TRANSPORT RESEARCH LABORATORY

The likely effects of motorway tolling on accident risks

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Executive Summary

A result of the proposed introduction of Electronic Motorway Tolling is likely to be the diversion of traffic from tolled motorways to alternative untolled roads, as drivers decide to minimise travel costs. Motorways generally have a good accident record compared to the alternative non-motorway routes, and the diversion of traffic will alter the pattern of accidents with the overall effect on accidents unclear. This preliminary report on Accident Risk considers the theoretical issues and evaluates the effects using a single-link accident model, and then discusses a more in-depth study proposed with the MCONTRM traffic model leading to the final report.

The single-link accident model is evaluated using illustrative values for the parameters. The model comprises a single motorway link and a single diversion link and indicates that a 10% diversion rate would lead to an increase of one fifth in the number of fatal and serious accidents (relative to the original number on the motorway). However this basic model excludes several important aspects, such as the likelihood that diversionary routes will normally be shorter than the original routes, but will often pass through built-up areas. It is also clear that the consequences for accidents will depend on local road network conditions, making it more difficult to draw national conclusions.

The change in the number of accident that might result from the introduction of motorway tolling depends on network effects that are difficult to reproduce with a single-link model.

A series of studies are proposed, which will use the MCONTRM traffic model with representative networks, in conjunction with accident assessment models developed for use with the COBA model. This approach will allow a more in-depth assessment of the altered pattern of accidents.

This preliminary report concludes by recommending that accident assessments be performed for the two networks described, two synthetic networks, and ideally three new MCONTRM networks chosen to complement the existing network models, enabling a more reliable estimate of the national effects of motorway tolling to be achieved.

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, but the overall effect on accidents is unclear. This report considers the theoretical issues and presents a proposal for traffic modelling designed to evaluate these effects on sample road networks.

Concern that the accident total may increase arises from the generally good accident record of motorways, which is achieved by their high design standards (and consequently high construction costs). This is shown by Table 1, each column of which expresses the accident and casualty rates per billion vehicle-kilometres travelled on non-motorway roads relative to the motorway rates. Thus, comparing journeys of equal length made on different types of road, a driver is 3.3 times more likely to be involved in a fatal accident if he travels along a major NBU (Non Built Up) trunk road than if he travelled by motorway. The ratio falls to 3.0 when serious accidents are included in the comparison, and to 2.0 when all accidents are included. The ratios in the other rows (for other road types) also fall as less serious accidents are included; the reason is that accidents are more likely to be fatal or serious on motorways than on other roads because of the higher average speeds.

Table 1 Relative accident and casualty rates per billion veh-km, GB, 1993

	Relative accident rate			*Relative casualty rate*		
	Fatal	*Fatal+ Serious*	*All*	*Killed*	*Killed or seriously injured*	*All*
Motorways	1.0	1.0	1.0	1.0	1.0	1.0
Major NBU roads:						
trunk	3.3	3.0	2.0	3.1	3.0	2.0
principal	4.8	4.8	3.2	4.2	4.7	3.2
all	4.0	3.9	2.6	3.7	3.9	2.6
Major BU roads:						
trunk	4.4	7.4	7.9	3.3	5.8	6.2
principal	4.4	8.4	8.9	3.7	7.0	7.1
all	4.3	8.3	8.9	3.6	6.9	7.0
Minor	3.3	7.6	7.0	2.8	6.3	5.6
All	3.4	5.6	5.1	2.9	4.9	4.3

Note: Built-Up (BU) roads have speed limits of at most 40 mph, Non Built-Up (NBU) roads have higher limits. Data come from the national accident reporting system (Stats19) and the National Traffic Census.

The table presents relative accident and casualty rates separately, for completeness. Traffic engineers tend to concentrate on accidents and accident rates, whereas road safety policies are normally judged in terms of their effects on casualties. The relative casualty rates are slightly less than the relative accident rates, but the differences are not important. A picture that is less slightly favourable to motorways appears if rates based on travel time instead of travel volume are considered, but rates related to traffic volume are clearly the appropriate choice in the present case.

Section 2 introduces a simplified model for investigating the safety consequences of traffic diverting from motorways to the non-motorway network. This is evaluated using illustrative values for the parameters, but it is clear that a network model is required for a thorough investigation. Section 3 outlines the proposed approach for network modelling, and describes two networks which are available. Section 4 then brings together the conclusions from this work.

2 A single-link accident model

2.1 A simple example

An example is presented as a preliminary to developing a modelling framework for evaluating the consequences of a diversion of traffic from the motorway to the non-motorway network. It is greatly simplified in order to focus on the main factors, but the example is developed in the next section to incorporate other factors.

Example A length of motorway is paralleled by an equal length of NBU trunk road, which provides the only diversionary route. The traffic flows before and after the introduction of tolling are:

	before tolls	after tolls
motorway	V_m	$V_m - V_d - V_0$
trunk road	V_t	$V_t + V_d$

where V_d is the volume of traffic diverting to the trunk road and V_0 is reduction in volume caused by drivers deciding that they no longer wish to travel. If A_m is the accident rate on the motorway and A_t is the rate on the trunk road then the expected number of accidents per year is $A_m.V_m + A_t.V_t$ without tolls and $A_m.(V_m - V_d - V_0) + A_t.(V_t + V_d)$ with tolls. Thus, the expected increase in the number of accidents per year is:

$$I = (A_t - A_m).V_d - A_m.V_0 \tag{1}$$

Table 1 showed that $A_t > A_m$ for each severity of accident, so provided V_0 (the reduction in the overall volume of traffic) is small then more accidents of all severities would be expected. Table 2 evaluates these equations using the 1993 accident rates and the following traffic data:

$V_m =$ 1 billion veh-km (1.6 per cent of motorway traffic).

$V_d =$ $0.1xV_m$ (i.e. 10 per cent diversion rate), $V_0 = 0$.

Table 2 Evaluation of simple example, 1993 accident rates and costs

	Expected motorway accidents without tolls	*Expected nett increase in accidents with tolling*	*Percentage increase*	*Extra cost of accidents (£k)*
Fatal	2.5	0.6	23	507
Fatal+Serious	18.0	3.6	20	810
All	108	11	10	880

In addition, the table calculates the extra accident costs using the standard DOT (now DETR) accident costings applied in the economic appraisal of highway investments. A toll of 1p per km would yield an income from tolls of £ 9m (not £10m since 10% divert!).

2.2 Further issues

The real world is, of course, much more complex. A number of factors which were omitted from the simple example might well affect the expected increase. The following issues appear to be significant: each is labelled (+) or (-) to indicate whether their inclusion in the modelling is likely on balance to increase or reduce the expected increase in accidents. Table 3 re-evaluates the results from Table 2 using certain assumptions; these cannot be exact, but should illustrate the magnitude of the adjustment that is required.

Table 3 Examples of adjustments to the simple example, 1993 accident rates and costs

	Increase in accidents (%)			*Extra cost of accidents (£k)*
	Fatal	*Fatal+ Serious*	*All*	
Simple example (from Table 2)	23	20	10	880
A Shorter diversion route	17	14	6	610
B Diversion route includes BU roads	26	31	25	1270
C Lower speeds on diversion route	18	17	9	730
Combined effect	14	20	16	770

A – Diversion routes are likely to be shorter (-)

Unless the origin and destination of a trip are close to motorway junctions, a driver will be able to travel more directly using the non-motorway network. Summing over these diverted trips, the increase in non-motorway traffic would be less than the reduction in motorway traffic, leading to a smaller increase in accidents than shown by the simple example. If V_d', the increase in non-motorway traffic, is α times V_d, the reduction in motorway traffic, then the expected increase in accidents per year would be only

$$I' = (\alpha.A_t - A_m).V_d - A_m.V_0 = I - (1 - \alpha).A_t.V_d$$

Non-motorway diversionary routes could, on average, be up to 20 per cent shorter than the original motorway routes, implying that $\alpha \geq 0.8$. Table 3 re-evaluates the results from Table 2 with the value of $\alpha = 0.8$.

B – Diversion routes are likely to pass through built-up areas (+)

Table 1 showed that non-fatal accident rates are higher on BU (Built Up) than on NBU roads, so the actual accident rate would exceed the rate for NBU trunk roads. Table 2 can be re-evaluated using higher rates, and as an example Table 3 presents results based on the supposition that one quarter of the diversion route is along BU trunk roads and three quarters along NBU trunk roads. The changes would be smaller if the proportion of mileage on BU roads were lower, but greater if the proportion were higher or non-trunk roads were included in the diversion route.

C – Mean speeds on diversion routes are likely to fall (-)

Injury severity increases with impact velocity, so the severity of accidents on a stretch of road tends to rise with mean speed. The diversion of traffic onto the non-motorway network will reduce speeds on the diversion route, and so may lead to lower accident rates; section 2.3 summarises recent research in this area. The accident rate reduction is likely to be greater for more serious accidents, and Table 3 evaluates an example where the speed reduction was sufficient to reduce the fatal accident rate on the diversion route by 5 per cent, the fatal+serious accident rate by 3 per cent and the rate for all accidents by 2 per cent. The reduced rates will apply to the traffic already using the diversion route as well as the traffic diverting from the motorway, so an assumption is needed about V_t (the other effects relate only to the diverting traffic, so no assumption about V_t was needed). The example assumes that the diverting traffic increases the existing volume of traffic on the diversion route by one half, i.e. $V_t = 2V_d$.

D – Mean speeds on motorways are likely to rise (+)

Reduced motorway flows will tend to raise speeds and increase accidents, but the effect is likely to be negligible since speeds are already high.

E – More than one diversion route will normally be available

Well-developed road networks will offer a wide choice of diversion routes. Drivers who are unfamiliar with an area will probably stay on the major roads, but those who are familiar with the minor roads might also use these to avoid bottlenecks on the major roads. The overall effect on accident numbers is not clear.

Table 3 evaluates three examples using the assumptions and coefficients described above. It also evaluates the combined effect of the three examples. The results are sensitive to the coefficients used, especially those representing the extent to which the diversion route includes built-up roads. This confirms that the accident effects will depend on local conditions. No plausible set of coefficients could be found which implied that the number of accidents would not increase.

Without detailed research to establish appropriate values for the coefficients, relatively little weight can be placed on these results, and even with such research it would be very difficult to make a single assessment of the national effect since the interplay of these factors will vary from one area to another. Nevertheless, the results do suggest that factors A and C broadly counterbalance the effect of factor B and that the increase in accidents shown in Table 2 is of the right order. This leads to the preliminary conclusion that introducing tolling is likely to lead to some increase in accidents.

It is clear that network effects are important. A network model will automatically deal with A, B and E, so there seems little point in refining the single link model used so far (existing accident models used in conjunction with network models take no account of speed effects, so no network model will automatically deal with C and D). Section 3 will instead describe a suitable network model.

2.3 The relation between speed and accidents

A paper (Baruya and Finch, 1994) provides current information about the relation between traffic speeds and accidents on urban roads. It describes a study of accidents on urban link roads in 1988 in which 300 links were surveyed to collect information about vehicle and pedestrian flows and road geometry. These data were combined with accident data from the preceding five years, and statistical models were developed relating the number of accidents on each link to the local conditions.

The paper presents equations which can show the general consequences of reducing speeds on urban roads as a result of traffic diverting from motorways. These general conclusions are likely to apply to *rural* roads as well, although specific research would be needed to extend the equations to rural roads. To concentrate on the effects of traffic diversion, the final model from this paper can be re-written:

$$A = V^{1.57} \cdot e^{4.43\,Cv} \cdot Qa^{0.54} \cdot C \qquad (2)$$

where A = total number of injury accidents,
V = mean traffic speed,
Cv = coefficient of variation of speed
= standard deviation/mean of speed distribution
Qa = annual average daily traffic flow,
C = combined effect of other factors.

Increasing the flow Qa on a link will lead to a reduction in V which can be estimated using conventional ‘speed/flow’ relationships, but the effect on Cv is less easy to predict. The paper reports that the equation Cv=0.448-0.0078.V represents the relation between V and Cv reasonably well. This suggests that Cv is likely to rise as V falls, so that the reduction of the $V^{1.57}$ term will be offset to some extent by an increase in the $e^{4.43\,Cv}$ term.

The paper groups all accidents together, irrespective of severity, so the assumption made in section 2.2 that the effect of a speed reduction is greater among the more severe casualties cannot be checked. It is understood, however, that it would be relatively straightforward to reanalyse the original data by accident severity to obtain equations corresponding to (2) for fatal and serious accidents. The extension of this work to rural roads would be more difficult, as it would involve collecting explanatory data for a suitable sample of links.

3 A network accident model

Network traffic models have already been applied with several sample road networks to assess the redistribution of traffic flow that would be expected from a motorway toll of 1 p per km. These have led to the general conclusion that approximately 10 per cent of motorway traffic would divert to the non-motorway network. A suite of accident assessment models has been developed for use with COBA; these are consistent with the accident assessment used with the single link model, and in addition incorporate models to predict accident numbers at junctions. This software could be used to evaluate the safety consequences of the new pattern of traffic flow (except for the speed effects C and D), although this has not been done so far.

It is recommended that the preliminary conclusion reached in the previous section should be tested on representative traffic networks, using the MCONTRM program in conjunction with the COBA accident assessment models. The network effects A, B and E would be handled automatically, the speed effects C and D would be handled in a final semi-automatic stage if the results indicated significant speed reductions along diversion routes.

MCONTRM has several facilities that would be particularly useful when studying the effects of motorway tolling. The program allows the percentage of diverting traffic to be controlled, and the diverting traffic can be restricted to particular routes. Consequently, various diversion scenarios can be directly compared for a single network, to investigate the sensitivity of the accident changes to diversion patterns.

The two suitable MCONTRM networks which at present are available for use with this project are described below.

3.1 Kent corridor

Figure 1 shows the Kent corridor network. It stretches from the M25 - a section of the southeast corner of M25 is included - to Dover and the Channel Tunnel. It includes the M20 and the associated parallel A20 in the south, and the M2 and A2 in the north. The area covered is approximately 90km long by 20km wide.

Traffic diverting from the motorways as a result of tolling may be carried by trunk roads or through urban areas such as Maidstone and Ashford. The original purpose of the model for corridor control is reflected in the fact that the urban areas are not modelled in any detail, and in fact Maidstone is not effectually a through route. The modelling of Maidstone can fairly easily be modified to represent a major route through the town centre.

Flow data exist for a 16 hour period starting at 0600, in half hour time slices. This model is the better of the two available for studying mixed traffic conditions.

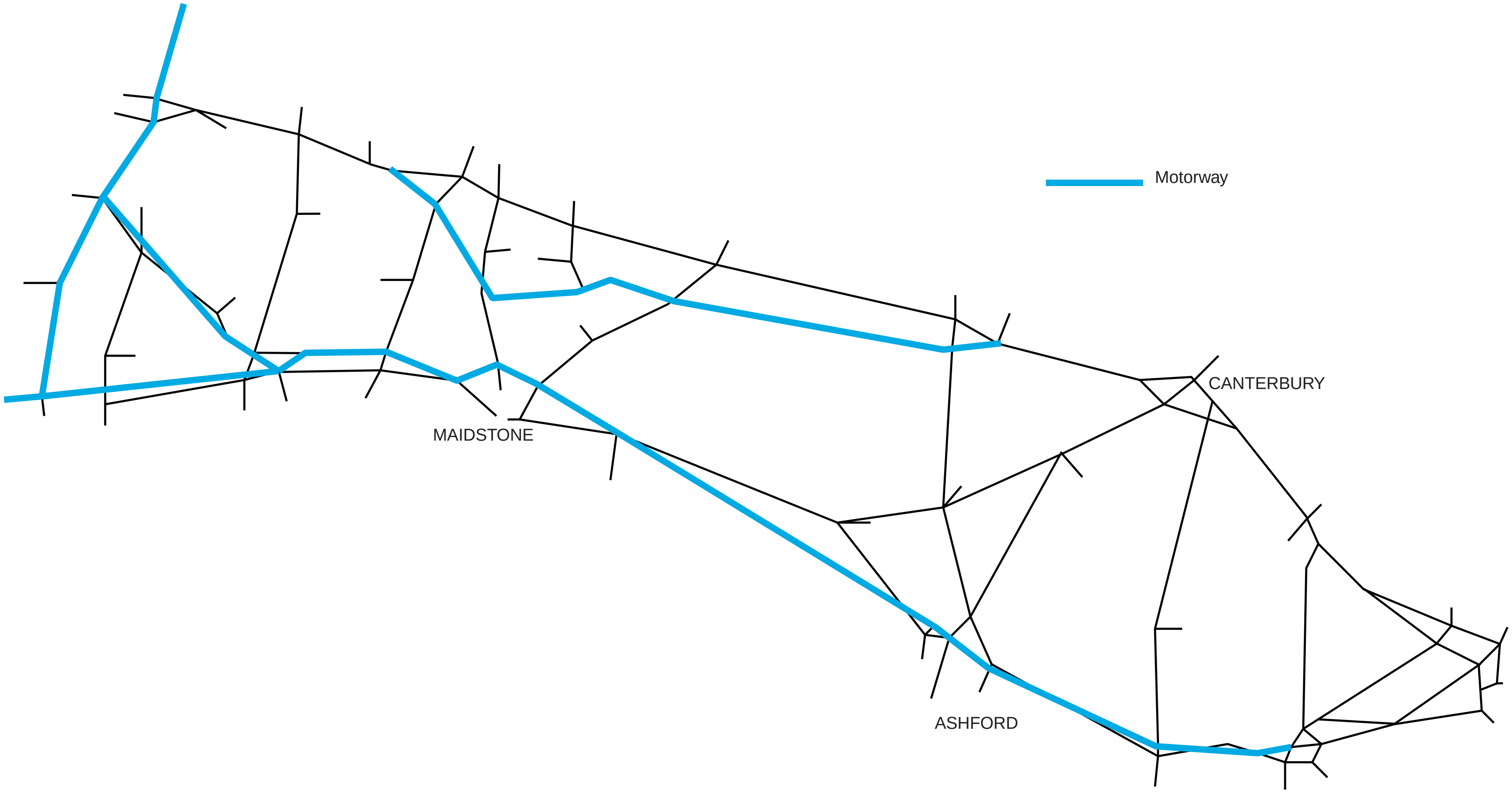

Figure 1 Kent corridor

3.2 Aalborg

Figure 2 shows the network for Aalborg, a town in Northern Denmark. The model is available to TRL through the DRIVE Project QUO VADIS, concerned with VMS control of traffic on motorways. The model includes the centre of the town and the motorways running through it, and the network is entirely urban; the area covered is approximately 11km square. The urban streets are quite extensively modelled, and plentifully supplied with traffic signals. There is a fjord running through the town from west to east which restricts north-south movements so that long-distance traffic diverted off the main motorway is forced to use the only other water crossing, but there is still opportunity for multiple routing within the town.

We hope to obtain full daytime traffic demands in the near future. A considerable amount of traffic data was available to the builders of this model, and this has been effectively used to validate the model to a high standard. Obviously this model is particularly well suited to the study of diversion effects in urban areas.

The single link model demonstrated that the accident changes that will result from tolling a particular stretch of motorway will depend on local characteristics such as the existence of attractive diversion routes and the extent to which these routes pass through built-up areas. Several networks representing the range of conditions found across the country need to be investigated in order to establish the national effects of introducing tolls on motorways: the two networks described above do not appear to be a sufficient sample for reaching reliable national conclusions. It is recommended that at least three additional MCONTRM networks, chosen to complement the two existing networks, be developed and accident assessments performed for them.

4 Conclusions

Concern that the introduction of motorway tolls might increase the number of accidents arises from the fact that motorways have a better accident record than the types of road onto which traffic would divert. A simplified model with a single motorway link and a single link diversion route has shown that even when the diversion route is of typical trunk road standard, a 10 per cent diversion rate could lead to an increase of one fifth in the number of fatal and serious accidents (relative to the original number on the motorway). This model excludes several important aspects, such as the likelihood that diversion routes will normally be shorter than the original routes, but will often pass through built-up areas. Once allowance is made for these, using illustrative values for the relevant factors, it is seen that the positive and negative adjustments broadly cancel out, so this result may be relatively robust. It is clear, however, that the consequences for accidents will depend on local conditions, making it more difficult to draw national conclusions. Also, the relative changes vary to some extent with accident severity, although these variations are conveniently handled by costing the changes using the standard DOT (now DETR) procedure for costing accidents.

The change in the number of accidents that might result from motorway tolling depends on network effects which are difficult to reproduce in a single-link model. Consequently, a network accident model should provide a more reliable estimate of the national effects of tolling. A method based on the MCONTRM model has been described, and two suitable networks which already exist have been described. It is recommended that accident assessments be performed for at least three new MCONTRM networks, chosen to complement the existing networks.

5 References

Baruya A and Finch D J (1994). *Investigation of Traffic Speeds and Accidents on Urban Roads*. Paper given at PTRC Conference. In Traffic management and road safety proceedings of 22nd PTRC European Forum. Seminar J, vol p381. PTRC Research Services, London. p219-30.

6 Acknowledgements

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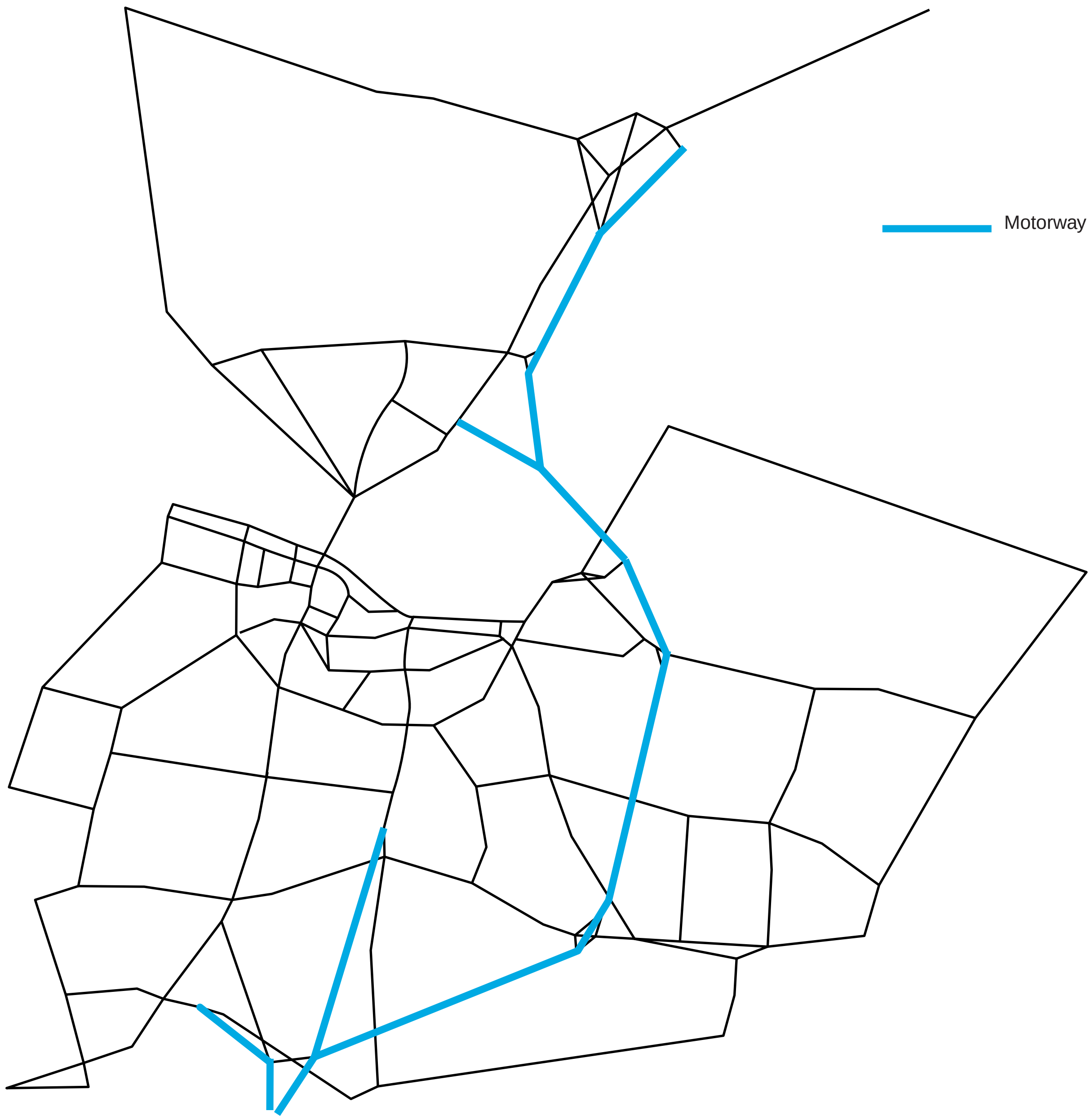

Figure 2 City of Aalborg

Abstract

A result of the proposed introduction of Electronic Motorway Tolling is likely to be the diversion of traffic from tolled motorways to alternative untolled roads.

Theoretical issues are considered and the effects evaluated using a single-link accident model which comprises a single motorway link and a single diversion link.

Results indicate that a 10% diversion rate would lead to an increase of one fifth in the number of fatal and serious accidents (relative to the original number on the motorway).

This basic model, however, excludes several important aspects, such as the likelihood that diversion routes will normally be shorter than the original routes, but will often pass through built-up areas. It is also clear that the consequences for accidents will depend on local road network conditions, making it more difficult to draw national conclusions.

The change in the number of accidents that might result from the introduction of motorway tolling depends on network effects that are difficult to reproduce with a single-link model.

More reliable assessments can be achieved by using the MCONTRM traffic model with representative networks.

Related publications

TRL345 *Measures for assessing on-board units for electronic toll collection — Parts 1 and 2* by J Holder and J Sutherland, 1998 (price £35, code H)

TRL348 *User requirements of on-board units for electronic fee collection* by P T McCabe. 1998 (price £35, code H)

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TRL359 *A preliminary study of in-vehicle interfaces for electronic toll collection* by D Watts, J Rattle and A Stevens. 1998 (price £35, code H)

TRL361 *Review of tolling and communications aspects of the US National Architecture* by J Holder and A Stevens. 1998 (price £35, code H)

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