AN INNOVATIVE METHOD TO COLLECT ROUTE CHOICE PREFERENCE DATA USING A SMARTPHONE APPLICATION

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ABSTRACT

Understanding route choice behaviour in congested, dense urban road environments is a key factor for the development of traffic demand models, transport policy formulation and the estimation of willingness-to-pay measures such as the non-work related value of travel time. However collecting reliable driver route choice preference data is not straightforward. To this end this paper describes the development of a smartphone-based application to collect route choice preference data from motorists. The preference data is intended for the development of route choice models using discrete choice methods which will be described in a subsequent paper. The paper provides a technical overview of the development and application of a survey methodology that combines revealed preference (RP) and stated preference (SP) methods with the advantage of generating route alternatives based on real-time traffic conditions. The Route Choice Application - University of Pretoria (RAPP-UP) application is a smartphone-based platform that generates two realistic route alternatives between user specified origin and destination (OD) locations with the route alternatives presented on a road map background. The associated travel time and cost attribute levels for each route are presented to participants in a choice set format. The application has been successfully implemented with a sample of Gauteng commuters.

1. INTRODUCTION

The development of this route choice survey methodology has been done against the backdrop of the need to obtain insights into motorist route choice preferences in South African urban areas. The reliable prediction of traffic demand is becoming more important as scarce resources for road infrastructure need to be efficiently allocated. Prato (2009) highlights that understanding motorists' route choice behaviour (and therefore the prediction of demand) in urban areas is necessary for several reasons. Firstly, to support transport policy development, for example, to understand the demand implications of travel demand measures including congestion pricing and user-pay schemes such as urban tolls. Secondly, to provide inputs into the economic appraisal of new road and road improvement schemes through the estimation of demand as well as key non-market related input measures such as the non-work related value of travel time (VTT) and the value of trip time reliability (VOR). And thirdly, to provide inputs into transportation demand models that are used in the planning and evaluation processes for demand prediction and for the calculation of the generalised costs that are used in the trip assignment sub-model. An example is the use of the VTT for the conversion of monetary-based trip costs into equivalent time units for the calculation of generalised time.

The collection of motorist route choice preferences on urban road networks using RP and/or SP methods is not straightforward. While RP methods have the advantage of measuring actual choices, there are the limitations of inadequate analyst control; the inability to gain user perceptions of road schemes or policies that do not yet exist; and the absence of insights into the alternative routes that may be considered by motorists. The high number of potential alternative routes between an origin and destination on a dense urban road networks is not an insignificant problem. While SP methods provide high levels of analyst control, there are limitations associated with the validity and realism of the trip attributes when describing the hypothetical alternative routes, i.e. low external validity. Also, respondents may not behave the same way in a hypothetical situation as in a real situation. This is termed “hypothetical bias,” which means that respondents in hypothetical settings tend to be willing-to-pay different amounts for travel time savings compared to estimates derived from RP data, i.e. when there are actual time and monetary consequences to their choice. A common shortcoming of RP and SP methods is their inability to address the practical issue of overlapping of alternative routes that could occur to varying degrees in a dense urban road network. This issue of route similarity, i.e. the correlation between overlapping routes, also undermines the independent and irrelevant alternatives (IIA) constraint for the application of multinomial logit (MNL) models and requires the application of models that take account of route correlation (Prato, 2009).

The position of various SP and RP methods for the collection of route choice data in the external validity/analyst control framework suggested by Bliemer (Bliemer, 2020) is shown in Figure 1. Field data-based RP methods have little analyst control, but high external validity. Experimental data methods such as SP have high analyst control, but low external validity. The external validity of SP methods can be improved when the attribute levels of the alternative route are pivoted off those of a current route. More recently, driver simulation systems that have been used extensively for road safety research have been adapted for route choice research. These systems combine SP and RP methods with the participant first selecting a preferred route in an SP setting and then introducing the RP component by requiring the participant to drive their preferred route. Driver simulation systems have high capital costs for equipment and software. The focus of the route choice research by Fayyaz et al. (2021) using driving simulators was on the estimation of the value of travel time and the value of travel time reliability.

In South Africa, several inter-urban route choice RP and SP surveys were undertaken for the planning of toll road schemes in the 1990’s and early 2000’s. The last route choice survey done in a South African urban commuting environment was by van Zyl et al. (2001). SP and RP surveys were carried out for the Gauteng Province Toll Road Study in 2001 which was a precursor for the Gauteng Freeway Improvement Project (GFIP) e-toll scheme introduced a decade later. The study considered the introduction of tolls on the provincial freeways using an express toll lane strategy. Both surveys were computer aided personal interviews (CAPI) that are done on a face-to-face basis. The SP survey defined two hypothetical alternative routes viz. a freeway alternative without intersections but with tolls, and an arterial road alternative with intersections but without tolls. The SP survey was limited to 4 attributes, i.e. toll fees, total trip time, stopped travel time and type of roadway (2 lanes for arterials and 4 lanes for freeways). Fuel costs and travel time reliability were not included. The RP survey was done with a sample of freeway users using the tolled N1 freeway near Pretoria, the N17 toll road in Johannesburg, and parallel alternative routes. The perceived current values of trip travel time and toll cost on the tolled and alternative routes were solicited from respondents. It was noted that respondents had difficulty estimating their perceived trip time and toll costs for their current and alternative routes. The resulting mode choice models showed a strong aversion by commuters to the tolling of the freeways in any form.

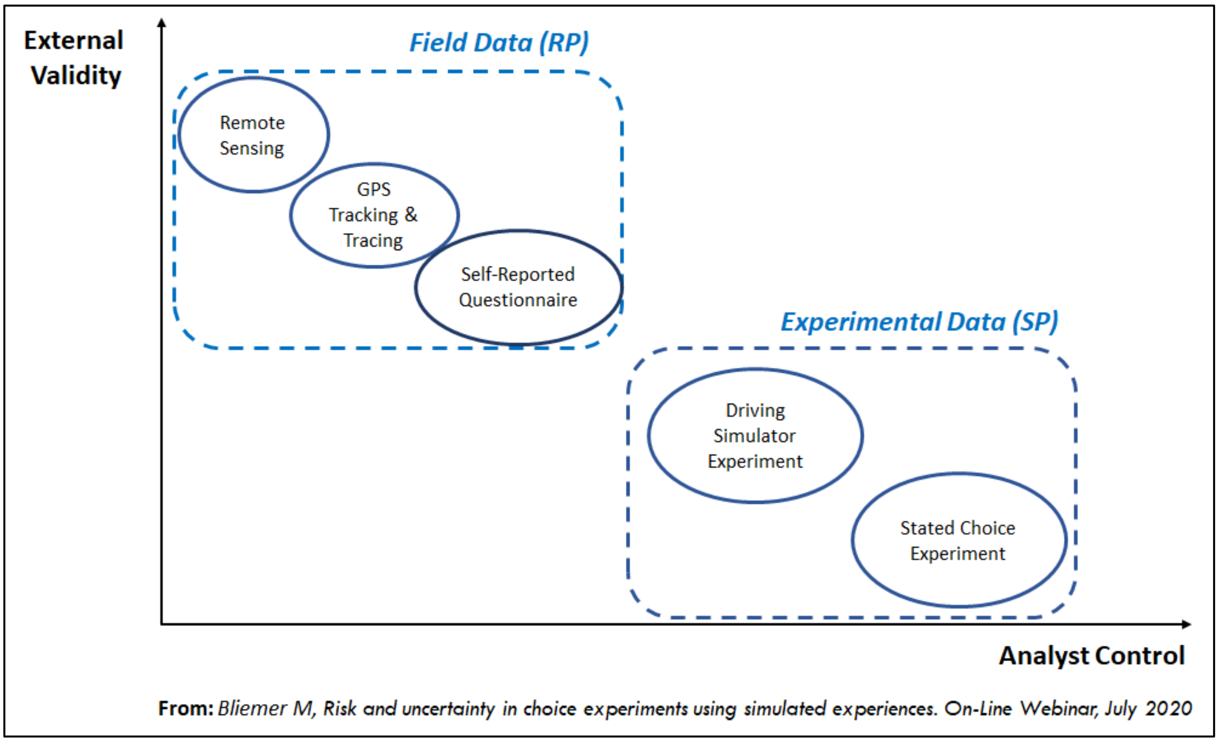

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Figure 1: External Validity / Analyst Control Framework for Route Choice Surveys

2. USING SMARTPHONES TO COLLECT TRIP DATA

The rapid development of vehicle tracking technology, especially by means of GPS devices in smartphones, has made the collection of RP data easier. There are examples of the application of transport surveys using GPS devices and smartphone GPS devices for the collection of vehicle (Geyer, Ellis, & Piwek, 2019; Vaca & Meloni, 2013), pedestrian (Vlassenroot, Gillis, & Bellens, 2014; Alvarez & Leeson, 2015) and public transport passenger tracking surveys (Xiao et al., 2012; Joseph et al., 2020). Paths and path distances can be accurately measured using coordinate data; departure, arrival and total travel times can be determined; and trip origins and destination locations accurately identified. Out-of-pocket trip costs such as the trip petrol cost can be deduced with assumptions about average vehicle fuel consumption, and toll costs (if any) can also be calculated.

Transport survey smartphone applications (apps) are now commonly used to collect trip data. Most of these are passive data collection tools, i.e. they do not require any intervention by the participant other than to download the app onto their smartphone, and to activate it for their trip. While many of these are bespoke apps that are developed by researchers, platforms such as *Itinerum* provide app-based survey frameworks for various types of surveys that allow for customisation for specific project applications (Patterson, Fitzsimmons, Jackson, & Mukai, 2019). These apps can be used in place of conventional household travel surveys, travel diary surveys, trip satisfaction surveys and origin-destination surveys. Flocktracker is another smartphone-based trip survey instrument developed by the Massachusetts Institute of Technology (MIT) that has had global application (MIT, 2021). However none of these apps allow for conducting mode or route choice surveys using RP and/or SP methods.

3. THE REQUIREMENTS OF A SMARTPHONE-BASED ROUTE CHOICE SURVEY APPLICATION

Recognising the need for research into route choice behaviour in the South African urban context and the need for a collection methodology that better balances external validity and analyst control, a smartphone application was developed to address these requirements. The application was called Route Choice Application - University of Pretoria (RAPP-UP). At this stage the app is only operational on Android based smartphones.

The objective was to provide a survey methodology that gave the analyst more control of the experimental design and to improve the route data accuracy based on real-time traffic conditions. The approach was to use the strengths of both SP and RP surveys. To reduce the occurrence of hypothetical bias, an economic experiment with monetary consequences for route choice was introduced. The SP component of the experiment required participants to choose a preferred route from two alternatives generated by the app based on the trip origin and destination as input by the user. The RP component required the participants to the actually drive their preferred route. The app provided route guidance for the chosen route, and participants were tracked when driving the route. The economic experiment required participants to experience a real financial loss when choosing a route where the Gauteng Freeway Improvement Project (GFIP) e-toll was applicable. Each participant was provided with a starting Rand amount in their survey account. If they chose a route with e-tolls, the toll value was deducted from their survey account. At the end of the experiment they were paid out the balance of their survey accounts

A key design element of the application was the transmission and storage of the route data in a remote cloud-based database. The route data collection, storage, processing and analysis framework is shown in Figure 2. Route data was collected via the participants smartphone, which was then downloaded to a secure, cloud-based remote database. The data is downloaded from the database in JSON format (Java Script Object Notation) which can be converted into CSV (comma separated variable) files that are editable in Microsoft Excel. The CSV route data files can be converted to GPX and KML files formats for use with Google Maps, Google Earth, OpenStreetMap, ArcGIS and other GIS software for plotting spatial data. The route choice set data was prepared in NLOGIT format for discrete choice model estimation.

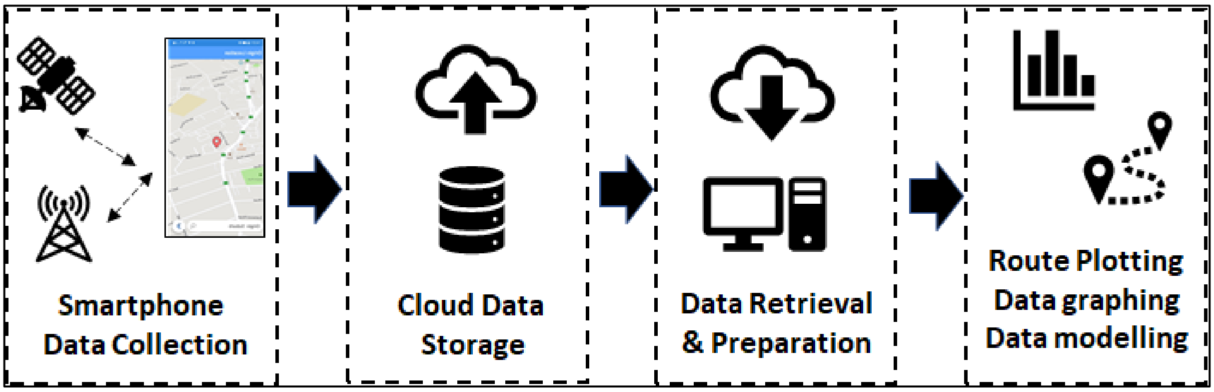


Figure 2: Route Choice Survey Data Capturing, Storage and Analysis Framework

An important consideration for the application was to be able to track participant's routes with appropriate accuracy. New smartphone technology, 4G technology, the increasing number of tracking satellites and increasing cell phone tower density in urban areas has significantly improved vehicle route tracking accuracy without the need for map-matching processes. Route tracking testing in the Pretoria / Johannesburg study area confirmed the Institute of Navigation (ION) global "rule of thumb" figure of 4.9 m location accuracy in 'open-sky' urban conditions (Van Diggelan & Enge, 2015). Route accuracy in the study area was mostly within 3 m which was sufficiently accurate for the survey. A key determinant of location identification is the frequency at which location pulses are sent from the smartphone to tracking satellites. A five second pulse frequency was found to provide high location accuracy levels even for vehicles travelling at higher speeds.

4. THE SPECIFICATION OF THE APPLICATION

The development of the RAPP-UP application required the definition of the route utility for a trip. The attributes included in the utility must be defined or derived from the traffic data for the routes such as travel distance and travel time. Platforms such as Google Maps and TomTom provide details regarding route segment co-ordinates and lengths, co-ordinate timestamps and travel times on each segment of the route. The segment travel times under different traffic flows are an indication of the level of service on the segments and are indicated by means of a route segment traffic flow level code. As an example, the ISO intelligent transport systems standard for traffic congestion coding (International Organization for Standardization (ISO), 2020) enumerates the possible values for type tec001:EffectCode that is shown in Table 1 for the route segment traffic flow level. In the app these have been translated into travel time classifications i.e. free-flow time (fft), slowed-down time (sdt) and stop-start time (sst) as shown in the table.

Table 1: Traffic Effects Code (TEC001) for Traffic Flow Descriptions and Travel Time Classifications

TEC Code	TISA English "Word"	Comment	Travel Time Classification
1	Traffic flow unknown	Shall be used if traffic flow is unknown. Note: This is often the case for local hazard warnings	Slowed-down time (sdt)
2	Free flow traffic	Traffic flow Is not restricted	Free-flow time (fft)
3	Heavy traffic	Traffic flow is restricted due to a large number of vehicles	Stop-start time (sst)
4	Slow traffic	Traffic is slower than normal	Slowed-down time (sdt)
5	Queueing traffic	Traffic is in queues, but is still moving slowly	Slowed-down time (sdt)
6	Stationary traffic	Traffic is stationary or barely moving	Stop-start time (sst)
7	No flow	Traffic is completely stopped or there is no flow due to the road being closed/blocked; the cause-component may give more information about the reason for "no traffic flow". For roads with at-grade junctions, how the closure/blockage affects cross-road traffic maybe further specified with the attribute *at Grade Junction Closure*	Stop-start time (sst)

The form of utility expression that was adopted was a linear-in-parameters form as follows for individual *i* using route alternative *j* out of *J* alternative routes with attributes *k*:

$$U_{ij} = V_{ijk} + \varepsilon_{ij} = \sum_{j=1}^{J} \beta_k X_{ijk} + \varepsilon_{jj} \quad (1)$$

Where U_{ij} is the utility of individual *i* using route *j*; β_k are the attribute coefficients to be estimated; X_{ijk} are the utility attributes for individual *i* using route *j* and attribute *k*; and ε_{ij} is the utility error term for individual *i* using route *j*. The observed utility V_{ijk} is also known as the deterministic or representative component of utility.

The maximum number of attributes *k* to be included in the RAPP-UP utility expression was determined practically by observing the number that could be fitted onto a smartphone screen in the format of a choice set and be understandable and legible. Based on several trial screen layouts, it was determined that not more than eight attributes should be shown. The route alignment on a map background was also to be shown together with the choice set for each route.

The arguments for and against simple time-money trade-offs versus more complex utility setups for stated preference experiments using stated choice methods are described by Hess et al. (2020). Simple time-money trade-offs are more commonly used in European countries for large national studies to determine national values of travel time for use in economic appraisals. The focus in Australia and Latin America is on more complex utility expressions typically developed for more localized studies where the application is in transportation demand models as well as estimating VTT for economic appraisals. South Africa has tended to follow the European approach with simple time-money trade-offs, but for application in localised studies. For this research a more complex form of the utility expression was adopted for the following reasons. Firstly, there was an objective to test more complex forms of utility expressions to ascertain whether the attribute coefficients were significant in the South African urban context. The second reason was to apply various forms of route choice models based on more complex forms of the utility expression. Thirdly the determination of non-work related VTT was to be made in a localised geographical area, namely the Johannesburg / Pretoria region of the Gauteng Province. Lastly, the inclusion of motorway tolls in the study area was necessary as a way of determining the motorist's willingness-to-pay for time and cost savings of the motorways making up the SANRAL GFIP e-toll scheme.

Based on the forms of utility used by Hensher and Rose (2004), Vrtic et al. (2009), and Prato et al. (2014), the attributes included in the utility expression included three travel time categories related to the levels of service, i.e. the time spent in free-flow (fft), the slowed-down time (sdt) and the time spent in stop-start conditions (sst). Two trip cost attributes were included, i.e. tolls cost (only on GFIP freeways) and petrol cost. Route travel time reliability was also included. For this experiment, the utility expression was defined as the linear-in-parameters sum of six attributes, viz. the trip time, cost and reliability attributes for individual *i* using route *j* as follows:

$$U_{ij} = b_1{*}fft_{ij} + b_2{*}sdt_{ij} + b_3{*}sst_{ij} + b_4{*}petcost_{ij} + b_5{*}tollcost_{ij} + b_6{*}pota_{ij} + \varepsilon_{ij} \quad (2)$$

Where U_{ij} is the trip utility for individual *i* using route *j*; b_1, b_2, … are attribute coefficients to be estimated; fft_{ij} is the free flow time on route *j* in minutes; sdt_{ij} is the slowed-down time on route *j* in minutes; sst_{ij} is the stop-start time on route *j* in minutes; $petcost_{ijk}$ is the petrol cost for route *j* in Rands; $tollcost_{ij}$ is the toll cost of route *j* in Rands (if applicable); $pota_{ij}$ is the probability of on-time arrival using route *j* in percent, and ε_{ij} is the error term for individual *i* using route *j*. The petrol cost of the route was calculated based on the route length, an average vehicle fuel consumption and the current cost of petrol. Note that the experiment is unlabelled so there is no alternative specific constant in the utility equation.

This form of utility expression was considered appropriate based on a review of route choice models used internationally as well as to investigate the nature of urban route choice preferences for South African conditions. Firstly it has been shown that motorists perceive different values of travel time for stop-start, slowed-down and free-flow travel time conditions, with stop-start VTT's being higher than slowed-down and free-flow values (Hensher & Rose, 2004). This has not been tested before in South African conditions. Secondly, there is a need to quantify motorist's willingness-to-pay tolls for travel time savings on urban freeways. Thirdly, the importance of trip time reliability has been highlighted as an important trip attribute in the route choice context (Asensio & Matas, 2007; Fayyaz, Bliemer, Beck & Hess, 2021; Brownstone & Small, 2005). This has not been quantified in South Africa. Trip time reliability was quantified in the utility expression using the probability of on-time arrival (*pota*) in percent for each route.

The probability of on-time arrival was calculated from the proportions of the route free-flow, slowed-down and stop-start time as shown in Equation 3. The higher the proportion of stop-start time, the lower the probability of arriving at the destination on time. The *factor* was applied to the *pota* value as part of the experiment discussed in the design of the experiment.

$$\text{Probability of On-Time Arrival (\%) Pota} = factor * \left[1- \frac{(0.8*sst+0.6*sdt+0.1*fft)}{Total\ travel\ time}\right] \quad (3)$$

5. ALTERNATIVE ROUTE GENERATION

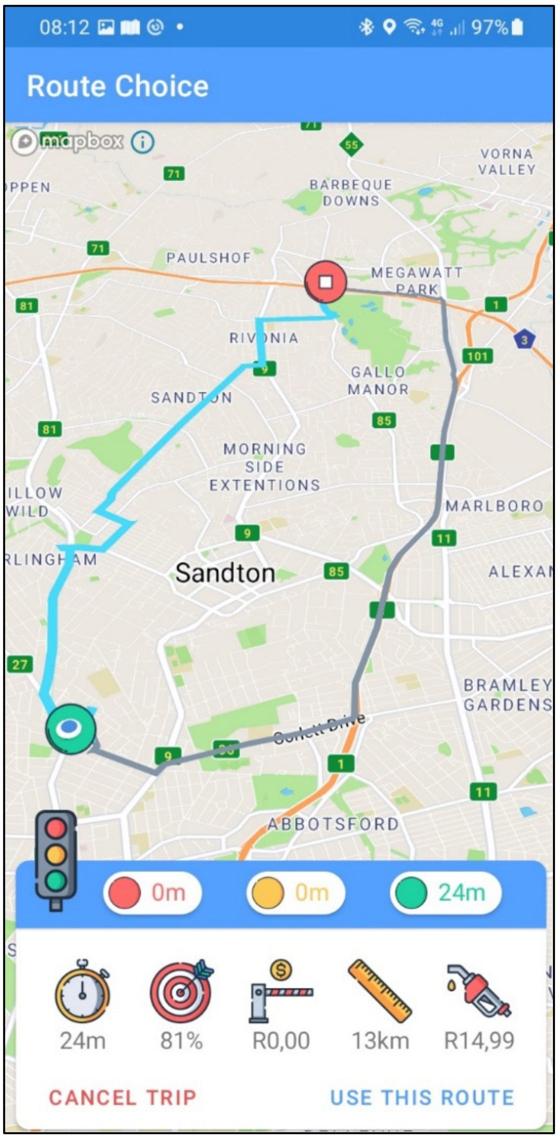
There are two steps required in the route generation process. The first is to generate the optimal route. This is normally defined as the route with the minimum travel time between origin and destination, but minimum travel distance and cost can also be used. Dijkstra's tree building algorithm (Dijkstra, 1959) is widely used for generating minimum time, distance or cost paths between a defined origin and destination in a network. Patented modifications of Dijktra's algorithm for speeding up the generation computational time are used by platforms such as Google Maps and TomTom. For RAPP-UP the minimum travel time has been used.

The second step is to generate an alternative route. For RAPP-UP only one alternative route was generated. These routes are defined by the route generation algorithm in TomTom based on the route characteristics. Alternative routes are identified as realistic alternatives to the optimal route. These routes are generated by considering three key criteria: firstly the extent of overlap of the alternative and optimal route; secondly, local optimality that considers the number of unnecessary detours on the alternative route; and thirdly, the stretch, being defined as the ratio between the length of an alternative route and the length of the optimal route. The number of alternative routes between an origin and destination in a dense road network can be substantial, so the list of candidate alternative routes is sorted according to an objective function to reduce the number of routes and speed up the processing time. For example, alternative routes with overlaps of more than 80%, stretches of more than 1.2 and two unnecessary detours will eliminate most alternatives.

An important measure that must be calculated for route choice modelling is the proportion of route overlap in kilometres for each route. This is necessary as the route overlap indicates the degree of correlation between two routes. The proportion of route overlap is not divulged to the survey participants.

6. DESIGN OF ROUTE CHOICE EXPERIMENT

To allow for a degree of analyst control of the experiment, the route toll cost and probability of on-time arrival (*pota*) was varied between choice sets from the actual value. For these two attributes, three levels of variation from the observed levels were used, i.e. -20%, 0% and +20%. A fractional factorial design for two alternatives, two attributes and three levels required a total of eight choice sets per respondent. Therefore the survey participants were required to repeat the experiment over eight days, each day representing an observation. The days did not have to be consecutive.



An example of a route with its choice set table showing the route attributes and levels is shown in Figure 3. The GPS device in the smartphone is used to fix the origin location and participants are required to locate their destination location by searching for the suburb by typing in the suburb name, and then positioning the exact street location by using the background map (origin is green pin, destination is red pin). Waypoints on the route, if any, can similarly be located. In the figure, the current route is highlighted in blue and the alternative in grey. Network zooming, panning and north orientation are done in the normal way. Switching between routes is done by tapping on the route outline. In the choice set table at the bottom of the screen for the highlighted route, the trip time attributes in minutes (specified as free-flow time, slowed-down time and stop-start time) shown by the green, orange and red traffic light icons are shown. The calculated route petrol cost in Rands is shown by the petrol nozzle icon. The adjusted toll fee (if applicable) is shown by the toll barrier icon (calculated for the current tolled routes in Rands and adjusted as per the experimental design). The adjusted probability of on-time arrival (*pota %)* at the destination is shown by the target icon. The route length is shown by the ruler icon (in kilometres). The meaning of these icons was carefully explained to each survey participant prior to the survey.

Figure 3: RAPP-UP Smartphone Choice Set Screen

Thorough pilot testing of the application was undertaken to ensure its reliability, and to make sure it operated successfully on most Android smartphones. It was found that the app did not operate efficiently on smartphones older than three years. Smartphones not more than three years old was specified as a requirement in the sample recruitment process.

7. PARTICIPANT RECRUITMENT AND SURVEY EXECUTION

To show proof of concept, a small sample of 57 participants was recruited. The participants all resided in the Pretoria / Johannesburg region. Each participant performed the experiment eight times, giving a total sample size for proof-of-concept of 456 observations. The weekday morning trip to work was focused on. Ethics approval and informed consent to participate was an important consideration given that the participants would be tracked when driving their preferred routes. The key conditions for participating in the survey were ownership of a recent model Android smartphone (not more than three years old) and undertaking regular trips to work as the driver of the vehicle during the weekday morning peak period. A socio-demographic questionnaire was completed by all participants prior to the start of the survey. Survey instructions and passwords were given to the participants to allow them to download RAPP-UP from the Google Play Store. They were asked to undertake dummy runs to ensure they understood how to use the app. Problems were addressed directly with each participant.

Due to the variety and age of Android smartphones owned by the participants, the survey was executed in two phases. To identify any potential problems with the smartphone, the app or with the transmission and downloading of data, the participants were requested to make their trip to work using their commonly used route for three days. The app was activated by the participants prior to starting the trip, but the stated preference component was deactivated, only allowing the participants to be tracked. Route tracking accuracy and the transmission of the route coordinates, time stamps and distance data to the remote database was checked and route plots were produced.

The second phase of the survey was the full implementation of the app, i.e. the stated and revealed preference components. Participants were shown the balance of their survey account after each trip. Many participants did not use any GFIP freeways on their alternatives routes and these participants were paid out the full starting balance of their survey accounts on successful completion of the survey.

A subsequent paper will describe the route choice models developed from the preference data collected using RAPP-UP.

8. CONCLUSIONS

Several conclusions can drawn from the research undertaken into the use of smartphones to collect travel data; the need for route choice experiments that provide a better balance between external validity and analyst control of the experiment; and the current state of understanding of route choice behaviour in South African urban conditions. Firstly, the use of smartphones and applications to design and collect travel data has been globally adopted. Their use significantly reduces survey costs and increase the possibility for the collection of large data sets. However participant data privacy is an important consideration that must be addressed in the design of the survey, secure storage of the data and sample recruitment. Secondly, the RAPP-UP application provides a better balance between analyst control and external validity. It is also flexible to allow for the inclusion of additional and different utility attributes and their variation in the choice sets. Finally, there are significant gaps in the understanding of urban route choice preferences in South Africa. The last surveys done in 2001 highlighted strong motorist resistance to the imposition of urban tolls. This has been illustrated by the failure of the GFIP e-toll scheme to adequately address the issue of motorist’s willingness-to-pay tolls for travel time and cost savings. The potential introduction of congestion pricing schemes to reduce carbon emissions will require a detailed understanding of driver route preferences. The relative importance of the value of travel time reliability in the trip utility expression has not been quantified in South Africa and could be significant for both route and mode choice modelling.

9. REFERENCES

Alvarez, P & Leeson, A, 2015. Big data helps pedestrian planning take a big step forward. *Transport Professional*, pp. 26-28.

Asensio, J & Matas, A, 2007. Commuters' Valuation of Travel Time Variability. *Transportation Research Part E*, 1074-1085.

Bliemer, M, 2020. Risk and uncertainty in choice experiments using simulated experiences. *Centre of Choice Modelling Online Seminar* (pp. 1-69). Sydney: University of Sydney.

Brownstone, D & Small, K, 2005. Valuating time and reliability: Assessing the evidence from road pricing demonstrations. *Transportation Research: Part A Policy and Practice*, 279-293.

Dijkstra, EW, 1959. A Note on Two Problems in Connexion with Graphs. *Numerische Mathematik* , 269-271.

Fayyaz, M, Bliemer, M, Beck, M & Hess, S, 2021. Stated Choices and Simulated Experiences: Differences in the Value of Travel Time and Reliability. *Transportation Research Part C, 128*, 1-20.

Gauteng Provincial Government Advisory Panel, 2014. *The Socio-Economic Impact of the Gauteng Freeway Improvement Project and E-Tolls Report.* Johannesburg: Gauteng Province.

Geyer, K, Ellis, D & Piwek, L, 2019. A simple location-tracking app for psychological research. *Behaviour Research Methods*, 2840-2846.

Hensher, D & Rose, J, 2004. *Determination of Value of Travel Time for Brisbane River Crossing.* Sydney: Hensher & Rose.

Hess, S, Daly, A & Borjesson, M, 2020. A Critical Appraisal of the use of Simple Time-Money Trade-Offs for Appraisal Value of Travel Time Measures. *Transportation,* 47:1541-1570.

International Organization for Standardization (ISO), 2020. *ISO 21219-15:2020(E): Intelligent transport systems - Traffic and travel information (TTI) via transport protocols experts group generation 2: Part 15 Traffic event compact (TPEG2-TEC).* Switzerland: International Organization for Standardization (ISO).

Joseph, L, Neven, A, Martens, K, Kweka, O, Wets, G & Janssens, D, 2020. Measuring individuals' travel behaviour by use of a GPS-based smartphone application in Dar es Saalam, Tanzania. *Journal of Transport Geography*, 1-8.

MIT, 16 September 2021. *Mobility Futures Collaboration*. Available at: https://mfc.mit.edu/flocktracker

Patterson, Z, Fitzsimmons, K, Jackson, S & Mukai, T, 2019. Itinerum: The open smartphone travel survey platform. *SoftwareX*, 1-7.

Prato, C, 2009. Route choice modelling: Past, present and future research directions. *Journal of Choice Modelling*, 65-100.

Prato, C, Rasmussen, T & Nielsen, O, 2014. Estimating Value of Congestion and of Reliability from Observation of Route Choice Behaviour of Car Drivers. *Transportation Research Record: Journal of the Transportation Research Board*, 20-27.

Small, K & Verhoef, E, 2007. *The Economics of Urban Transportation.* London: Routledge.

Vaca, A & Meloni, I, 2013. Route Choice Analysis using a GPS-Based Data Collection. *World Conference on Transport Research (WCTR) 2013* (pp. 1-20). Rio de Janeiro: WCTR.

Van Diggelan, F & Enge, P, 2015. The World's First GPS MOOC and Worldwide Laboratory using Smartphones. *Proceedings of 28th International Technical Meeting of the Sattelite Division of the Institute of Navigation* (pp. 361-369). Tampa: Institute of Navigation.

van Zyl, N, Oberholzer, J & Chen, Y, 2001. South African Experience with the Estimation of Values of Time from Stated Preference Studies and their use in Toll Road Models. Pretoria: South African Transport Conference 2001.

Vlassenroot, S, Gillis, D & Bellens, R, 2014. The Use of Smartphone Applications in the Collection of Travel Behaviour Data. *International Journal of ITS Research*, 17-27.

Vrtic, N, Schuessler, M, Erath, A & Axhausen, K, 2009. The impacts of road pricing on route and mode choice behaviour. *Journal of Choice Modelling*, 109-126.

Xiao, Y, Low, D, Bandara, T, Pathak, P, Lim, H, Goyal, D, Santos, J, Cottrill, C, Pereira, F, Zegras, C & Ben-Akiva, M, 2012. Transportation Activity Analysis using Smartphones. *IEEE Consumer Communication and Networking Conference.* Las Vegas: Institute of Electrical and Electronics Engineers.