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Multiple purposes at single destination: A key to a better understanding of the relationship between tour complexity and mode choice.

By

Chinh Quoc Ho and Corinne Mulley

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TITLE: **Multiple purposes at single destination: A key to a better understanding of the relationship between tour complexity and mode choice.**

ABSTRACT: This paper investigates the nature of tours undertaken by public transport and car. Using a new approach to the typology of tours, which takes into account not only the number but also the spatial distribution of activities chained into a tour, the paper sheds light on the reasons why conflicting findings exist in the research literature. Descriptive and modelling analyses on a home-based tour dataset created from the Sydney household travel survey show that tours using car or public transport are different in nature. For public transport, activities chained into a tour have destinations which are typically in close proximity and reachable by walking whereas the car was found to be utilised for travel involving multiple purposes at multiple destinations. The new approach to the typology of tours proposed in this paper which takes the destination into account gives clearer and more significant relationships between tour complexity and mode choice, allowing potential policy and planning implications for promoting public transport ridership to be drawn. The results indicate that the spatial dispersion of activities chained into a tour significantly reduces public transport use for all travel purposes. Conversely, public transport use increases as the number of activities sharing a destination with others chained into a tour increases. These findings suggest that planning strategies to increase public transport use need to focus on providing multiple purposes at a single destination.

KEY WORDS: *Tours; mode choice; MPSD; spatial distribution; public transport; tour typology.*

AUTHORS: **Ho & Mulley**

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CONTACT: INSTITUTE of TRANSPORT and LOGISTICS STUDIES (C37)
The Australian Key Centre in Transport and Logistics Management

The University of Sydney NSW 2006 Australia

Telephone: +612 9351 0071
Facsimile: +612 9351 0088
E-mail: business.itlsinfo@sydney.edu.au
Internet: <http://sydney.edu.au/business/itls>

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1. Introduction

Even though a tour is generally referred to as travel involving single or multiple purposes to single or multiple destinations, the destination itself is rarely investigated. Research has so far treated tours as travel involving either single or multi-purpose with little regard for the spatial distribution of activities. Specifically, explicit representation and quantification of travel involving multiple purposes at single destination (MPSD) are noticeably absent from activity and tour based analyses. Research on the relationship between tour complexity and mode choice has shown mixed evidence. Some studies find that as tours become more complex public transport as an inflexible travel mode is less likely to be used (Hensher and Reyes, 2000). However, other studies suggest that the nature of tours via public transport and car is *different* as opposed to *inflexible* (Primerano et al., 2008; Currie and Delbosc, 2011). This paper explores the nature of tours via public transport and car using evidence from the Sydney household travel survey. The central question being addressed is whether tours undertaken via the two modes is different, by considering whether the activities chained into tours are to single or multiple destinations and whether the mode used in accessing destinations is by motorised or non-motorised modes.

Understanding the nature of tours undertaken by public transport and car is important for developing policy and the planning of public transport. If public transport is relatively inflexible to complex tours compared to the car, then public transport ridership will decrease in the future if complex travel increases. On the other hand, if the nature of tours of the two modes is different rather than due to the inflexibility of public transport, there are opportunities for promoting public transport ridership even with increasingly complex travel patterns, and planning strategies advocating mixed land use developments and multipurpose activity centres could promote public transport use.

This paper proposes a new method of classifying the complexity of tours which takes into account the nature of the destination. It compares the relative complexity of public transport tours to car tours using comparative analysis with alternative ways of defining tour complexity. The results from these alternative definitions are compared and contrasted with the findings from previous studies to provide insights into why previous research has not found consistency in the relationship between tour complexity and mode choice. The paper provides new evidence on the strength of the relationship between tour complexity and mode choice through the development of a nested logit model.

The paper starts with a review of the literature on the relationship between tour complexity and mode choice, embedding the definitions of terms used in this paper. This is followed by the identification of hypotheses being tested and a review of methodology. Descriptive and model estimation results are then presented. The paper ends with a summary of the main findings and a discussion of the implications for public transport policy and planning practice.

2. Literature review

A *tour* is a sequence of trip segments starting and ending at the home and containing single or multiple activities done at single or multiple destinations (Strathman and Dueker, 1995; Shiftan, 1998). The tour can be relatively simple involving one activity or complex with multiple activities taking place at multiple destinations. Analysing tours, as opposed to unlinked trips, may provide a better understanding of travel behaviour and a more appropriate framework for examining responses to transport policies. For instance, the scheduling of so-called 'discretionary' activities during peak hours appears illogical in the context of unlinked trips but is perfectly understandable with tour-based analyses because these non-work activities are frequently linked to commutes (Strathman and Dueker, 1995). Also, the need to satisfy non-work obligations in commuting journeys could explain the findings elsewhere of workers' reluctance to rescheduling their commutes (Small, 1982; Wilson, 1989).

Tour complexity appears to be heavily dependent on household and individual characteristics including household size, household income, lifecycle, vehicle ownership, gender, age, and employment status. Trip attributes such as travel purpose, time and mode of travel, day of week,

vehicle occupancy, and accessibility at trip origin and destination also influence the complexity of tours (Strathman et al., 1994; Strathman and Dueker, 1995; Krizek, 2003; Ye et al., 2007; Primerano et al., 2008; Currie and Delbosc, 2011).

Research has found that complex tours were less likely to be public transport based. Hensher and Reyes (2000), using data from the 1991-1992 Sydney household travel survey, found public transport use decreased as a tour became more complex. Using the Mobidrive data in Karlsruhe and Halle, Germany, Cicillo and Axhausen (2002) found that as individuals move from simple to complex tours, the propensity to use public transport decreased while car use as a driver increased. Wallace et al. (2000), using the Puget Sound Transportation Panel data, found that public transport tours were less complex than car tours. More recently, Ye et al. (2007) developed recursive binary probit and simultaneous logit models to examine and distinguish three possible causal relationships between tour complexity and mode choice. These were that the mode choice decision comes first and influences tour complexity; second that the activity pattern (or tour complexity) is determined first and influences mode choice; and finally that the two choice decisions are determined simultaneously. Their research found that for both work and non-work tours, tour complexity drives mode choice rather than the choice of mode determining the incidence of chaining additional activities into a tour. Also, Krygsman et al. (2007) found that for a majority of home-based work tours, the activity decision is made before the mode decision. These findings lend credence to the hypothesis and empirical evidence that the need to make a complex tour requires the flexibility of the car mode. Other studies, however, have found evidence challenging the hypothesis that public transport is inflexible and results in less complex tours. Primerano et al. (2008) found in Adelaide that mass public transport tours on average involved more activities than car tours. Currie and Delbosc (2011) found in Melbourne that tours by train and tram were more complex than car tours (5.5 percent and 9.6 percent more stops (including 'returning home') respectively) while tours by bus involved 8.4 percent fewer stops than car driver tours. A survey in New Zealand indicated that the differences between simple and complex tours for both public transport and car were different across travel purposes; the proportional decrease in public transport use for complex tours was far greater than that in car use for work and education tours, but this reversed for non-work, non-education tours (O'Fallon and Sullivan, 2005).

An important caveat to these findings is that tour-based analysis has so far treated tours as travel involving either single purpose or multiple purposes with little regard for whether these purposes are done at single or multiple destinations. The relationship between tour complexity and travel mode has thus been analysed with a focus on a categorical classification of tours as simple, i.e., travel involving a single purpose at single destination (SPSD) or complex, i.e., multiple purposes at multiple destinations (MPMD). An exception is the study by Currie and Delbosc (2011) where tour complexity is represented by the number of activities chained into a tour. However, approaches to examining tour complexity have not taken into account the high number of tours which are multiple purposes but single destination (MPSD). This paper undertakes this analysis and investigates the role of MPSD in mode choice, adopting the causal link from tour complexity to mode choice that has established in the literature.

Furthermore, the research literature has tended to combine all non-work, non-education activities into one group but the tour complexity which includes these activities may be quite different. Primerano et al. (2008) found that the average number of activities chained into social and recreational tours (1.19) were much fewer than other non-work, non-education tours (ranging from 1.69 to 2.10). Also, given an increasing interest in understanding school travel patterns and distinct population segments undertaking work tours vs. education tours, it is important to disaggregate the so-called 'subsistence' activities into the separate categories of work and education.

2.1 Definitions and concepts

This section defines the concepts used in this paper. Activities are classified into three broad groups based on Stopher et al. (1996) and Bhat and Misra (1999) as follows:

- Subsistence activities are typically frequent activities with fixed location and timing. These activities are essential to providing the finance for pursuing other activities. Subsistence activities

are further divided into work/work-related and education with the latter including school and childcare

- Maintenance activities are activities undertaken on a regular basis but with variable timing and location. Activities clustered into this group include shopping, personal business/services, and serve passenger (accompanying or dropping off/picking up someone)
- Discretionary activities are performed on an irregular basis with variable location and timing. These activities are mainly social and recreational motivated by cultural and psychological needs

Tour complexity is examined using the concept of a home-based tour. This is defined as a series of trips that begin and end at an individual's home (Adler and Ben-Akiva, 1979; Strathman and Dueker, 1995; Shiftan, 1998). Individual segments of a tour are referred to as trip legs. A trip leg involves an intervening activity (e.g., education or shopping) but can also involve returning home or changing mode. Thus, a home-based tour contains at least two trip legs and one intervening activity. Each tour is classified into one of four different types according to its main purpose which is assigned on a hierarchical basis with work being the highest priority activities, followed by education, maintenance, and discretionary activities.

Last, tour complexity has been studied in the literature using two different approaches: one is a categorical classification and the other focuses on the number of activities or trip legs within a tour. The categorical classification scheme defines a tour as *simple* or *complex* depending on the number (and sometimes the combination) of activities chained into a tour with a single activity being simple and multiple activities being complex (see, e.g., Hensher and Reyes, 2000; Ye et al., 2007). The second refers to tours as *more* or *less* complex using the number of activities or trip legs as a continuous variable to define tour complexity (see, e.g., Currie and Delbosc, 2011). This paper builds on these approaches and uses a definition where tour complexity is characterised by the number of destinations visited and activities chained into a tour. This is discussed in more detailed in Section 0.

2.2 Hypotheses

The paper examines the nature of tours undertaken by public transport and car users to explore the relationship between tour complexity and mode choice. More specifically, the paper examines whether public transport tours can be as complex as car tours but for different tour complexities or whether public transport tours are always less complex. The paper also considers how travel involving MPSD influences mode choices and whether the effect of MPSD is different across travel purposes. These principal research questions are addressed through the following hypotheses:

H 1. The nature of tours undertaken by public transport and car are different in terms of the type of activities and proximity of activities chained into a tour.

H 2. Tour complexity measured as the number of activities chained into a tour has an ambiguous and/or less significant correlation with mode choice as compared to tour complexity measured as the numbers of destinations visited and secondary activities.

H 3. The effects on mode choice of tour complexity in terms of the numbers of destinations visited and secondary activities are different across travel purposes, including between non-subsistence activities and between subsistence activities.

3. Methodology

3.1 Home-based tour dataset creation

The three hypotheses are tested using the three years of pooled data (2007/08, 2008/09, 2009/10) from the Sydney Household Travel Survey (HTS). The Sydney HTS was first conducted in 1997/98 and has been running continuously since then. To date, the dataset includes thirteen consecutive waves with approximately 3,500 households surveyed annually (BTS, 2011). Each wave includes a survey of household characteristics, person characteristics for each participant and a 24-hour travel diary for each participant. The three years pooled dataset contains 88,754 unlinked person trips with their

corresponding characteristics. Only fully responding households were chosen for analysis, reducing the dataset to 81,850 unlinked person trips. No sampling weights are used in the descriptive analysis or in the model estimation.

Unlinked person trips were chained into home-based tours based on the way all travel can be viewed as round-trip journeys, beginning and ending at the home. A small number of respondents reported travel diaries that began or ended at an out-of-home location, effectively changing the beginning or ending of tours. These tours were discarded from the sample due to potential difficulty in interpretation.

An extensive process of restructuring and cleaning the data created 23,259 tours. By mode, the tours were spread across ferry, train (including light rail and monorail), bus, car (including driver and passenger), taxi, cycling, walking, and other. A single tour may involve more than one travel mode. A tour's main travel mode was assigned based on the priority order of modes of the preceding sentence. The reason for this ordering is that higher priority modes are most likely to take up the longest part of the tour, especial in time (BTS, 2011). Another reason is that lower priority modes can be considered "feeder" modes (Currie and Delbosc, 2011). Given the focus on mode choice between public transport and car, 19,866 eligible tours which involved public transport and the car are studied.

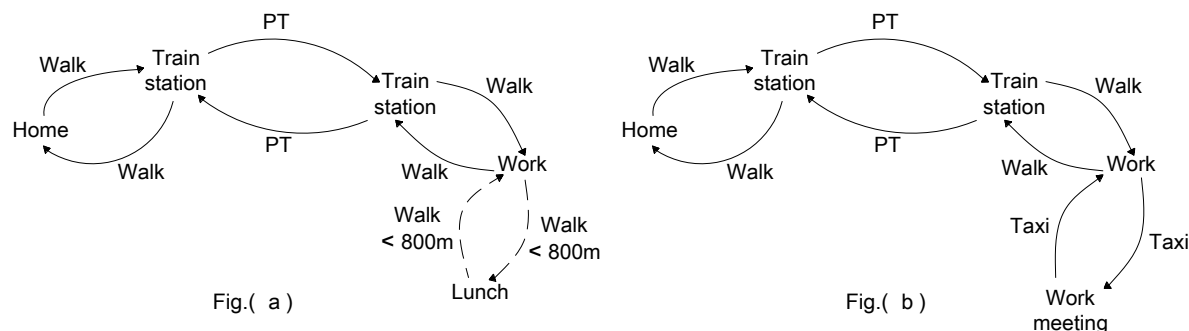
The Sydney HTS records "changing mode" as one type of purpose/stop. Consequently, the constructed tour-based dataset includes trip legs with the purpose of changing mode. Using the number of trip legs in a tour may artificially increases the complexity of tours, especially public transport tours. Thus, this paper analyses tour complexity using the number of intervening activities (not changing mode, not returning home) rather than trip legs.

3.2 MPSD identification

An activity chained into a home-based tour was considered as sharing the destination with others, and therefore a home-based tour was considered involving multiple purposes at a single destination, if three conditions were simultaneously satisfied. First, the trip leg to that activity involved an intervening activity. Second, that activity location was reached by walk (other non-motorised modes were rare) and the location was within a walkable distance of 800 meters from the immediately preceding activity.¹ Third, the purpose of the immediately preceding trip leg was not 'changing mode'. The third condition is introduced to ensure activities taking place at a single destination are all intervening activities. Using this approach, destinations and the number of activities chained into tours were equal to the total number of activities minus the number of activities sharing a destination with others (i.e., MPSD). Figure 1 illustrates two home-based tours with one involving MPSD and shows how tours are coded by the three different approaches to examining tour complexity discussed in Section 0.

For multiple activities at one destination, one activity is considered as the primary activity, (the main reason for visiting the destination) while others are referred to as secondary activities. In the example tour plotted in Figure 1a, work is considered as the primary activity and is also the main purpose of the whole tour. On the other hand, 'lunch' and 'return to work' are considered as secondary activities, sharing the same destination with the work activity. Primary and secondary activities are not applied to tours without the presence of MPSD. The proposed typology of tours classified tours without the present of MPSD as multiple purposes at multiple destinations (MPMD) tours (Figure 1b) or single purpose at single destination (SPSD) tours. The latter is referred to as *simple* while the former is referred to as *complex* with the categorical classification approach. With the approach using the number of activities, SPSD tours are *least complex* and MPMD tours are *more complex* (than, e.g., SPSD).

¹ A walkable distance of 800 metres was chosen after reviewing the available literature on this topic with a special consideration on studies in Australia (O'Sullivan and Morrall, 1996; Rastogi and Krishna Rao, 2003; Burke et al., 2006; Burke and Brown, 2007; Daniels and Mulley, 2011) and the purpose of the walking trip between activities sharing a destination which was to an activity site rather than to change mode.



Tour typology	Tour Complexity Fig.(a)	Tour Complexity Fig.(b)
Categorical classification	Complex	Complex
Total no. of activities	Quite complex with 3 activities (Work; Lunch; Return to work)	Quite complex with 3 activities (Work; Work-related; Return to work)
Destinations & no. of activities	MPSD Main activity = Primary activity: work Secondary activities: lunch; return to work	MPMD with 3 activities Main activity: work

Figure 1: Example tours and tour complexity defining methods

3.3 Analysis approach

This paper approaches the relationship between tour complexity and mode choice using both descriptive and modelling analyses. The descriptive analysis provides a basic understanding of the nature of tours undertaken by car and the sub-modes of public transport. It also offers an opportunity to compare the results across different studies in this field, especially those from Australia, which exclusively used descriptive analysis. Additionally, the descriptive analysis serves as a precursor to modelling the relationship between tour complexity and mode choice. The results are discussed in the next section.

4. Results

4.1 Descriptive analysis

Figure 2 shows the distribution of tours by tour complexity classified as MPMD, MPSD, SPSD on an average day in Sydney. Travel involving MPSD represented nine percent of all home-based tours (1,748/19,866 = 9%) and about one-fifth of ‘complex’ tours (1,748/ [1,748+6,512] = 21%). Although the car was the dominant mode overall, MPSD tours were much more likely than MPMD and SPSD tours to be done by public transport (33 percent compared to 9 percent and 12 percent respectively). Consequently, the imbalance of modes was much smaller for MPSD tours than for MPMD and SPSD tours. For instance, the average probability for car and public transport for MPSD work tours is respectively 0.185 and 0.177; in contrast to MPMD work tours of 0.253 for car and 0.04 for public transport.

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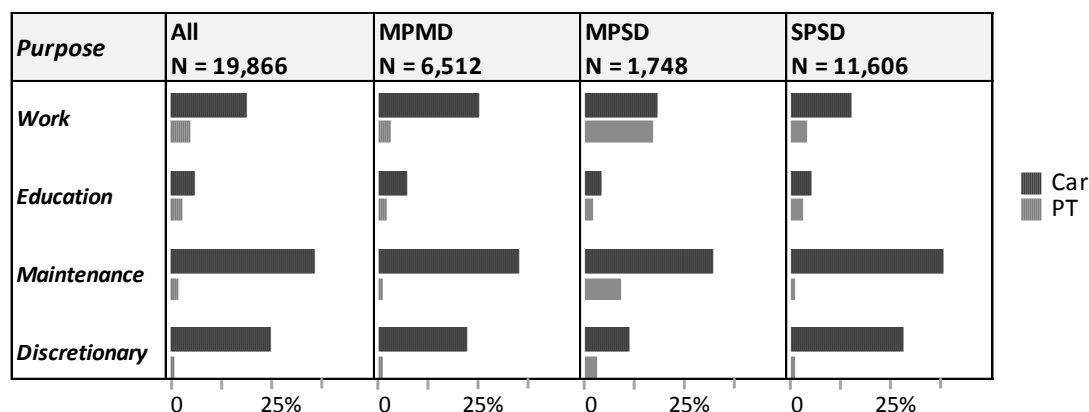
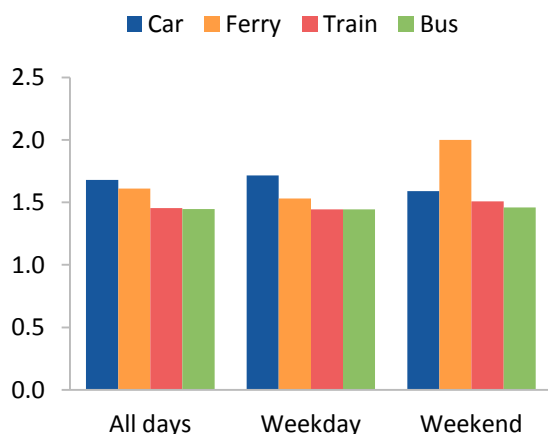


Figure 2: Proportion of tours by tour complexity, average day in Sydney

Much of the literature on tour complexity focuses on the number of activities chained into a tour. To compare with other studies and using two ways of defining tour complexity, Figure 3 shows the difference in complexity for all modes of public transport compared to car. When activity locations are taken into account in defining tour complexity (Figure 3a), public transport tours are statistically significantly *less* complex than car tours except for the ferry tours on weekends. This finding lends credence to the conclusions derived by Hensher and Reyes (2000) that as a tour becomes more complex public transport would less likely to be used. However, when tour complexity is measured as the number of activities within a tour (Figure 3b) public transport tours are statistically significantly *more* complex than car tours. This finding is consistent with the results from Adelaide and Melbourne (Primerano et al., 2008; Currie and Delbosc, 2011).

(a). Average destinations and activities per tour



(b). Average activities per tour

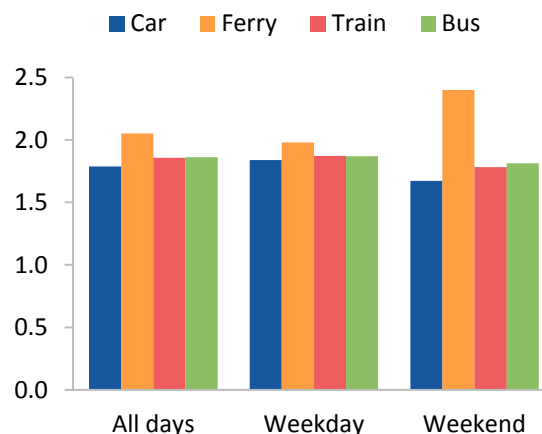
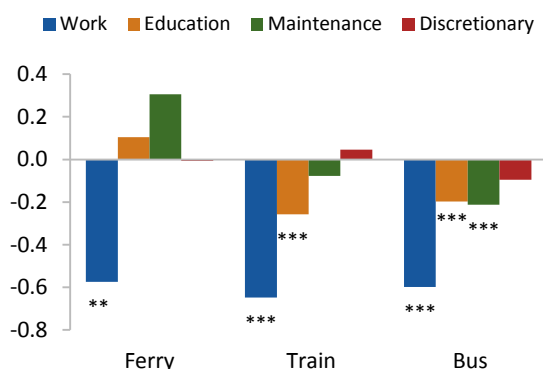


Figure 3: Tour complexity by mode and day of week: two approaches to tour complexity

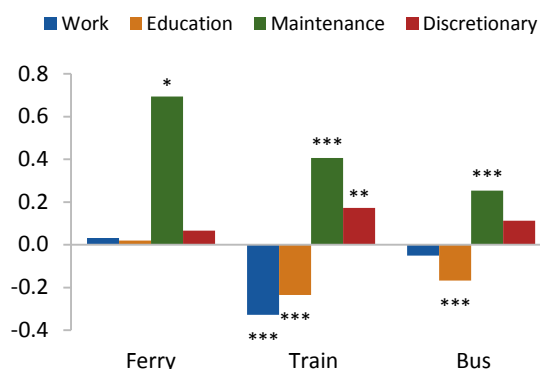
The breakdown of travel purposes shown in Figure 4 indicates differences in complexity of public transport tours relative to car tours across the two methods of defining tour complexity. When destinations visited are taken into account, public transport tours are less complex than car tours for all purposes where differences are significant. Conversely, when tour complexity is represented by the number of activities without regard to destinations, public transport tours are more complex for non-subsistence activities, especially maintenance but less complex for subsistence activities than car tours. Clearly, travel involving MPSD has substantial impacts on tour complexity and can completely change conclusions of the relationship between tour complexity and mode choice.

(a). Difference in destinations and number of activities



Note: *** p < 0.01; ** p < 0.05; * p < 0.10

(b). Difference in number of activities



Note: *** p < 0.01; ** p < 0.05; * p < 0.10

Figure 4: Difference in complexity for public transport tours compared to car tours by tour main purpose: two approaches to tour complexity

Figure 5 shows the relationship between mode choice and tour complexity with activities chained into a tour being classified into two groups: those done at different places and those done at the same destination with others. As the number of activities done at different places chained into a tour increased, public transport use decreased. Conversely, the more activities sharing destinations with others was chained into a tour, the more likely public transport was used. Thus, combining the two types of activities having different relationship patterns with mode of travel would result in an ambiguous relationship between tour complexity and mode choice.

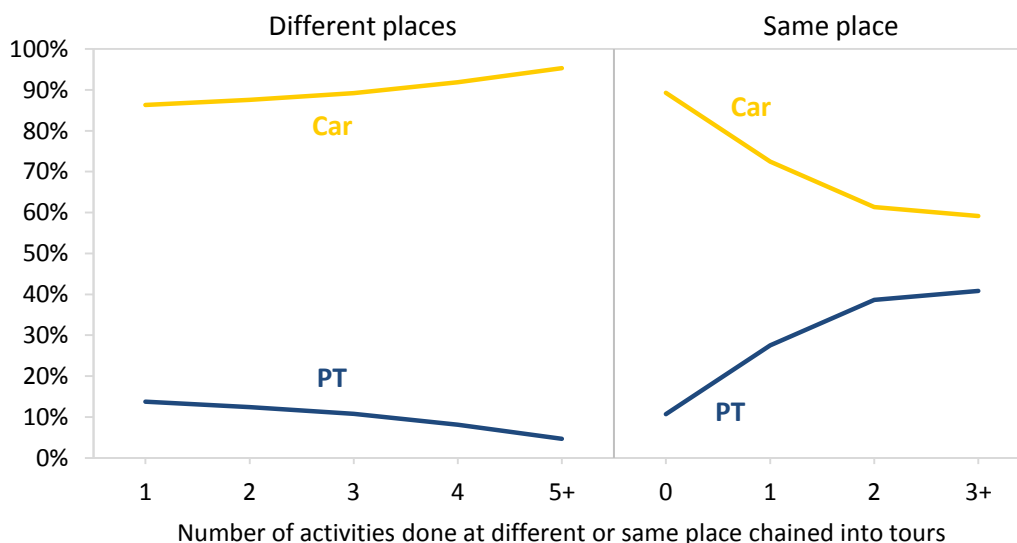
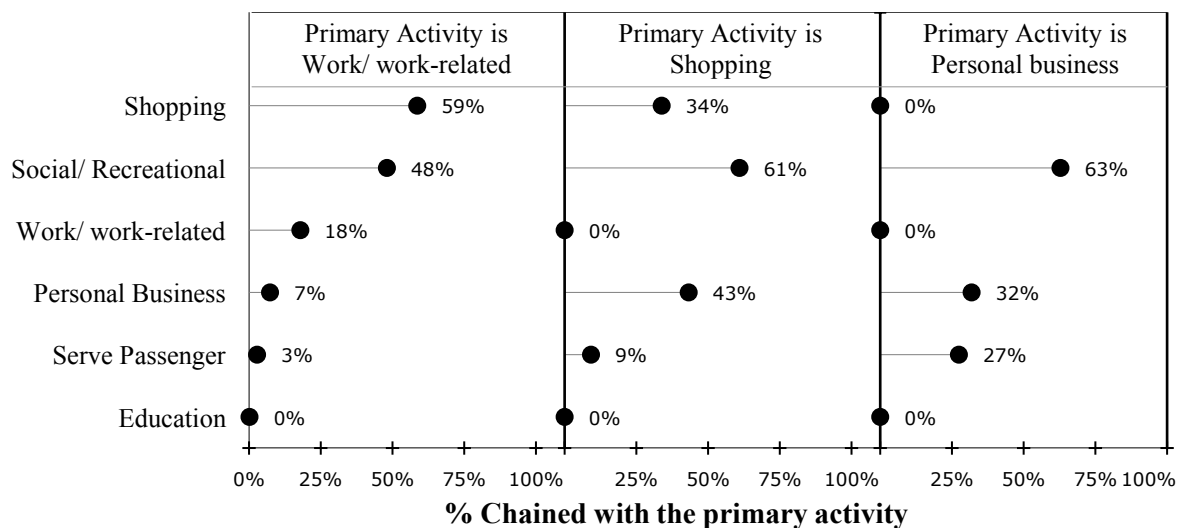


Figure 5: Modal share of home-based tour by two indicators of tour complexity

Because public transport use increases with the number of secondary activities chained into a tour (Figure 5), further analysis investigated the kinds of tours in which people have tended to cluster activities into a single destination. Discretionary and maintenance activities were significantly more likely to involve MPSD than subsistence activities. The majority (80 percent) of weekday non-subsistence public transport tours involving MPSD were made during off-peak periods. Of weekday public transport tours involving MPSD with the main purpose being non-subsistence made during peak periods, the bus share was twice the train share. This reflects the difference in the fare system between train and bus in Sydney, where off-peak ticket fares are available for train but not for bus.

The tendency for a primary activity to have secondary activities pursued within a single destination is also investigated. Figure 6 shows the occurrence of secondary activities by selected primary activities. Of tours involving MPSD, social/recreational activities appeared to be chained the most with personal business, shopping, and work or work-related business. Shopping and personal business also showed a high propensity to be chained with work and activities of the same types. Primerano et al. (2008) report a similar results but they do not differentiate between MPMD and MPSD tours.



Note: Sum of percentages do not equal 100% because there were MPSD tours with more than one secondary activity.

Figure 6: Occurrence of secondary activities by selected primary activities of MPSD tours

Descriptive analyses have partially addressed the first two hypotheses identified in section 2.2 above. However, the tests which are possible with descriptive analyses suffer from the limitation of being unable to postulate and confirm a direction or the nature of causation. Thus the correlation between tour complexity and mode choice may be created by individual and household characteristics that influence both choices, such as gender or the presence of children and hence to fully consider the hypothesis, the next section develops a nested logit model which controls for individual, household characteristics, and tour attributes.

4.2 Travel alternative identification

As Table 1 demonstrates, the tours undertaken by people in the dataset are varied. The tours vary across the main purpose and main mode of travel. There is a minority of tours for subsistence activities and, a substantial proportion of public transport tours for non-subsistence activities. The mix of travel modes and travel purposes makes it important to include both mode and purpose as part of the alternatives for analysis within the nested logit model development.

Table 2 provides an overview of the explanatory variables used in the model specification plus their definitions and descriptive statistics. Apart from household, individual and tour characteristics, variables representing transport-related fringe benefits are also tested with the model specification. Several variables in Table 2 require further explanation. Car-negotiating households are defined as households with fewer cars than licence holders while car-sufficient households (base) are those with at least as many cars as licence holders. Tour complexity is represented by two variables. The variable *N_Acts* represents destinations and the number of activities chained into a tour and the variable *MPSD* represents the number of secondary activities sharing a destination with others in the presence of MPSD. Travel party size (variable *Partysize*) is introduced to explain the demand of household members for a household car, the efficiency of car use and the interactions between/among household members in arranging daily activity-travel patterns. Travel party size is a raw count number of household members involved in a home-based tour.

Table 1: Choice frequencies across home-based tours

Choice number	Main purpose	Main mode	Frequency	Percent
1	Work	Public transport	1,080	5.4%
2	Work	Car	3,815	19.2%
3	Education	Public transport	605	3.0%
4	Education	Car	1,207	6.1%
5	Maintenance	Public transport	438	2.2%
6	Maintenance	Car	7,334	36.9%
7	Discretionary	Public transport	396	2.0%
8	Discretionary	Car	4,991	25.1%
Total tours			19,866	100%

Table 2: Explanatory variables: definitions and descriptive statistics

Variable name	Variable description	Mean	Std. Dev.
<i>Household characteristics</i>			
Car-nego	Car-negotiating household (1/0)	.32	.467
No-car	No-car household (1/0)	.07	.255
HiInc	Annual household income > A\$ 67,600 (1/0)	.66	.473
MidInc	Annual household income = A\$ 31,200 - 67,600 (1/0)	.21	.409
Child0_5	Number of children aged 0 -5 years in household	.30	.624
Predri	Number of children aged 6 - 16 years in household	.79	1.054
<i>Individual characteristics</i>			
Male	Respondent is male (1/0)	.49	.500
Student	Respondent is student (1/0)	.11	.315
Worker	Respondent is worker (1/0)	.59	.492
Retiree	Respondent is retiree (1/0)	.12	.328
FullFlex	Respondent with fully flexible working time (1/0)	.01	.114
PartFlex	Respondent with partially flexible working time (1/0)	.10	.305
<i>Tour attributes</i>			
N_Acts	Destinations and no. of activities chained onto tour	1.63	1.009
MPSD	Number of secondary activities (see Fig. 1)	.14	.506
Partysize	Number of household members participating in tour	2.02	1.153
<i>Transport-related fringe benefits</i>			
FreePark	Free parking provided (1/0)	.21	.409
CompCar	Company car provided (1/0)	.08	.273
CarCost	Car costs provided (1/0)	.10	.301
PTFare	Public transport fares provided (1/0)	.01	.119
ParkCost	Parking costs provided (1/0)	.04	.193
FuelCost	Fuel costs provided (1/0)	.11	.318

4.3 Model estimation results

All models are estimated using NLOGIT 5.0. This section presents estimation results of the preferred nested logit model after investigating a number of tree structures in which different variances of the

random components were likely to exist for a subset of alternatives. The preferred model found the variance of the unobserved component to be different between public transport and car tours. The inclusive value parameter of car tours was one (fixed) while that of public transport tours was 0.472 (freely estimated). The latter is significantly different from 1.0 at the one percent level, leading to the conclusion that this partition is consistent with random utility maximisation theory. McFadden's adjusted Rho-squared is 0.293 indicating a relatively good fit to the data.

4.3.1 The nature of tours via public transport and car

Table 3 shows the estimation results of the unrestricted model that assumes activities done at different places and activities sharing a destination with others have different effects on mode choice. As identified above, tour complexity measured by the two variables *N_Acts* and *MPSD* is statistically significantly different from zero, with *N_Acts* being negatively correlated and *MPSD* being positively correlated with public transport use. This finding supports the hypothesis that tours undertaken by public transport and car are different, where car is utilised in travel involving MPMD whereas public transport is more suitable for tours with activities being in close proximity and reachable by walking or non-motorised modes. Thus, the barrier to public transport use is not necessarily the number of activities chained into a tour but is strongly linked to the spatial distribution of the activities.

Table 3: Estimation results for the unrestricted NL model of tour-based mode choice

Tour type	Work - PT		Edu. - PT		Maint. - PT		Discr.- PT		Edu.- Car		Maint. - Car		Discr. - Car	
	Coeff.	Sig.*	Coeff.	Sig.*	Coeff.	Sig.*	Coeff.	Sig.*	Coeff.	Sig.*	Coeff.	Sig.*	Coeff.	Sig.*
<i>Tour attributes</i>														
N_Acts	-0.183	***	-0.216	***	-0.126	***	-0.128	***						
MPSD	0.779	***	0.353	***	0.850	***	0.517	***						
Partysize	-0.333	***	-0.161	***	-0.310	***	-0.264	***						
<i>Transport-related fringe benefits</i>														
PTFare	0.701	***			0.391	*	0.439	*						
FreePark	-1.037	***			-0.644	***	-0.658	***						
CarCost	-0.607	**			-0.643	*	-0.571	**						
CompCar	-0.723	***												
FuelCost	-1.934	***	-3.622	***	-2.155	***	-2.043	***						
<i>Individual characteristics</i>														
FullFlex	0.415	***												
PartFlex	0.190	***												
Male	-0.206	***	-0.207	***	-0.502	***	-0.193	***	-0.319	***	-0.591	***	-0.392	***
Worker	2.366	***									-0.551	***	-0.894	***
Student			0.979	***					0.979	***				
Retiree					0.672	***					0.672	***		
<i>Household characteristics</i>														
HiInc	-0.683	***	-1.017	***	-1.292	***	-1.196	***	-1.029	***	-0.620	***	-0.747	***
MidInc	-0.617	***	-0.691	***	-0.856	***	-0.947	***	-0.823	***	-0.602	***	-0.722	***
Child0_5	-0.165	***	-0.419	***	-0.264	***	-0.680	***						
Predri			0.396	***			-0.152	***						
No-car ^a	2.296	***	2.296	***	2.296	***	2.296	***						
Car-nego ^a	0.308	***	0.308	***	0.308	***	0.308	***						
Constant	-1.426	***	-0.330	**	0.363	**	0.533	***	-0.227	*	1.798	***	1.699	***
Inclusive value parameter of public transport tours					0.472	***								
Inclusive value parameter of car tours					1.0	fixed								
<i>Summary statistics</i>														
Number of observations					19,866									
Log likelihood function					-29,180									
Pseudo R-squared adjusted (constants)					0.0977									
Pseudo R-squared adjusted (zero)					0.2933									

Note: *Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level. ^a Coefficients were constrained to be equal across public transport alternatives.

4.3.2 *Tour complexity and mode choice: effects of classification schemes*

The second hypothesis is tested by estimating the restricted model where all activities chained into a tour are restricted to have the same effect on mode choice regardless of where they take place. The results are compared with the unrestricted model using a likelihood ratio test. Table 4 shows the outcome for the coefficients associated with the two indicators of tour complexity (i.e., *N_Acts* and *MPSD*). The restricted model is soundly in favour of the unrestricted model ($p < 0.0001$). Three of the coefficients associated with the tour complexity for public transport alternatives in the restricted model were significantly *greater* than zero and, although the estimate associated with education tours has the expected sign it is only statistically significant at the ten percent level. This suggests when complexity is simply represented by the number of activities or trip legs chained into tours rather than taking account of spatial distribution, public transport tours maybe found to be more complex than car tours. In summary, therefore the second hypothesis is strongly supported.

Table 4: Estimates of the two indicators of tour complexity and specification tests of the restricted vs. the unrestricted NL models*

Main purpose of PT tours	Restricted model		Unrestricted model	
	<i>N_Acts</i>	<i>MPSD</i>	<i>N_Acts</i>	<i>MPSD</i>
Work	0.144***	0.144***	-0.183***	0.779***
Education	-0.057*	-0.057*	-0.216***	0.353***
Maintenance	0.209***	0.209***	-0.126***	0.850***
Discretionary	0.055*	0.055*	-0.128***	0.517***
Log-likelihood	-29,406.34		-29,180.17	
2* Log-likelihood difference			452.32	
Significance level			< 0.0001	

* Significant at the 10% level; *** Significant at the 1% level

4.3.3 *Mode choice of complex tours for different activities*

This section aims to determine whether tour complexity is a generic barrier to public transport use across travel purposes. In this regard, Hensher and Reyes (2000) found that trip chaining influence impacts most on simple non-work tours and least on complex non-work tours. Their research investigated the barrier of tour complexity to public transport use through the use of an indirect measure, the number of cars in a household. This paper measures tour complexity more directly with the two variables, *N_Acts* and *MPSD*.

As can be seen in Table 3, the effects on public transport use of activities done at different places chained into a tour (*N_Acts*) were larger for subsistence activities than for non-subsistence activities. This finding does not fully support the conclusions derived by Hensher and Reyes (2000) described above. To investigate further, several hypotheses about complexity as a generic barrier to public transport use across all and a subset of travel purposes are tested. It does this by imposing equality of coefficients associated with the two variables representing tour complexity before re-estimating the model with the likelihood ratio test being used. Table 5 shows the hypothesis testing results. The hypothesis that tour complexity is a generic barrier to public transport use across all purposes is rejected. This finding is consistent with Hensher and Reyes (2000). However, the results are mixed for two measures of tour complexity when considering subsets of subsistence or non-subsistence activities. The likelihood ratio tests cannot reject the null hypothesis that spatial separation of activities chained into a tour (*N_Acts*) is a generic barrier to public transport use when considering subsistence activities or non-subsistence activities. On the other hand, *MPSD* was found to ease public transport use to different levels for different travel purposes. This suggests that chaining an additional activity

done at a different location from others into a work tour or education tour has the same effect on public transport use while the effect of chaining an additional activity done at the same destination as others is different between work tours and education tours. A similar interpretation can be drawn for non-subsistence activities.

Table 5: Testing results of hypotheses that tour complexity is a generic barrier to public transport use

Tour complexity indicator	Tour complexity is a generic barrier to public transport use		
	Across all purposes ^a	Within subsistence ^b	Within non-subsistence ^c
N_Acts	Reject the null at p = 0.008	Cannot reject the null at p = 0.10	Cannot reject the null at p = 0.10
MPSD	Reject the null at p < 0.001	Reject the null at p < 0.001	Reject the null at p < 0.001

Null hypothesis: ^a $\beta_{work} = \beta_{education} = \beta_{maintenance} = \beta_{discretionary}$; ^b $\beta_{work} = \beta_{education}$; ^c $\beta_{maintenance} = \beta_{discretionary}$

4.3.4 Other factors influencing mode choice

Although the developed NL model was intended to test three hypotheses, the results highlight some other issues. Household car ownership has a significant influence on public transport use, with no-car households being most likely and car-negotiating households being more likely than car-sufficient households (base) to use public transport for all travel purposes (see Table 3). In contrast, the propensity of public transport use decreases as travel party size increases, reflecting the demand for a household car and intra-household interactions in mode choice for joint household travel. This is further reinforced with a significant negative influence of the presence of pre-school children (*Child0_5*) in the household on public transport use. The impact of pre-school children is likely to be twofold. First, the propensity of undertaking tours with more household members involved increases with the presence of pre-school children because they normally do not stay home alone. Second, servicing the children's needs contributes to the increasingly spatial dispersion of tours, resulting in lower utility associated with the use of public transport.

The barrier and motivation to public transport use is strongly linked to the type of transport-related fringe benefits provided to the worker. The probability of undertaking working tours by public transport increases if public transport fares are provided; conversely, if benefits favour the provision or running of a car, this significantly reduces the use of public transport. Interestingly, these effects 'spill over' to maintenance and discretionary travel, albeit less significantly unless the benefit includes the payment of fuel costs where the spill over effect is significantly stronger.

The opportunity for decreasing commuting tours involving a car tends to increase if the worker has a flexible working time. This is reinforced if the workplace is among clusters of services and activities that can be reached by non-motorised modes. This suggests mixed land use developments at workplaces are important as workers are significantly less likely to generate purely maintenance and discretionary tours involving a car.

Gender differences in mode choice and activity allocation are evident with men being less likely than women to commute by public transport; men are also less likely to undertake purely non-work tours involving a car or public transport. This result confirms previous results where gender structures in car availability and household task allocation have been acknowledged (Schwanen et al., 2007; Scheiner and Holz-Rau, 2011). The results of this model show the much greater gender difference in maintenance activities, which has not previously been reported.

The impact of household income on travel mode and activity generation is significant for seven of the eight alternatives. *Ceteris paribus*, as household income increases, the propensity to

generate commuting tours involving a car tends to increase. Perhaps higher income households, which tend to be dual-earner couples, are more sensitive to the longer travel time of public transport modes while less sensitive to the higher cost incurred by the ownership and use of a car. Also, as household income increases, increasing the demand for accessing work, the probability of purely non-work tours being undertaken is less with an increasing number of non-work activities being tied to the commuting tour. This is consistent with Hensher and Reyes (2000).

5. Discussion and conclusions

This paper adds to the understanding of how the complexity of tours influences travel mode choices and sheds light on the reasons why conflicting findings exist in the literature. Using the Sydney three years pooled household travel survey data, this paper proposes a new approach to the typology of tours which takes into account not only the number but also the spatial distribution of activities chained into tours. In Sydney on an average day, tours involving multiple purposes at a single destination represent about 20 percent of complex home-based tours (i.e., tours involving more than one out-of-home activity) and have significant impacts on mode choice. This paper has demonstrated, using both descriptive and modelling evidence, that failing to account for the spatial distribution of activities chained into tours results in an ambiguous and counter-intuitive relationship between tour complexity and mode choice.

Research suggests that car reliance of complex tours coupled with increasing complex tour patterns in modern life implies a bleak outlook for public transport ridership (Levinson and Kumar, 1995; McGuckin et al., 2005; Ye et al., 2007). The findings from this paper, while supporting the conclusion that complex tours are less likely to be public transport oriented, pinpoints the areas most in need of help to promote public transport use. Tours undertaken by car and public transport were found to be different in nature, with public transport activities chained into a tour being in close proximity and reachable by walking. On the other hand, the car was found to be utilised for travel involving multiple purposes at multiple destinations. The analysis investigating the types of activities that people tend to chain into a single destination suggests that planning strategies to increase public transport use need to focus on providing multiple purposes at a single destination. For instance, a cluster of activity centres where people can do social/recreational, shopping and personal business at one place without the need to travel in between by motorised modes could promote public transport use. Also, increased mixed land use developments at workplaces to allow workers to do multiple activities near their workplaces would reduce car commutes.

In spite of the growing efforts to make the use of public transport easier, the existence and presence of crowding together with user preferences for less crowding will continue to be a barrier in increasing public transport ridership (Hensher et al., 2011; Li and Hensher, 2011). This study suggests that in Sydney on an average weekday, of non-work, non-education public transport tours made during the peak period which involved multiple purposes at a single destination, the bus share was twice the train share. Whether an introduction of off-peak tickets for bus would encourage people to reschedule these non-subsistence activities and therefore reduce crowding levels on buses during peak periods is open to question and requires further research.

Household vehicle ownership leads to less public transport use. This paper finds in addition that the spatial distribution of activities chained into a tour significantly contributed to or took away the relative utility of the public transport mode. Whether these activities are undertaken at a single destination or at multiple destinations had different implications as did the effect of travel purpose.

The existing literature suggests that barriers to public transport use are strongly linked to household lifecycle, individual characteristics, and trip attributes. This paper examined, in addition, the impact of transport-related fringe benefits and intra-household interactions in the

organisation of travel needs. Transport-related fringe benefits were found to influence public transport use significantly and the effects were not limited to commuting but spilled over to other travel purposes. Regarding intra-household interactions, the analysis suggests that, as the number of household members involved in the tour increased, the utility yielded from using the car increased for all travel purposes. Because joint household travel represents a substantial amount of regional travel demand, interactions between household members and joint decisions in travel need more attention (Vovsha et al., 2003). This study starts this discussion through its introduction of the travel party size as a simple way to take into account interactions between household members, but again is an area requiring further research to model directly joint household decisions as part of the mode choice models.

As the proposed model does not directly recognise endogeneity, the parameters associated with public transport use for the numbers of destinations visited and secondary activities must be interpreted carefully and transferred elsewhere with caution. It is possible that the strength of the relationship between tour complexity measured by these two indicators and mode choice will change in a model which recognises endogeneity (Train, 2009). Future research needs to consider the endogeneity issues and investigating the extent to which the relationship between tour complexity and mode choice are sensitive to model specification.

One step further is to investigate if there are any demographic factors underlying the generation of tours involving multiple purposes at a single destination (MPSD). Given that public transport has the strength to compete with the car in tours involving MPSD, understanding the circumstances under which travel as MPSD prevails would help to segment and target the public transport market accordingly. Furthermore, these tours were found to be scheduled more frequently for non-work, non-education activities which are currently lying somewhat outside the targeted market of public transport, so that this knowledge would suggest complementary approaches to increase public transport ridership. Another direction that needs further investigation is the land-use characteristics of places where people were found to chain multiple purposes into a single destination. This knowledge would be useful to planning practices that reduce the need for travel involving a car.

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