MODELLING OF VEHICLE-KILOMETRES OF TRAVEL BY CAR FOR THE JOURNEY TO WORK IN SYDNEY, AUSTRALIA

Putu Alit Suthanaya[1]

Abstract: In low density, car-dependent cities such as Sydney there have been two drivers of increased VKT: increasing use of the car for the journey-to-work; and increasing spatial separation of homes and workplaces. Descriptive analyses of data from the Census of Population and Housing, Journey-to-Work Tabulations by local government area (LGA), show how person-kilometres of travel by outer suburban residents (greater than 20km for the Sydney CBD) has mushroomed from 1961 to 1996, and how VKT by car has also exploded in the same suburbs (from 1981 when modal data were first reported).

The paper describes a modelling framework that allows future VKT by car for the journey to work from LGAs in Sydney to be estimated as a function of future urban form and socio-economic characteristics at the LGA level. Cross sectional and inter-census change statistical models of LGA travel behaviour and urban form (such as, accessibility to employment, density) are fitted. Spatial modelling (the intervening opportunity model) represents the third approach and the LGA preference function (for longer or shorter job destinations) is evaluated across LGAs and through time. A statistical model relates the slope of the preference function (and hence the LGA trip length frequency distribution) to urban form. Nine different scenarios of urban form have been formulated for the year 2011 to test a range of assumptions - existing trends and centralisation / decentralisation of homes and workplaces – and the practical application of the models are demonstrated to evaluate progress towards sustainable transport targets.

Keywords: modelling, VKT, journey to work.

PEMODELAN KENDARAAN-KILOMETER UNTUK PERJALANAN KERJA DI KOTA SYDNEY, AUSTRALIA

Abstrak : Pada daerah perkotaan dengan kepadatan penduduk rendah, kota yang tergantung pada pemakaian kendaraan pribadi seperti Kota Sydney, terdapat dua hal yang mendukung peningkatan Kendaraan-Kilometer, yaitu: peningkatan penggunaan kendaraan pribadi untuk perjalanan kerja dan peningkatan jarak spasial antara permukiman dan tempat kerja. Analisis deskriptif terhadap data dari Sensus Penduduk, tabulasi perjalanan kerja per LGA, memperlihatkan pergerakan orang-kilometer untuk penduduk yang tinggal di luar kota (lebih dari 20 km dari pusat Kota Sydney) telah meningkat dari tahun 1961 hingga 1996, demikian pula terjadi peningkatan Kendaraan-Kilometer.

Paper ini menguraikan kerangka pemodelan untuk memperkirakan Kendaraan-Kilometer dengan kendaraan pribadi untuk perjalanan kerja di Kota Sydney sebagai fungsi dari karakteristik struktur kota dan sosial-ekonomi di masa mendatang pada tingkat LGA. Pendekatan dilakukan dengan analisis data statistik yang bersifat cross-sectional dan perubahan inter-census. Pendekatan ketiga adalah dengan pemodelan spasial (the intervening opportunity model) dimana fungsi keinginan (preference function) dievaluasi untuk seluruh LGA dan secara historis. Suatu model statistik digunakan untuk menggambarkan hubungan antara slope fungsi keinginan terhadap struktur kota. Sembilan skenario yang berbeda dari struktur kota dirancang untuk

[1] Dosen Jurusan Teknik Sipil, Fakultas Teknik, Universitas Udayana, Denpasar.

tahun 2011 untuk menguji beberapa asumsi meliputi: kecenderungan eksisting, sentralisasi, desentralisasi. Aplikasi praktis dari model dijelaskan untuk mengevaluasi progres terhadap pencapaian target-target indikator sistem transportasi berkelanjutan.

Kata kunci: pemodelan, kendaraan-kilometer, perjalanan kerja.

INTRODUCTION

Car dependence is a fundamental problem in the sustainability of those cities with low-density suburban sprawl. Many cities are experiencing significant increases in vehicle kilometres of travel (VKT) - for example, in Sydney total VKT increased by 23.5 percent from 1991 to 1997. Environmental implications of growth in VKT – such as deteriorating air quality - are alarming because predicted growth is likely to outstrip measures to improve the energy efficiency and environmental performances of vehicles (NSW Department of Transport, 1999). Transport planners agree that sustainable transport indicators are needed to track progress in meeting targets (May, *et al*, 2001), and one appropriate indicator is VKT by car (Miller and Ibrahim, 1998).

Mathematical models are useful to determine the future VKT implications of land-use and transport policies, and any progress towards meeting targets. The report by the Ecologically Sustainable Development Transport Working Group of the Commonwealth Government advocated change to the transport sector to achieve sustainability, but when the 40 recommendations for urban transport are classified by the systems planning framework (Black, 1996), it is apparent they aim primarily to alter the value system, by specifying new goals and objectives, or prescribe policy solutions, such as higher density cities. Noticeably absent from the set of recommendations are appropriate "sustainability" indicators, and analytical tools suitable to examine urban sustainability issues. The Institution of Engineers Australia, New South Wales Transport Panel convened a seminar that confirmed little progress had been made in

Australia on analytical tools and performance indicators for sustainable transport (Black, Paez, and Suthanaya, 2001).

This paper proposes vehicle kilometres of travel (VKT) for the journey to work by car as one performance indicator of sustainable urban travel. For strategic metropolitan transport planning, the aggregate (local government area) models reported in this paper are sufficiently robust to examine urban form changes and their implications for journey-to-work VKT by car. (In 1999, commuting in Sydney accounted for 18 per cent of all trip purposes but about one third of journeys by distance.) Our aim is to develop analytical tools linking aggregate travel behaviour and explanatory variables for urban form and demographic/socio-economic factors as a basis to estimate the strategic travel implications of alternative urban development scenarios.

LITERATURE REVIEW

The common practical method to estimate the future amount of urban travel (including VKT by car for the journey to work) is the application of the four-step transport-planning model with exogenous inputs for future land use at the spatial resolution of traffic zones. One problem with this approach is the fundamental difficulty of estimating accurately the future values of the land-use input variables for the very fine spatial resolution of the traffic zone. Another problem is that the mean trip length estimated by the gravity model (and hence VKT) is insensitive to radically different distributions of land-use activity (homes and workplaces) – a weakness long recognised (Black and Katakos, 1981).

The literature on urban form and travel has informed us on the most likely variables to consider, and their working definitions (Suthanaya and Black, 2001). Evidence suggests that urban form is a significant factor in car dependence and VKT by car (Newman and Kenworthy, 1999). Many cross-sectional analyses at the macro (census tract) and micro (neighbourhood, household or individual) level have been conducted, but the influence of density is mixed. Brunton and Brindle (1999) found that, in Melbourne, density variables (population and activity density) are not a suitable predictor for average car distance travelled when other urban form variables (such as accessibility to activities, socio-economic factors or a welfare index) are included. Miller and Ibrahim (1998) argued that population density was an insignificant predictor for VKT in Toronto when other urban form variables (such as zone distances from the CBD) are considered.

METHODOLOGY

The study area is the Sydney Statistical Division defined by the Australian Bureau of Census, comprising 40 local government areas (LGA) in the County of Cumberland plus the four adjacent areas to Wollondilly, the Blue Mountains, Gosford and Wyong. Earlier Census of Population and Housing had divided the same study area into 38 LGAs. Figure 1 shows a diagrammatic map of Sydney region. The 44 LGAs were grouped into three regional rings: inner, middle and outer - consistent with those used in the Department of Urban Affairs and Planning studies (NSW Department of Urban Affairs and Planning, 1995). Results obtained for each LGA for vehicle (and personal) kilometres of travel for the journey to work are presented with reference to these three rings.

Primary data sources are the 1961, 1966, 1971, 1976, 1981, 1991, and 1996 Journey-to-Work data for Sydney Metro-politan Area. The Australian Bureau of Statistics (ABS) conducts the Census and the data are aggregated from census tracts for the Statistical Local Area (SLA) levels and cover 44 Local Government Areas. This research draws on tabulations provided by the NSW Department of Transport, Transport Data Centre (TDC) and any minor discrepancies between ABS and TDC data are a result of this process. Microsoft Access was used to compile relevant cross-tabulations and summaries from these data. Tabulations were then converted to Microsoft Excel spreadsheets to allow presentation and modification of format.

There are two distinct data sets aggregated at the LGA level. The first is for the longer period – 1961 to 1996 – but is only journey-to-work behaviour for all modes of travel. The second data for 1981, 1991, and 1996 set allows journey-to-work travel to be stratified by transport mode (although our macro analysis considers only the main modes of drive by car, bus and train). Journey-to-work travel by LGA is the dependent variable – specifically defined in various ways: person (or vehicle) kilometres of travel, trip lengths (by transport mode) and mode share. Independent variables include: urban form, socio-economic and demographic variables that have been identified as possible explanatory variables of travel behaviour.
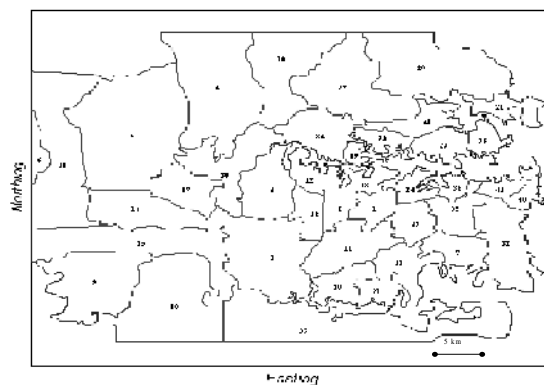

Figure 1. Sydney LGA Boundaries and Zoning System

Initially, urban form and travel behaviour trends were analysed descriptively at the LGA level using seven census data sets over 35-years from 1961 to 1996. Graphical plots were used to show the trends visually, at the metropolitan, the ring and the local government area level (Suthanaya and Black, 2001). This careful application of descriptive statistics has provided the springboard for later hypothesis testing and developing a suite of statistical models. These techniques are described fully in Black, Paez and Suthanaya (2002). They include: descriptive statistics – exploratory and graphical methods; correlation analysis; spatial mapping; spatial statistics, especially to identify geographical patterns and to identify outliers in the data; univariate and multivariate analyses; and travel preference functions based on Stouffer's intervening opportunity model.

Two statistical models are used to estimate future VKT by car for the journey to work in each LGA in the Sydney region. Both cross-sectional (1996 Census data) and change over time (1981, 1991 and 1996) between urban form and VKT by car have been investigated at the LGA level of spatial resolution using multiple regression analysis (stepwise approach) that includes socio-economic and demographic factors. The working hypothesis is that the aggregate amount of VKT travel by car in an LGA is explained by urban form and socio-economic variables. The screening procedure of the stepwise regression in the SPSS-software package was used to identify the best set of the explanatory variables. As different explanatory variables entered in the model for different census years it was also hypothesised that the amount of change in LGA VKT travel was a function of the change in urban form and socio-economic variables. Analysis of variance was applied to compare the travel behaviour among inner, middle and outer area residents. The input variables to the models are future urban form and socio-economic factors.

RESULTS AND DISCUSSION

Cross-sectional Analysis

The main findings from cross-sectional analyses of journey-to-work census data are summarised as follows:

(a) No consistent model with the same explanatory variables could be found for the total amount of travel by car over time.

(b) Urban form variables were more important predictors for the total amount of travel by car than the demographic or socio-economic characteristics of the residents.

(c) The total number of workers (or the proportion of metropolitan workers) living in a LGA was consistently found to be the main determinant of the total amount of travel by private car.

(d) Other key urban form variables that consistently entered the model were: accessibility to jobs; the ratio of residential workers to jobs; and the proportion of residential workers employed locally. These variables entered the regression model consistently over time. Therefore, these urban form variables might be selected for estimation purpose.

(e) Non-urban form variables that entered the regression model - the proportion of low-income workers; the proportion of labourers; and proportion of workers aged between 30 to 49 years – but only in some census years.

In the light of the above findings, caution should be exercised when applying a cross-sectional regression model for estimation purposes. For our purposes of estimating LGA journey-to-work travel under different land use scenarios, the model fitted to 1996 census data has been selected for estimation purposes. The constant and all explanatory variables are statistically significant. No

collinearity is identified as indicated by the tolerance value (>0.1) and variance inflation factors (VIF<10) obtained. The model is as follows:

$$Y = 4\,770\,475 + 11.9\,X_1 - 376\,244$$

$$Ln(X_2) - 112\,048\,Ln(X_3) - 193\,868$$

$$Ln(X_4)\ (r^2 = 0.95)$$

Where,

  Y = estimate of total amount of LGA journey-to-work travel (VKT) by car;

  X_1 = total number of residential workers in a LGA;

  X_2 = LGA accessibility to jobs (Hansen index using road distance as the denominator);

  X_3 = ratio of residential workers to jobs in a LGA; and

  X_4 = proportion of residential workers in a LGA employed locally.

The Hansen index for the accessibility of an origin LGA zone is obtained by summing the quotient of the number of jobs located in each LGA in turn divided by the road distances from the origin zone to those destination zones (the number of jobs in the origin zone divided by an average intra-zonal distance is included in these calculations).

Analysis of Inter-Census Change

Although analysis of inter-census change involves a reduction in the number of models that could be specified to predict change requires information from two census periods, we speculated that dependent and independent variables defined as a five-year change might pro-vide a more stable forecasting model. The average changes in urban form and socio-economic variables per 5 years from 1981 to 1996 in Sydney were used as inde-pendent variables. The dependent variable was specified as the average change in the total amount of travel by private car (VKT) per 5 years during the same period of time. The hypothesis is that change in the amount of VKT by car by each LGA

is a function of change in urban form and change in socio-economic factors. Urban form variables are better predictors travel patterns than socio-economic and demographic factors, and only the proportion of household with zero-cars entered the model. The model is:

$$Y = 63\,769 + 10.3\,X_1 - 12.5\,X_2 - 37\,140$$
$$X_3 - 3\,845\,X_4\ (r^2 = 0.94)$$

Where,

  Y = average change in the total amount of travel by car of a LGA per 5 years;

  X_1 = average change in the total number of residential workers in a LGA per 5 years;

  X_2 = average change in the accessibility to jobs (Hansen index using road distance as the denominator) of a LGA per 5 years;

  X_3 = average change in mean distance to jobs from a LGA per 5 years; and

  X_4 = average change in the proportion of households with no car in a LGA per 5 years.

Intervening Opportunities Model Based on Preference Functions

Mindful of the treacherous nature of regression models when applied to long-term forecasts we have formulated a very different approach structured within the framework of spatial interaction models, but one that remains sensitive to urban form changes. Its novelty is that over-comes the weakness of the gravity model with a fixed calibration parameter that demonstrably is inaccurate in estimating future mean trip lengths (Masuya, Shitamura, Saito and Black, 2002). Unlike the conventional intervening opportunity model, with its calibration against all inter-zonal trips (Ruiter, 1967) we have fitted mathematical functions to each zonal (LGA) origin – destination trip pattern. These LGA "preference functions" for longer or for shorter destinations (analogous to the l-factor in

the intervening opportunity model) are used to investigate the spatial (across LGAs) and temporal (intercensus) commuting behaviour when the spatial distribution of job opportunities are normalised as the percentage of metropolitan jobs at increasing distance from each origin LGA.

A preference function is thus an aggregate of the individual travel behavioural responses for an LGA, given a particular opportunity surface distribution of jobs surrounding those commuters in that LGA across the whole of the study area. Empirically, non-linear shaped preference functions are obtained for the proportion of trips from an LGA stopping plotted against the proportion of total metropolitan jobs reached by increasing distance by road from that LGA. Mathematical transformations are used to produce linearity and the gradient of the slope of the preference function gives information on whether the LGA exhibits an aggregate "maximising" travel or "minimising" travel behaviour (Black, Cheng, Ton and Masuya, 1993). Steep slopes imply a propensity to take up the nearer opportunities; shallow gradients imply nearer opportunities are by-passed and there is a propensity to travel longer distances. Similar gradients across all LGA would imply a common travel behavioural response to the normalised opportunity surface.

Our research using journey-to-work data sets from 1981 to 1996 in Sydney has found that variation in urban form across LGAs is associated with variation in the slope of the commuting preference function by car. In this analysis, we have stratified the LGA by LGA journey-to-work trip matrix by mode (car travellers) and estimated the (negative) slope of the transformed function. For 1981, the minimum slope was - 0.274 and the maximum – 0.033 (mean = - 0.195); for 1996, the mean had increased to – 0.208, with a range from – 0.303 to – 0.076.

Variations in the slopes of the LGA commuting preference functions by car were found to be associated with the variation in the LGA mean trip length by car. The slope of the preference function is explained by urban form variables in a regression model. Urban form variables better predict commuting preference functions by car than do socio-economic factors. The average job distance was found to be the most important predictor for the absolute slope of commuting preferences by car based on multiple regression analysis that was repeated for data from three census years - 1981, 1991 and 1996. Although the average job distance variable entered into the model for these three census years no consistent set of explanatory variables could be identified, as was the case with the multivariate statistical analyses. Therefore, the 1991 model was selected because it had the strongest explanatory power amongst the three data sets with the model explaining 93 percent of variation in the commuting preferences by car:

$$Y = 0.297 – 0.0026\,X_1 + 0.021\,X_2 – 0.003 X_3 + 0.0017\,X_4 – 0.000002\,X_5$$

Where,

Y = slope commuting preferences by car;

X_1 = average job distance (kilometres);

X_2 = proportion of metropolitan jobs in the LGA;

X_3 = proportion of residential workers employed locally;

X_4 = LGA distance in kilometres from the CBD; and

X_5 = job density (gross).

Future values for these explanatory variables (see below) allow future estimates of the LGA preference function to be made. For any future land-use scenario the total amount of travel by car (VKT) for an LGA can be estimated from the predicted LGA mean trip length by multiplying the mean trip length by car of

a LGA by the total number of residential workers living in that LGA.

Development of Scenarios

No attempt has been made to adopt government estimates of future geographical patterns of homes and workplaces. The authors developed three extreme scenarios for the distribution of jobs by LGA in the Sydney study area in the year 2011: existing trends; centralisation; and decentralisation. For each scenario, the distribution of residential workers for each LGA followed existing trends, was centralised or was decentralised, as shown summarised by ring. Hypothetical distributions have been defined to bring out the differences between urban consolidation and suburban sprawl. These future land-use values provided input data to calculate the future explanatory variables required by the three models described above.

Estimation of Journey-to-Work VKT by Car, 2011

The daily total amount of journey from home to work VKT by car for all of the 44 LGAs in 1981 (the first year that transport mode questions were asked at the Census) was 9.7 million. It increased by a half to 14.4 million VKT in 1996 and it is predicted to reach 19 million VKT in 2011. By 2011 this VKT extrapolation will be about 96 percent higher than its 1981 value, or 33 per cent higher than the 1996 value (Table 1).

Table 1: Daily VKT by Car in the Journey from Home to Work, Sydney Metropolitan Area, 1981 to 1996 and Extrapolated Value to 2011

Census Year	Vehicle Kilometres of Travel by Car	Index (1981 = 100)
1981	9 728 796	100
1991	12 564 640	129
(1996)	14 388 616	148
2011	19 085 836	196

When this extrapolation is disaggregated at the LGA level (Figure 2) a dramatic increase in VKT for 2011 is seen for the outer ring of LGAs beyond 20 km from the CBD. On the assumption of trend extrapolation, the average total amount of VKT travel by car for the inner ring of LGAs will increase by 29 percent from its 1996 value. The average total amount of VKT travel by car in the middle and outer rings will increase by 11 and 40 percent, respectively, from their 1996 values.

As the total amount of VKT travel by car in the outer suburbs of the study area is expected to increase dramatically if trends continue we now concentrate on those 16 LGAs in the outer ring of Sydney.
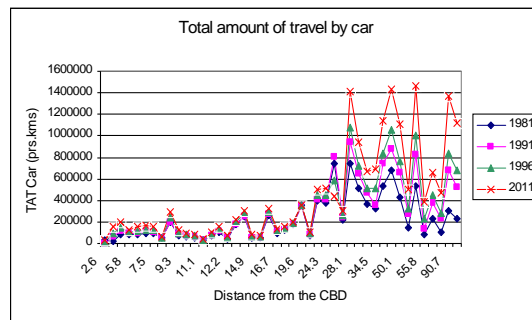

Figure 2. Total Amount of LGA Journey-to-Work VKT Travel by Car in Sydney, 1981 – 1996, and Trend Extrapolation by LGA to 2011

By applying the three models described above with input data from radically different land-use scenarios for 2011, we assess the contribution to VKT that different patterns of urban form might make. The results from the three models are summarised in Table 2 by the 9 land-use scenarios (column 1). Because of the inherent uncertainty in the forecasting accuracy of each method, an average of the three are taken (column 5), and this is expressed as the total VKT estimated for the outer LGAs in 2011 (column 6) and the increase from 1996 represented as a base of 100.

Table 2. VKT by Car for the Outer Ring LGAs in Sydney Based on Three Different Prediction Models by 2011 Land-use Scenario

Scenario	Urban form 1 (cross section)	Urban form 2 (longitudinal)	Slope Reference	Mean of the Three (VKT-car/LGA)	Total for Outer ring	Index 1996 =100
S1a	746 123	890 482	1 483 256	1 039 954	16 639 259	164
S1b	401 173	591 330	803 168	598 557	9 576 912	95
S1c	1 027 027	1 134 093	1 993 901	1 385 007	22 160 112	219
S2a	683 660	945 637	1 234 704	954 667	15 274 672	151
S2b	409 308	646 484	670 933	575 575	9 209 200	91
S2c	628 350	1 189 247	1 650 662	1 156 086	18 497 381	183
S3a	674 023	812 909	1 819 077	1 102 003	17 632 048	174
S3b	515 980	513 757	981 834	670 524	10 728 379	106
S3c	1 035 067	1 056 519	2 457 654	1 516 413	24 262 613	239

Irrespective of the future distribution of jobs in 2011, centralisation of residential workers (Scenarios S1b and S2b) - such that 70 per cent of the homes of workers are located in the middle and inner rings of Sydney - is expected to slightly reduce VKT of journey-to-work travel total amount of travel by car, or in the case of Scenario S3b, increase it slightly by 6 percent. These totally impractical land-use scenarios (consumer resistance to high density and urban consolidation, the impossibility of reversing development trends in fifteen years, lack of suitable sites for redevelopment, and so on) only highlight the futility of the government pretending that the equivalent VKT target currently set of a 15 per cent increase (for all journey purposes) over the 1996 base by 2011 in *Action for Transport 2010* is achievable.

CONCLUSION

The growth in person kilometres of travel in outer suburbs is a problem of concern in making cities more sustainable. A new modelling framework to address these kinds of policy questions has been described. Three models of the relationship between LGA journey-to-work travel by car and urban form and socio-economic variables by using successive census data from 1981 to 1996 have been formulated. These have been compared and contrasted with trend extrapolation from 1981 to 1996, and then to 2011 based on hypothetical distributions of homes and workplaces (scenarios), that demonstrates their applicability in sustainable urban transport analysis. For the whole of the metropolitan area, extrapolation suggests an increase of VKT of 33 per cent above the 1996 level; the worst-case land-use development scenario suggests a doubling of VKT. The models are sufficiently robust to allow strategic land-use policy scenarios for Sydney to be evaluated.

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