Appendix A

Issues in the Modelling of Road User Charging

DISTILLATE PROJECT F

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1 INTRODUCTION

The objective of this technical note is to review the requirements for modelling various road user charging schemes, compare these with the current modelling methods employed in traditional forecasting models and thus identify gaps and possible areas of improvement or where further research is required.

In this paper, it is pointed out that traditional modelling techniques, even with substantial improvements, may not be able to model some of the schemes and the responses realistically. Some areas that require further research will be highlighted. Those that are feasible within our budget and in our models would be identified as case studies.

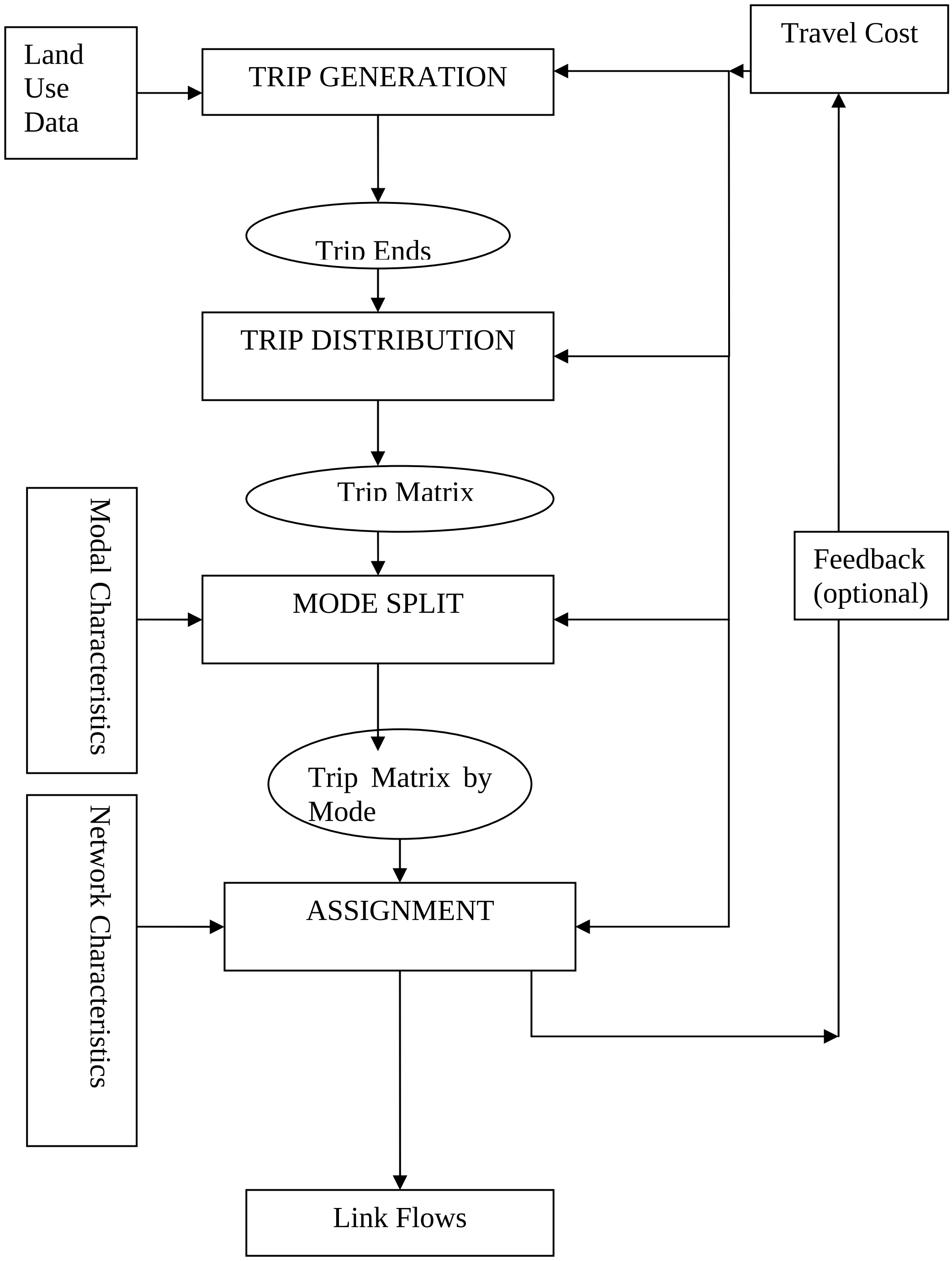
The structure of this paper is as follows: Section 2 discusses the various road user charging schemes while Section 3 looks at the various responses to tolls that have surfaced in the literature. Section 4 examines the modelling of road pricing concentrating primarily on the Road Pricing Feasibility Study (DfT, 2004). Section 5 develops an improved modelling framework while Section 6 identifies some contributions from the recently issued variable demand modelling advice(DfT, 2005). Sections 7 and 8 look at the gaps in realistic modelling of schemes and responses respectively. Section 9 highlights some issues that should be looked at in realistic modelling and where research should be headed next.

2 CONVENTIONAL MODELLING METHODOLOGY

In the last three decades or so, the basic form of the travel demand model that has dominated the literature and has usually been applied by practitioners is the “four stage travel demand model” as described in texts such as Ortuzar and Willumsen (1994). Figure 1 below shows the typical form of this category of travel forecasting model. Land use data provides information regarding jobs/employment/recreational opportunities. These are fed into the model to determine trip generation. The key output of this process is the calculation of trip ends which allocate trips to destinations (trip distribution). The trip matrix produced is split by mode depending on the modal characteristics and assigned to a network to provide link flows. The feedback loop is not always included in this form of a model and was only introduced because of earlier criticisms of the model form (Bonsall, 1997).

The following summarises the key characteristics of these models (Algers, 2000)

- built on a zonal basis but land use data is usually only input and usually separate from the main model.
- demand is on a per trip basis
- static structure (the demand and supply is related a one point in time)
- structured set of travel choices usually incorporating elements of the four stage models (i.e. trip generation, trip distribution, mode choice and route assignment)
- iteration to equilibrium
- treat user prices as an additional element of generalised cost (e.g. parking charges)



Four Stage (Sequential) Travel Demand Model
(Figure 5.8 from Bonsall, 1997)

Figure 1 FOUR STAGE TRAVEL DEMAND MODEL

In this paper modelling based on variations of the four stage model bearing the above key characteristics can be regarded as conventional traffic models. One objective of this paper is to consider the implications of applying this model form when incorporating road user charging.

3 ROAD USER CHARGING SCHEMES

There are various methods of implementing the concept of road user charging. They can be listed below and taken mainly from Mackie et al (2005):

Point Based Charges – Mackie et al (2005) defined this as a charge levied to pass a point on the road network. For example, this would be such as in the scheme in Durham or tolls on motorway bridges (such as those that apply on motorways in France).

Cordon charges – All crossings of a cordon or screenline might be charged. The main difference between a cordon and a screenline is that cordons form a closed loop (usually around a city centre). Good examples of cordon schemes are those in operation in Norway and Tronheim (Larsen and Østmoe, 2001). There may be multiple cordons as in the case of Singapore (Menon, 2004). Recent research evidence has shown that optimising cordon designs can increase the benefits compared to relying on expert judgement alone (Sumalee et al, 2005).

Area Charge –An area licence scheme involves a payment for a period during which the vehicle may be used or kept on the road inside the charging area. For example the London Congestion Charging Scheme is one such example. In the London scheme, the driver is charged for making use of the highway network within the Congestion Charge area.

The primary difference between an area charge and a cordon charge has been highlighted in ROCOL (2000) as follows: “an area licence can be compared to a ‘season ticket’ or ‘day pass’, while a cordon charge is more akin to a ‘fare’ for each journey”.

Distance Charges – This imposes a charge related to the distance travelled. The charge itself might be uniform (flat rate) or vary by time of day/area/road type or a combination of these characteristics (Mackie et al 2005). In the Road Pricing Feasibility Study (RPFS) report (DfT, 2004), the distance related charges were dependent on road type (e.g. Motorway/A road) /location (e.g. urban/rural). In the Netherlands, there have been proposals for distance based charges (“*kilometerheffing” or* “*Mobimiles*”) (Teule, 2002)

Congestion based charges and time based charges are two other categories of congestion charges that have been considered in the past (e.g. May et al, 1997). It has also been recognised that time based charges approximate “theoretical” first best charging regimes. However, research has shown that these charges appear to lead to unsafe driving behaviour (Bonsall and Palmer,1997) and are no more effective than distance-based charges (May and Milne, 2004). Hence in what follows we neglect consideration of these forms of charges.

In addition the charges imposed within these schemes may vary by time of day and vehicle type (e.g. motorcycles are exempt) and can vary by other factors such as vehicle occupancy (e.g. carpoolers are allowed to travel free)

4 RESPONSES TO ROAD USER CHARGING

In general the literature has documented the following as responses to road user charging (Stopher (1993); SACTRA (1994); ROCOL (2000); Paulley (2000, 2003); Mattson (2004); Toner and Mackie(2005); Bonsall et al (2005))

1. Route diversion
2. Reducing the frequency of trips
3. Mode switching
4. Change destinations (in short run, this is practicable for only trips that are of a discretionary nature such as shopping rather than the commute trip)
5. Retime trip
6. Not make the trip
7. Consolidate trips (trip becomes part of a trip chain)
8. Change vehicle occupancy

Note that the work reported in SACTRA(1994) concentrated on evaluating capacity expansion. Nonetheless this framework can be employed to understand traveller responses to road user charging as well. As Bly et al (2001) have mentioned, "SACTRA concentrated on extra "induced" traffic, and viewed these responses in terms of increases in the use of road vehicles, especially car, but the mechanisms can work in both directions so that changes which make road travel slower or more expensive will result in fewer road trips".

There are also "second round" responses reported in the literature such as:

- Vehicle sale (changes in vehicle ownership)
- Long term destination changes (i.e. change employment/work from home) as opposed to the short run changes identified above.
- Land use changes

An interesting second order effect has been presented by Toner and Mackie (2005). They give an example of the introduction of an area charge scheme within the city centre. The first round effects might see vehicles divert to routes around the cordon which would increase congestion on the periphery. This in turn would make destinations outside the city centre less attractive; public transport might become more crowded, making them less attractive for trips to the city centre. Thus there are second round responses that need to be modelled as well.

Furthermore, there is evidence that the response itself is dependent on the charge and the response mechanism seems to be that at low charge levels, rerouting and retiming are more pronounced; at higher charge levels significant mode shift may occur (depending on modal alternatives), together with some destination switching. This evidence is based on work carried out for the Scottish Executive (2003).

It is evident that not all of the above responses and be captured within the framework of the conventional travel demand model presented in Section 2. In particular trip chaining (elaborated below) and vehicle occupancy changes are some of the responses that cannot be captured within current frameworks.

ROCOL (2000) has mentioned that the responses depend on the road user charging regime in place. For example, with an area license scheme, there is the possibility to "re-scheduling trips to exploit its 'season ticket' or 'day pass' characteristics". Once a licence has been bought the marginal charge per trip is zero. Hence ROCOL (2000) pointed out that "*there could be a small percentage increase in trips overall by licence holders on those days for which they possessed a licence…*" and that "*some of these trips would be additional car trips, some re-scheduled from other days*".

4.1 Trip Chaining

As mentioned in Section 2, mainstream transport models regard each trip as an independent entity for analysis. This assumption, on which the structure of the four-step procedure hinges, leads to a number of serious limitations which stem from the fact that trips made by an individual are linked to each other and the decisions underlying the respective trips are all inter-related (Kitamura,1996). We are thus unable to model the consolidation of two or three trips into one (response 8) in the conventional modeling framework

The following example from Kitamura(1996) summarises the issue succinctly: Consider a home-based trip chain (a series of linked trips that starts and ends at the home base) that contains two or more stops. The four-step procedure would examine each trip separately and determine the best mode for it, leading to two major problems. Firstly the result may violate the modal continuity condition; mode choice for a trip with non-home origin is conditioned on the mode selected for the first home-based trip. Secondly, the result ignores the behavioral fact that people plan ahead and choose attributes of each trip (including mode, destinations, and departure time) while considering the entire trip chain, not each individual trip separately.

It is known that in reality trips consist of a 2 leg-tour (Bly et al,2001). Following Axhausen (2004) a tour is a sequence of trips starting and ending at the same location. IHT (1997) states that it is essential to deal with all the trips made in the course of a round tour as one, "to ensure temporal logic and consistency in aspects such as the duration of stay at certain destinations" and it acknowledges that the modeling of road pricing requires the use of tours instead of the trip basis. IHT(1997) has suggested that the role of the time-of-day choice model when tours are modelled, becomes one of prediction of "the simultaneous choice of the time of the outward and return portions of the tour, as a function of the differences in the perceived generalized cost of the round tour". The modeling of tours can be handled within the PTV VISION (Fellendorf et al, 1997) and the EMME/2 (Spiess, 1996) packages. These are elaborated further in a later section.

Even when one successfully models tours e.g. in the Orestad Transport Model (Section 5 below), this modelling may only be partial because it continues to make the assumption that the tour for a commuter trip is say home to work and work to home. This is indeed the case in the Orestad Transport Model (Jovicic and Hansen (2003)) However when road pricing is introduced, this tour could be broken and travellers might be forced to go to the shops on their way home from work so that they can get their shopping done and pay a lower road price. Hence even when models are built around tours, they may not be able to predict changes to the trip chains or the formation of new chains. In addition, due to the extensive amount of data collection required for trip chain modelling, their widespread adoption by practitioners is slow in coming.

4.2 Evidence of Responses

Overall there is obviously very limited evidence of responses to road user charges directly reported in the literature primarily because there are limited examples of road user charges in operation.

It is usually assumed in the conventional literature that changes in tolls have the same effects as changes in driving costs. On the one hand, there seems to be some empirical evidence from Stated Preference data in Denmark that "respondents accept tolls essentially in the same way as they do driving costs" (Jovicic and Hansen, 2003). However, in that same paper, they concluded that parking costs are real out of pocket costs as compared to driving costs (such as fuel) which are already included in the household budget and there is also evidence that the value of parking costs is actually higher than that of driving costs. Since there is limited evidence of toll elasticities, researchers have attempted to give indications of the elasticities by proxying changes in driving costs. Annex A to this note provides some evidence of elasticities by type of response to changes in driving costs based on the paper by Toner and Mackie(2005).It must be remembered that Toner and Mackie (2005) have made the assumption that changes to say fuel prices and parking costs have the same effect as that of changes in road user charges and have attempted on this basis to draw inferences as to the magnitudes of the resulting changes in trip length and trips in a similar fashion.

Annex B summarises the literature on the Singapore experience particularly in terms of the traffic flow changes and the elasticity responses based on the available literature.

Despite the fact that experiences from one area may not be transferable to another, there are still some ideas of responses that were important. The three most important responses noted in Singapore (Watson and Holland, 1978) were mode switching, vehicle occupancy increases and most importantly trip retiming/rescheduling. This rescheduling manifested itself in a surge in traffic entering the charging zone in the half hour before the charge was operational and another surge at the end of the charging hours. It is also important to point out that the hoped for increase in park and ride were never realised.

The London experience indicates that that mode switching was important (despite the fact that a lot of trips into the charge zone were made on public transport before the introduction of the scheme.). Of the car trips removed from the zone, 70% switched to public transport/other modes and route diversion around the charge area accounted for between 10% to 20% of the car trips removed (Murray-Clark, 2003). This reinforces the research result that the design of the cordon is vital to obtaining the maximum benefits (Sumalee et al, 2005). TfL (2004) suggested that there has been an increase, although does not seem to be statistically significant, in the use of powered two-wheelers circulating within the congestion charge zone. This point is interesting as the license requirements for riding mopeds in Great Britain are not particularly stringent and potentially available to anyone possessing a license for a car.

In the first couple of months of the Stockholm trial implemented in January 2006, the main response seemed to be a transfer from private car to train and private transit, although it is still too early to judge the longer term impacts of the scheme (http://www.marketwire.com/mw/release_html_b1?release_id=112062).

5 MODELLING ROAD USER CHARGING IN PRACTICE

5.1 Experiences Overseas

In this section, we present some literature review of the experiences in modelling road user charging outside the UK. All of these (except the Singapore experience) are all desk studies of schemes that have yet to be implemented.

5.1.1 Oslo Study

In order to study the impacts of differentiated toll rates for various cordons within Oslo, Larsen and Østmoe (2001) reported on attempts to model the following:

- Timing of car trips within the peak period
- Choice of mode for travel
- Route Choice

However, it was assumed that trip generation and destination choice would be unaffected by the pricing policy. They recognise that this is “clearly wrong” but also mentioned that it “was too complicated to include all demand responses in a single model system, given the time and resources available”.

In addition, this study did not allow for trips shifting from one period to another. Given that this study was intended to study differential toll rates, this could be construed as limiting factor of the model. However, they allowed trip makers to shift their departure time choice during each discrete model period.

5.1.2 Copenhagen Study

The interesting study by Jovici and Hansen (2003) reported on an attempted to apply the Orestad Transport Model (OTM) to model road pricing in Copenhagen[1]. In this paper, they demonstrated that this model produced robust forecasting results in

[1] The main purpose of the OTM was a passenger travel demand model but its main purpose was NOT for the modelling of road user charging. It is a general workhorse for short to medium term forecasting in the Greater Copenhagen area.

general. An interesting fact is that this model was built not on a trip basis but using tour modelling. However, they defined a tour as a sequence of two trips and did not allow for intermediate stops. In reporting their results for the road pricing tests, they did not mention whether the model would predict changes to any tours or the "breaking of tours" or the formation of new chains.

As they had empirical Stated Preference evidence to suggest that respondents accepted tolls in the same way as they do driving costs, they extended the car driver and passenger utility functions with this cost coefficient to model the impact of road user charging applied on a distance basis in Copenhagen (details were not available in the main paper).

The conclusions were as follows:

- car person trips dropped by 6%, with business travellers being insensitive to the road user charge. This 6% reduction was caused by the commuter and leisure traffic which accounted for over 70% of the trip making within the model.
- There was a 11% reduction in vehicle kilometres. Compared with the 5% reduction in car traffic, they concluded that the large reduction in traffic is for longer trips that change destination and mode choice with traffic changes.

5.1.3 Dutch Studies

In the Netherlands, road user charging had been a topic for discussion and modelling for the last decade and a half. At present there are no firm proposals and historically, many proposals have been rejected for implementation usually on political grounds.

The National Modelling System (LMS) is used as the main basis for the results reported in the literature. In addition, the work looked at congestion charging within the *Randstad* area (comprising the main cities of Amsterdam, Rotterdam, The Hague and Utrecht) Some results of modelling are as follows:

- For flat rate distance charging ("*kilometerheffing*") at the rate of 5.4 eurocents per km on all roads would lead to reduction in car-kilometres of approximately 10% in 2020. There is also evidence of some destination changes i.e. trip makers shifting their choices of destinations closer to their place of residence.
- Static congestion charging at 9 eurocents per km at locations with recurrent congestion. This lead to a reduction in car km by 4% with congestion on the motorway network decreasing by up to 50%
- Dynamic congestion charging at locations dependent on the congestion level at between 4.5 to 18 eurocents per km. This lead to similar results as static congestion charging above but with less reduction in car km.
- Charges for driving on the Randstad motorway network at €3.50 would lead to reduction in the congestion by about 36% but increases on other roads by about 19%.
- Cordon charging ("*Rekening Rijden*") around the cities of the *Ranstad at a rate of* €3.50 in the AM peak, leading to a reduction of 27% in congestion on the motorway network and reduction in car-km of around 4%.

There was also the "*Select Systeem*" of express lanes free for carpoolers and trucks but other vehicles had to pay €2.30 in the AM and PM Peak. This is similar to the scheme operating in California at present (Sullivan,2002). The simulations were only carried out for selected roads in Rotterdam and showed that congestion in the morning peak fell by 8% but the secondary road network actually saw an increase of 12% in car km.

5.1.4 Asian Studies

In Hong Kong, Wheway and Cheuk (1999) reported on a desk study assessing the implications of road pricing commissioned by the Hong Kong government. In this study they considered highlighted that some of the likely responses are paying the road charge, changing travel time, changing route, switching to Park and Ride, increasing vehicle occupancy for ERP, suppressing of trip making. They developed a large scale strategic model that had 7 segments including 3 segmented by income bands.

In Singapore, a well segmented strategic (EMME/2) model with feedback loops into a highway (SATURN based) and EMME/2 based Public Transport Model is used to model road user charging (Lim and Le, 2003; Anonymous, 2005).

5.2 Experience in the UK – The ROCOL Study

There have been a few road user charging studies in the last few decades in the UK beginning with the Smeed Report (196?) One of the latest studies for road pricing in central London was presented in ROCOL (2000). The information presented below are based on results from that study and uses the APRIL model which was developed for the London Congestion Charging Research Programme

5.2.1 APRIL Model Structure

The APRIL model covered the Greater London area and comprises 8 trip characteristic segmentations 4 of which are actually tour based. A detailed breakdown of this is presented in Table 1 below alongside the possible responses.

Table 1: TRIP SEGMENTATION AND POSSIBLE RESPONSES IN APRIL

Trip Purpose	Tour/ Trip	Change time of travel	Change Route	Change destination	Change frequency	Change Mode
Home to/from Work	Tour	YES	YES	NO	NO	YES
Home to/from Employers Business	Tour	NO	YES	NO	NO	YES
Home to/from Education	Tour	NO	YES	NO	NO	YES
Home to/from Other	Tour	YES	YES	YES	YES	YES
Non home based	Trip	NO	YES	NO	NO	NO

employers business						
Non home based other	Trip	SOME	YES	NO	YES	NO
Light Goods	Trip	NO	YES	NO	NO	NO
Heavy Goods	Trip	NO	YES	NO	NO	NO

In addition, this model was further segmented by income, car ownership and employers motoring subsidy. However it must be pointed out that even the attempt to incoporate tour modelling has a limitation. This is because it defines a tour as a set of inbound and outbound journey with the SAME destination. This implies that it will not be able to consider responses to road user charging whereby people might be tempted to "join up their journey" by forming trip chains. It is less likely to be the case in area license schemes (as we have pointed out earlier that the marginal cost of an extra trip is effectively zero when the license has been purchased) but might be significant if cordon charging was tested since payment is required for every trip crossing a cordon. It must also be pointed out that ROCOL (2000) clearly states in Annex E that "the facility to allow trips to change destination or frequency was not used" (Chapter 8: p 154). Another model, known as "AREAL", is adjoined to the APRIL model to measure the propensity of households, with different income categories with different car ownership levels, to buy the area license coupons.

5.2.2 Modelling Results

The tests postulated several scenarios under the umbrella of road user charging. The scenarios are as follows:

- Core scenario of £5 per day charge for cars and light vans and £15 for heavy goods vehicles to drive within Central London between 0700 and 1900 on weerkdays WITH NO SIGNIFICANT EXEMPTIONS
- Same as core scenario with associated public transport improvements
- Same as core scenario but with lower charges of £2.50 and £10 for respective vehicle types
- Central area charge but only during peak periods
- Same as core scenario but extension into Inner London

It is important to point out that the actual London Congestion Charging scheme that is in operation has substantial exemptions for residents. Why this was not postulated as an additional scenario was not reported in ROCOL (2000). It is probably the difficulty of modelling exemptions to residents that limited the scenarios tested. We return to this point later in the paper.

The main results are presented below for the Core scenario which is very similar to what was implemented in central London. They are as follows:

- Home based car trips predicted to fall by 35% over the whole charging day
- There is a 14% increase in public transport trips to/from Central London
- Total vehicle km in Central London projected to fall by 10 to 15%
- Small reduction in the outer area

- Traffic on the Inner Ring Road would be increase as trips divert around the charging area.
- There would be a greater reduction in car trips into Central London charging area by those from lower and middle income households than by those from higher income households. (50% reduction from the former vis a vis 20% from the latter).

5.3 Experience in the UK - The Road Pricing Feasibility Study

As part of the Road Pricing Feasibility Study (RPFS), DfT commissioned several commercial consultants to undertake tests of road pricing strategies in three areas covered by the multimodal studies. The studies and their corresponding geographical areas were as follows:

- South and West Yorkshire Multimodal study (SWYMMS)
- London and Oribital Multimodal Study (ORBIT)
- Cambridge to Huntingdon Multimodal Study (CHUMMS)

More information regarding the RPFS is available in DfT(2005).

5.3.1 Charge Options Modelled

The objectives were to test distance-based charges and cordon charges. The distance based charges were provided by the DfT using the National Transport Model (NTEM). The most complex form of these charges was segmented by road type/ location and volume capacity ratio and allowed negative charges as well. In addition, the ORBIT model reported results using flat rate distance charges (which simplified the structure of the charging mechanism) (KBR,2004).

The consultants were required to optimise cordon charges (i.e. find charges that optimises traveller time and money impacts across all modes but excluding scheme or operating cost).

5.3.2 Responses to charges

With reference to the previous discussion on the types of responses to road user charging, Table 2 shows the types of responses that can be modelled within the framework of the various multimodal studies.

Table 2: RESPONSES MODELLED WITHIN THE ROAD PRICING FEASIBILITY STUDY

STUDY	South and West Yorkshire Multimodal Study (SWYMMS)				London Orbital Model ("ORBIT")		Cambridge to Huntingdon Multimodal Study (no variant)
Model Variant	SWYSM (Strategic Model)	Land Use Transport Interaction with Strategic Model	Detailed Transport Model	Detailed Transport Model with SATEASY	NAOMI	LASER	
Route diversion	✓	✓	✓	✓	✓	✓	✓
Reduction in Frequency of trips	✓	✓	✓	P	P	✓	✗
Mode switch	✓	✓	✓	P	P	✓	✓
Change destinations	✓	✓	✓	P	P	✓	✓
Trip Retiming[2]	✓	✓	✓	P	P	✗	✗
Trip chaining	✗	✗	✗	✗	✗	✗	✗
Changes in Vehicle Occupancy	✗	✗	✗	✗	✗	✗	✗
Vehicle sale	✗	✗	✗	✗	✗	✗	✗
Land use changes	✗	✓	✗	✗	✗	✓	✓

Key:

- ✓ Response can be modelled
- ✗ Response cannot be modelled
- P Response can only be partially modelled or subsumed

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[2] Only Time of Day (i.e. Macro time period choice not micro level)

Some interesting comments can be made regarding the models within the RPFS.

- Trip chaining cannot be modelled; this is a recognised weakness of conventional modelling (Kitamura et al,1996)
- Trip retiming response is at the broad macro level and not in a dynamic fashion.
- Changes in vehicle occupancy cannot be modelled
- Changes in vehicle ownership cannot be modelled

For models utilising SATEASY (Hall et al, 1992), the "elastic assignment" is assumed to encompass a wide range of the responses subsumed within the elasticity of demand with respect to cost factor; it is recognised that this elasticity method is not sufficient (Oladeinde(2005), DfT(2005)).. Up to the release of the VADMA advice (see Section 7), practitioners carrying out variable trip matrix assignment assumed that trips between an Origin Destination (OD) pair were simply a function of cost of travel between that OD pair **ONLY** and this ultimately is influenced by the elasticity of demand, often input as an exogenous parameter. A single exogenous elasticity parameter cannot capture the whole range responses of changes to the travel choice set because elasticities themselves are not constant and would change when the travel choice set changes.

5.3.3 Conclusions of the RPFS

As Mackie et al point out, the tone of the report of the RPFS was "cautionary" (Mackie et al, 2005) and that the plans tested were not specific proposals for introduction. In addition DfT was at pains to point out that there is much uncertainty about the results and suggest that more confidence should be placed on the "relative outcomes" rather than the absolute numbers (DfT, 2005).

Bearing this in mind, there were still some important conclusions drawn from these studies.

RESULTS FROM DISTANCE BASED STUDIES

Table 3 tabulates the results of the charging from the models utilising the DfT specified distance-based charges and the alternative flat rate charge implemented only within the NAOMI system.

It is important to note that a "link" in modelling terms may not be the same as a road as a road itself may comprise several links. There is a semantic issue in the definition of the links. It is not clear from the report what definition was used. One can imagine that no driver would be able to cope with sudden changes in the tolls as she drove from one link to another and yet was still on the same road, simply because the Volume/Capacity ratio on two different parts were different as suggested by the modelling efforts.

Note that Net Present Value refers to the sum of all time and money (operating cost and charges) benefits and disbenefits to users, revenues accruing to the charging authority and changes in indirect taxes (due primarily to vehicle operating cost changes since fuel is taxed). This was assessed using the DfT's approved TUBA software.

Table 3: ABSTRACT OF DISTANCE CHARGING TEST RESULTS

	Distance based charges based on DfT Specification			Alternative Distance-based charge
	SWYMMS	NAOMI[3]	CHUMMS	NAOMI
Average Charge	7.6 pence per km	7.6 pence per km	-0.7 pence per km	6.8 pence per km
Change in Daily Trips	-15.4%	-12%	0%	-12%
Change in Daily Vehicle Kilometres	-23.9%	-14%	+ 2.6%	-17%
Change in Average Trip Length	-10.1%	-3%	+2.6%	-6%
Net Present Value	-£467 m	-£62m	-£27.5m	£80m
Annual Revenues	£1129 m	£756m	-£50.3m	£770m

Source: (MVA, 2004)

For SWYMMS and NAOMI, there was a reduction in trips, vehicle kilometres and trip length. However the net present value was negative primarily because of circuitous rerouting. Graphical evidence is presented in the study report (MVA, 2004) to show extremely circuitous routeings as a result of the distance-based charges utilising the DfT's specification. In CHUMMS, the reference case congestion was much lower and most of the links were actually subsidised. But we must bear in mind that negative tolls as specified by the DfT are prone to abuse and would be impractical and could have led to routing for selfish benefits.

RESULTS FROM CORDON CHARGE STUDIES

Table 4 shows the results of the "optimum" cordon charge tests in the various specifications compared vis-à-vis a reference case.

It is important to point out that that the charges for cordon tolls within the RPFS were all given as pence per crossing. Charges in reality may be levied per day rather than per trip. This leads to a discrepancy between what modellers are able to model and the practical road user charging proposals.

In addition the report does not allude to any work done to optimise the location of charge points in the cordon. It was effectively around the various city centres in the models which the areas encompassed.

[3] Since NAOMI models only the AM Peak, Net Present Values and Annual Revenues relate to the AM peak charges only and hence are not strictly comparable with other models.

Table 4: ABSTRACT OF CORDON CHARGING TEST RESULTS

	SWYMMS	NAOMI[4]	CHUMMS
Change in Daily Trips	-2.6%	-6%	0%
Change in Daily Vehicle Kilometres	-6.2%	-6%	-2.6%
Change in Average Trip Length	-3.7%	0%	-1.1%
Net Present Value	£109m	£17m	£5.6m
Annual Revenues	£224m	£770m	£30.7m

Source: (MVA, 2004)

Two key points can be inferred from the results

- Cordon charge revenue was a fraction of that obtained from distance based charges; this is because cordon tolls are applied to only trips that cross the cordon (hence only a subset of trips)
- Because the cordon charges were economically optimised, the benefits were generally positive and this was even before the locations of the cordons were optimised.

GENERAL CONCLUSIONS

Most of the models allowed for feedback in the response (i.e. cost information from the assignments were fed back into mode choice, trip distribution and trip generation.). It was found that rerouting was the most common response but that changes in trip frequency/generation were least likely. The rerouting phenomenon was observed less when distance charges were flat (equal across all links) compared to when charges were applied following the DfT's specifications.

It has been recognised in the modelling work that "there is little experience of using such models for this (road pricing) purpose and even fewer examples of pricing in practice against which such models can be validated" (MVA, 2004).

The DfT's specification for distance charging was complex as the charge on the road depended on the type of road, the area and the existing volume/capacity ratio. Firstly, there is no outturn evidence to validate the results from these models. Secondly, there is also the issue that the modelling of responses to a complex structure of prices is fraught with difficulties and is a topic of ongoing investigation (Bonsall et al,2005).

[4] Since NAOMI models only the AM Peak, Net Present Values and Annual Revenues relate to the AM peak charges only and hence are not strictly comparable with other models.

Originally, the DfT wanted the consultants to explore area charges but the consultants lacked the expertise to model area charges (KBR, 2004) within the timescale of the RPFS. This issue is further explored in this paper in later sections.

Evidence from the tests conducted in this study is that complicating the pattern of charges could yield responses that were undesired manifesting in circuitous rerouteing leading to increased trip lengths and negative net present values.

Simpler patterns of charging (flat rate distance based) and cordon tolls could yield positive results in the "right" direction (reduced trip lengths and positive net present values).

Tests with land use models showed that these charging regimes caused households and employment to migrate outside the charged areas. This might be important unless a national policy of road charging was introduced as compared to being purely local policies.

Cordon charging led to reduced revenues compared to flat rate distance based charging. This is simply due to the fact that cordon charges only affect certain trips while distance charges apply on all links affected all trips.

6 DEVELOPING AN IMPROVED MODELLING FRAMEWORK

6.1 Adequacy of Spatial Representation

The supply side of the transportation system, in modelling terms, is represented by the network. Generally speaking, not all roads are modelled with the same degree of accuracy. The IHT Guidelines (IHT,1996) reminds that "networks for road traffic assignment models should be of sufficient extent to include all realistic choices of route available to drivers". In modelling road pricing, spatial representation is vital because route switching is one of the most common responses to the implementation of a road user charging scheme and the extent depends on the charging regime.

If the toll were flat, studies have shown (KBR 2004, MVA 2004) that the route switching were less likely and that trip lengths were generally lower than where tolls were dependent on road type. This will have implications for evaluating the benefits from the scheme because circuitous routeing will lead to increased journey times or trip lengths which negate some of the potential benefits of the tolls.

6.2 Convergence of Existing Techniques

Generally speaking, as was the case with the multimodal studies, multi-tiered models, e.g. where Land Use/ Trip Generation/ Trip Distribution and Mode Choice are at the upper level while the highway assignment and public transport assignment are at the lower level, there is no guarantee that the upper and lower levels will give consistent predictions for a set of given assumptions. A warning from Paulley (2000) is that "if demand responses are modelled, it is important that the assignment and demand models are iterated to an acceptable degree of convergence, otherwise the scale of responses cannot be accurately predicted".

To some extent, VaDMA (see below) has dealt with this aspect as it embodies algorithms that have been developed to ensure some form of a reasonable convergence so that the issues raised in Paulley (2000) have been overcome.

6.3 Segmentation

Segmentation is the division of travellers into different "categories" which are themselves a function of some travel attribute(s). In the context of road pricing, the most important attribute is the value of time. There is vast amount of literature relating the importance of the value of time attribute to the concept of the optimal congestion charge (Walters, 1961; Dial, 1995; Li, 2002). Improving the modelling of these segments will consequently improve the response of the model to the road user charges in some respects. Burris and Pendyala (2002) report that several socio-demographic groups (e.g. elderly, unemployed, those who have more flexible working hours, low income travellers) are more likely to alter their travel time at greater frequency with variable tolls.

The value of time varies by journey purpose (MVA et al,1987) and it is already common practice for segmentation by trip purpose to be carried out in many models. In addition, Paulley (2000) has noted that variation of the value of time with income and with purpose has produced a greater level of diversion than using a single VOT for all drivers. Income has a direct effect on the value of time and will exert an important influence on the trade-off between congestion charges and improved travel times (Mackie et al, 2005).

In the RPFS, most of the models (excluding consideration of the strategic level models) had some form of segmentation by willingness to pay charges except for CHUMMS. Interestingly the CHUMMS results also seem to be slightly different from the rest of the models. It is difficult to tell if difference in segmentation played any role here but the possibility is highlighted.

6.4 Delay Representation

Given that rerouting is one of the most common and logical responses to road user charging, Paulley (2000) has mentioned that delay on competing routes must be properly represented in the reference case. Otherwise there will be over estimation of the diversion. In this connection, Paulley points out that in most cases, even when the validation of a model is acceptable, it does not necessarily imply that delays are adequately represented because the response of the speed flow curve to delay has to do with the gradient rather than the absolute flow levels.

7 VARIABLE DEMAND MODELLING ADVICE (VADMA)

Some conventional models cannot model any response other than route diversion. These are the so called "fixed matrix" assignment models that are used by several local authorities and development of more complex models may not be justified by these practitioners due to expense, expertise and computational experience. Of course following the SACTRA(1994) report current practitioner developed models that have attempted to carry out some form of "demand modelling" tend to use the journey time elasticities calculated from the information contained within DMRB (Particularly the Guidance on Induced Traffic in Section 12 Part 2.) (Highways Agency,Various Years).

The DfT has recently issued draft guidance[5] on Variable Demand Modelling. (VaDMA). The aim of VaDMA is to ensure that scheme appraisal considers "extra trip making, redistributed trips, modal transfer" (Oladeinde, 2005). This is a recommended way forward in modelling as perceived by the DfT. This framework can be applied within the context of modelling road user charging.

VaDMA in its simplest form is an implementation of the four stage model that utilises the logit form for the specification of a choice hierarchy that allows interaction through the various stages of the conventional four-stage transport model. VaDMA in essence pictures trip generation, trip distribution and mode choice as representing the "Demand" side of the transportation system and these outputs (matrices) are subsequently assigned (i.e interacted with the supply represented by the network) and costs obtained are fed back to the Demand system through cyclic iteration so that some equilibrium is reached.

In addition, VaDMA gives reasonably clear guidance on the segmentation issue that was discussed above (in TAG Unit 3.10.2). These guidelines are the minimum and they do not imply that adhering to this minimum would always be adequate. The minimum segmentation is given in TAG Unit 3.10.2 (page 13) as follows:

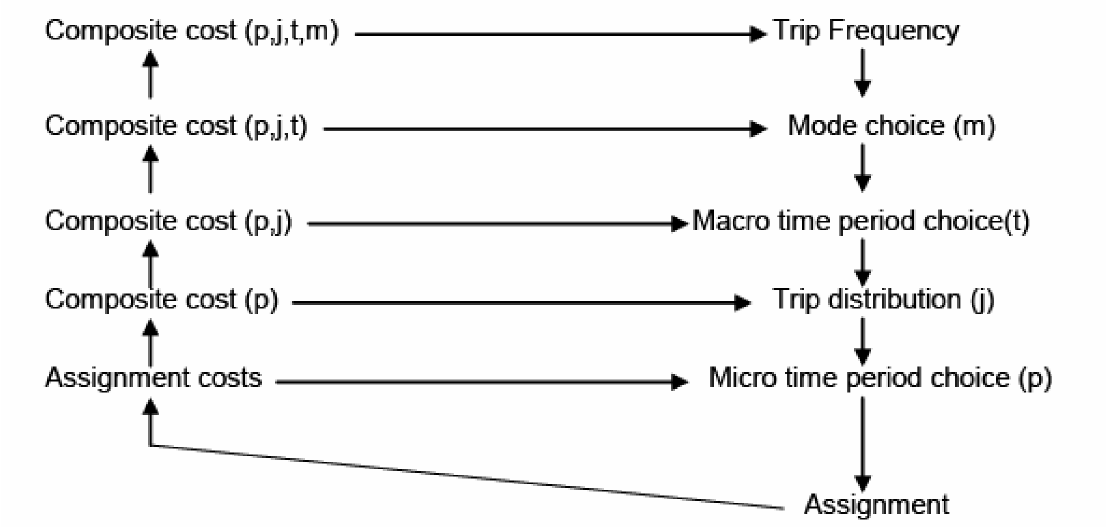
- Household type and traveller attribute (segmentation into car-available/no-car available or by household car ownership of 0, 1 or 2+ cars)
- Value of Time accommodated by the trip purpose split; In addition explicit advice is provided for schemes specifically involving charging in that there should be some segmentation by willingness to pay or income and trip distance. The latter is particularly important if there is a large range of trip distance.
- Trip Purpose: Segmentation into Work/Employer's Business/Other
- Mode: Car/ Public Transport
- Road vehicle types: Car and Other (e.g. Freight).

VaDMA provides a "sample" VADMA model structure which is a variant of the conventional four stage model (see Figure 2). This sample does not mean that it is the recommended model but rather based on the available empirical evidence collected thus far (Bly et al, 2001), this would be the most appropriate form for a variable demand model. This would be valid for Highways' Agency type schemes that are essentially interurban. But this model structure may not be suitable in application to

[5] Draft guidance was released in September 2005 with a consultation period of 3 months but thus far the guidance has not been formalised (see http://www.webtag.org.uk for further information.)

urban schemes such as those involving the introduction of road pricing in city centres of the UK.

Figure 2 SAMPLE VADMA MODEL



(Source: From TAG UNIT 3.10.3 page 22 copyright DfT,2005)

Some elements stand out in this model structure:

- As this model is based on hierarchical multinomial logit, to provide sensible responses, the least sensitive elements appear at the top (i.e. trip frequency) while the most sensitive elements are at the bottom (i.e. assignment). Hence it is interesting to note that in this default model structure, trip distribution is more sensitive than mode choice. This is a result of the evidence gathered through a review of a number of UK and overseas models presented in Bly et al (2001).

- One of the new elements central to the VADMA approach introduced is "time period choice". This is subdivided into macro and micro time choices .Macro time period choice, involving the transfer of trips between broad time periods, can be modelled as a logit choice in a similar way to the choice mechanisms described for the other stages of demand modelling and that these should be considered when strong cost differentials between time periods are expected to develop or change. Hence this is particularly important for differential pricing schemes where different charges apply say, during the AM peak and the Interpeak. VADMA also emphasises micro time period choice, more commonly referred to as "peak spreading". Evidence exists to show that travellers can alter their departure times and the probability of peak spreading increases with worsening congestion (the peaks become longer).

- Trip generation stage is almost taken as synonymous to trip frequency stage but trip frequency embodies the response of the trips to changes in travel cost.

In practice, little has been reported utilising the VaDMA methodology for modelling of road pricing schemes given the date of release of the VaDMA guidance and hence there is little to comment here in this respect.

It is important to note that the micro time period choice model suggested to be incorporated within VaDMA has not yet been fully developed. The software for this ("HADES") (Van Vuren 2002) has been developed but not on general release to practitioners as at date of writing of this note. Hence while the recommendations in VaDMA suggest that micro time period modelling be carried out as a matter of course the advcice also recognises that "its modelling is complicated and uncertain". There is contiuous research looking at the integration of the departure time choice models within VaDMA (Oladeinde, 2005). Finally there is little information at time of writing about the convergence requirements to be adhered to when using Variable Demand Models for forecasting, although we understand that its release would be imminent.

In the following sections we identify some gaps in the modelling of road user charging systems which can be categorised into two distinct themes.

- Gaps in the Modelling of Schemes themselves
- Gaps in the Modelling of Responses to the schemes

8 GAPS IN THE MODELLING OF SCHEMES

8.1 Area Charge Schemes

There is a difficulty in modelling schemes such as area charges where vehicles are charged for utilising the highway network within a particular defined area as in the case of the London scheme. One key point from the consultants involved in carrying out the RPFS was that "it was difficult to model easily an Area Charge" (KBR, 2004). Thus there exists a severe gap between reality (the London scheme is an Area charge scheme) and the practitioner's ability to model such a scheme realistically. This problem arise because as mentioned earlier the modelling assumptions are centered on a trip basis whereas charges are often levied on a per day basis. For example the London system allows the users, having paid the £8 congestion charge for the day, to drive in and out of the congestion charge zone as many times as they so wish (https://tfl-cc.custhelp.com/cgi-bin/tfl_cc.cfg/php/enduser/std_alp.php).

This characteristic can have two important consequences for the results of the modelling exercise:

- it will over predict the revenue gained and this could be significant
- it will over predict the diversion onto alternative routes not taking into account that the toll has already been paid

8.2 *Modelling of Exemptions/Discounts*

Often to ensure that an area charge or cordon scheme is politically feasible, it would be necessary to grant exemptions to residents in the area. However, within the current modelling framework, it is difficult to deal with this effectively. This is attributable to the difficulty in data matching since a blanket assumption cannot be made that all trips originating from the exempted zones are entirely made by residents and are entitled to the exemption. As mentioned, ROCOL(2000) did not actually make explicit the modelling of exemptions. A probable reason why this was not done could be that it would have complicated the modelling effort.

In addition, there might be exemptions or large discounts for vehicles with increased occupancy. This is discussed later in Section 7 below where such exemptions can alter the travel pattern and shift persons from being drivers to carpooling or ride sharing. Conventional models have a difficulty representing these responses.

8.3 *Modelling of Staggered Charge Regimes*

Staggered road user charges, also known as time-varying tolls, are in operation in Singapore (Menon, 2004) and in the US (Sullivan, 2002). In these regimes, charges are differentiated by time so that the "peak of the peak" travellers pay more than shoulder peak travellers. The conventional static assignment model does not represent the effects of differentiated arrival and departure times. For example, in the static framework of a modelled hour, any trip appearing within the origin-destination matrix would be implicitly assumed to have reached their destinations within that modelled hour and face the same toll penalty even though the charges may have changed in the course of the journey. Some advances have been made in dynamic assignment but their use in the modelling of road user charging is limited. While there have been theoretical advances in dynamic traffic assignment since Vickrey proposed the bottleneck model, there continues to be a long gestation period before research becomes accepted as general modelling practice. An example of such a framework would be the METROPOLIS model (De Palma and Marchal, 2002) implemented within the commercially available PTV VISION modelling suite (http://www.english.ptv.de/cgi-bin/traffic/traf_vissim.pl). If the time element is not incorporated into the model, then it would not be possible to model the effects of temporally dependent charges

8.4 *Representation of Delay*

In conventional assignment models such as SATURN (Van Vliet,1982), the representation of delay given by the speed-flow curve can actually present problems. Although this is a more general modelling problem, it is important in this context as the speed flow curve is vital for congestion charging (Hau, 1992). The theoretical speed flow curve (Haight, 1963) actually has a backward bending portion. However there exists two optima under such circumstances which leads to problems when solving the Beckmann's transformation (Beckman et al,1956) for Wardropian equilibrium. Hence for numerical computation purposes when flow exceeds capacity, SATURN allows the user to have a flat portion or to have a continuous portion.

The implementation of system optimal tolling in SATURN therefore be a problem in this context. If one opts for the flat portion when flow exceeds capacity, it is possible for the marginal cost to decrease as flow goes from just below to just over capacity (Van Vliet and Hall, 2005). This can lead to convergence problems and/or multiple equilibria. If one opts for a continuous portion of the curve one will obtain unrealistically large travel times. This unrealistic representation brings us back to what Paulley (2000) has mentioned regarding accurate representation of delays on alternative routes when attempting to model road user charging.

The problem of modelling speed changes consequent on changes in traffic levels is recognised as a problem in the ROCOL study (ROCOL,2000 Ch 5 p 66). The speed flow relationship has serious implications for measuring the benefits of the road user charge scheme. One possible way forward in circumventing this problem would be the use of sheared delay curves. The problem then becomes one of integrating these curves for the purposes of solving the system optimal traffic equilibrium problem.

8.5 Modelling of Payment Options/Structure

In the simplest road user charging scenario, tolls can be collected at toll plazas but more often than not, tolls are paid in advance and toll passes may be bought say monthly. The problem arises in that the conventional modelling framework does not take into account the fact that some users opt for the monthly option which implies that the toll charge then becomes a sunk cost and would not be a consideration factor in their trip making behaviour.

In the above example, the reality is that the trip maker might make more trips because he has paid the toll. However conventional modelling methods will show some form of suppression due to generalised costs assumptions embedded within the assignment. Hence suppression/rerouting will be over predicted.

9 GAPS IN THE MODELLING OF RESPONSES

In order to correctly model the responses to road user charging, there are several issues that need to be addressed. Within the context of the traditional four stage model (IHT, 1997;Ortuzar and Willumsen, 2001) used in modelling only some of the responses in the literature can actually be modelled (Stopher, 1993; Bly et al,2001) within the framework of the four stage model.

- trip generation(responses 2 and 6 noted in Section 3 above)
- trip distribution (response 4 above)
- mode split (response 3 above)
- assignment (response 1 above)

Thus this analysis recognises that at present models are only partially able to deal with trip retiming (response 5) but not trip chaining (response 7) or change in vehicle occupancy (response 8).

In the following a discussion is presented on several of the recommendations suggested within the literature for improving modelling of some of the recognised responses in the framework of the traditional four stage model.

9.1 Vehicle Availability Ownership and Occupancy

There are three critical concepts interrelated in the concept of vehicle ownership. Vehicle ownership affects mode choice and hence implications for trip distribution. It is known that the distribution of trips is sensitive to whether one has a vehicle available for the journey. Obviously one can travel further with the private car and are not perceived as being captive to public transport options.

9.1.1 Vehicle Ownership Modelling

Whelan (2001) has shown that car running costs have an impact on car ownership. As Bly et al (2001) point out, it is desirable in multi-stage models incorporate a car ownership model so that costs from the assignment model can be fed into it to determine changes in the level of ownership. Section 3 has noted that some of the longer term responses to road user charging could possibly be the sale of the car in households that own more than 1 car. Hence there will be implications for trip generation and will affect the “competition” between household members for use of the car (Mackie et al 2005).

9.1.2 Vehicle Availability Modelling

The USDOT have recognized that vehicle availability modelling has important implications for trip generation, mode choice and has indirect effects on trip distribution and on household location choices (USDOT, 1998). In the UK, VaDMA recognised that car availability segmentation is important for multi-stage demand modelling (DfT, 2005).

Due to lack of data, the conventional practice is to categorise travellers into 3 general household car ownership levels of 0,1 or 2+ cars. Ideally, Mackie et al (2005) have argued that it is vital for three particular categories to be modelled **explicitly** as follows:

- Car not available
- Car potentially available, in competition with other household members
- Car freely available

Mackie et al (2005) have pointed out that there are generally more license-holders than cars in a household, with employed males receiving priority in the allocation of the use of the car and discouragement of car use in one area could result in the car being freed to make local journeys currently suppressed and this could have significant local impact. This implies that road user charging can potentially free up the car for trips by other members of the household in non-charged areas or times of the day. However there are no mechanisms at present to deal with transfer between users in the household at present.

9.1.3 *Vehicle Occupancy*

Even with the introduction of VaDMA, changes in vehicle occupancy cannot be predicted (which is one of the responses noted above in Section 3). The guidance (TAG Unit 3.10.2 subsection 1.6) states that "car occupancy factors need to be applied to the private travel demand matrices to convert them to vehicles". In the same vein it has been stated in (TAG Unit 2.9.2 subsection 1.3.5) that "few models attempt to predict the transfer from car passenger to driver" or in the face of road pricing, vice versa.

In other words the demand mechanism operates in terms of persons while the supply-side (network representation) operates in terms of vehicles. Hence these vehicle occupancy factors are exogenously determined usually using published values using say, published values in Transport Economics Note (DfT, 2004). This inability to handle vehicle occupancy implies that forecasts of changes of vehicle occupancy that can reasonably be anticipated with road pricing measures cannot be determined from this model.

The inability to model vehicle occupancy changes utilising conventional models presents a problem when modelling schemes where high occupancy vehicles are exempted as alluded to in the previous section. A good example of this kind of scheme was the Area License Scheme in Singapore (Watson and Holland, 1978) where vehicles with four or more were not required to pay the charge. Incidentally the current Electronic Road Pricing scheme no longer offers exemption on this basis.

In the US, examples of such schemes abound where substantial discounts are given to high occupancy vehicles can be seen from the schemes such as "SR91 express lanes" in California (http://www.91expresslanes.com) where there is a 50% discount for vehicles with 3 or more persons travelling during the peak. In addition, there is the I-15 HOT lanes (San Diego) (http://fastrak.sandag.org) which allows free travel for High Occupancy vehicles (i.e. vehicles in a carpool).

At present, it is not possible to model any of these schemes realistically because vehicle occupancy is not endogenous within the modelling framework. For example none of the local models in the RPFS mentioned in Section 4 have attempted to model this. As Bonsall et al (2005) have pointed out, vehicle occupancy is dependent on the availability of potential, compatible passengers and there will be implications on network loadings when drivers become passengers.

A way forward in incorporating vehicle occupancy changes could be through a model structure based on say, a nested logit approach that models the decision whether to drive or be a car passenger (as part of mode choice decision process) and if the decision is to drive whether to take on additional passengers or otherwise to go alone. However, whatever approach the model take, it must be recognised that identification of the choice set facing the traveller is not necessarily straightforward in such complex situations and evidence for parameter values is scarce.

9.2 *Park and Ride Modelling*

Closely allied to the above discussion about changes in vehicle occupancy is a discussion regarding park and ride. Bly et al (2001) highlight the fact that "park and ride is an evasive composite mode that transport modellers have not yet fully come to grips with". Attempts have been made (Zhou, 2005) to model this such that there is some ability at present to model not only choices between park and ride sites and but also between car for the whole journey or park and ride choice. Park and Ride is being incorporated into the Strategic Transport Model (reference?) and being used as a case study for DISTILLATE.

9.3 *Land Use Changes*

The assignment model used within the VaDMA methodology generally utilises the concept of Wardrop's equilibrium (deterministic assignment) which Liu et al (2006) remind, is used for "predicting a long-term average state of the network". However there is an inherent contradiction because this long run average state of the network does not allow for some responses to charging that are known to be evident over a longer period of time, such as land use changes which cannot be predicted using the VaDMA methodology.

One suggested remedy could be to have a Land Use Modelling System sitting on top of model developed by the VaDMA methodology so that there is some form of interaction between the land use pattern and the overall modelling framework.

While there are land-use models available such as DELTA, MEPLAN and MENTOR, such models are expensive to set up and operate and thus only larger authorities are likely to possess this form of modelling capability. The difficulties of operating models have decreased with increase in computing power. However the calibration and validation of such models demand a high amount of data collection which may not be feasible for the majority of local authorities. As an alternative, one could use a strategic model which contains some form of land use response (Pfaffenbichler, 2003).

9.4 *Dynamic Modelling*

In the discussion of time varying tolls presented above, this note has alluded to the importance of dynamic rather than static assignment. By not modelling the choice of departure time, a likely consequence of this shortcoming is that there would be an underestimate of the traffic reduction during the operational hours of the scheme but more importantly this will overestimate the overall reduction effect (Mattson, 1994).

Bonsall et al (2005) as part of the GRACE project pointed out that attempting to model the following:

- ***marginal shifts in departure time***
- ***the fact that the delay created by vehicles who arrive in a queue early on is greater than that created by vehicles who arrive towards the end of the life of the queue***

all require a dynamic simulation framework. These are examples of some of the tasks that cannot be tackled within the scope of models in mainstream practitioner use. Thus dynamic modelling is seen to play a crucial role in real world attempts to model both the regimes as well as the responses involved.

In terms of responses, a static model cannot model trip retiming to avoid the highest charge (even utilising the quasi-dynamic framework of SATURN) in the face of a staggered system. Obviously the extent of the response itself depends on the trip. Work trips tend to be less susceptible to retiming than discretionary trips but with staggered work hours, this is also changing. SATURN and HADES do model some form of trip re-timing but these are determined by the smallest time period modelled.

The issue of departure time choice is particularly important in congestion charging regimes where the charge may only be in effect for say some hours in the morning peak. Annex B to this report presents evidence from the Singapore experience to show that it was indeed the case.

9.5 Trip Chaining/ Tours

The generic problem with conventional traffic modelling techniques is highlighted by Kitamura (1996). He has raised 3 key issues that surround the disadvantages of four stage models. These are particularly important when attempting to utilise these models to model road user charging. These may be summarised as follows:

- Lack of a Time Dimension
- Lack of Behavioural Basis
- Trip Based

9.5.1 Lack of Time Dimension/Behavioural Basis

It is interesting to note that these criticisms have been remedied somewhat by VaDMA in that a feedback process is recommended to feed cost information to higher levels in the model. This feedback mechanism overcomes some of the known problems with modelling as compared to the traditional four-staged models presented in the 1960s.

9.5.2 Trip-Based

In Section 4 trip chain changes were pointed out as a response to a road user charge regime. This is the primary criticism of traditional models that is not addressed by VaDMA..

According to IHT(1997) and Bly et al(2001), the APRIL model developed for the London Congestion Charging Study is capable of handling tours in this fashion. Similarly researchers in the US have put forth a model ("AMOS") (Pendyala et al, 1995) which has been utilised to model transportation demand measures including congestion pricing covering the responses discussed in Section 3 above (Bowman and Ben-Akiva,1996). Since the 1990s, there may have been more models developed to overcome this criticism of the current modeling approach. For example macros are available within the EMME/2 package (Spiess,1996) to model trip chains via logit modeling.

In addition PTV VISION handles trip chains by modification of the four stage model: The process is outlined as follows (details are available in Fellendorf et al, 1997).

- Establish categories of traveller classes (segmentation by car owner vs non car owner, employment status etc)
- Introduce the activity probability chain (the probability of a chain being formed) and cross tabulate traveller classes with the actitvity probability chain
- Form the destination choice (this is synonymous to the trip distribution stage of the traditional four stage model) and is in fact carried out with the deterrence functions
- Carry out the modal split and obtain the Car and Public Transport Matrices. It is designed such that the modal continuity condition is not violated i.e. if a traveller begins the trip chain by car mode, he will return via the car mode. The traveler chooses his mode considering the activitiy for the rest of the day
- Traffic Assignment (as per Four Stage Model)

In the main, these models are not widely used, in part due to the cost and effort of model validation and calibration. It is recognized that a large amount of data is required to assemble travel diaries and compute activity chain probabilities.

10 THE WAY FORWARD

This section is for the team to draw some comments and see if we can proposed a way forward in the modeling and choose a "case study". Based on our identified gaps in the disparity between theory and practice, the following are outlines of some possible research.

POTENTIAL RESEARCH ISSUES/CASE STUDIES

10.1 Candidate Topics for Further Research

Listed below are the outlines of some possible topics for further research that could be incorporated within the scope of DISTILLATE.

- Better Representation of Delay

It was noted that the use of sheared delay curves in SATURN as described in section 7.4 would provide theoretically more correct analysis when demand approaches capacity and would impact on the optimal level of any road user charges. This could be incorporated into SATURN for a more robust representation of delay.

- Improved modelling of Area License Schemes in general and modelling of Exemptions/Discounts and choice of payment mechanisms as well as response to different payment mechanisms

This is a large area that could be considered in a SATURN case study using a logit model to cover charges for users and non-users and to look at issues of charging per trip or per day/week/month. To some extent this also covers the issue of discounts for monthly/weekly tickets.

- Comparisons of micro time choice dimensions

While this could be a potential issue for research, it may not fall within the scope of DISTILLATE. There may be some merit in investigating the issues of micro and macro time period modelling discussed in relation to the VaDMA guidance within the context of road user charging. The objective could be to compare various implementations of micro time choice within the various packages available. This could be CONTRAM/SATURN/HADES which implement "quasi-dynamic" assignment of some form. This could fall within the framework of DISTILLATE if we use these packages to modelled representations to charges.

- Modelling of vehicle occupancy changes/ownership changes and vehicle availability

A way forward in incorporating vehicle occupancy changes could be through a model structure based on say, a nested logit approach that models the decision whether to drive or be a car passenger (as part of mode choice decision process) and if the decision is to drive whether to take on additional passengers or otherwise to go alone. There is literature on vehicle ownership and availability but there is no suggested implementation method for dealing with the possible phenomenon of "competition" of car use within a household. Some form of game theoretic type model could be used for this. Currently there is no case study in DISTILLATE which looks at this issue.

10.2 Potentially Large Areas

Listed below are some areas of modelling that could potentially be too large a topic to be handled within DISTILLATE. These may be regarded as general drawbacks with the current modelling approach. These approaches are different from the standard practice and if accepted into standard modelling practice would improve the modelling of road user charging schemes.

- Tour Modelling /Trip Generation with Trip Chaining

One potential way forward would be to incorporate trip generation and trip chains into the current modelling framework. For example Goulias and Kitamura (1991) and Fellendorf et al (1997) have developed models to describe both trip chains and trip generation simultaneously and these can be incorporated into the conventional modeling framework in place of the traditional home-based/non home-based trip generation models.. As reported earlier, the Danish Orestad Traffic Model and the APRIL model have implemented some tour modelling. In addition, it seems that while theoretical advances thus far have made it possible to develop models accounting for trip chains, their take up rate by practitioners can be considered quite low primarily due to the extensive data collection required for their construction.

- Generalised Cost Definitions

The traditional modelling framework makes the assumption that trip makers consider road user charges in the same way as they do general driving costs. While there seems to be some empirical Stated Preference evidence to back this assumption (Jovicic and Hansen, 2003), we cannot be certain that this can be generalised and the possibility exists that road user charges are perceived differently from other types of charge (eg parking), and therefore incur a different response from that currently assumed. This could have implications for the formulation of Generalised Cost in models.

- Modelling of Staggered Charges /Dynamic Assignment

There is currently a research within this field and it could be utilised to enhance understanding of the individual behaviour and response to time varying tolls.

- Alternative Specifications within VaDMA framework and their impacts
- Land use changes
- Park and Ride Modelling

These are probably more general modelling issues that would probably be investigated by DfT (VaDMA) and other researchers. We understand that the MARS case studies will include a land use element for all strategies and are not limited to just road pricing instruments and the Strategic Transport Model case study for Essex will include land use scenarios and test alternative strategies in this context.

10.3 Enhancing Evidence on Responses

This section suggests some interesting empirical data collection that could be useful to enhance understanding of response to road user charges. As mentioned in section 3 there is a real lack of evidence on the elasticities required for modelling the responses to road pricing – this should be covered by the monitoring of real schemes as they are implemented. Some interesting empirical data collection could follow from:

- Increase in congestion charge from £5 to £8 and its effects
- Changes in Tolls on the M6

A potential difficulty with this would be the willingness of the relevant operators/authorities to provide some data (especially the M6 which is commercially sensitive).

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12 ANNEX A ECONOMIST'S EVIDENCE OF RESPONSES

The main point raised in this paper is that while immediate elasticities might be very small implying a large road price, failure to allow for diversion to competing alternatives would cause the derived price to be too high.

The introduction of a road user charge may also have impacts on alternatives and these forces lead to second order changes that may need to be modelled. Utilising an example from the paper, if an area license scheme is in operation in a city centre, it is conceivable that roads on the periphery might face more congestion as vehicles divert to avoid the charge and hence this makes destinations outside the scheme less attractive and also buses become more crowded making them less attractive for trips into the city centre (assuming that the Mohring effect does not occur where frequency increases with demand.) Hence this has implications for the extent whereby the congestion charge regime can conceivably led to several rounds of adjustments that throw the market out of equilibrium before finally settling to a new equilibrium.

A suitable proxy as to the impact of road user charge on traffic levels has to be inferred by studying the impact changes in fuel prices on fuel consumption and on traffic levels as there is no real world evidence (as we are aware) of road user charges on traffic levels.

Car Own Price Elasticities	Reported Elasticities		Reference
Measurement Method	Short Run	Long Run	
Change in Fuel Consumption with respect to Fuel Price Changes	-0.2	-0.7	Fowkes et al (1991)
	-0.3	-0.8	Graham and Glaister (2002)
Change in Traffic Levels with respect to Fuel Price Changes	-0.1	-0.3	Fowkes et al (1991)
	-0.15	-0.3	Graham and Glaister (2002)

CAR PRICE ELASTICITES SEGMENTED BY JOURNEY PURPOSE

De Jong and Gunn (2001) have reported the following short and long term elasticities of car trips and car kilometres with respect to fuel price disaggregated by journey purpose.

Purpose	Trip elasticity –short run	Trip elasticity – long run	Veh kms elasticity – short run	Veh kms elasticity – long run
Commuting	-0.20	-0.14	-0.12	-0.23
Home-based business	-0.06	-0.07	-0.02	-0.20
Non-home-based business	-0.06	-0.17	-0.02	-0.26
Education	-0.22	-0.40	-0.09	-0.41
Other	-0.20	-0.15	-0.20	-0.29
Total	-0.16	-0.19	-0.16	-0.26

Suppose we look at the commuting elasticites

- Using the short run figures: For a given 10% percent increase in fuel price, we have a larger reduction in the number of trips than the vehicle kilometres travelled (i.e 2% fall in trips but only a 1.2% fall in vehicle kilometres).

- Using the long run figures: The effect is reversed, we have a larger reduction in Vehicle kilometres than the number of trips (i.e. 1.4% fall in trips but 2.3% fall in vehicle kilometres).

One conclusion that can be drawn is that in the short run, the consumer respond to changes in the fuel price by modifying the number of trips made but cannot change much of their destinations (that is one reason why trip lengths are less adjusted in the short run) in the longer term will make even bigger adjustments to the trips made as well as the distance travelled. Hence this implies that people not only make fewer trips but also travel shorter distances.

PARKING CHARGES SEGMENTED BY JOURNEY PURPOSE AND TRIP LENGTHS

De Jong and Gunn (1999) also present some elasticities segmented by journey purpose dependent on trip lengths. The table is reproduced below from the paper by Mackie and Toner (2005).

Term/Purpose	trips < 5km		trips between 5km and 30km		trips between 30 km and 100 km		trips > 100 km	
	trips	car kms	trips	car kms	trips	car kms	trips	car kms
Short term:								
Commuting	-0.17	-0.10	-0.04	-0.02	-0.01	-0.01	-0.02	-0.01
Business	0.00	0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00
Education	-0.15	-0.12	-0.03	-0.02	0.00	-0.00	-0.00	-0.00
Other	-0.36	-0.30	-0.09	-0.06	-0.01	-0.01	-0.02	-0.02
Total	-0.21	-0.18	-0.04	-0.03	-0.01	-0.01	-0.01	-0.00
Long term:								
Commuting	-0.14	-0.13	-0.07	-0.06	-0.02	-0.02	-0.00	-0.00
Business	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.03
Education	-0.19	-0.17	-0.08	-0.06	-0.02	-0.01	-0.00	-0.00
Other	-0.41	-0.36	-0.21	-0.18	-0.06	-0.05	-0.00	-0.00
Total	-0.24	-0.22	-0.11	-0.10	-0.03	-0.03	-0.02	-0.02

Suppose we look at the commuting elasticites

- In the short run, given a price increase in the parking charge, (for a constant category of trip length) there is a larger reduction in trips than in vehicle kilometres (fall in 1.70% for trips compared to a 1% fall in vehicle kilometres

- In the short run, for a given price increase in the parking charge, longer distance trips tend to be less responsive to parking charges than shorter distance trips. (elasticity of -0.17 for trips < 5km compared to elasticity of -0.04 for trips between 5 km and 30 km long). This is also true in the long run as well (elasticity of -0.14 for trips < 5km compared to elasticity of -0.07 for trips between 5 km and 30 km long).

This observation has been led Mackie and Toner (2005) to conclude that, while parking charges do not vary by trip length (people are not charged according to how far they have travelled when they park), but the impact (or response) of the parking cost in overall trip cost reduces with the trip length. They point out that this is analogous to area/cordon based charging regimes and hence we can draw similar inferences from these observations when modelling the responses of road user charging schemes.

- Comparing the short run against the long run, for a given trip length category, given a price increase in the parking charge, the short run response would be to reduce the trips more than the vehicle kilometres (This is as we have noted earlier). For most trips purposes the difference in the effect on trips and the effect on trip length is small and effectively vanishes in the long run, and this effect is more pronounced with longer trip distances.

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13 ANNEX B – OBSERVATIONS FROM ROAD USER CHARGING IN SINGAPORE

13.1 Objective

A lot of literature has been written about the implementation of Road Pricing in Singapore. The primitive “Area License scheme” where drivers had to buy a pass to travel into the Central Business District (CBD) was introduced in 1975. The charging system was changed many times over the years and in 1998, Electronic Road Pricing (ERP) was introduced. Electronic Road Pricing has allowed Singapore to experiment with variable time of day congestion charging. The purpose of this review note is three fold.

Firstly, it is the objective of annex to summarise some of the traffic impacts from the Area Licensing Scheme (ALS) that was introduced in Singapore in 1975. The information for this comes from Watson and Holland (1978).

Secondly, because ERP has allowed for regular road price revisions, this provides a source of evidence regarding driver responses so as to examine the elasticity of number of demand with respect to the road price. It would be interesting to compare some of these figures with that obtained from Norwegian toll rings.

13.2 Traffic Flow Impacts of the ALS

In June 1975, an area license scheme was introduced in Singapore. This requires the driver to pay a charge to travel into the CBD and this charge was on a per trip basis. When first implemented, the scheme was actually running for only the morning peak from 7:30 to 9:30. One of the earliest studies of the traffic flow changes was done by a team of observers from the World Bank and reported in Watson and Holland (1978).

13.2.1 Traffic Entering in AM Peak

TABLE 1: VEHICLES PER HOUR ENTERING CBD BEFORE AND AFTER INTRODUCTION OF ALS

	Mar-75	Jul-75	% change	Oct-75	% change
7:00 - 7:30	19,600	23,200	17%	22,146	13%
7:30 - 9:30	27,657	14,766	-47%	15747	(-43%)
9:30-10:15	24,935	25,443	2%	12,938	(-48%)
10:15-10:45	NA	NA		27,850	
10:45-11:15	NA	NA		25,378	
Peak Half-Hour	29,948	28,082	(-6%)	27,850	(-7%)
	(8:00-8:30)	(9:30-10:00)		(10:15 - 10:45)	

(Figures are vehicles per hour averaged over the duration of the period)

Table 1 shows the changes in vehicles per hour on roads leading to the Restricted Zone (11 roads) in March 1975 (before the charging) and July 1975 (after the charging). In addition, there is another column showing some information for October 1975. Some observations on these results are presented:

The figures show that ALS had a large impact on the number of trips entering the Restricted Zone during the charging hours. There is an appreciable 47% dip in traffic during the charging hours from 7:30 to 9:30 in July 1975 compared to March 1975.

One can clearly see that there is a surge in traffic entering just before the commencement of the charging hours (i.e there is a 17% rise in traffic entering between 7:00 to 7:30).

The next surge occurs when the charging period ends (i.e 9:30 to 10:15) and traffic during that time period grew by 2%.

We can thus observe also two new peaks forming. In an attempt to tackle this problem, the congestion charge hours were revised to last from 7:30 to 10:15. The October figures reported in Table 1 were collected after this change.

The above measure was only partially successful. Note that the peak half-hour is from 9:30-10:00 i.e. when the charge ended looking at the July data but the peak half hour becomes 10:15-10:45 when the hours were extended.

13.2.2 Other impacts

There were three further impacts worth mentioning from the Watson and Holland (1978) review:

As car pools (defined as vehicles with 4 or more occupants) were exempted from the charges, there was a surge in the number of car pools travelling. While the number of cars entering during the charging period fell by 75% (Table 4.2 Watson and Holland 1978), the number of carpools increased by over 53% in the before and after study.

The number of goods vehicles entering the CBD during the charging period had increased. The argument is that operators were rescheduling trips to take into account reduced congestion.

While motorbikes and mopeds were exempt, they noted only a small increase in their use following the implementation of ALS. This does not accord with the observations made in TfL (2004) in the case of London.

13.2.3 Outbound Evening Peak Traffic

One very interesting issue that was highlighted in Watson and Holland (1978) that must be mentioned was that while the traffic flow was curtailed (see Table 1) in the morning peak, the evening peak DID NOT actually face any decrease (Table 4.14 in Watson and Holland 1978, page 59). They could not provide an answer for this and could only conclude “it is puzzling that the levels of evening traffic, which must have included large flow of home-bound commuter, was apparently not affected by the measures that induced many commuters not to drive into the Restricted Zone during the morning restricted hours”. It was only in June 1989 that the ALS was extended to cover the hours from 4:30 pm to 7pm on weekdays (Chin, 2002).

13.3 Electronic Road Pricing

13.3.1 Description

One of the recognised deficiencies of the ALS system was that of the sharp and short peaks of traffic volume entering the RZ. This point was illustrated above. Hence the government introduced “shoulder charging” or having intermediate rate to smoothened out the peaks (Chin, 2002). It would have been impossible to implement shoulder pricing using the manual system.

Simultaneously in the 1990s technology for road user charging was being developed using Dedicated Short-Range Communication (DSRC) and this was combined with the ultimate objective of shoulder charging to develop the electronic road pricing scheme that is now in operation in Singapore.

13.3.2 Transport Policy Focus

The basic policy of the transport authorities in Singapore is to ensure efficient utilisation of the infrastructure (Chin,2002; Phang and Toh (2004)). Chin (2002) gives details of the adjustment methodology for reviewing road prices. The stated policy is that speeds on roads in the Central Business District should be between 20 kmh to 30 kmh while the speeds on expressways should be between 45 kmh to 65 kmh. Should speed go above the upper threshold, too few vehicles were utilising the roads and hence the road price should be revised downwards while conversely if the speed fell below the lower tolerance, this implied that there was too much traffic on the road and implies that the road price should be increased. It thus becomes incumbent on the authorities to review the road price regularly to ensure efficient utilisation and that prices were not over restraining or under restraining traffic. In fact rates are revised every three months (Chin, 2002;Olsewski, 2003)

13.3.3 Key Features

It is important to point out that the ERP charge was levied on a per pass basis. i.e. vehicles were charged each time they cross the gantry. This was applied on expressways (good quality “A” dual carriageways) and some arterial roads as well as on roads leading to the Central Business District cordon.

In addition the charge structure allows for charging for roads leading to the CBD to be levied between 7:30 to 19:00 (with a “free period” between 10 am to 12 noon) while for other roads, only morning peak traffic was charged.

13.3.4 Reported Elasticities

Olszewski (2003) recognised that they could use the ERP rate adjustments to monitor driver behaviour and hence determine traffic volume changes to changes in price. This would enable the elasticity of demand with respect to price to be calculated.

In fact Olszewski and Xie (2005) reports on these results in detail as follows:

TABLE 2: Elasticities for various vehicle categories during AM peak hours

Vehicle Category	CBD Cordon	Expressways
Car	-0.106	-0.195
All	-0.069	-0.151

(Source: Table 2 in Olszewski and Xie (2005))

Based on this they have concluded the following

- Expressways show a higher (Absolute) elasticity than the CBD Cordon because there is more opportunity for rerouting and diversion.
- Cars show higher elasticity than other vehicles.

TABLE 3: Elasticities of traffic entering the CBD by time period

Time Interval	Cars	All Vehicles
7:30 – 9:30	-0.106	-0.069
15:30 – 17:30	-0.123	-0.143
17:30 – 19:00	-0.324	-0.265
7:30 – 19:00	-0.123	-0.118

(Source: Table 3 in Olszewski and Xie (2005))

Based on this they have concluded the following

- Elasticity is lowest in the morning and increases throughout the day. There is less flexibility in adjusting the morning commute.
- Many drivers can postpone their evening trips to avoid the highest peak charge if they want to do so. This explains the higher elasticity in the evening peak.

13.3.5 Comparisons with Literature

TABLE 3: Comparisons of Cordon Toll Elasticities (Cars in AM Peak) in Norway and Singapore

Location	Elasticity	Reference
Trondheim	-0.30	Polak and Meland (1994)
Singapore	-0.106	Olszewski and Xie (2002)

TABLE 4: Comparisons of Point Tolls (all vehicles in AM Peak) in Norway and Singapore

Location	Elasticity	Reference
Alesund	-0.45	Jones and Hervik (1994)
Singapore	-0.151 to -0.215	Olszewski and Xie (2002)

Table 3 compares the elasticities estimated for the Trondheim toll ring and the Singapore cordon for cars in the AM Peak. Table 4 compares the elasticities for a point toll in Alesund with a point toll in Singapore.

The results do not seem compatible, with elasticities in Norway tending to be very much larger than in Singapore. However, we reiterate the point raised by Olszewski and Xie (2005) that cordon pricing tends to have lower elasticity than tolls applied at a point. This is probably conjectured that people can divert away more from point tolls than from cordon tolls (i.e. they still need to cross the cordon).

It is interesting to note that the elasticities in Singapore are much lower and one reason for this could be the extremely high cost of vehicle ownership in Singapore. A conjecture is that once a car is purchased (usually by the affluent) they will make the most use of it (and they can run it only for 10 years anyway) and charges like tolls will have only a minimal impact in their overall calculation of the running cost of the car. This supports the point raised in the main paper that vehicle ownership responses are important for the modelling of road user charging.

13.3.6 Conclusions

This short note has demonstrated some impacts of the road user charging policy in Singapore. When the license scheme was introduced in 1975, there was strong observed evidence of trip retiming with drivers avoiding the charge by shifting either the half-hour before the charge was in effect or the half-hour following the charge period. Thus it suggest that departure time choice changes could be a significant response to road user charging initiatives.

Secondly, we have presented elasticity estimates from the latest available literature of staggered charging hours. While the experiences from Singapore are not necessarily transferable to other countries, nonetheless they serve as a gauge of the driver responses to road user charging systems. The elasticities are larger for point tolls than cordon tolls primarily because drivers have more route choices when faced with point tolls while they are generally constrained by destination choices when faced with cordon tolls.

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