Integrated Land Use and Transport Modelling; Evaluating the Four-Step-Model

James Njiraini Gachanja[1] and **Mathenge Mwehe**[2]
[1]Kenya Institute of Policy and Research & [2]Maseno University, Kenya
Corresponding [1]*Email*: njirainigachanja@gmail.com [2]*Email:* mathengemwehe@yahoo.com

Abstract
Models are the basic tool of analysis for planners working in the fields of transportation and land use forecasting. Integrated land use and transportation interaction models enable policy makers to foresee and evaluate the effects of transport and urban plans hence enabling the solution of common planning problems. In seeking to model travel demand and predict the effect of transportation system changes on the transportation network, transport planners have relied on the Four Step Model (FSM). However, weaknesses have been identified in the FSM mainly because it does not really capture the interaction between land use and transport. Another concern is that the sequential approach of the FSM creates a situation where no feedback is provided from one step to the other leading to inaccurate outputs. This research focused on evaluating the (FSM) in order to assess the factors that influence its accuracy. The City of Istanbul in Turkey is used as the case study. The methodology involves comparing the FSM daily traffic against the actual observed daily traffic derived from RTMS records. A total of six FSM runs are then undertaken using different inputs. The results from these six model runs are assessed for accuracy by using the %RMSE statistic. F-*test* and omega squared ($\acute{\omega}^2$) are used to measure the effect size of using each different input. Results show that the population and employment forecasts are overestimated while those for students are underestimated. The planned road network significantly differs from the actual road network. The %RMSE accuracy assessment results for the FSM under different inputs is as follows; projected data (204.43%); actual data (195.02%); disaggregated TAZs (181.81%); actual highway (138.78%); new parameters (100.92%); and feedback (170.75%). In terms of effect size, the use of new parameters has the most significant effect ($\acute{\omega}^2$=.549) followed by application of a feedback mechanism ($\acute{\omega}^2$=.501). The land use and socio economic projections account for the greatest inaccuracy in the FSM while the use of new parameters and feedback improves the accuracy of the FSM significantly. The study recommends improving the quality of input data, application of feedback and estimation of the trip generation parameters at different time steps in the forecasting horizon based on anticipated changes in travel behavior.

Keywords: Land use, transport modelling; Four step transport model; Accuracy assessment.

1 Introduction

Urban land use and transportation are known to interact and influence each other. However, it is common practice for urban planners to prepare plans without regard for transportation, while transportation planners design and implement transportation strategies without consideration of urban plans for land use (Henscher et al., 2004). As a result, the interventions from these separate plans and strategies are often sub optimal or conflicting. For example, the findings from a study by Lefèvre (2009) on integrated land use and transport planning indicate that the savings obtained from the integration of transport and land use policies are much more important than the savings obtained from a transport investment alone. It was observed that energy consumption and emissions of green house gases would only increase by 9% if the land use and transport policies were integrated, whereas they would increase by between 50-70% if integration was not implemented. Furthermore, the chances of conflicting land use and transport plans and projects are significantly reduced where shared land use-transport (LUT) visions and concepts are in place (Te Brömmelstroet and Bertolini, 2008).

One of the key barriers to integration of land-use and transportation planning is the lack of a "common language" in the form of tools, instruments and indicators that can support planners from both domains in developing integrated land-use and transportation strategies (Te Brömmelstroet and Bertolini, 2008). Despite this barrier, there have been efforts by urban researchers to formalize the relationship between land use and transport using mathematical, statistical and logical models capable of predicting changes to transportation and land use systems as the result of policy measures in both fields (Iacono et al., 2008). The traditional Four Step Transport Model (FSM) is an example of such models developed through research and practice (Hensher and Button, 2000).

However, the FSM has been identified as weak point in achieving a "common language" in the respective domains because it does not explicitly consider land use effects. It instead depends upon land use methods and models to make demographic and socio-economic projections which are treated exogenously. Land use data with base year figures for population, employment, facilities and location choices are used in the model to estimate the total number of trips originating from and attracted to a zone of the study area (trip generation). The problem arises because these data are used as exogenous input and are not changed during the modelling process. Another concern is that the sequential approach of the FSM creates a situation where no feedback is provided from one step to another. This means that results of the final step (assignment) of the FSM do not have an influence on the previous steps (trip generation, distribution and modal split). This leads to inconsistency between the inputs and the outputs of the model and hence inaccuracy in representation of reality. It is noted therefore that the FSM in its traditional form does not really capture the interaction between land use and transport (Bates, 2000; McNally, 2000; Tillema, 2004).

This paper evaluates the application of the traditional FSM and assesses factors that influence its accuracy in forecasting travel demand using the case of Istanbul, Turkey. The purpose is to demonstrate the weakness of the FSM and make suggestions for its improvement based on evidence and emerging technology. The importance lies in highlighting the factors that need to be considered when using the FSM and how improved results can be obtained in land use and transportation modelling.

1.1 Models in Transport Planning

The fundamentals of transport modelling can be traced back to the Detroit and Chicago transportation studies in USA in the 1950s (Bates, 2000). The last 40 years has seen the development and application of a large number of statistical and mathematical procedures directed towards improving the understanding of the behaviour of agents who make decisions that impact the transport system (Hensher and Button, 2000). Bates (2000), notes that transport models have evolved from many disciplines, most notably: economics, psychology, geography, sociology, and statistics. He notes that the initial focus was on estimating peak demand for transport services and predicting what provision should be made for this peak. The FSM was originally designed for the analysis of urban highway investment although substantial improvements have now made it usable in the public transport field (Ibid).

In practice, travel demand forecasting models are used to help in planning transport infrastructure and in anticipating exogenous changes in travel demand patterns (Fox et.al., 2003). Within the transportation domain, modelling focuses on the ways in which one can simplify and abstract important relationships underlying the provision and use of transport, focusing mostly on the behaviour of individuals (Hensher and Button, 2000). The models have been applied in establishing the determinants of transportation demand and supply. The focus of the supply relationship in transport has been on the non-monetary items and on time in particular because many of the issues of demand with which transport analysts are concerned with affect performance of the transport system. Supply functions in these models have reflected the response of the transport system to given level of demand (Bates, 2000). Congestion is an important indicator that the models also try to capture. Ortúzar and Willumsen (2001) note that congestion is one of the most important features of transport supply which arises when demand levels approach the capacity supplied by a facility.

1.2 The Four Step Transport Model

In seeking to model travel demand and predict the effect of transportation system changes on the transportation network, transport planners continue to rely on the FSM (Hensher and Button, 2000). This model sequentially comprises four sub-steps namely: trip generation; trip distribution; mode choice; and traffic assignment. The model predicts future travel demand and its implications on the transportation system. Through a sequence of computations, the model is able to predict the future volume of traffic on each transport network link, it also provides other indicators such as total number of trips, vehicle speeds, travel times and congestion per link among others (Hensher and Button, 2000; Bates, 2000; McNally, 2000). Transportation planners use these indicators to evaluate the impact of proposed policies, plans or projects on the transport system performance. On this basis, the FSM is seen as an important planning and decision support system.

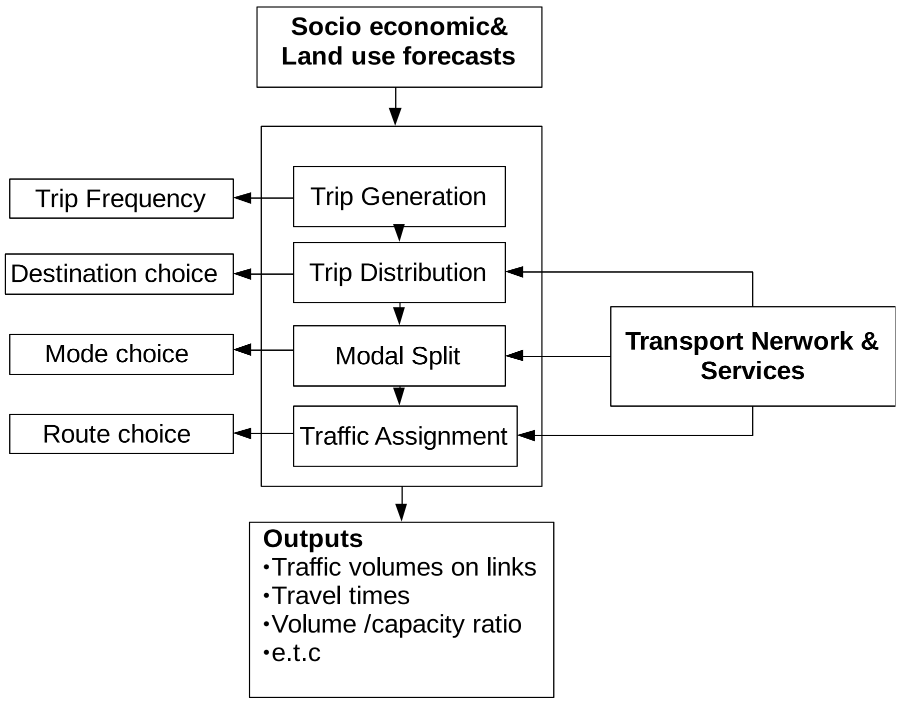

Figure 1-2: The Four Step Transport Model (FSM)

The initial step of the FSM, *trip generation*, makes use of land use and socioeconomic data such as population, household size, and household income to determine the number of trips produced by and attracted to analysis zones. The second step referred to as *trip distribution* determines the spatial distributions of trips that are generated from the first step. The third step, *modal split*, shares the trips into different modes of transport such as private car, bus, train and walking. The fourth and final step, *traffic assignment*, allocates the trips in different modes to the transportation network (Levinson and Kumar, 1994; Tillema, 2004).

1.3 Weaknesses in the FSM

While the FSM is seen as an important planning and decision support system for travel demand modelling and transport planning, concerns about its accuracy have been raised by various scholars (Bates, 2000; McNally, 2000; Tillema, 2004). For instance in the trip generation step, interdependency in trip making is not considered yet decisions of one household member are dependent on others. Another concern is that there are limited trip purposes used in the trip generation model and combinations of trips are ignored. Furthermore, there are feedback as well as cause and effect problems relating to how the FSM calculates trips as a function of factors that in turn could depend on how many trips there are (Beimborn, 1995). Errors emanating from this step are propagated through to the other stages of the FSM and contribute to its overall inaccuracy.

The main methodological concerns of the trip distribution step of the FSM according to Beimborn (1995) include the use of constant trip times; the use of automobile travel times to represent 'distance'; the limited effect of social-economic-cultural factors and the lack of feedback due to the sequential nature of the FSM . Bates (2000) adds that the deterrence function used at this step of the FSM poses a problem because it attempts to explain a large amount of variation using a very small number of parameters, which means that the matrix produced, is not sufficiently realistic to carry forward to the remaining stages of the model. He proposes the formulation of the trip distribution problem in terms of destination choice, use of additional parameters, use of observed matrices or the introduction of a number of constants as solutions to the problem. He also adds that the distribution model is a major weakness in the FSM.

Within the modal choice model, weaknesses arise out of the fact that choice is only affected by time and cost characteristics. More so, other factors such as crime, safety and security are omitted. Personal factors affecting modal choice are not generally taken into account and there is usually no treatment of walk or cycle modes. Another concern is that access times are simplified, and the model applies constant weights where the importance of time, cost and convenience is assumed to remain constant for a given trip purpose, yet in reality this may not necessarily be the case (Beimborn, 1995).

In the assignment stage, the methods generally focus on link travel times ignoring or placing less emphasis on intersection delays. Capacities are often over simplified neglecting to allow for such things as heavy vehicle movements or highway geometry. Intra-zonal travel is ignored and the zone-network system is a simplification of reality where some links may not be included in the network. Times of day variations are not modelled while the models are unable to represent how travellers often cope with congestion by changing the time they make their trips. Emphasis is on peak hour travel meaning the duration of congestion beyond the peak hour is not determined. Finally variations in travel by time of year or day of the week are usually not considered (Beimborn, 1995). These weaknesses together with the errors from the previous steps are compounded to contribute to the overall inaccuracy of the FSM outputs.

2 Empirical Studies Evaluating the Accuracy of the FSM

Various scholars have undertaken empirical studies to assess the accuracy of the FSM. A report by Zhao et.al., (2005) investigated the performance of the four step model by measuring the effect of input data on the accuracy of traffic volumes projected for Florida in the USA. Different input data, namely, updated zonal data; the actual highway network and two digit coding system were used to run the model. The modelled traffic volumes were compared with the field collected traffic volumes using the percent Root Mean Square Error statistic (%RMSE). The study found that the zonal data had been underestimated and that the use of updated zonal data improved the accuracy of the model. It was also found that not all the committed highway improvement projects had been undertaken, noting that the use of an updated traffic network had a more significant effect on model accuracy. The use of the two-digit coding system improved model performance and was identified to be the key factor in achieving model accuracy. The study found that the three factors, zonal data, the traffic network and the two-digit zoning system, were not independent meaning that the presence of one factor enhanced the effect of the other.

A similar study by Parthasarathi and Levinson (2008) tested for the presence of inaccuracy in roadway traffic forecasts and identified the reasons for this. The analysis involved looking at the input assumptions (roadway network, socio-economic forecasts and trip rates) that went into creating the forecasts. The study found that errors in the socio-economic inputs that feed into the model, the inability to incorporate shifts in trip generation/travel behaviour and differences between the assumed highway network and the actual in-place network were reasons for forecast inaccuracy. It was also found that the inability of the travel demand models to incorporate fundamental shifts in travel behaviour such as changes in trip length, trips per capita, trips per household, auto occupancy and persons per household could be an important reason for inaccuracy in traffic forecasts. Other factors seen to affect model accuracy included the number of years between the report year and forecast year, the highway type, highway functional classification and roadway direction. The researchers also note that the long-term nature of the forecasting process makes it difficult to anticipate changes and control for errors.

The stability of transport demand model outputs was investigated by Zhao and Kockelman (2002) by quantifying the variability in model inputs. They used inputs such as zonal socioeconomic data and trip generation rates and simulated the propagation of their variation through demand models based on a 25–zone network. Their study found that uncertainty compounds itself over a series of models. Errors in prediction from the earlier stages of the multi stage models such as trip generation were found to amplify across later stages. The simulation results from the study suggest that the trip assignment equilibrium technique may reduce the overall uncertainty. The study also involved a sensitivity analysis to identify which model inputs are key contributors to uncertainty in model output. It was found that the parameter that had the strongest correlation with link flows is the trip generation rate. The overall outputs were seen to be sensitive to the demographic inputs which in this study were the number of households and employments. The study also made use of regression analysis to identify the most important contributors to overall uncertainty. From this it was found that the major contributors to variation in flow estimates are the parameters from trip generation step and total employment input levels per Traffic Analysis Zone (TAZ).

According to Niles and Nelson (2001) major differences can be observed when actual model outcomes are compared with past forecasts. In their paper titled 'Identifying uncertainties in forecasts of travel demand', they review different transport forecast studies and conclude that there are many forces at work shaping the urban system and increasing its complexity and the uncertainty of travel forecasts. They found that the aggregate uncertainty attributed to the planning horizon of 20 or more years may lead to highly problematic estimates of travel demand and that it is important to build an accounting of uncertainty and risk needs into the planning process. The paper identified the following sources of uncertainty in travel demand modelling: uncertainty in model design and structure; transportation network uncertainty; demographic and behavioural uncertainty and uncertainty resulting from social-political bias.

Krishnamurthy and Kockelman (2003) investigated the propagation of uncertainty in outputs of a standard integrated model of transportation and land use. Model predictions of residence and work locations were used as inputs to a travel demand model and the resulting travel times were fed forward into the future period's land use models. Monte Carlo sampling of 200 scenarios were used to accommodate covariance in inputs. The study analysed the variances in land use and travel predictions over time and as a function of input values. The results found that output variations were most sensitive to the exponent of the link performance function, the split of trips between peak and off-peak, and several trip generation and attraction rates. The study also found that central point estimates of key model outputs were likely to fall 38% to 50% below or above the mean value. It was concluded that such substantial variation was due solely to standard model parameter and input uncertainties, it was also noted that uncertainty about the future and human behaviour also exists and will add further variation.

Wegmann and Everett (2008) in their report titled "*Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee",* mention that calibration and validation of travel demand models is essential to accurately model current and future travel for metropolitan areas. They add that there are a number of evaluations and reasonableness checks that can be performed to enhance the travel demand model's forecasting ability and that these should be performed after each step of the four-step modelling process. They recommend that evaluation and reasonableness checks should be applied during the process of calibrating each individual step of the FSM and this should be followed by overall model validation.

In summary, literature reveals that there are four main factors that account for most of the inaccuracy of the FSM outputs. The first fast factor is prediction or forecast errors of the land use and socio economic variables used as inputs to the preliminary stages of the FSM; the second is the difference between the planned road networks and the actual road network; third is errors in estimating the parameters and rates used in the different steps of the FSM; and the fourth is the model design/set up and techniques used for running the model.

3 METHODOLOGY

A case study methodology was employed where the City of Istanbul in Turkey was used. Istanbul city was chosen because of its dynamic nature in land use and transportation. The city has witnessed growth driven largely by socio economic, political, physical and environmental factors. There have been transportation master plan studies conducted in 1985, 1987, 1997 and the most recent being the 2007-2023 transport master plan. This provided the research with ample historical and current data to meet the objectives. The forecast period for this research was between 1996 and 2006.

A comparison between the actual and forecast land-use and socio economic data in the TAZs was undertaken to determine the differences that could explain FSM accuracy. A similar approach is used in the work by Wegmann and Everett (2008) and Zhao et.al., (2005). The actual data was based on the TAZs for the 2007-2023 Istanbul Transport Master Plan study conducted by Istanbul Metropolitan Municipality (IMM) and Japanese International Cooperation Agency (JICA), in which surveys were carried out within Istanbul to establish base line information for the study (JICA and IMM, 2007). The forecast data was based on TAZs used in the 1997-2010 Istanbul Transport Master Plan. The TAZ data from the 1997-2010 Transport Master Plan was forecast to 2006 to allow for comparison with actual data. The statistical comparison entailed computing the absolute error (AE), percentage error (PE), mean absolute error (MAE), mean percentage error (MPE), root mean square error (RMSE) and percent root mean square error (%RMSE) between forecast and actual data.

In comparing the 1996 and 2006 highway networks, data analysis involved comparing the planned highway networks based on the 1997-2010 Istanbul Transport Master Plan with the transport network for the year 2006. The rationale was to determine whether the transport networks were developed as planned and to establish the effects on accuracy of applying planned and actual networks. A similar approach is used in the work by Zhao et.al., (2005). Using ArcGIS 9.3 software, both highway road networks were compared in terms of the total lengths and total number of links by summarising the attribute data. A visual inspection of the highway networks was also undertaken to establish differences. Finally road density maps for both highway networks were prepared in ArcGIS in order to make comparisons.

The analysis also involved the simulation of factors that affect the accuracy of the FSM. The factors simulated in different model set ups were: land use and socio economic data; highway network; model parameters; disaggregation of TAZs; and use of feedback mechanisms to capture the effect of congestion. The FSM was executed using a combination of Flow Map 7.3 (Professional version), ArcGIS 9.3, OmniTRANS version 5.1, SPSS and MS Excel. A total of six simulations were executed based on variation of input variables perceived to have an effect on accuracy. The traffic and the volumes from the six simulations were then analysed to establish the variation from actual traffic volumes to establish accuracy using %RMSE.

Actual traffic data was obtained from the Istanbul Traffic Control Center (TCC) database. The TCC data is collected using a network of Remote Traffic Microwave Sensors located along the major roads in Istanbul. The RTMS data containing actual traffic volumes was processed and converted from Key hole mark-up language (KML) format and visualized using Google earth and ESRI ArcGIS 9.3. The point data did not have a spatial reference and thus could not be directly related spatially with the highway network. Hence, a new point feature shapefile was created in ArcGIS and the X and Y coordinate values from the KML file were used to capture the RTMS points. Attributes of RTMS_ID were added and a visual check done to confirm position accuracy.

Finally, in order to determine the effect size of the various FSM variables analysed in this research, one way repeated measures ANOVA was computed in SPSS to determine the F-ratio and effect size. This statistic compared the size of the variation due to the experimental manipulations with the size of the variation due to random factors (Field, 2005). The percent error on the 31 case study links based on FSM traffic assignment results under actual data input were used as the control against which the percent error of the other 5 model runs were measured. The rationale for this was based on the fact that actual data had been used to set up the FSM for 5 out of the total 6 model runs in this study

4 RESULTS AND DISCUSSION

The results from various analyses undertaken in this study indicate that the FSM has a %RMSE of between 100-200% depending on the inputs used. Various inaccuracies of the FSM model were observed as expounded below.

4.1 Land use and socioeconomic data

The comparison between the projected and the actual land use and socio economic variables for the year 2006 indicates that population and employment were overestimated while the student projections were under estimated. The percent error for employment is the greatest with a value of 20 % while that of students was -14% and population 6%. The averages for the TAZs give a %RMSE for population as 134%; for Employment at 135% and for students at 125%. The outcome of the error assessment suggests high inaccuracy between the forecast and actual figures for population, employment and students.

One of the reasons explaining the error between forecast and actual values could be the fact that the land use development did not take place as planned between 1995 and 2005. It should also be noted that errors in land use and socio- economic projections are unavoidable (Hanson and

Giuliano, 2004). These results tally with the findings in the work by Zhao et.al., (2005) and Parthasarathi and Levinson (2008).

Results indicate that when using projected data for inputs, the FSM overestimates the Average Daily Traffic (ADT) by 68.43% PE with a %RMSE of 204.43% indicating high level of inaccuracy. However, when actual data is used, the FSM overestimates the ADT by 68.45% PE with a %RMSE of 195.02% which still indicates a high level of inaccuracy. For the projected data, inaccuracy could be explained by projection errors as observed. The results from this analysis also indicate that the FSM underestimates the ADT even when actual data for 2006 is used in the model. This could mean that the actual land use and socio economic data used was not accurate or that there are other factors explaining the model inaccuracy, such as, the highway network, the model parameters, the model set up and errors arising from approach used in this study in associating RTMS data to the case study links. Studies by Zhao and Kockelman, (2002), Horowitz and Emslie, (1978), Parthasarathi and Levinson, (2008), Bonsall et al., (1977) mention these factors. The FSM performed slightly better when run using actual data than when using projected data which means that emphasis should be placed on achieving accurate forecasts. These results differ from the observation made in the work by Zhao et.al., (2005) because the application of actual data did not improve the %RMSE by a large magnitude.

4.2 Planned versus actual highway network

The planned highway network in 1996 was compared with the 2006 highway network in order to establish whether the network was developed as planned. The results indicate that there is a difference between the planned and the actual highway network. The main reason explaining this is the manner in which the networks were modelled and prepared for use in the FSM. The planned highway network is greatly simplified and the geometry does not reflect the network on the ground. Key informants in this study revealed that simplification and generalisation of the network was done in order to make it easier to implement with the software used to run the FSM. The actual network for 2006 was modelled differently and resembles the real network on the ground; a visual inspection with Google earth images showed a good match. The abstract nature of the planned highway network could account largely for the differences witnessed.

Model simulation results indicate that the FSM overestimates the ADT by 49.63% PE when using the highway network for year 2006 with a %RMSE of 138.78%, this indicates a high level of inaccuracy. Model results from this analysis suggest that the FSM reports high inaccuracy when using the actual high way network, but the results are better than when using the planned highway network which records a %RMSE of 195.02%., all other variables held constant, marking a difference of 56.245. This highlights the importance of the highway network used in the FSM, and its magnitude of effect on accuracy. The error reported in this analysis could largely be explained by the fact that the networks were prepared differently and also by the fact the perhaps the planned network consisting of committed and proposed projects was not developed as planned between 1997 and 2010. A similar observation can be found in the work by Giuliano (1984), Zhao et.al., (2005) and Parthasarathi and Levinson (2008).

4.3 Model Parameters

The general observation was that the FSM underestimates the ADT by -38.40% PE using model parameters for year 2006. The RMSE was 55,757 and the %RMSE was 100.92%. The results indicate that the parameters used have a positive effect on the FSM accuracy when compared to results from the other simulations. This analysis made use of trip generation parameters for the year 2006 and implemented regression analysis. It is observed that the trip rate changed between 1996 (1.54) and 2006 (1.74) and this could be a major factor affecting the accuracy of the model, the error could have arisen because it is difficult to predict the trip rate accurately as this depends on the socio economic and land use situation at the specific point in time. A similar observation can be found in the work by Niles and Nelson (2001), Krishnamurthy and Kockelman (2003).

4.4 Disaggregated TAZs

The TAZs were disaggregated from 250 to 451 and results indicate that the FSM overestimates the ADT by 92.16% PE using model parameters for year 2006. The RMSE was 100,451 and the %RMSE was 181.81%. The % RMSE when using 250 TAZs was 138.78% marking a difference of 43.03% due to disaggregation. While it was expected that disaggregation would lead to better accuracy of the FSM, the results indicate that it lead to less accuracy. This outcome could be explained by the number (31) of RTMSs used, it is suggested that further analysis based on more RTMS data points that cover the entire highway network could provide better results that explain the effect of disaggregated TAZs.

4.5 Feedback Analysis

The results of implementing a feedback mechanism between traffic assignment and trip distribution indicate that the FSM overestimates the ADT by 53.18% PE. The RMSE was 94,340 and the %RMSE was 170.75%. When compared with the results from the previous model runs, it is observed that the use of a feedback mechanism between the assignment step and the trip distribution step by means of applying the (Bureau of Public Roads) BPR congestion function on travel time improves the performance of the model. The %RMSE for the FSM with feedback was 170.75% while that for a similar model set up without feedback was 195.02% indicating an improvement of 24.27%. These results can be interpreted to mean that the use a feedback mechanism in the trip distribution step of the FSM is more logical and represents reality better. This is because in the traditional form of the model, trip distribution relies on free flow travel time which fails to capture the realistic traffic situation on the ground, in which travel time on links is affected by the volume of traffic in relation to the capacity of the links. The estimates of actual travel time are not available until after completion of traffic assignment hence the need for iterations as noted in Deakin et al(1993).

4.6 Effect Size of Manipulating FSM Using Different Inputs

The F-ratio was used to determine the effect size of using different FSM inputs. The results show that using new parameters and applying feedback to the FSM has the greatest effect on model performance, the within-subject contrasts revealed an F-ratio of 12.962 and 10.073 respectively with $p<.05$ indicating that there was significant difference between FSM results when these variables were used, they also give large effects of .549 and .501 respectively. Manipulation of the FSM by using disaggregated TAZs, actual highway network and projected data also leads to differences in the model results but these differences are not significant with values of $p>.05$ and effect sizes of .142, .062 and .142 respectively. These results differ with the observations made in the work by Zhao.et.al., (2005) where the effect of using the actual highway network was the most significant but are similar to the observations by Zhao and Kockelman (2002) where the trip generation parameters were seen to have the most significant effect.

5 CONCLUSION

The focus of this paper was integrated land use and transport modelling, with emphasis on investigating the sources of error in travel demand forecasting models. The paper undertook an evaluation of accuracy in the FSM. According to literature it was shown that there were different inputs and modelling techniques used in the FSM that acted as factors affecting the accuracy of model outputs. Conceptually these factors can be categorised into three groups namely: basic physical, land use and socio economic factors (such as road networks, population, employment and students); behavioural factors (model parameters for trip rates); and model structure factors (feedback mechanism).

It can be concluded that the land use and socio economic projections were inaccurate because they did not match with the actual data. They account for the greatest source of inaccuracy within the FSM when measured in terms of %RMSE because when other inputs are used in the model, the %RMSE improves significantly. Despite the inaccuracy reported by the FSM, it is still applicable for use because based on the F-test; the results obtained were on account of model manipulation above and beyond the effect of extraneous factors. The behavioural factors were seen to be the most important factors to be considered in the FSM followed by the model structure and finally the physical, land use and socio economic factors. There were a number of limitations observed in this research which should be considered when interpreting the findings and appreciating the conclusions.

It is recommended that estimation of the trip generation parameters in the FSM should be improved by making the process dynamic in order to capture the anticipated changes in trip making behaviour over the planning horizon. The FSM structure should include components of feedback between the different steps of the model where the congestion effect is applied on travel time and speed. A dynamic model of land use should be developed to compute the changing land use variables over the planning horizon with the outputs from this model being applied in the FSM in an iterative process. With the advancement in Information and Communication Technology (ICT) and road based traffic sensors such as RTMS, new data sources are emerging that could revolutionise the modelling approaches. Application of the FSM could be improved or augmented by use of historical and real time data from the monitored links to plan for land use and transport system interventions.

REFERENCES

Bates, J. (2000). 'History of demand modelling', in *Handbook of transport modelling*, eds. Hensher, D.A. and Button, K.J., Elsevier Ltd, Oxford, pp.11-33.

Beimborn, E. (1995). *A Transportation modeling primer*. Center for Urban Transportation Studies. Wisconsin, Milwaukee.

Bonsall, P. W., Champernowne, A. F., Mason, A. C., and Wilson, A. G. (1977). 'Transport modelling: sensitivity analysis and policy testing', *Progress in Planning*, 7(3), pp. 153-237.

Deakin, H. and Skabardonis, I. (1993). *Manual of regional transportation modelling: practice for air quality analysis*. The National Association of Regional Councils, Washington, DC.

De Bok, M. (2009). 'Estimation and validation of a microscopic model for spatial economic effects of transport infrastructure', *Transportation Research Part A: Policy and Practice*, 43(1), pp. 44-59.

De Jong, T., Breukelman, J., Brink, G. and Floor, H. (2009). Manual Flowmap, Version 7, [online], Faculty of Geosciences, Utrecht University. Available from: < http://flowmap.geog.uu.nl/Index.html#Download> [12th February, 2010].

Field, A. P. (2005). *Discovering statistics using SPSS*, Sage, London.

Fox, J., Daly, A.J. and Gunn, H. (2003). Review of RAND Europe's transport demand model systems, [online], RAND Europe. Available from: < http://rand.org/pubs/monograph_reports/MR1694> [13th February 2010]

Geertman, S. (2006). 'Potentials for planning support: a planning-conceptual approach', *Environment and planning B: Planning and Design*, 33(6), pp. 863-880.

Geurs, K. T. and van Wee, B. (2004). 'Accessibility evaluation of land-use and transport strategies: review and research directions', *Journal of Transport Geography*, 12(2), pp.127-140.

Giuliano, G. (1984). Standard transportation forecasting techniques: how they fail, [online], Institute of transportation studies, University of California. Available from: < http://www.its.uci.edu/its/publications/its.html>[12th February, 2010]

Hanson, S. and Giuliano, G. (2004). *The geography of urban transportation*, 3rd ed. The Guilford Press, New York.

Hensher, D.A. and Button, K.J. (2000). *Handbook of transport modelling* (Vol. 1), Elsevier Ltd, Oxford.

Horowitz, J. and Emslie, R. (1978). 'Comparison of measured and forecast traffic volumes on urban interstate highways', *Transportation Research*, 12(1), pp.29-32.

Iacono, M., Levinson, D. and El-Geneidy, A. (2008). 'Models of transportation and land use change: a guide to the territory', *Journal of Planning Literature*, 22(4), pp. 323-340.

JICA., IMM. (2007). Study on the integrated transportation master plan for Istanbul metropolitan area in the Republic of Turkey, progress report (English version).

Krishnamurthy, S. and Kockelman, K. (2003). 'Propagation of uncertainty in transportation land use models: Investigation of DRAM-EMPAL and UTPP Predictions in Austin, Texas', Transportation Research Record. *Journal of the Transportation Research Board*, 1831(-1), pp. 219-229.

Levinson, D. and Kumar, A. (1994). 'Integrating Feedback into the Transportation Planning Model', *Transportation Research Record*, 1413, pp. 70-77.

McNally, M. (2000). 'The four step model', in *Handbook of transport modelling*, eds. Hensher, D.A. and Button, K.J., Elsevier Ltd, Oxford, pp. 35-52.

Niles, J. S. and Nelson, D.(2001). Identifying uncertainties in forecasts of travel demand, [online], Preprint for the Transportation Research Board's 80th Annual Meeting, Washington D.C. Available from: < http://www.bettertransport.info/NilesNelson2001.pdf> [20th December, 2009].

Ortúzar, J. D. and Willumsen, L. G. (2001). *Modelling transport*, Wiley, West Sussex.

Pacione, M. (2005). *Urban geography: a global perspective* (Second edition), Routledge, London.

Parthasarathi, P. and Levinson, D. (2008). Post-construction evaluation of traffic forecast accuracy. Working Papers 000042, [online], University of Minnesota: Nexus Research Group. Available from: < http://rational.ce.umn.edu/Papers/ForecastAccuracy.pdf> [20th December, 2009]

Te Brömmelstroet, M. and Bertolini, L. (2008). 'Developing land use and transport PSS: Meaningful information through a dialogue between modelers and planners', *Transport Policy*, 15(4), pp. 251-259.

Tillema, F. (2004). *Development of a data driven land use transport interaction model*. PhD thesis, University of Twente, Enschede.

Wegmann, F. and Everett, J. (2008). Minimum travel demand model calibration and validation guidelines for the state of Tennessee,[online], University of Tennessee, Centre for Transportation Research. Available from: <web.utk.edu/~tnmug08/misc/valid.pdf> [12th February, 2009].

Zhao, Y. and Kockelman, K. (2002). 'The propagation of uncertainty through travel demand models: an exploratory analysis', *The Annals of regional science*, 36(1), pp. 145-163.

Zhao, F., Li, M.T. and Ding, Z. (2005). Comparing short-term traffic projections with traffic counts – the JUATS 2015 Model, final report, [online], access date [5th December, 2009] access at: http://www.fsutmsonline.net/images/uploads/reports/FDOT_BD015_11_rpt.pdf