A comparison of different methods of modelling long distance highway demand for toll roads and their effect on the revenue forecasts

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Abstract

There is a debate raging about how accurate toll road traffic and revenue forecasts are (eg Bain, 2009). The accuracy of these forecasts is critical to the success or failure of a particular scheme and to whether they ever get built. We have undertaken many toll road traffic and revenue modelling exercises with different kinds of model to suit each toll road's sometimes very different, circumstances. This paper brings together that collective wisdom with the objective of drawing some conclusions about the recommended approaches to take under different circumstances.

Diversion curves – common practice in the US until recently - have at last been superseded. Common modelling practice in some circumstances is to develop a simple elasticity model considering the point-to-point traffic from one end of the proposed tolled road to the other – perhaps having different elasticities for different market segments. But this considers traffic as having one origin-destination pair so a better method is to use a trip matrix approach with elasticities or even better with a logit model of route choice. The logit model of route choice can be enhanced to model the longer term changes of destination and trip frequency with a nested set of logit models. Sometimes these models include stated or revealed preference surveys to measure the value of time, willingness to pay, perception of the toll road etc. Sometimes they have only a few market segments and sometimes they split the demand into many. These different methods are compared and contrasted using a toll road model based on a model recently developed for a set of tolled roads in Nigeria.

The paper compares and contrasts the strengths and weaknesses of the different forecasting methods and draws conclusions about their relative accuracy. This is a very important subject – vital to the success or failure of important transport infrastructure - but it does not get sufficient consideration, so this paper attempts to open up the whole subject for debate.

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1. Introduction

The road network can be considered as one of the most important lifelines in any society offering mobility, accessibility, and economic growth. Conversely, the cost associated with inadequate road infrastructure can amount to billions of pounds and can significantly affect the economic growth of any advanced society. Traditionally, government departments financed transport infrastructure using the pay-as-you-go method, where the government pays for all the costs in advance using government revenues largely derived from vehicle related taxes such as fuel tax. However, governments are increasingly unable to raise enough revenue to finance these projects leading to long waiting times for new infrastructure or major improvements in the existing ones.

The last few years have witnessed a very sharp increase in governments' interest in using private capital to finance, design, construct, operate, and maintain the road for a specific period of time (i.e., concession). The private company collects the toll revenue from the facility to cover the cost of construction, maintenance, profit, and of operating the road during the specified concessionary period. At the end of the contract period, the road is transferred back to the government at no cost. The success of this new approach is heavily dependent on reliable traffic and revenue forecasts. For the developer of a toll proposal (whether it is a public agency or the private sector) reliable traffic and revenue forecasts are required to achieve investment-grade ratings and avoid high risk premiums. However, unreliable toll revenue and traffic forecasts can also impact government policy—even if they are not the developer—as such toll traffic and revenue forecasts might skew public decision-making and result in (a) the over or under compensation of risk, (b) prevent investments in feasible projects that had underestimated forecasted traffic and revenues, or (c) result in costly renegotiations.

There is a debate raging about how accurate toll road traffic and revenue forecasts are (eg Bain 2009). Bain (2003) compared a sampled 68 toll facilities including highways, bridges, and tunnels across world and analyzed the data on each sampled toll project. He concluded that on average toll traffic forecasts are overestimated by 25 percent in their first operational year. By dividing the sample into facilities from countries with a history of toll projects such as Australia, and countries where tolling is a relatively new occurrence, Bain concluded that countries with a history of tolling were on average more reliable than for countries without a history of tolling. He demonstrated that on average actual toll traffic was overestimated by 42 percent in those countries with no history of tolling compared to 19 percent in those countries with a history of tolling. It was suggested in Prozzi et al, (2009) that this difference is partly due to better understanding of the consumer response to tolling (i.e., availability of revealed preference data).

In Flyvberg et al 2005, 183 international facilities including highways, bridges and tunnels that opened between 1969 and 1998 were examined. Flyvberg claimed that at a 95 percent confidence level, no difference existed in the forecast accuracy of the various facility types—i.e., highways, bridges, and tunnels. His research found that the traffic forecasts were overestimated as much as they were underestimated during their first year of operation. Half of the facilities had forecasts that were off by plus or minus 20 percent.

Another study on 20 toll projects in operation over 8 different states by Mueller (Mueller, 2002) supported the claims by Bain and Flyvberg. In his study, he segmented the data into 4 groups. The first group consists of toll faculties located in high congestion and suburban areas; the second group includes outlying roads of Metropolitan areas; the third group is made up of developed corridors parallel to existing roads; and the forth group consists of the facilities located in less developed areas. Mueller's analysis showed that actual revenues realized on the toll facilities over a five year period are much lower than predicted with the exception of faculties in group 1, where the actual revenue exceeded the predicted revenue. The situation was much worse for facilities under group 4, where the actual revenue was just 20% of the predicted revenue in the first year to 50% of the predicted revenue in the 5th year of operation.

There is also a common view that the problem is not just a technical one (Davidson, 2011). In Flyvbjerg (2008) he argues that technical problems would tend to lead to symmetrically distributed errors – with as many over-predictions as under-predictions. However Davidson,(2001) noted that, while other factors such as psychological and political-economic explanations for error are undoubtedly important, there are likely systematic flaws in our modeling processes.

We have undertaken many toll road traffic and revenue modelling exercises with different kinds of model to suit each toll road's sometimes very different, circumstances. This paper brings together that collective wisdom with the objective of drawing some conclusions about the recommended approaches to take under different circumstances.

Diversion curves – common practice in the US until recently - have at last been superseded. Common modelling practice in some circumstances is to develop a simple elasticity model considering the point-to-point traffic from one end of the proposed tolled road to the other – perhaps having different elasticities for different market segments. But this considers traffic as having one origin-destination pair so a better method is to use a trip matrix approach with elasticities or even better with a logit model of route choice. The logit model of route choice can be enhanced to model the longer term changes of destination and trip frequency with a nested set of logit models. Sometimes these models include stated or revealed preference surveys to measure the value of time, willingness to pay, perception of the toll road etc. Sometimes they have only a few market segments and sometimes they split the demand into many. These different methods are compared and contrasted using a toll road model recently developed for a set of tolled roads in Nigeria to assess their potential for developing them as public private partnerships (ppp).

2. Toll road traffic and revenue forecast methods

2.1. Introduction

It is difficult to get good, publicly available, information on the structure of the models used for toll assessment. The situation is even worse for projects developed as Public Private Partnerships (PPP) as most of the information is commercial in confidence, even after the contracts have been awarded so methods discussed in this paper are those we have experienced as been used by other consultants and in the literature. We group the methods discussed in this paper into two. The first approach we called the *non-spatial methods* consists of methods where the traffic on the toll road is forecast without any reference to geography of the proposed toll road. These methods generally do not have zone system, do not treat different origin-destination pairs differently, and are normally based on traffic counts on routes parallel to the proposed toll road. The second approach is the use of spatial methods, where the study area and its zone system are well defined with an estimated traffic demand between zones.

2.2. Non-spatial methods

Here the methods considered are the linear own elasticity method; the exponential own elasticity method, and spreadsheet logit model. Each of these methods is described in detail below.

2.2.1. Linear own elasticity

This method assumes that changes in the demand for travel on the toll road can be adequately estimated purely as a function of the change in generalised costs.

The procedure is as follows:

1. Obtain an initial estimate of traffic on the proposed toll road using the traffic count if the road already exists or get an approximation from a parallel road.
2. Compute the generalised cost of the using the toll road with zero toll
3. Compute the generalised cost for a given level of toll.

4. Use the initial traffic estimate and the two generalised costs to calculate the expected toll road demand for the given level of toll.
5. Use the toll and the estimated traffic to calculate the revenue

The formula for computing the expected toll traffic is given as:

$$T_1 = T_0 * \left(\frac{G_1}{G_0} \right)^E$$

Where

T_0 is the initial estimate of traffic on the road without toll.
T_1 is the expected traffic on the road when tolled
G_0 is the generalized cost of using the road with zero toll value
G_1 is the generalised of using the road with toll.
E is the toll price elasticity

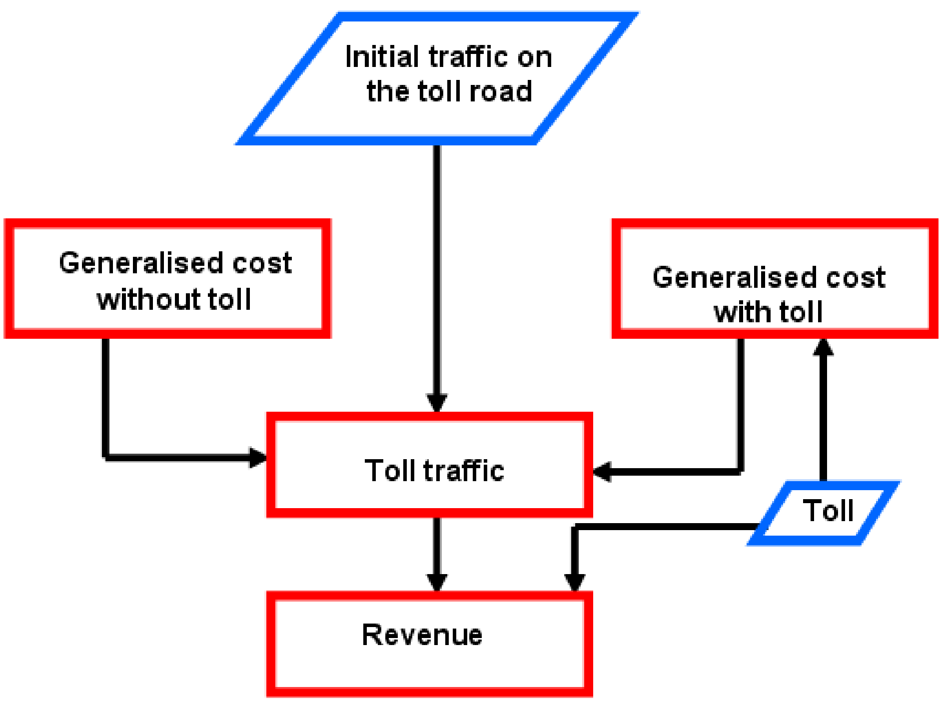

Fig 1: Linear elasticity method

2.2.2. Exponential own elasticity

This is similar to the linear own elasticity method, except the formula for forecasting the toll traffic is different.

The formula for computing the expected toll traffic is given as:

$$T_1 = T_0 * \exp\left(E(G_1 - G_0)\right)$$

Where

T_0 is the initial estimate of traffic on the road without toll.
T_1 is the expected traffic on the road when tolled
G_0 is the generalized cost of using the road with zero toll value
G_1 is the generalised of using the road with toll.
E is the own elasticity

2.2.3. Logit with count method

This method takes the form of a logit function, using the relative cost or travel time between the toll and non-tolled routes as the key explanatory variables to predict the market share of the toll road. The curves can be fitted empirically for different market segments (characterized by trip purpose, income level, automobile occupancy and time period) to derive detailed tolled and non-tolled demand. Here the numbers of alternative routes are usually clearly defined and limited to 2 or at most 3, where at least one route consists of the toll road. The formula for predicting the toll demand is expressed as:

$$T_{toll} = T_0 * \frac{\exp\left(U_{toll}\right)}{\sum_{r=1}^{R} \exp\left(U_r\right)}$$

Where

To	The initial estimate of traffic demand on all the identified routes
U_{toll}	The utility of using the toll route
U_r	The utility of using route *r (r = 1, 2…, R)*
T_{toll}	Forecast traffic on the toll route/link

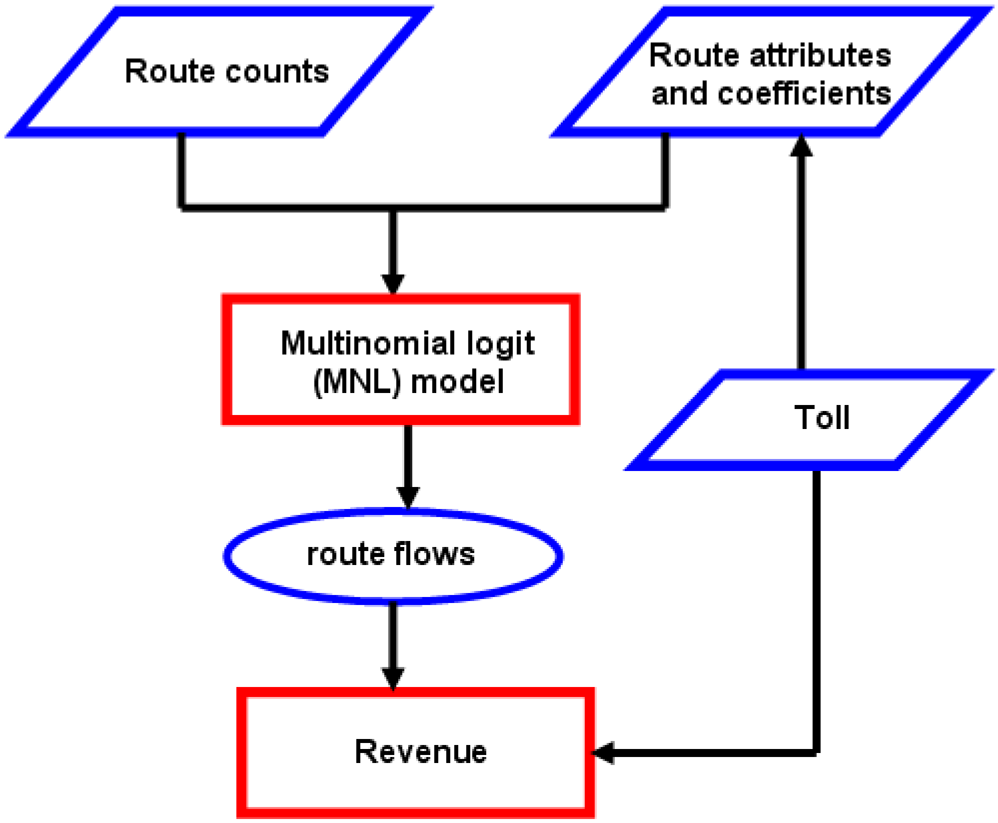

Fig 2: Logit method with counts

2.3. Spatial methods

The methods considered under this section are the Network toll methods (also called assignment only method); Network toll with distribution model; and the full model. The sections below describe each of these methods.

2.3.1. Network toll method

This is simplest method under this class of methods. A traffic assignment model is used to allocate traffic among the routes of the transport network. Separate assignments can be made for each of the different vehicle classes. The toll road is included as a standard link in the network, and the toll is included as a cost component on that link. This is usually done by converting the toll into time using the value of time (VOT) and then added to the toll link generalised time before running the assignment.

The traffic assignment model will assign traffic to the toll road whenever it is a part of the shortest path for a particular travel segment (trip between an origin and a destination). In the absence of congestion, most common assignment methods such as the method of successive averages (MSA) or Frank-Wolf algorithm reduce to an all-or-nothing process. In this paper we used the MSA algorithm, where the traffic on the toll road depends upon the number of all-or-nothing paths which take the toll road.

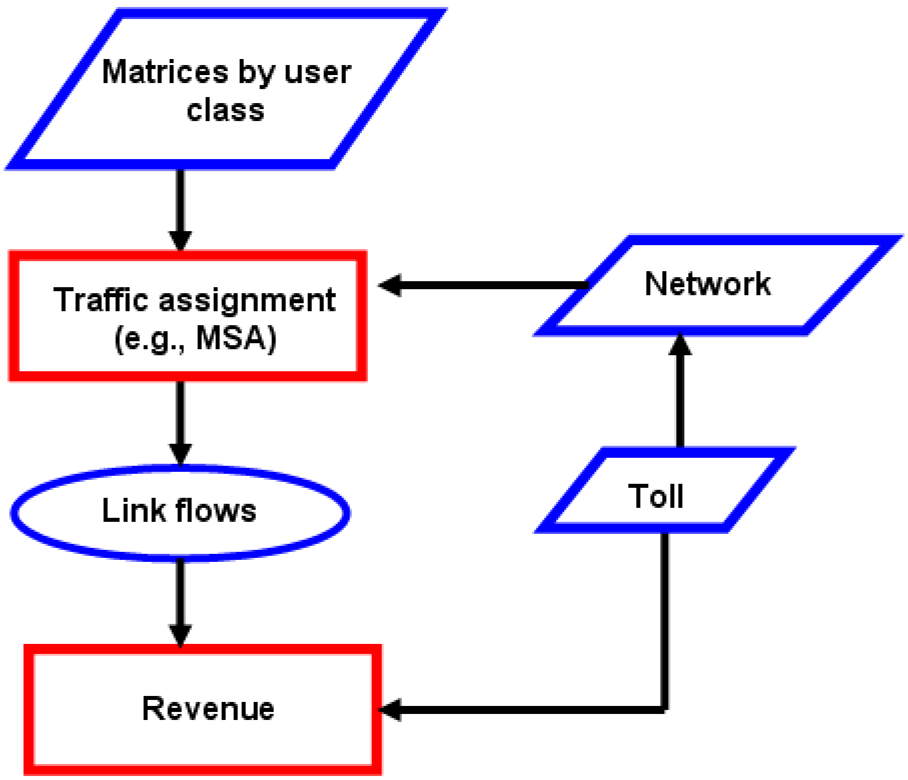

Fig 3: Network toll method

2.3.2. Network toll with distribution model

This method is an extension of the Network toll method to allow for travellers to change their destination as a result of the toll or changes in the network conditions. Furthermore, new flow patterns may result from changes not directly tied to the transportation system but rather changes in the general activities in the study area such as new shopping malls or new job centers. These facilities will attract people to use the improved facility to reach there. Additionally, the improved road may make existing facilities more accessible to people who previously have difficulties accessing them.

The process first starts by assigning the trip matrices to the road network to produce new level of service variables (e.g., distance, time, etc). These new level of service attributes, then go into the distribution model to produce a new set of matrices, which are in turn used to produce new traffic flows and hence new level of service attributes. This procedure continues until equilibrium or a pre-defined number of iterations are reached

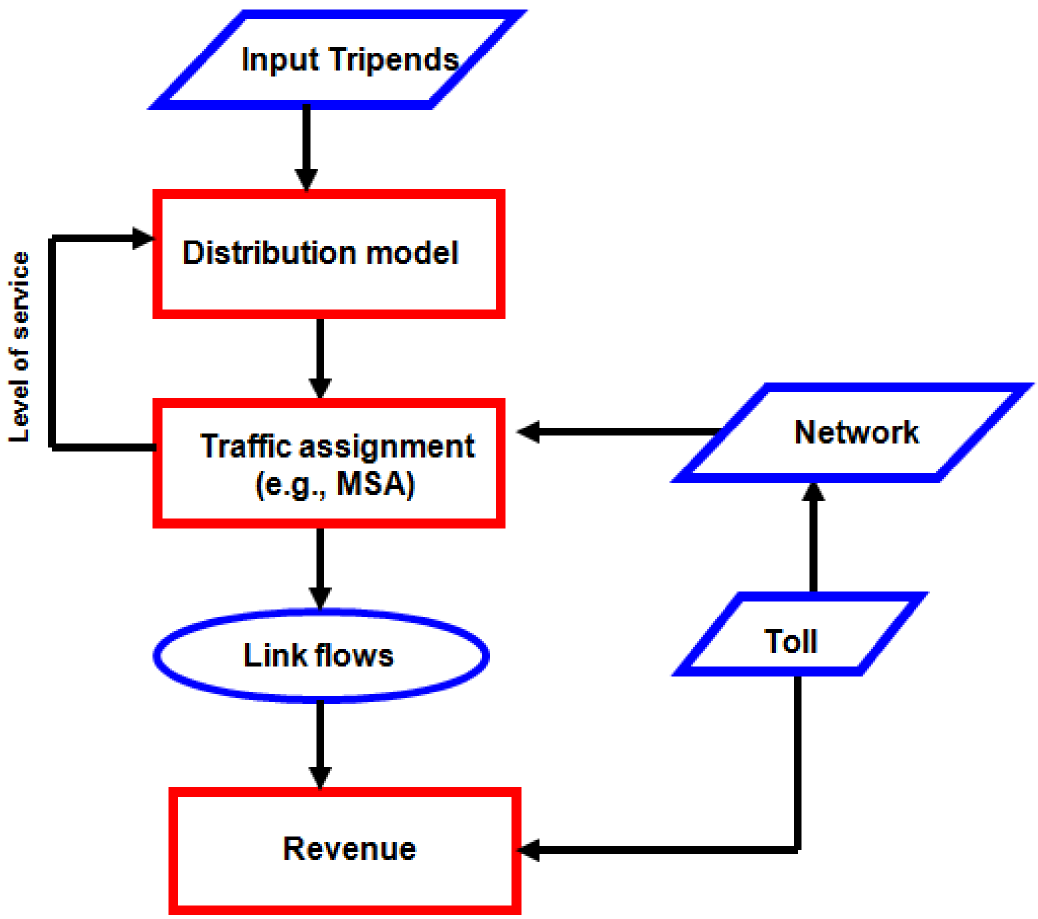

Fig 4: Network toll with distribution model

2.3.3. Full model

We refer to the full model, as one which allows some of the main behavioural changes resulting from the introduction of toll to be properly modelled. The introduction of a toll on either an existing road or a new road is expected to cause significant changes in travel behavior of drivers. Travelers who did not initially use this road may subsequently make use of it and so may reduce the benefit of the existing users and in terms of tolling may generate extra revenue. A new road is also very likely to attract users of parallel roads unto it. This driver behavior under this model architecture is captured by a dedicated model called the route choice model.

Furthermore some drivers may alter the timing of their activities by either departing earlier or later due to the improvement in the road conditions due to the introduction of tolling. This behavior is captured by the Time of the day choice model. This model can also be used to inform the tolling strategy; whether to implement a flat toll across the day or different tolling régimes for different time of the day. Furthermore, new flow patterns may result from changes not directly tied to the transportation system but rather changes in the general activities in the study area such as new shopping malls or new job centers. These facilities will attract people to use the improved facility to reach there. Additionally, the improved road may make existing facilities more accessible to people who previously have difficulties accessing them. These changes in travel patterns can be captured by the distribution model. Finally the tolling and or the improved facility may cause people not to travel at all or make more trips depending on where they live and the purpose of their trips. This behavioral pattern can be captured by the Trip frequency model.

This model architecture also captures the ripple effect a change in one behavior (e.g., changes in route) is likely to cause on the other behaviors such as trip frequency, distribution or time of the day choice. Ultimately, these ripple effects will lessen and, after a while, the system will stabilize at a new *equilibrium* point with no more significant changes occurring. At this point, the frequency of trips, the trip destinations, departure times and the chosen routes will be stable throughout the transportation network. These rippling effects are captured by the demand-supply equilibrium model.

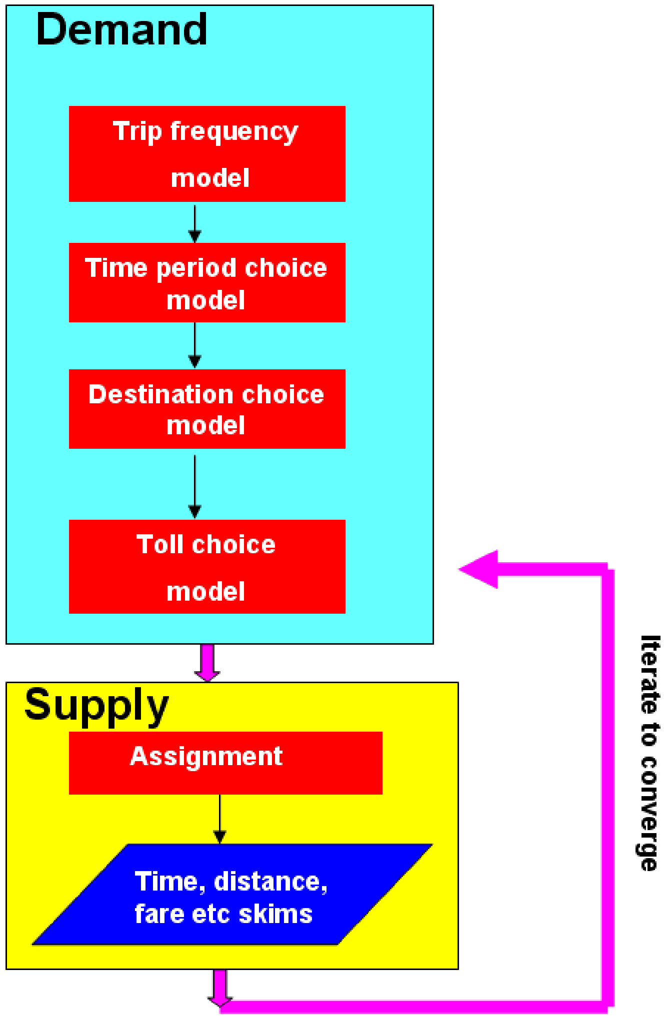

Fig 5a: Full model architecture

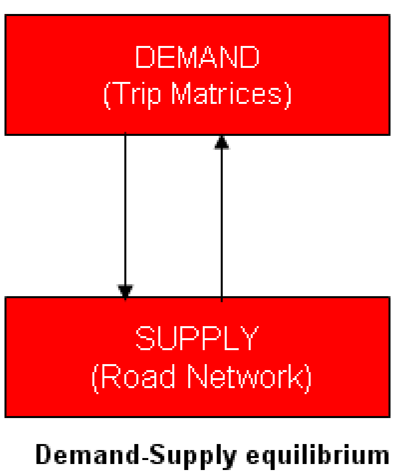

Fig 5b: Demand-supply equilibrium architecture

Toll choice model (TCM)

$$P_{toll} = \frac{\exp(U_{toll})}{\exp(U_{toll}) + \exp(U_{nontoll})}$$

$$T^{toll} = \sum_{\forall i,j} T_{ij} P_{toll}$$

Where

T_{ij}^{toll} Toll road traffic demand between origin zone *i* and destination zone *j*.

T^{toll} Toll road traffic demand for all O-D pairs.

$U_{nontoll}$ Utility for non-toll route for each O-D pair.

U_{toll} Utility for toll route for each O-D pair.

T_{ij} Forecast trips between each O-D pair.

Destination choice model (DCM)

$$P_{ij} = \frac{\exp(U_{ij})}{\sum_{j=1}^{J} \exp(U_{ij})}$$

$$U_{ij} = Asc_j + \alpha * Logsum_{ij}$$

$$Logsum_{ij} = In(\exp(U_{toll}) + \exp(U_{nontoll}))$$

Where

$Logsum_{ij}$ Logsum for each O-D pair in the choice set.

U_{ij} Utility for each O-D pair in the choice set.

P_{ij} Probability for each O-D pair in the choice set.

Asc_j A constant for each destination zone.

α Sensitivity parameter

Time period choice model (TPM)

$$P_{ik} = \frac{\exp(U_{ik})}{\sum_{k=1}^{3} \exp(U_{ik})} \quad \forall k = 1,2,3$$

$$U_{ik} = Asc_k + \beta * Logsum_{ik}$$

$$Logsum_{ik} = In\left(\sum_{\forall j \in N_k} \exp(U_{ij}) \right)$$

$Logsum_{ik}$ Logsum for time period *k* for origin zone *i*.

U_{ik} Utility for time period *k* for origin zone *i*.

P_{ik} Probability for time period *k* for origin zone *i*

Asc_k A constant for each time period.

β Sensitivity parameter

Trip frequency model (TFM)

$$T_{i1} = T_{i0} * \exp(\gamma (L_{i1} - L_{i0}))$$

Where

T_{i1} Forecast trips due to changes in the network for origin zone *i*.

T_{i0} Base year trips for origin zone *i*.

L_{i1} Logsum for origin zone *i* due to network changes

L_{i0} Logsum for origin zone *i* in base case

γ Scale factor.

Four of the five described stages form the demand part of the model architecture and the last stage form the supply part. In figure 5a the toll route choice model is conditional on the distribution model which in turn is conditional on the time period choice model, which is conditional on the trip frequency model. These models are connected in the opposite direction through the measure of accessibility called the logsum. Once the level of service attributes (travel time, distance, toll level etc) are known for the toll route and the non-tolled routes, the logsums for each origin-destination zone pair in each time period are calculated within the toll route model. These logsums then enter into the destination choice model (next level) as attributes and it computes the logsums for each origin zone. These enter the time period choice model which finally assembles them for the trip frequency model where they represent the trip generation power of each origin zone.

Once the trip frequency model receives the logsums, the model system first executes the trip frequency model, then produces the demand within each time period using the time period choice model, then uses the distribution model to distribute the trips from each origin zone to all available destination zones and finally splits them by whether they use the tolled facilities or not. At this point peak and off peak period toll/non-toll trip matrices are produced for each market segment. These matrices are then combined to produce peak and off peak hour matrices by vehicle type using factors derived from the observed travel pattern within the study area. The matrices are then assigned to the road network to produce new level of service attributes (travel time, cost, etc). These new level of service attributes then go back to the demand model to produce new trip matrices for assignment. These iterative process between the demand and supply is shown in figure 5b.

3. Case study

In order to test the validity of the above toll modelling methods, we implemented them on a cut-down version (figure 6) of a model used to forecast traffic and revenue for a recent toll road study in Nigeria. In this paper we investigate how each of these methods predicts the optimal toll and also forecast traffic and revenue in the future years**.**

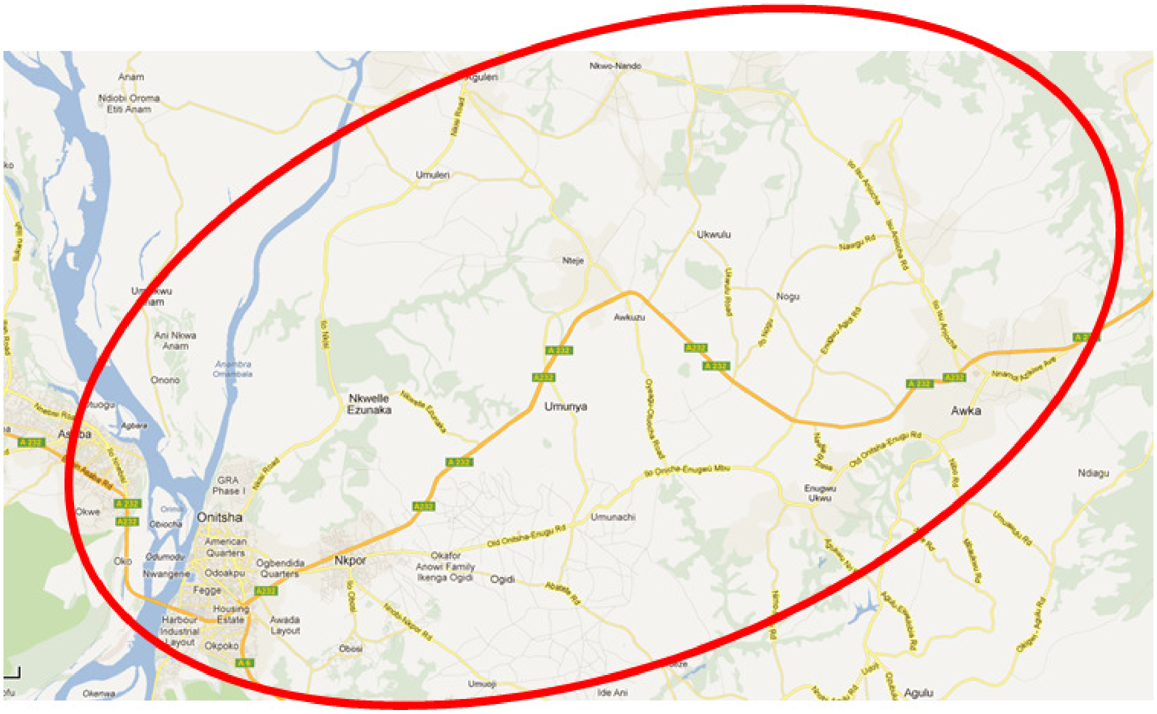

Fig 6: Study area

The corresponding coded network and the proposed road to toll is given in figure 7

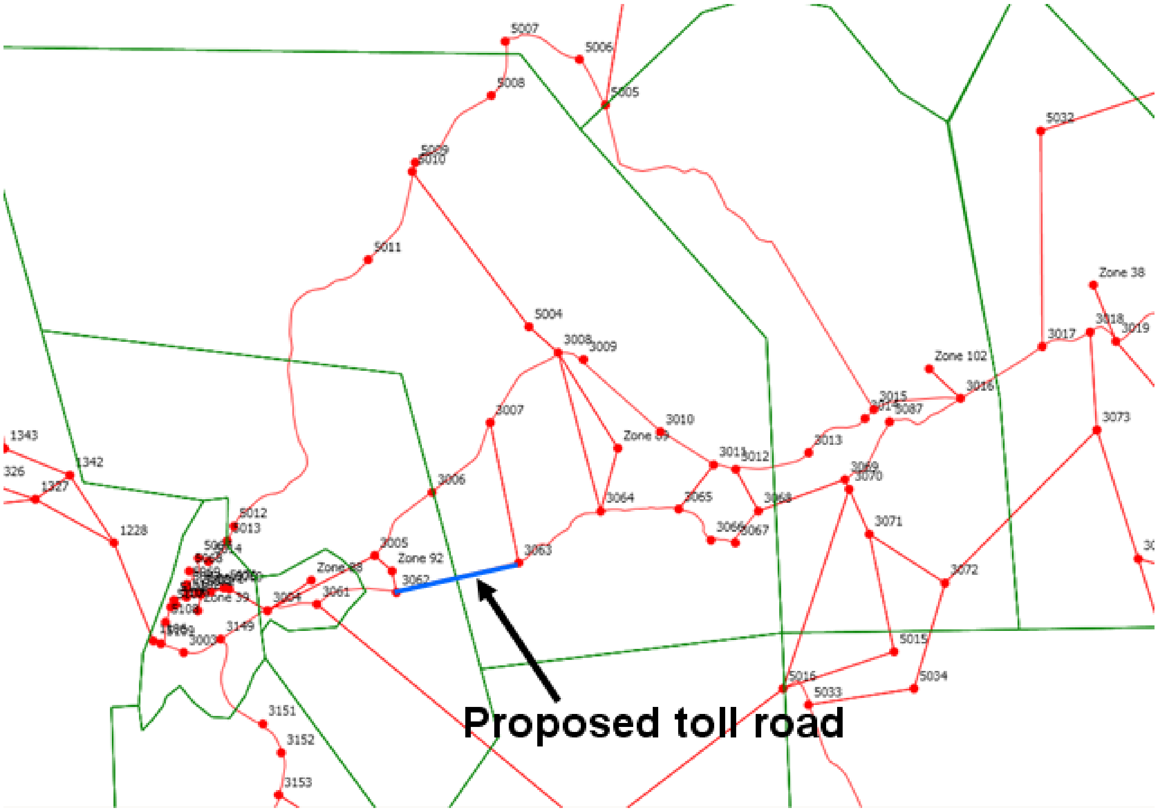

Fig 7: Coded network around the study area

All the data used in this analysis were real data obtained through surveys. The surveys conducted include highway inventory to get the characteristics of the road network, speed surveys, stated preference surveys for the estimation of value of time, manual traffic counts and roadside interviews. The proposed toll road is shown in figure 7.

The utility equation

The formulations for the generalized cost and utility are the same, except that the generalized cost is positive whilst the utility can be negative (generally called disutility). The utility equation is expressed as:

$$U = \beta\left(T + D * \frac{VOC}{VOT} + Toll * \frac{1}{VOT}\right)$$

Where

β Is the scale parameter

VOC Is the vehicle operating cost in pence per km

VOT Is the value time in pence per minute
Toll Is the toll pence charged for using the toll road
D Is the distance in km

Choice elasticities

Research by Transport Research Board (1994) found toll price elasticities to be from -0.1 to -0.4. The formulation of the two elasticity methods implies that the higher the elasticity in absolute terms, the smaller the toll road traffic and hence the smaller the revenue. For conservative reasons we chose elasticity value of -0.4 and applied it in the two elasticity methods. The choice of this value gives the least toll traffic and hence revenue.

Calibration and Validation

All the methods were calibrated to ensure that the traffic on the toll road matches the observed counts. For methods with no alternatives to the toll road, this was straight forward. However, for all other methods with competing alternatives to the toll road/route, we employed several techniques such as the changes to the speed-flow curves, and/or addition of alternative specific constants to ensure that the baseline synthesized toll traffic matched the observed. The synthesised trips on the toll by the different methods are shown in the table below.

Table 1: Calibrated toll road trips

Methods	Calibrated traffic	%Difference
Count	18,167	
Linear Elasticity	18,167	0%
Exponential elasticity	18,167	0%
Spreadsheet logit	18,167	0%
Network toll	18,644	-3%
Network toll +distribution model	18,834	-4%
Full mode 1	18,108	0%

4. Optimal toll analysis by different modelling methods

Under this section we investigated how these modelling methods could be used to determine the optimal toll based the on the current demand and network conditions. In all the methods we kept the demand fixed and varied the toll level. For the non-spatial methods, it also means that the only varying variable in the generalized cost function is the toll level. For the spatial methods the assignment process allowed the service variables like distance and time to change depending on the traffic on the toll road and capacity restraint. The traffic and revenue for each toll level are given in the figures 8,9 and 10.

The results show that all the methods appear to be sensitive to toll. Thus increases in the toll level reduce the traffic on the toll road as shown in fig 8. However, it appears that some methods are more sensitive that others. For example the linear elasticity method is the least sensitive method to changes in toll, resulting in a much higher toll traffic compared to the other methods. Considering the two, elasticity methods, the exponential own elasticity method is much more sensitive to toll than the linear method.

In the two network methods, there appear to be discontinuities in toll road demand with varying toll levels. In both methods there is zero traffic on the toll road for tolls above 40 pence. This may be due to that fact that the toll link stops being on all shortest paths after a toll level of 40 pence. In both methods the only thing causing any spread in behaviour in route choice is congestion, which causes traffic to equilibrate between similar routes. This all-or-nothing nature of the assignment process resulting in the discontinuities in traffic means that these methods may be less suitable for optimal toll analysis.

The exponential based methods such as the exponential own elasticity method, count multinomial logit method and the full model appear to be much behavioural and sensitive to toll levels. In terms of computing the optimal toll, one would expect that when the toll level approaches zero (the point at which no one pays toll), then the revenue also approaches zero. Similarly, when the toll level approaches a very high value, then revenue approaches zero as nobody can afford to use the road at all. It was also expected that as the toll is increased from zero, less traffic would use the toll road but that initially at least, those that did use the toll road would pay more which may lead to more revenue. However an optimal level of toll exists above which increases in toll would not lead to more revenue because the toll road would be carrying too little traffic.

Looking at the linear own elasticity method in figures 10a and 10b, the estimated revenues under varying toll levels in appear to be unbounded, which is counter intuitive to reality. No level of toll exists (at least among the toll levels considered in this study) where the revenue begins to drop as a result of increasing toll levels. This implies that this method could be unrealistic and inappropriate to apply in practice. Based on this analysis we concluded that this method is unlikely to be appropriate for modelling toll traffic and revenue.

The two network methods (Network toll and network toll + distribution model) of predicting optimal toll level are also unlikely to be realistic (see figures 8 and 9). This is because these methods only assign traffic to the toll road, only if it is on the shortest path and ignores it completely even if it is on a path whose cost is slightly higher than the shortest path. Clearly this method is not behavioural and heavily depends on the assignment paths and the traffic situation of the network. Based on this analysis we concluded that these two methods are unlikely to be appropriate for modelling toll traffic and revenue.

The elimination of the above methods reduces the methods under consideration to three. Among the three, the exponential own elasticity produced much higher optimal toll and revenue. This may partly be explained by the fact that this method considers the toll road in isolation without any reference to the parallel or competing roads in the network. It is less behavioural because it does not present travellers with any form of real choice. In reality some travellers are likely to respond to the toll by switching routes to avoid paying the toll. Some may even change their destination or not travel at all. The absence of these behavioural mechanisms in this model could mean it is over predicting the traffic and revenue of the toll road. The spreadsheet multinomial logit method offers travellers some form of choice of which route to take. As shown in figure 10b it is more sensitive to toll than the exponential own elasticity method, partly because travellers are given some form of choice to avoid paying the toll. Here the alternatives presented are fixed (in this study 3 alternative routes are considered) and does not take account of changes to network conditions. This method also ignores other behavioural mechanisms such as change in destinations.

Based on the analysis done so far we can conclude that the full model is the most appropriate method among the ones considered in this paper for modelling tolls. This method is more behavioural and takes account of the key changes in behaviour mechanisms resulting from the introduction of a toll. It produced more conservative optimal toll and revenue than the other methods.

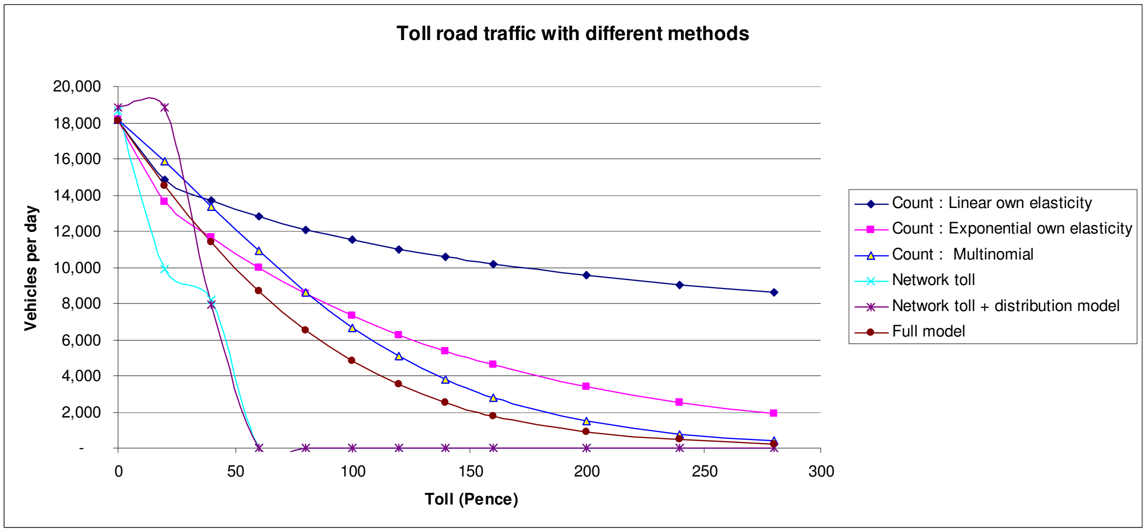

Fig 8: Traffic profile with increasing toll level (overview from 0 to 300 pence)

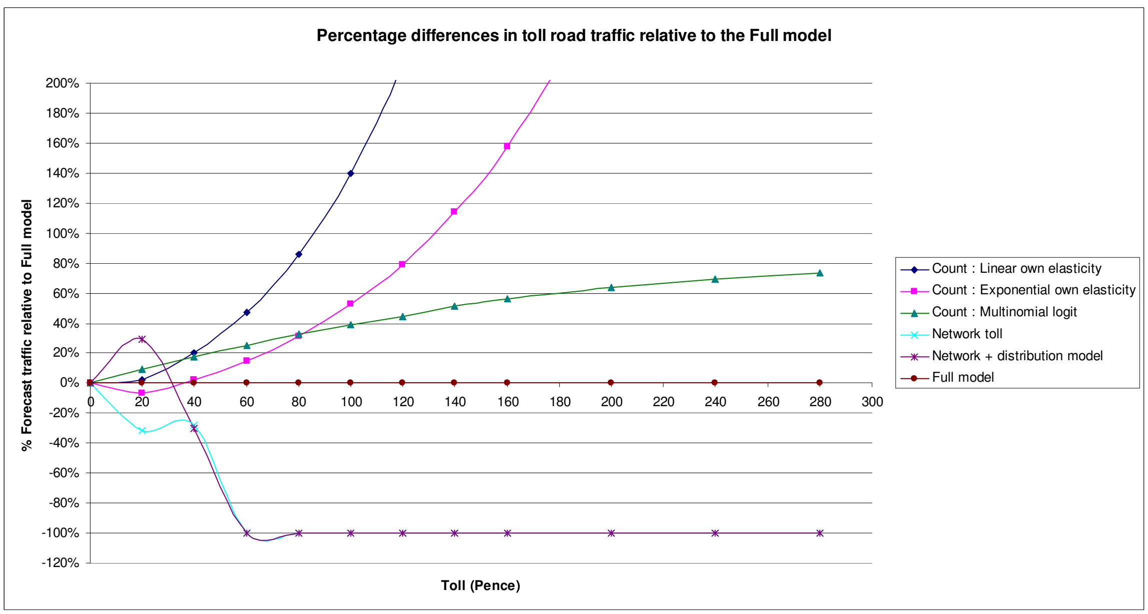

Fig 9: Traffic profile with increasing toll level relative to full model (zero line)

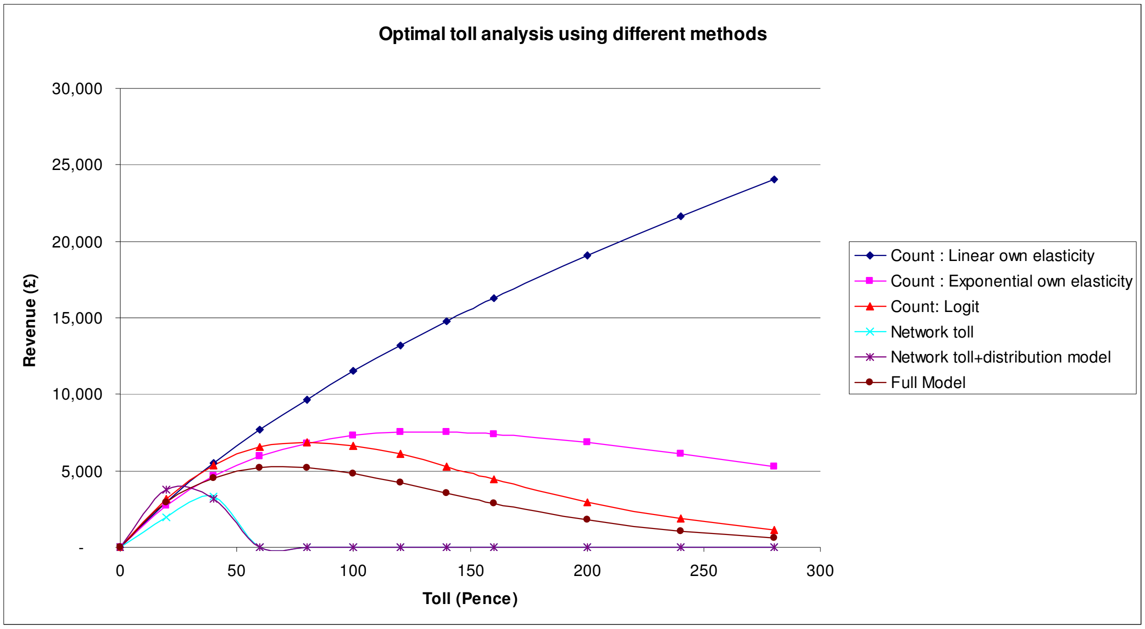

Fig 10a: Revenue profile with increasing toll level

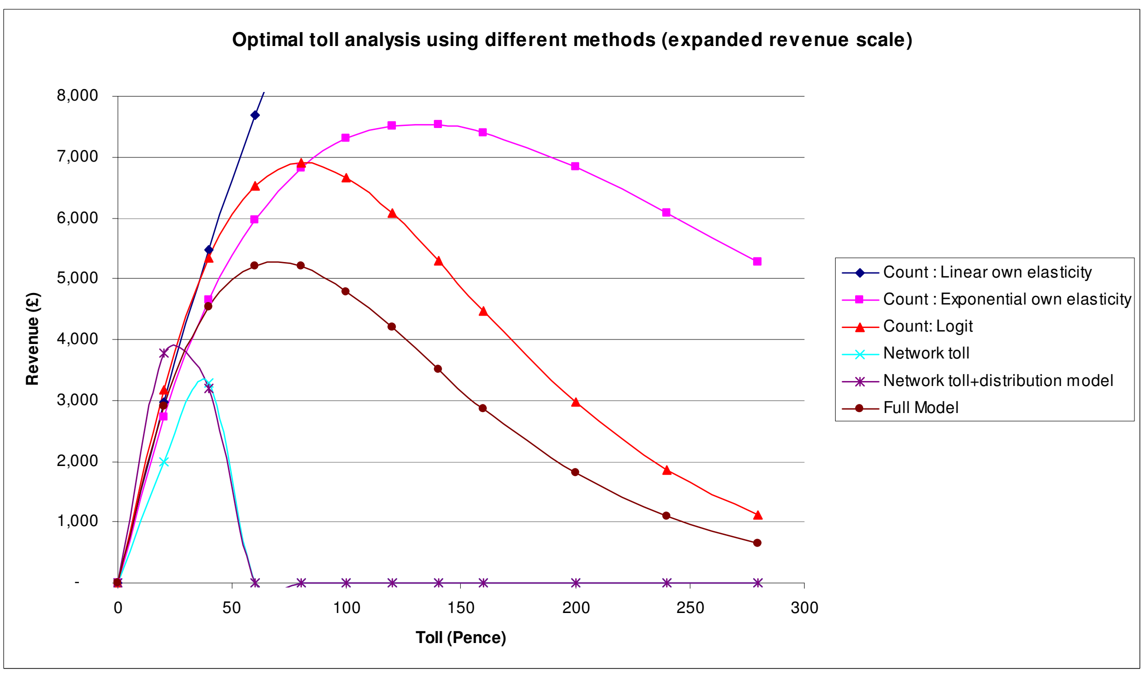

Fig 10b: Revenue profile with increasing toll level (expanded revenue scale)

5. Traffic and revenue forecasting by the different methods

Turning now to the ability of each method to forecast traffic and revenue for the 30 year period. Because each method results in different optimal toll values and the fact that some did not actually produce any optimal toll value, we applied one toll value for all the methods. The optimal toll applied was the optimal toll from the full model run, which was about 60 pence (see figure 10). Figure 11 reveals that the network toll method did not generate any revenue over the forecast periods. The network toll with distribution model only starts generating revenue after 2030. The rest of the methods produced higher revenues than the full model in each forecast year. The rate of increase in revenue in the full model is seen to be lower than that of the other methods.

Figure 12 shows the daily traffic forecast of the other methods relative to the full model over the forecast periods. This figure shows that the exponential own elasticity method predicted between 15% to 16% more traffic over the forecast years than the full model. The spreadsheet logit model predicted about 25% to 27% more traffic over the forecast years than the full model. The consistencies over the years may be due to the absence of congestion in the network. The linear own elasticity forecasts are shown to increase exponentially with increasing forecast years relative to the full model forecasts. The network toll method did not forecast any toll traffic over the forecast periods whilst the network toll with distribution model only started forecasting some toll traffic after 2030. The results for the two network models are expected as the network is uncongested and the toll link may not be on any of the shortest paths.

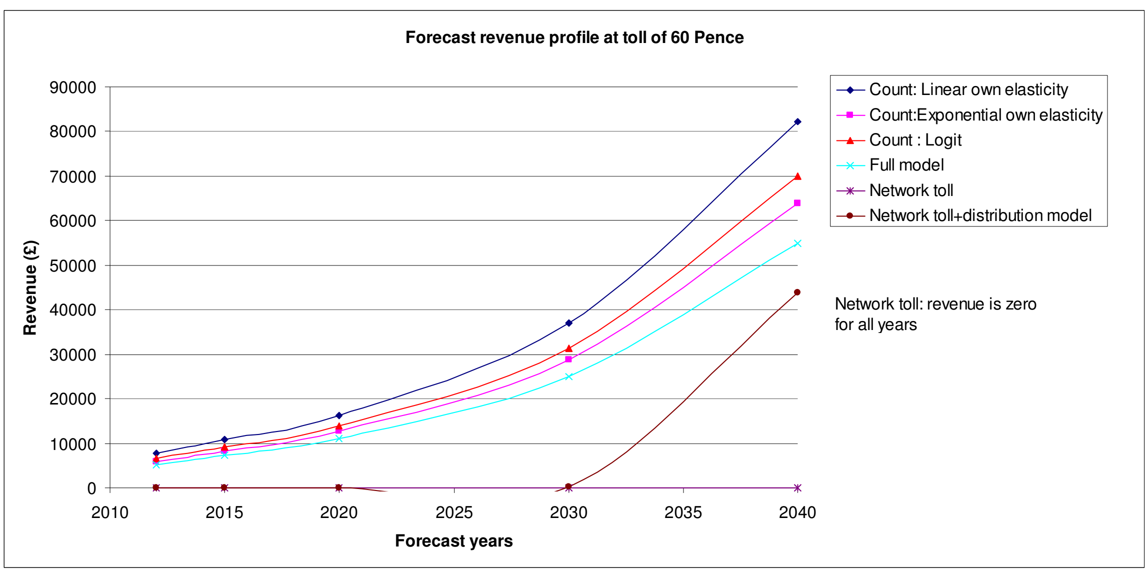

Fig 11: Daily revenue forecasts

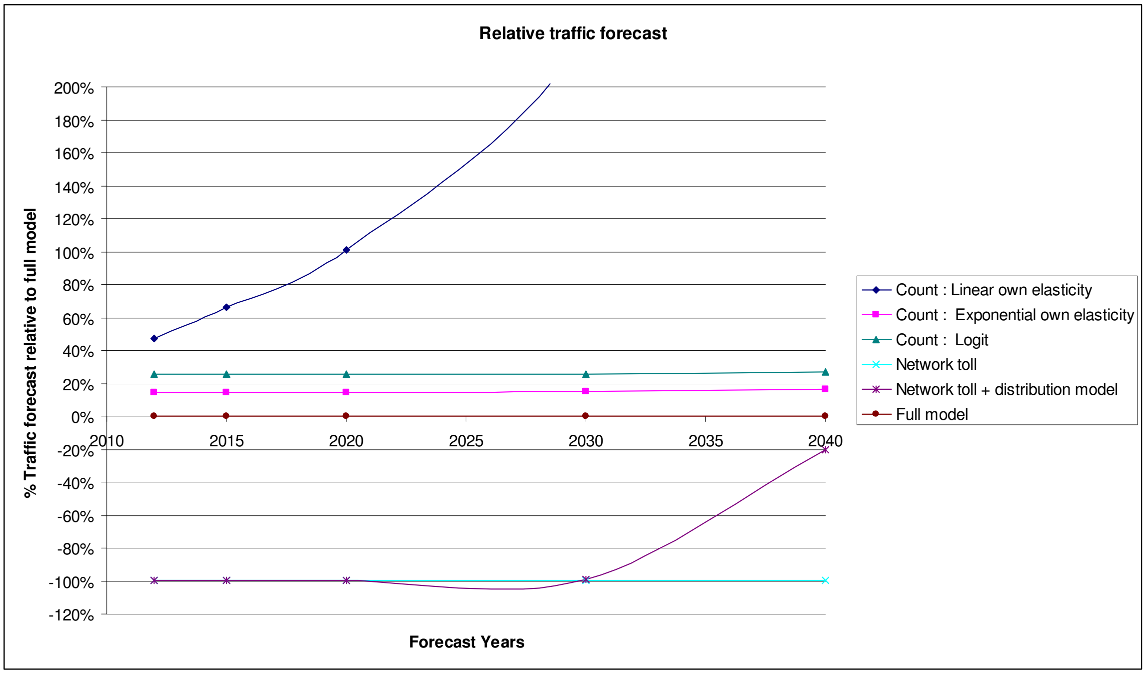

Fig 12: Relative daily revenue forecasts

6. Conclusion

In this paper we tested the validity of the several existing toll modelling methods, using a cut-down version of a model used to forecast traffic and revenue for a recent toll road study in Nigeria. We investigated how each of the methods predicted the optimal toll and also forecast traffic and revenue in the future years**.** The methods presented were grouped under non-spatial and spatial methods.

The non-spatial methods considered were linear own elasticity method; the exponential own elasticity method and spreadsheet logit model. This consists of methods where the traffic on the toll road is forecast without any reference to the geography of the proposed toll road. They generally do not have a zone system or node-link structure and do not treat different origin-destination pairs differently. The linear own elasticity method fails to forecast an optimum toll level (at least among the toll levels considered in this study). The other non-spatial methods also produced different optimal toll levels and different traffic and revenue forecasts for any given toll. Additionally, the spreadsheet multinomial logit method is the only method among the three which offers travellers some form of choice of which route to take. It was also shown to be more sensitive to toll than both the linear and exponential own elasticity methods. However, all these methods do not take account of changes to network conditions and also ignore other important behavioural mechanisms such as change in destinations.

The spatial methods considered were the Network toll methods (also called assignment only method); Network toll with distribution model; and the full model. The spatial methods are methods with well defined zone system and node-link structure. The first two network methods were shown to produce unrealistic traffic and revenue forecasts. They generally only assign traffic to the toll road only if the toll road is on the shortest path and ignore it completely even if it is on a path whose cost is slightly higher than the shortest path. They are also non-behavioural and heavily depend on the assignment paths and the traffic situation of the network. The full method is more behavioural and takes account of the key changes in behaviour resulting from the introduction of a toll. It also produced a more conservative optimal toll and revenue than all the other methods.

All the methods discussed in this paper were shown to predict different traffic and revenue forecasts. Generally the more detailed the method the lower the forecast. Thus we have demonstrated albeit based on the case study in this paper, that the choice of toll modelling method could have a significant impact on the magnitude of the forecast traffic and revenue.

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