 5 Kent network: change in results against motorway toll rate

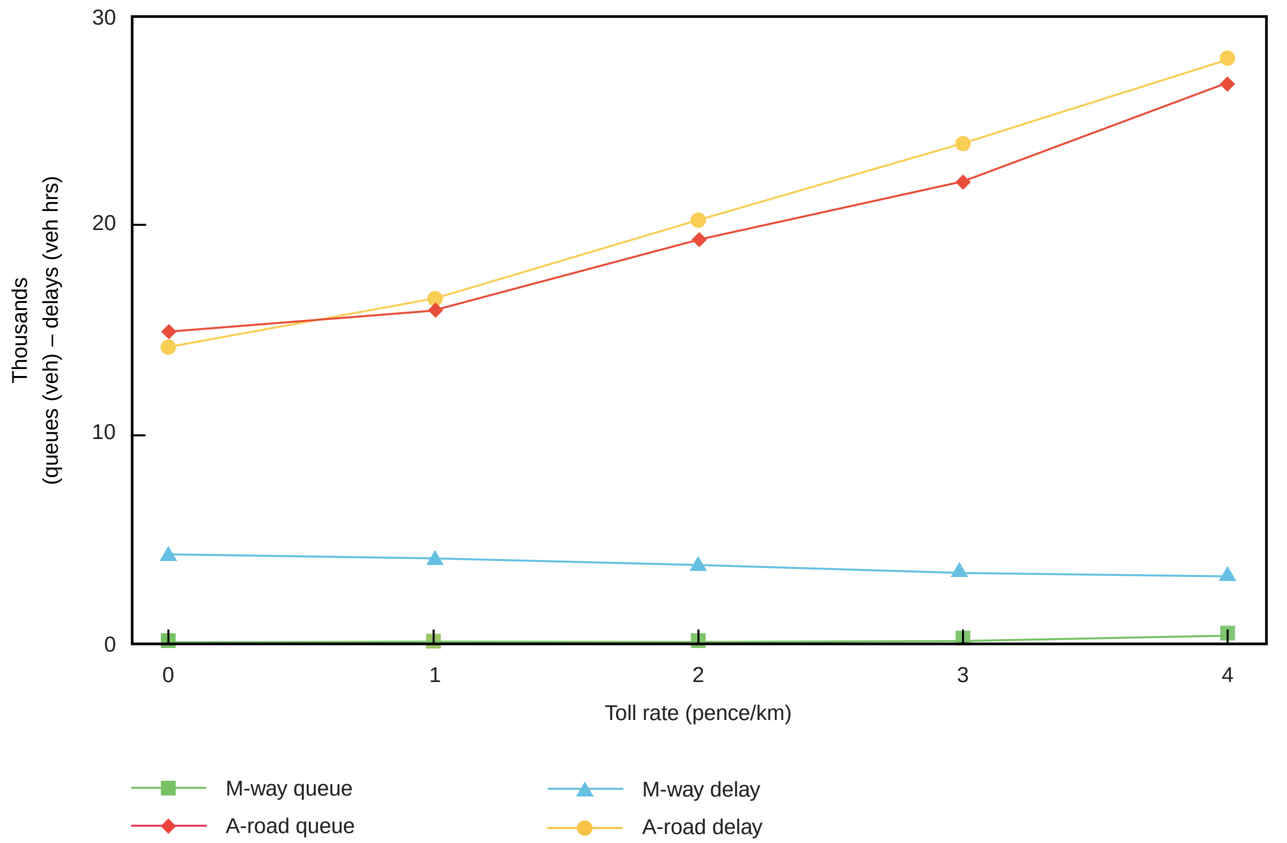

Figure 6 Kent network: queues and delays

Birmingham Motorway Box model. By failing to model sufficient roads other than motorways, the model loads excessive traffic onto the few roads modelled, as traffic can only enter or leave the area by using a road which intersects with a motorway junction. Not only does this overload those roads, it also interferes with the operation of the junction to greater extent than is justified in reality, when traffic would use other major roads which cross the motorway box without intersecting individual motorways.

Two specific areas for further work are recommended:

1 It should be remembered that the Birmingham Box model was not designed to represent the full scale of all traffic movements in the area. Much more confidence in model predictions could be achieved if the Birmingham model were expanded to include many more of the major roads in the area, particularly those which would be expected to be used by traffic diverting from the motorway. Care would need to be exercised in modifying the O-D matrix to ensure that the newly modelled roads were loaded with traffic in a realistic fashion.

2 If any other busy, mixed road networks can be located it would be useful to perform similar tests to ascertain the ways in which the Birmingham Box is unique, and in what ways networks were similar in their behaviour. It is quite usual in traffic studies to find strong site effects, and it is thus extremely useful to be able to pick out common factors in traffic behaviour. At present it is difficult to make judgements on wide area traffic effects of tolling without more investigations of different situations, in terms of traffic levels and network complexity.

Abstract

The introduction of motorway tolls would be expected to cause some traffic to cease use of motorways, and transfer to alternative non-tolled routes. The MCONTRM model was used to estimate the effects on congestion in terms of delays and queues in two areas: the motorway box round Birmingham, and the M2/M20 corridor in Kent.

Queues and delays increased on the all-purpose roads and delays decreased on the motorways. There was evidence of some increase in queuing on motorway off ramps, but estimates of the levels of queuing to be expected would require more extensive modelling of all-purpose roads, especially for the Birmingham area.