

SOUTH AFRICAN EXPERIENCE WITH THE ESTIMATION OF VALUES OF TIME FROM STATED PREFERENCE STUDIES AND THEIR USE IN TOLL ROAD MODELS

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1. INTRODUCTION

The route choice behavior of potential toll route users and their perceived value of time (VOT) which determines their choice of route are critical in modeling the toll income stream of a proposed toll road. This is also fundamental in assessing the financial risks of the financiers of the toll road investment.

Internationally the most acceptable approach is to use individual choice or discrete choice models calibrated on the potential users' actual route choice behavior (revealed preference) as well their intended behavior (stated preferences).

The VOT is subsequently used in network transport models such as EMME/2 and SATURN so that these models reflect the correct distribution of trips amongst alternative routes for each Origin-Destination pair of the trip matrix. The VOT is therefore a critical parameter in the trip assignment process and it is important that the VOT is accurately estimated.

This paper describes the value of time studies that were conducted for the calibration of traffic models for the purpose of two toll road studies:

- Scheme development of N4 Platinum toll road conducted by the Bakwena Platinum Corridor Concessionaire (BPCC)
- Development of Gauteng province toll road model by the PWV Consortium for Gautrans

The paper discusses the theory of estimating VOT's from the discrete choice model, reviews the history of value of time studies in S.A., summarises overseas experience, presents the RP and SP surveys and VOTs estimated for the Gautrans and N4 studies, and finally describes methods to incorporate the VOT's in network models.

1.1 Estimation of values of time from discrete choice models

Discrete choice models, or individual choice models, are very popular worldwide to simulate the choice behavior of transport users for policy testing and travel forecasting purposes. Traditionally, most of these models were developed for mode choice studies. With the international trend to finance new high order roads by means of tolling, route choice studies have become more popular. Discrete choice models are specifically used to estimate values of time of road users as the models accurately capture the underlying choice behavior of the specific target market of the planned toll road. The models also allow the impact of

any factor influencing the VOT to be estimated such as the trip purpose, income, road standard, etc.

The VOT is estimated as follows from the formulation of the logit discrete choice model: Consider the simple route choice situation between a toll road and its alternative, or parallel, non-tolled road. The utility that the road user derives from each route can be formulated in terms of toll fee and travel time:

$$U_{\text{toll}} = c \cdot C_t + t \cdot T_t + M_t \quad \text{Equation 1}$$

$$U_{\text{alt}} = c \cdot C_a + t \cdot T_a \quad \text{Equation 2}$$

Where:

- U_{toll} and U_{alt} are the utilities of the toll road and alternative road respectively
- C_t and T_t are the user cost and the travel time on the toll route respectively
- C_a and T_a are the cost and time on the alternative route
- c and t are the cost and time coefficients which are estimated on survey data of road users' perceived travel times and costs by means of special logit model calibration programs
- M_t is the constant, attached to the utility of the toll road, which then captures any factor not related to the variables in the model, cost and time in this case, which may relate to safety and convenience of using the toll road relative to that of the alternative road.

In general terms, the value of time is defined as the rate of change of utility relative to the rate of change in travel time, divided by the rate of change of utility relative to the rate of change in the cost. For a linear utility function such as equations 1 and 2, the VOT is simply the ratio of the time coefficient to the cost coefficient:

$$\text{VOT} = t / c \quad \text{Equation 3}$$

If time was measured in minutes and cost in cents, the VOT is given in cents per minute.

Any variable in the utility function can be expressed in terms of monetary values by taking the ratio of that variable's coefficient to the cost coefficient. By taking the ratio of the toll road constant M_t to the cost coefficient, one gets the value of the safety and convenience that road users attach to the toll road. This is often referred to as the motorway bonus by international literature.

By making the utility functions more complex one can derive more information from the model. For example, by breaking up the cost variable into running cost and toll fee cost, one can estimate the values of time related to running cost and to toll fee. The surveyed data can also be segmented by trip purpose and/or income level to estimate the VOT's for different trip purposes and income levels.

Louviere and Hensher (2000) derived a value of time function by introducing quadratic and multiplication cost and time terms in the utility function. In this way they could estimate how the VOT would vary by the level of the toll fee and the travel time.

Various market research techniques can also be used to obtain information from targeted road users. Revealed preference surveys obtain road users' current route preferences, costs and times, for existing toll route corridors. Stated preference surveys present potential toll

road users with hypothetical choices between the proposed toll road and the alternative road and request their stated choices between the routes.

Stated preference (SP) models normally performs better than revealed preference (RP) models, as RP data often lacks variation and suffers from empirical correlation's and interactions which hides the underlying choice behavior. However, SP models suffers from various biases in responses, such as strategic/policy bias in which respondents try to influence the experiment to favour a certain strategy/policy, or errors between intended as opposed to real life choice.

The differences in RP and SP values of time are further discussed in the paper.

1.2 Historic review of South African VOT studies

At the time of the bidding phase of the N4 toll road scheme by the BPCC, it was found that there was no recognised database in South Africa in respect of the values of time for traffic and transportation studies. However, there were different sources of information which permitted a value judgement to be made. These sources of information were:

- a) Values of time as ascertained by the Central Economic Advisory Service in the late 1980's. These values are normally used in economic evaluation studies, but are not sufficiently accurate to explain route choice behaviour of road users in a particular road network context.

Values of time of medium and high income workers in 1992 was estimated as R24 and R69 per hour respectively, for Gauteng. These related to incomes of R 9 500- R 38 000 per annum for medium, and greater than R38 000 per annum for high income workers.

- b) Revealed Preference survey work conducted for the N3 toll road and which concluded that the attraction to this toll road is best defined in terms of a cumulative monetary value (i.e. inclusive of time, safety, comfort and convenience costs) for light (Class 1) vehicles of R80.00 per hr (1997 Rand value).
- c) Stated Preference survey work conducted on the N4 Maputo Corridor, which concluded relatively low values of time, but in conjunction with high motorway bonuses (i.e. to account for safety, comfort and convenience factors and a preference for higher standard routes).

For the N4 bidding phase it was decided to follow a scenario approach by using a range of VOT's inclusive of safety, comfort and convenience for light vehicles.

The BPCC subsequently recommended that the NRA develop a values of time data base for South Africa as this would greatly assist in the various future toll road studies. When appointed as Preferred Bidder, the BPCC and its traffic auditors decided to conduct comprehensive RP and SP studies in order to refine the VOT's for use in the final traffic model.

During the same time Gautrans initiated its toll model study which also provided the opportunity for further RP and SP studies.

The contributions of GIBB Transport Consulting (SP study for N4) and Africon (RP study for Gautrans) are acknowledged.

2. REVIEW OF INTERNATIONAL EXPERIENCE

In order to learn from overseas experience a literature search was conducted on SP surveys for route choice and toll road modelling. Limited information was found as most SP studies dealt with mode choice

Useful information extracted from overseas literature are summarised below:

- The following are important factors influencing road users route choice in the urban environment: (Abdel-Aty, TRR 1493)
 - Travel time
 - Road Type
 - Congestion
 - Occurrence of stops and traffic signals
 - Uncertainty/unreliability of travel time
- The heterogeneous nature of routes, with varying characteristics along the length of the route, makes route choice modelling more complicated than urban mode choice modelling (Bony, TRR 1037).
- Values of time may vary by trip purpose, income group, mode, occupation group, varying personal circumstances, amount of leisure time available and travel conditions (Bradley, TRR 1285).
- Market research amongst users of the SR91 toll road in California during 1996/97 indicated:
 - Implied VOT's are \$13 to 14 per hour. This is R78 to R84 per hour using an exchange rate of 6 Rand per Dollar.
 - Many commuters overestimate their actual time savings i.e. 20 minutes perceived versus 13 minutes actual.
- A major research study conducted by the Institute of Transport Studies at Leeds University (England) makes available the net outcome of a very large amount of British empirical evidence regarding the impact of a large number of travel attributes on Values of Time (Wardman, 1998). The relevant key findings of the study are:
 - Not only do the money values vary across different circumstances, but there can also be considerable variation in the valuations expressed in units of in-vehicle time.
 - Business values are, as expected, the highest, followed by commuting values which in turn tend to be higher than leisure values.
 - The effect from distance on the money values was in most cases positive and very similar although not particularly strong. This is in addition to higher values for inter-urban trips of 30 miles or more.

- There is a reasonable degree of correspondence between RP and SP values of in-vehicle time. However, this correspondence is progressively weakened for out-of-vehicle time, headway and interchange. Indeed, the divergence between the RP and SP values for headway and interchange is a cause for some concern.
- There is evidence that the money value of an attribute will vary with the monetary unit used. Valuations expressed in units of toll charge are the lowest whilst those expressed solely in terms of car running costs are highest.
- Values of time increase at around 1% per annum, which is equivalent to a GDP elasticity over the period in question of around 0.5. This is highly consistent with cross-sectional evidence obtained from discrete choice models.

3. REVEALED AND STATED PREFERENCE STUDIES CONDUCTED IN SOUTH AFRICA

3.1 Survey methods and sample sizes

3.1.1 Gauteng toll road model

RP and SP studies were conducted for the calibration of the Gauteng Toll Road Model (PWV Consortium, 2000). A short description is given here of the survey method and sample size.

The SP study targeted users of the R21 and N1 freeways between Pretoria, Midrand and Johannesburg. A sample of users were recruited at work places and interviewed during lunch time in a group set up

In total 54 organisations in Pretoria, Midrand and Johannesburg were identified and requested to participate in the survey. The targeted organisations covered the public sector and private companies for various sectors i.e. manufacturing, information technology, finance, consulting and transport. It was tried to obtain an approximate equal sample from the three trip purposes (Commuter, Business and Social/Other), but most respondents felt more comfortable responding in terms of commuting and business.

The final number of completed questionnaires amounted to 212 and was distributed as follows:

•	Commuter	-	156
•	Business	-	43
•	Social/Other	-	13

Each respondent provided 12 records for the SP database which yielded a total sample size of 2544 for modeling purposes.

It was decided to keep the SP experiment as simple as possible due to the complexities involved and the time limitation of interviewing respondents at work. As the main focus of the study was to determine value of time (VOT) of toll fees, it was decided to focus on travel time and toll fee variables.

Apart from travel time and toll fees, two additional variables were considered. As congestion plays an important part in urban route choice, the time stopped at robots on the metropolitan route parallel to the tolled freeway was selected as another SP variable. The standard of road of the metropolitan route also impacts on congestion and this factor was therefore defined in terms of a single versus dual carriage way road.

Although fuel cost would have been ideal to include to determine the possible difference in VOT between fuel cost and toll fee, the limit on the number of questions did not allow inclusion of fuel cost. Fuel cost was however considered in the Revealed Preference Survey.

The route choice context in which the variables were presented to respondents was also kept simple. Respondents were requested to consider the Pretoria-Johannesburg corridor and the introduction of tolling the existing Ben Schoeman freeway.

Respondents were asked to choose between the tolled freeway and the alternative metropolitan road for each hypothetical route choice scenario. Presenting the new PWV9 toll freeway as part of the SP experiment would have resulted in a too complex choice situation and was therefore not considered.

The SP design yielded three variables at three levels each, and one variable at two levels.

The RP survey involved interviewing a sample of users of existing toll roads in Gauteng as well as potential toll road users on parallel routes. Road side interviews were conducted and respondents requested to provide information on perceived travel times and toll fees of their preferred route and the alternative route. From this RP information, values of time was estimated based on user's actual trade-off between travel time saving and toll fee.

Toll corridors covered were the N4 between Pretoria and Hartebeespoortdam and the N17 between Springs and Johannesburg. In total 626 road side interviews were conducted.

The RP data had to be validated according to strict criteria in order to eliminate illogic choices, and unrealistic low or high travel times. It seems that road users find it difficult to provide realistic travel times and distances for their current and alternative routes. This problem is aggravated by the difficult roadside interview survey circumstances i.e. short available interview period and road users delayed in their journey. Of the 626 interviews, 243 were useable for the RP models.

3.1.2 N4 Platinum toll road

Both RP and SP studies were conducted to estimate VOT's for the toll traffic model that was calibrated for the purpose of the N4 Platinum Toll Road bid. The RP and SP studies were conducted independently by two study teams (Stewart Scott, 2000 and GIBB Transport Consulting, 2000). The background questions were made compatible to compare the sample profiles.

For the RP study, road users on the N1 North toll road corridor in Northern Province and the N17 toll road corridor in the East Rand were interviewed using road side interviews. This data was combined with the RP data obtained from the Gauteng Toll Model Study.

In total 869 respondents were interviewed consisting of 619 light vehicles, 97 commercial LDV's and 153 heavy vehicles. The sample on the N1 north covered the Kranskop and Nyl toll plazas and the R101 alternative route. The N17 sample in the East Rand covered the

Gosforth and Dalpark toll plazas and alternative metropolitan routes. The N4 sample in Pretoria West covered the Quagga toll plaza and R104 alternative route.

Similar to the Gautrans RP survey experience, the data had to be thoroughly validated in order to obtain reliable models.

For the SP study, 500 light vehicle users and 100 heavy vehicle users were interviewed on the N1 North at the Petroport, and on Zambesi drive (Pretoria North).

Two variables, travel time saving and relative user cost, with 5 levels each were presented in the SP questions. Respondents were asked to choose between a tolled freeway and a parallel highway. The total number of combinations were too many and therefore respondents were randomly divided into 3 groups and each group was offered 8 to 9 choices to cover the whole range.

3.2 VOT Results

3.2.1 Gautrans study

Table 3.1 gives the range of VOT's from the RP and SP models calibrated on the Gautrans survey data. From the results it is concluded:

- Of all the user segments, SP models for commuters performed the best due to the larger sample available for commuters. Stopped time saved by the toll freeway relative to the alternative route in terms of delays at robots, gave better models than the total travel time saving.
- VOT's from the RP study are higher compared to those of the SP study. It seems there was strategic bias in the responses of the SP survey i.e. respondents objecting against the tolling of the N1.
- Business users have the highest VOT's, followed by commuters, while social trips have the lowest VOT's. This is consistent with international findings.
- Time stopped at robots is valued at 23 to 70 per cent higher than total travel time. This relates to international findings that out-of-vehicle time (walking and waiting time), which has a higher level of inconvenience, are valued more than in-vehicle time.
- The standard of the alternative route available has a significant impact on toll route usage. A dual carriageway alternative route instead of a single road will have the same effect as an additional toll on the toll freeway.
- Higher income users value their time higher.
- The VOT is much higher than the average income rate.

Table 3.1: Summary of VOTs (Rand per hour) according to user segment and model type for Gautrans toll model

User Segment	Time Variable	Cost Variable	VOT (R per hr)
Ave Income (Income Rate)			R6 500.00 to R9 900 per month (R40 – R60)
Commuter All periods	Stopped Time	Toll Fee	20 - 30
Commuter All periods	Total Time	Toll Fee	20 - 70
Business All periods	Total Time	Toll Fee	40 – 50
Social/Other All periods	Total Time	Toll Fee	5 - 10

3.2.2 N4 Platinum study

The RP and SP values of time obtained from the N4 Platinum study are provided in Table 3.2.

The following patterns in the VOT's are apparent:

- For light vehicles, business trips display the highest VOT's followed by commuters, and Other trips indicating the lowest VOT's. This is similar to international experience.
- PDI's have lower VOT's than non-PDI, which may be a combined income and cultural effect.
- For heavy vehicles, the larger vehicle classes that pay higher toll fees, display higher VOT's.
- The VOT's seem to be in the correct order and the differences between the user segments seem instinctively correct.
- Similar to the finding in the Gautrans study, the VOT is much higher than the average income rate.

Table 3.2: Summary of VOT's by trip purpose and user segment for N4 Platinum toll model

User Segment	Non-PDI	PDI
	VOT (R per hr)	VOT (R per hr)
Ave Income-Commuters (Income rate)	R5 600 per mnth (R32 per hr)	
Light Vehicles:		
Commuters	50 – 60	30 –50
Business	80 – 90	60 – 90
Other	40 – 50	30 - 45
Heavy Vehicles:		
2 axles	80 – 90	
3-4 axles	110 – 130	
5 x axles	120 - 130	

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- In general there are very good similarities between the RP and SP VOT's. The following few differences are apparent:
 - The RP VOT for PDI commuters and Other trips are somewhat lower than the SP VOT.
 - The RP VOT for PDI business is higher than the SP VOT. The RP VOT's are similar for non-PDI and PDI business trips, while the SP VOT's show a lower VOT for PDI's compared to non-PDI's.

Motorway bonuses were also estimated in the SP study. This indicates that factors such as safety and convenience are valued at approximately 20 per cent of the time value.

When comparing the VOT's between the RP and SP studies the possible differences in the socio-economic characteristics of the East Rand sample, which was included in the RP sample, and the Pretoria/N1 sample targeted by the SP sample needs to be considered.

When comparing the low SP VOT's of the Gautrans study with the higher VOT's of the N4 study, it is evident that the VOT is sensitive to the route choice context and that there is very strong disapproval of tolling the Ben Schoeman without providing additional capacity at the same standard. (A low VOT indicates a general preference for the non-tolled alternative route. The higher the VOT, the greater the preference for the tolled route for a given travel time saving).

In order to reduce any bias in SP models it is common practice to scale the coefficients of the SP model by applying the SP coefficients to the RP data and estimating a scale factor. A more sophisticated method is to calibrate a joint RP and SP model using both data sets. Combining SP and RP data has not been tried during the reported studies, and further research is necessary to determine whether the reliability of the VOT's can be improved by this technique.

4. CALIBRATION OF NETWORK MODELS USING VALUES OF TIME FROM SP STUDIES

Various problems were encountered in applications in S.A. when trying to apply the VOT estimated from a discrete choice logit model directly into the SATURN or EMME2 network models.

The first problem encountered is that applying the logit model in an EMME2 network assignment routine using a straightforward deterministic equilibrium assignment does not converge under congested network conditions. Florian has done interesting research on this subject. He formulated a simplified assignment algorithm based on the logit model which does converge for toll road applications.

The second problem is that there are various differences between discrete choice models and network models. Firstly, EMME/2 or SATURN are aggregated network models, while the discrete choice model is disaggregated model simulating individuals' behaviour. Secondly, the Stochastic User Equilibrium (SUE) assignment algorithm in SATURN assumes a normal distribution of the generalised time variable, while the discrete choice model is based on the logit function. Thirdly, the SP value of time are often lower than that found from observed behaviour i.e. Revealed Preference (RP), because people think they would be more averse to pay toll compared to what they really do when faced with an actual toll road.

To overcome the above problems a calibration procedure in the network model, EMME/2 or SATURN, was developed which proved to be very successful. Firstly, the SUE assignment in the network model is used which is a stochastic model. The logit discrete model is also stochastic which gives some basis for similarity between the two models. The principle of the SUE assignment model is that the cost as defined by the model is the 'correct' average cost but that there is a distribution about the average as perceived by individuals. The perceived cost is therefore simulated by selecting a cost at random from the perceived distribution of costs on each link.

The network model is applied to a simple two route network along the same corridor where the SP/RP model was calibrated to ensure that both models are applied to the same situation. Two parameters are subsequently adjusted until the network model's toll diversion function (% use of toll road vs alternative route as a function of the toll fee) fits the toll diversion curve which is obtained from the SP model.

The first parameter adjusted in the network model is the Spread parameter which indicates the variance of the generalised time around the average time. The second parameter is the VOT parameter which is used to convert the toll fee into equivalent travel time in order to determine the generalized time.

The toll diversion curve is fitted to the SP/RP model's logit function by using the R-Square value and the GEH statistic explained in the SATURN manual.

The above calibration method was tested in SATURN and EMME/2 and both provided good fits. The following observations were made:

- (a) The VOT which represents the best fit SUE assignment does not necessarily agree with the VOT used in the supplied curve. It is better to view the VOT as a calibration parameter, rather than a constant specified by the SP/RP model. If the VOT is fixed, an inferior SUE calibration will be obtained.
- (b) In the SATURN test, a rectangular probability distribution gave the best calibration results, superior even to a normal distribution.
- (c) Congestion effects will gradually override any stochastic effects as traffic increases, reducing the importance of SUE and elevating the role of the speed flow curves in determining route choice. The importance of the SUE calibration relates to the uncongested off-peak assignments, and to provide a smooth transition of user behaviour from uncongested to fully congested peak periods.

In the Gautrans toll model where EMME/2 was used, a normal distribution was used to perform the SUE assignment. The SUE assignment results obtained using the value of variance of 0.1 were found to best fit the calibrated LOGIT models in all tested scenarios (i.e. RP and SP as well as for all time periods). A R-Square value of 0.96 was obtained.

International traffic auditors prefer a different approach to the one developed in S.A. The SP values of time are used directly in the SATURN model, without any further adjustment. The motorway bonus factors are also added to the generalised costs of the toll routes' generalised cost function. Alternatively, the motorway bonus factor is subtracted from all non-tolled routes to serve as a penalty. The Spread parameter is also fixed to a value of 0.2 which is recommended by the SATURN manual. This method was used for the N4 Platinum toll model, and the calibration and validation results complied with very strict international criteria.

Direct comparison between the two approaches were not conducted, and further research is recommended to compare the calibration results of both methods in the same application.

5. CONCLUSIONS AND RECOMMENDATIONS

A set of values of times for various trip purposes and user segments were established for certain sample segments of Gauteng road users that can serve as an initial benchmark for future studies in South Africa. VOT's were estimated from Revealed and Stated preference discrete choice models. Two methods to incorporate these VOT's into network toll route models were described which both gave very good model calibrations.

VOT's governing the route choice behavior of road users were found to be much higher than the average income per working hour that are normally used in economic evaluation studies. For the purpose of toll road feasibility studies, it is therefore important that VOT's are estimated for each toll road context.

Various factors that significantly impact on the value of time were quantified i.e. trip purpose, income and socio-economic status, the level of congestion experienced, and the standard of the roads.

Prior to the N4 Platinum toll road study, experience indicated that SP values of time were significantly lower than RP values indicating a certain degree of aversion to toll roads by road users within the specific context of the SP experiments. In contrast, independent RP and SP studies for the N4 Platinum toll study found very similar VOT's. It seems that the SP context presented to potential road users and how this relate to the actual RP context is an important factor to consider. It is important therefore to make the SP choices as realistic as possible in presenting the proposed toll road context. Despite the difficulties experienced with RP surveys, it is essential to conduct a RP survey and to select an existing toll road as close as possible to the SP context.

It is recommended that further research be conducted on the following aspects:

- Evaluating alternative methods to obtain more reliable RP route choice data from road users. It is expected that face to face interviews, in an unhurried environment, would give better results. The use of aids to assist the respondent, such as maps indicating route distances and travel times, should also be evaluated.
- Direct comparison of RP and SP values of time by applying both methods on the same sample of road users in the context of an existing toll road.
- Direct comparison of the two methods that were described to incorporate the SP/RP VOT's into SATURN or EMME/2 network models.

Finally, it is recommended that the NRA continue to support comprehensive SP and RP studies for all future toll road studies in order to build up a comprehensive data base for South Africa.

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