TRANSPORT RESEARCH LABORATORY

The likely effects of motorway tolling on accident risk — phase 2

Prepared for Tolled Roads and Crossings Division, Department of the Environment, Transport and the Regions

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Executive Summary

This report describes work carried out by the Transport Research Laboratory on behalf of the Tolled Roads and Crossings Division of the Department of Transport (now the Department of the Environment, Transport and the Regions). The report extends and consolidates a previous study which considered the theoretical basis for studying the likely effects of motorway tolling on accident risk.

The imposition of motorway tolls is expected to cause a diversion of some traffic from motorway use to the untolled alternative routes. An evaluation of the extent of this effect was made by modelling the changes in traffic movements resulting from new tolls. The MCONTRM model was used to study the effects in two real networks, one in the Kent M2/M20 corridor, and the other in the wholly urban network in the Danish town of Aalborg. Existing network models were modified to represent the conditions under investigation, especially the redistribution of 10 percent of normal motorway traffic, which is expected in response to a 1p per km toll on motorway traffic. The sensitivity of the results was tested using a range of factors which bracketed the expected level of 10 percent.

The accident rates were derived by the methods used in COBA. The two networks differ in several respects: in level of detail, degree of urbanisation and road mix. However, the results are credible, suggesting that a 10 percent diversion of traffic would result in an overall increase in the accidents in Kent of about 3½ percent. The rate in Aalborg is about one third of this; the difference is partly caused by the lower flows on the Aalborg network.

The relationship between accident costs and toll costs is much more consistent between the two sites: increases of 29 percent and 26 percent for a 1p per veh-km toll in Kent and Aalborg respectively. An explanation of this consistency is given.

The overall conclusion is that the introduction of motorway tolls will lead to an increase in the total number of accidents.

1 Introduction

One consequence of the proposed introduction of motorway tolls is likely to be a diversion of traffic from tolled motorways onto adjacent untolled roads. This will occur as a proportion of drivers who currently use the motorways decide to minimise their travel costs in the new regime by driving on untolled roads. This diversion of traffic will undoubtedly alter the pattern of accidents, so an earlier report considered the theoretical issues. It also evaluated a simple model consisting of a single motorway link with a single parallel link to which traffic could divert. This provided a useful illustration of the likely consequences, but concluded that only representative network models could give reliable results.

This report presents the results of applying the MCONTRM model to two networks described briefly in the earlier report:

i the Kent Corridor, a rectangle approximately 90 km long by 20 km wide stretching from the M25 in the West to Dover and the Channel Tunnel in the East; the M2 and M20 run through the corridor, with the A2 and A20 providing the main diversions,

ii an area of approximately 11 km square around Aalborg, a town in northern Denmark; the model includes the centre of the town and the motorways running around the centre, and is entirely urban.

The technical details of modelling the diversion effects of motorway tolling are presented in section 2. In addition, this section explains how MCONTRM has been linked for this project to the accident modelling component of COBA, the standard DOT highway appraisal program (the normal MCONTRM model only deals with traffic flows, and does not model accidents). By using the COBA accident cost models, the predicted accident changes will be entirely consistent with the DOT's (now DETR's) standard procedure.

Section 3 then presents the results from the two network models, and considers their sensitivity to the actual level of diversion. Section 4 discusses these results and the conclusions that can be drawn.

2 Technical details of MCONTRM modelling

The networks modelled, and the work required to render them suitable for the purpose of this project are described in the following. There are unfortunately only a very small number of suitable areas for which some sort of model already exists. The extraction of the relevant data from the results is explained.

2.1 Kent corridor

This network consists of the major roads in the M20/M2 corridor: the total lengths of the links modelled is 1,235 kilometres. The major traffic movements are along the corridor rather than across it. This region was chosen as an example of a major motorway corridor, with limited interference from the surrounding areas.

The existing model for this area had been created for a project on the use of simulation modelling for assessing methods for the control of motorway traffic by means of VMS. Although this gave a model which was close to the needs of the present project, a number of modifications had to be made. In particular, the first aim of the model was to represent the motorway layout as accurately as possible, and the modelling of other routes was not carried to the same level.

Because some traffic was to be modelled as being reluctant to use the motorway, provision had to be made to ensure that such traffic was able to travel to its destination by other roads. In many cases this was possible, but a check had to be made for routes which could only reach some destinations by means of lengthy detours because of the fact that not all alternative roads had been modelled. This was done by examining routes on a graphical representation of the network, and by looking at the output data of an assignment for unduly long journey times and anomalous queues. The result of this examination was that links had to be added, especially in the Maidstone area, to provide alternative routes.

The estimation of accident risks depends, among other factors, on the types of road in use. It was therefore necessary to categorise all the links in the network according to their status as motorway, urban or rural roads. This had to be done manually, as the model differentiates roads by their characteristics relating to traffic behaviour, but does not record road type specifically.

2.2 Aalborg

This network is formed by the motorway through the town of Aalborg, in northern Denmark. This model is available to TRL through its work in the DRIVE II project QUO VADIS, concerned with the control of motorway traffic using VMS. The network is entirely urban, and covers an area about 11 kilometres square. The total length of links modelled is 359 kilometres, with detailed modelling of the town centre, including a large number of traffic signals. Aalborg is divided by a fjord with only two crossings, one of which is the motorway (which is in fact in a tunnel). Thus traffic wishing to cross the fjord but not wishing to pay a toll must use the only alternative route across the bridge. However, traffic not wishing to cross the fjord has a wide range of alternatives because of the dense urban network. The motorways are not very heavily loaded.

As with the Kent network, the Aalborg network had to be carefully checked to ensure that it was capable of providing routes for traffic which was choosing to avoid motorways. In the case of Aalborg, because the motorways were intimately connected to the urban network, the non-motorway roads had been well modelled. Only minor modifications were needed to enable alternative routes to be used. Categorisation of road types was done manually, as for Kent.

2.3 Representation of non-toll payers

MCONTRM was designed with the purpose of modelling traffic control by imparting information to all or some drivers who could then alter their route as a result of the information received. In this case however, a proportion of former motorway users would have to be modelled as avoiding motorways.

It is thought that motorway tolls at the level currently envisaged (1p per veh-km for cars and light vehicles) would lead to the diversion of about 10 percent of motorway traffic, so this is the principal model considered. Although a higher toll has been proposed for HGVs, it is expected that fewer will divert to avoid tolls, and that their contribution to accident levels will be extremely small; therefore no account of them is taken in the diverted traffic. Thus the proportion of drivers changing their routes to avoid motorway tolls has been set at 10 percent for the purpose of this paper.

The first proposal for modelling 'toll avoiders' was to install VMS at every motorway on-ramp, and to force 10 percent of drivers to leave the motorway. This was rejected on two counts. Firstly, because the VMS were located on the on-ramps traffic would have to continue onto the motorway, even if it left at the next available opportunity. Moving the VMS further upstream, onto the roads which led to the on-ramps, but far enough away to permit traffic to divert before being obliged to use the motorway increased the number of VMS's, and complicated the design of the network, as well as not answering the second failing of this method. The second problem is that traffic which was diverted at one motorway access point might rejoin at the next, and not be affected by the VMS. This would lead to a situation in which, at one on-ramp, 10 percent of users were diverted, but a considerable proportion could then rejoin the motorway at another point. Thus although motorway traffic might be reduced by 10 percent, the actual routeing would not reflect a decision not to use motorways, but more the effect of something like a severe form of ramp metering.

The proposal next considered, and finally adopted, was to use the facility in MCONTRM to ban specific turning movements for selected vehicle classes. It is possible to model up to three different classes of vehicle in MCONTRM, and it was decided to designate the third of these classes as 'toll avoiders', and to prohibit class three vehicles from entering motorway links. This presented no problems, as the demand data for the networks did not use all the classes: in Kent the only classes were 'cars' and 'heavies', and in Aalborg only one class was represented. A program was written to convert a given percentage of the traffic demand to the third class of vehicle for each of the demand files. Where this led to fractional vehicles, the fractional flows were carried over into subsequent time slices. The effects were small, although percentage changes were larger on very small O-D demands, but such demands are not very significant.

It was also necessary to modify the network description. All the links giving entry to the motorway were designated as links which would not allow class three vehicles to pass. Thus when MCONTRM assigns traffic to the network all the class three vehicles can use any links except motorways. Because the aim of the modelling was to study the changes in traffic movements caused by the introduction of motorway tolls (and hence to estimate changes in accident risks), it was necessary to model two situations. In the first, with no tolls applied, all traffic is free to use all the routes as appropriate. In the second it is assumed that tolls are in operation on the motorways, and that a given proportion of traffic chooses routes which avoid using motorways as a consequence. The practical difference between the two computer runs is that in one case the motorway entries are banned to class three vehicles.

In fact the process was repeated for two different levels of traffic avoiding motorways as well as the 10 percent figure referred to above, at roughly 5 percent and 15 percent. It is difficult to be absolutely accurate in reducing motorway flows by a given percentage. Although it is comparatively simple to make a given percentage of any O-D demand into toll avoiders, this does not automatically translate into an equivalent drop in motorway usage, partly because some traffic is obliged to enter the network on a motorway despite being a toll avoider because there is insufficient information about precise origins to indicate the location of a non-motorway input. The actual level of toll avoiders was adjusted to give a 10 percent reduction in motorway flows.

2.4 Derivation of COBA accident rates from MCONTRM data

In COBA, the figures for accident levels are calculated by applying various factors to the traffic flows on modelled links. The factors used depend principally on the type of road involved, and are designed to give values of personal injury accidents per million vehicle kilometres.

Because MCONTRM models links in greater detail than COBA there is not a simple method of converting an MCONTRM network into the COBA format. For the purposes of this project the accident figures were obtained by extracting the vehicle-kilometres for each class of link from the MCONTRM output data (by combining link flows and corresponding link lengths) and applying the appropriate accident risk factors.

3 Results of network modelling

3.1 The Kent corridor

MCONTRM was run three times in order to test the sensitivity of the model's results to the level of diversion, using diversion factors of 5, 10 and 15 percent. As stated in section 2.3, the anticipated avoidance level is about 10 percent of motorway traffic, so this is the principal model and its main results are presented in Table 1. The model is based on the traffic on a single typical day, between 6 am and 10 pm.

These results relate to the network modelled rather than the full network in the area. Thus, traffic is predicted to rise by one-fifth on those rural roads which form part of diversion routes, but the proportional increase would be much less

Table 1 Main results for the Kent Corridor network model, 10 percent diversion

	Baseline	*With tolls*	*Increase (%)*
Number of injury accidents	4.1054	4.5992	12.0
Cost of accidents (£x1000)	228.4	255.7	11.9
Motorway traffic (veh-kmx1000)	10376	9341	-10.0
Rural traffic (veh-kmx1000)	5322	6442	21.0
Urban traffic (veh-kmx1000)	1333	1569	17.7
Total traffic (veh-kmx1000)	17031	17352	1.9
Total journey time (veh-hrx1000)	216.3	231.9	7.2

when calculated over the entire network of rural roads.

The number of injury accidents appears rather small, but can easily be shown to be of the correct magnitude. 5910 injury accidents were reported to the Kent police in 1993, which is equivalent to 16.2 per day. Nationally, 88.3 percent of accidents occur between 6 am and 10 pm, so about 14.3 per day occurred during the period represented by the models. The model does not cover the entire county; in particular the representation of built-up areas is limited to likely diversion routes. Since, nationally, three-quarters of injury accidents occur on such routes, the model would only represent one quarter of the Kent total. Therefore the 14.3 injury accidents expected in the county per 16 hour day translates to something more than 3.5,which is close to the 4.1 predicted by the model.

The model predicts 4.1054 accidents, whereas we know from published statistics that Kent has 14.3 accidents over the same period: the model under-represents accidents by a factor of 3.58. Therefore, the 12 percent increase in accidents in the model translates to a 3-3½ percent increase for Kent as a whole.

The revenue predicted from a motorway toll of 1 p per veh-km would be £93410 per modelled day. If this toll leads to a 10 percent diversion, the cost of accidents would rise by £27262 per modelled day, i.e. 29 percent of toll revenue.

The earlier report concluded that diverting traffic from motorways would increase congestion on non-motorway roads and hence raise travel time costs. The reduction in mean speeds could also reduce the number and severity of accidents, and the report reviewed the evidence currently available. This shows that lower mean speeds tend to be associated with fewer accidents, although the variance of the speed distribution is also influential and can offset the effect of lower speeds.

The COBA accident cost models take no account of congestion, so it remains to consider qualitatively whether increased congestion might mitigate the modelled increase in the number of accidents. One statistic reported by MCONTRM is the total journey time, which is included in Table 1. Ideally, the program would also report the distribution of changes in mean link speeds, but at present an extensive analysis of the model's detailed results would be required to achieve this. Instead, using an assumed mean speed for motorway traffic, one can calculate the mean speed on the diversion network, grouping rural and urban roads together. This suggests that the mean speed for non-motorway roads would fall by less than 1 percent, although clearly some links could suffer increased congestion, possibly sufficient to produce a reduction in injury accidents. This effect will be very network specific, depending greatly on the level of saturation on the diversion routes and the number of alternative routes available. Toll avoiders are not simply displaced onto routes paralleling the motorway, but may well vary the line of their journey quite considerably once the decision has been made not to use the motorway. Thus the overall effect is likely to be small. Consequently, it appears at this stage that increased congestion would have little effect in offsetting the increase in the number of accidents.

Figure 1 summarises the sensitivity of the change in accidents to the modelled diversion. The percentage increase is relative to the number of accidents on the network with no tolls, and would be much lower if expressed relative to the number of accidents in the county. The figure shows that the number of injury accidents increases in almost exact proportion to the diversion of motorway traffic over the likely range of diversion factors:

Increase in injury accidents (%) = 1.20 * Diversion of motorway traffic (%)

The increase in journey time does not increase linearly, and if higher tolls induce a higher diversion rate, the reduction in the mean speed for non-motorway roads may be sufficient to offset the increase in accidents (although, as noted above, the variance of the speed distribution can have a contrary effect). This indicates that MCONTRM is operating realistically, and shows that high tolls can lead to increases in congestion that may be sufficient to affect the number of accidents.

3.2 The Aalborg area

The Aalborg model is based on the traffic on a single typical day, between noon and midnight (due to the availability of traffic data). The Kent model covered a longer part of the day, but this difference only affects the factor needed to convert the modelled change in accidents to a daily or annual basis. As daily or annual baseline accident figures are not available for Aalborg, and differences between accident reporting procedures in non-fatal accidents in Great Britain and Denmark would probably invalidate any attempt at comparison, the difference in time period has no effect on the interpretation of the results.

MCONTRM was run five times to test the sensitivity of the model's results to the level of diversion, although it proved more difficult with this network to match the desired diversion levels. Table 2 presents the principal results from the 10 percent diversion model.

The Aalborg network differs from the Kent Corridor in many respects, principally:

a it is much smaller and entirely urban,

b the Aalborg motorway is less heavily trafficked,

c the model is more detailed, and represents a higher proportion of the roads in the area.

Thus, while Table 2 suggests at first sight that the consequences for road accidents in the Aalborg area will

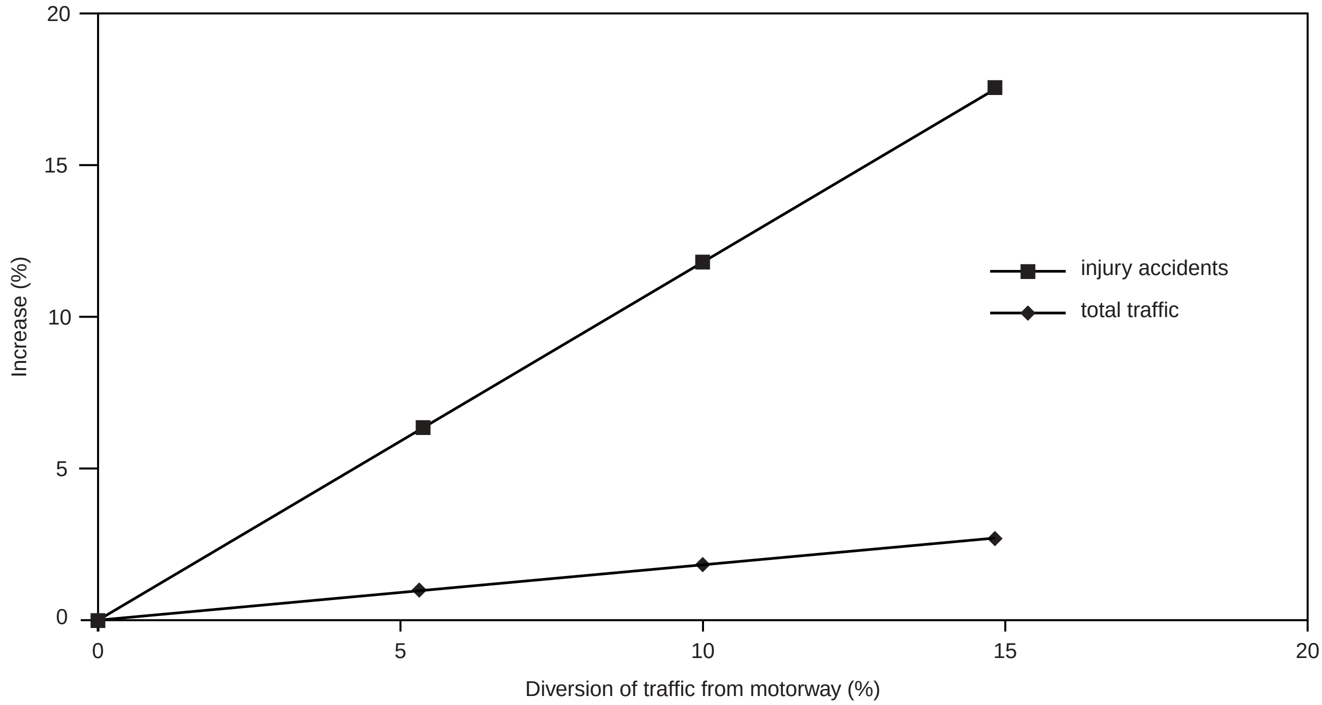

Figure 1 Results from Kent corridor network model

Table 2 Main results for the Aalborg area network model, 10 percent diversion

	Baseline	*With tolls*	*Increase (%)*
Number of injury accidents	0.7740	0.7918	2.3
Cost of accidents (£x1000)	25.06	25.56	2.0
Motorway traffic (veh-kmx1000)	212.2	191.0	-10.0
Urban traffic (veh-kmx1000)	752.8	772.7	2.6
Total traffic (veh-kmx1000)	965.0	963.7	-0.1
Total journey time (veh-hrx1000)	35.37	35.49	0.3

be only one fifth of those found in the Kent Corridor, the difference is less when calculated relative to the accident total for the whole area. The proportion of accidents in the Aalborg area that occur on roads included in the network model is not known, but the relatively dense network suggests that it could be about one half. This would imply an increase in accidents of about 1.2 percent for Aalborg, about one-third of the effect found in Kent. This difference can be accounted for, at least in part, by the fact that the traffic is lighter on the Aalborg motorway.

The ratio of the increase in accident costs to the toll revenue is similar for the two networks. For Aalborg, the revenue predicted from a motorway toll of 1 p per veh-km which leads to 10 percent diversion is £1910 per modelled day, while the cost of accidents would rise by £502 per modelled day, i.e. 26 percent of toll revenue. The corresponding figure from the Kent modelling is 29 percent.

Figure 2 summarises the sensitivity of the change in accidents in the Aalborg model to the modelled diversion. As with the Kent results shown in figure 1, the number of injury accidents increases linearly with the diversion rate:

Increase in injury accidents (%) = 0.25 * Diversion of motorway traffic (%)

The total vehicle mileage scarcely varies with the diversion rate, in contrast to the result from Kent. This is probably caused by the semi-circular route of the motorway as it bypasses Aalborg: when vehicles travelling North-South divert to pass through the town, their routes will often be shorter. The mean speed on the non-motorway network is scarcely affected by the diverting traffic, so again it appears that, at this level of toll avoidance, increased congestion is unlikely to offset the increase in the number of accidents to any significant extent.

3.3 Accident cost to toll revenue ratio

It is relatively simple to show that the ratio of the increase in accident cost to the toll revenue should be relatively invariant to network details such as motorway flow and level of network detail. If the volume of diverting traffic is X veh-km, then

Toll Revenue = X * toll rate * [(1/diversion factor)-1] (where diversion factor >0)

i.e. revenue is proportional to X irrespective of traffic levels or network details. It has been established that the increase in accident cost is proportional to Y which represents the mileage of diverting vehicles on non-motorway roads.

It can be seen in the two network models there is little increase in the total mileage due to diverting traffic, so it can be assumed thay Y is approximately equal to X, therefore

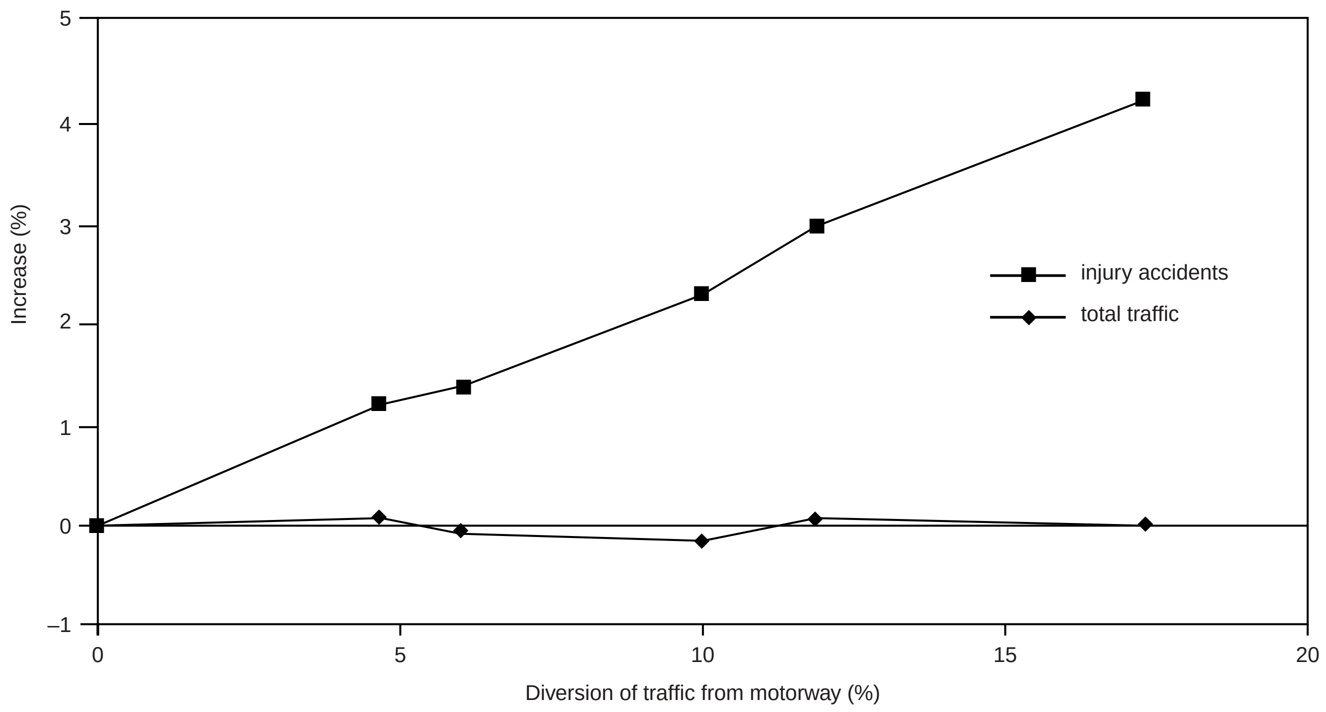

Figure 2 Results from Aalborg area network model

Increase in accident costs

$$= \text{cost per accident} * Y * (a_o - a_m)$$

$$\approx \text{cost per accident} * X * (a_o - a_m)$$

where a_m is the accident rate on motorways and a_o is the rate on other roads. Hence

$$\frac{\text{Increase in accident costs}}{\text{Toll revenue}} \approx \frac{\text{cost per accident} * (a_o - a_m)}{\text{toll rate}*[(1/\text{diversion factor})-1]}$$

a_o depends on the types of road available to diverting traffic, and there may be second-order effects, but to a first approximation the ratio depends only on the toll rate and the diversion factor, not on the network details. Hence, the ratio found with any model network will approximately equal the ratio found in Kent and Aalborg for any particular motorway toll rate and diversion factor.

4 Conclusions

This report has presented the main results of a study of the effects of motorway tolls on the number of accidents. The MCONTRM program was used to model the redistribution of traffic flow for two highway networks: the Kent corridor and around the Danish town of Aalborg. Accident costs were calculated using the cost models from COBA. Comparison of the two sets of results is complicated by the differing levels of network detail: the Kent model covers a large area and includes relatively few minor and urban roads, the Aalborg model covers a much smaller area in greater detail. The different levels of motorway traffic are also important.

Nevertheless, the results are credible. It is estimated that a 10 percent diversion of motorway traffic from the motorways in Kent would increase the number of injury accidents in the entire county by about 3½ percent. The estimated increase in accidents in the Aalborg area with this level of diversion is less, about one third of the figure found for Kent; this difference is partly due to the lower flows on the Aalborg motorway.

The accident cost models are not sensitive to the effects of congestion caused by the diverting traffic. The modelling provides global estimates for the changes in mean speed, but these are very small: they appear to be too small to indicate any likelihood of the estimated accident increases being offset by congestion effects to any significant degree.

Despite the difference between the increases estimated for the two areas, there is a means of expressing the results that yields consistent results. The cost of injury accidents increased by 29 percent of the revenue from a 1 p per veh-km toll in Kent and by 26 percent in Aalborg. A simple explanation was provided for this consistency in the presence of notable differences between the two networks.

The results from this detailed modelling of the road safety effects of introducing motorway tolls confirm the main conclusion reached in the earlier report on the basis of a simplified mathematical model, namely that the total number of accidents will rise.

Abstract

This report presents the main results of a study of the effects of motorway tolls on the number of accidents. The MCONTRM program was used to model the redistribution of traffic flow for two highway networks: the Kent corridor and around the Danish town of Aalborg. Accident costs were calculated using the cost models from the Department of Transport’s (now the Department of the Environment, Transport and the Regions) COBA program.

It is estimated that a 10 percent diversion of motorway traffic from the motorways in Kent would increase the number of accidents in the entire county by about 3½ percent. The estimated increase in accidents in the Aalborg area with this level of diversion is less, about one third of the figure found for Kent. The difference between the two areas is partly caused by the lower flows on the Aalborg motorway.