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Greening demand chains in urban passenger transport: Emissions saving from complex trip chains

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ABSTRACT:

It is well known that a significant amount to passenger trip activity involves multiple modes, destinations and trip purposes. For example, with multi-worker households, we observe a car commuter taking a child to a child care centre en route to work and also dropping their partner off at another location such as a railway station. This example is one of many trip chain configurations that represent the complexity of travel activity, and which have important implications on how we represent travel demand in transport planning models. What is not well understood is the impact that trip chaining has on greening the demand chain. We are unaware of any studies that have investigated the greening of passenger demand chains associated with the complexity of trip chains. This chapter uses the Sydney Household Travel Survey and an econometric model to identify the impact that the changing nature of trip chains has on CO2 emission. Results suggest that trip chains were stable in Sydney over a period of 15-year from 1997/87 to 2011/12. Emissions saving from chaining multiple activities into a single chain were found to vary between 5% to 19% depending on whether the mode of travel is car, bus, or train.

KEY WORDS: ***trip chains, travel activity, CO_2 emission, transport modes, tour complexity, green travel demand***

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1. Introduction

Continuing concerns over global warming and pollution have called for prompt action to reduce energy consumption and greenhouse gas (GHG) emissions. In the transport sector, much of the focus has been on the opportunities to reduce car use, notably vehicle kilometres travelled (VKT), as this is the single most relevant driver of resource consumption and environmental degradation. One way of reducing the travel input while still fulfilling individual and household needs is to chain multiple out-of-home activities into a single trip chain. This tactic is well described in the literature as the travelling salesman problem if the objective is to minimise distance travelled. However, the problem of cutting GHG emissions with the trip chaining initiative deals not only with distance travelled but also with mode of travel. The impact of trip chaining on GHG emissions is therefore ambiguous as (spatially) complex trip chains are more likely to be undertaken by car, and the average emission rate of the private car is usually higher than that of public transport.

This chapter explores the impact of trip chaining on CO_2 emission using evidence from the Sydney Household Travel Survey. The central question being addressed is whether different ways of arranging daily activities into trip chains have a significant impact on CO_2 emission by considering the complexity of trip chains and the travel mode used to access activities. We are unaware of any studies that have investigated the greening of passenger demand chains associated with the complexity of trip chains.

This chapter brings together different methods of classifying the complexity of trip chains in the transport literature and proposes a modelling approach to provide insights into the impact of trip chains on CO_2 emission. The research expands on the literature by considering multimodal trip chains in comparison to those involving car only. It also considers the differences in CO_2 emission for alternative arrangements of activities into multiple simple trip chains or a single complex trip chain, given the number of daily activities and their locations.

The chapter is structured as follows. We begin with a brief review of the literature related to trip chaining, including its relationship with travel mode. This is followed by a description of the data and the selection of a method for analysing the influence of trip chaining on CO_2 emission. Estimation and simulation results are then presented, and the chapter concludes with a summary of the key findings and a discussion of the implications for greening passenger demand chains.

1.1 Literature review

There exist different definitions of a trip chain, with the most popular one, coined by Adler and Ben-Akiva (1979), defined as a series of trips that begin and end at an individual's home. By this definition, a trip chain is equivalent to a home-based tour, and thus these terms are used interchangeably in this chapter. A trip chain can be very simple with only one activity accessed by a single mode, but it can also be very complex, involving multiple activities, multiple destinations and multiple modes. To reflect the complexity of trip chains, different trip chain typologies have been proposed in the literature and these can generally be classified into three types. The first typology uses only the number of activities chained into a tour to classify trip chains (e.g., Currie and Delbosc 2011). The second typology also considers the sequence of activities chained into a tour and provides a more detailed coding scheme (Strathman et al. 1994; Golob 1986). The final typology takes into account both the number and the spatial distribution of activities chained into a tour and classifies tours into single purpose at single destination, multiple purposes at single destination, or multiple purposes at multiple destinations (Ho and Mulley 2013a).

An adopted typology needs to consider the purpose of the study and has to be simple and clear to make it useful and manageable (Krizek 2003). Primerano et al. (2008) provided a comprehensive review of trip chain typologies and proposed a classification shown in Table 1. We adopt this tour typology as it is quite flexible to turn this typology into a sophisticated coding by considering the primary travel purpose or a combination of the primary and secondary activities. For example, the simple chain shown in Table 1 can be translated into a simple work chain or a simple non-work chain described in Strathman et al. (1994) and Hensher and Reyes (2000), depending on the travel purpose of the activity being work or non-work.

Table 1 Trip chain typology proposed by Primerano et al. (2008)

Trip chain type	**Configuration**
Simple chain	H – P – H
Complex to primary activity	H – {S} – P – H
Complex from primary activity	H – P – {S} – H
Complex to and from primary activity	H – {S} – P – {S} – H
Complex at primary activity	H – P – {S} – P– H
Complex to, at, and from primary activity	H – {S} – P – {S} – P – {S} – H

Note: H = Home, P = Primary activity, {S} = one or more secondary activities.

Trip chaining is an important aspect of travel that has a significant impact on mode choice and distance travelled, which in turn influence GHG emissions. Research on the relationship between the complexity of trip chains and the choice of travel modes has established a causal link from the former to the latter (Krygsman et al. 2007; Ye et al. 2007) and a preference for the private car to public transport for making (spatially) complex trip chains (Hensher and Reyes 2000; Ho and Mulley 2013a; Cicillo and Axhausen 2002). Thus, any reduction in GHG emissions resulting from chaining multiple activities may be offset by the need of using the private car for undertaking complex trip chains. We investigate the relationship between trip chaining and GHG emissions, taking into account the effect of travel mode.

Taking a closer look at the existing literature on changes in trip chaining behaviour, some studies find that trip chains are becoming increasingly complex (McGuckin et al. 2005; Levinson and Kumar 1995), while other studies suggest no change in the complexity of trip chaining over time (Currie and Delbosc 2011). This calls for a deeper investigation of the change in trip chaining behaviour as these different findings may result in part from changes to household structure, vehicle ownership and travel purpose, given that these factors are known to influence tour complexity (Strathman et al. 1994). Understanding the changing nature of trip chains is important for developing policy to reduce GHG emissions and to limit individual reliance on the private car. If trip chains become more complex as people are busier, then car use will increase in the future and greener cars are required to cut GHG emissions. However, if trip chaining behaviour stays stable, promoting public transport ridership can also be counted as a possible way to reduce the impact of travel on the environment. This chapter provides evidence on the change of trip chaining behaviour over a 15-year period from 1997/98 to 2011/12, using the Sydney Household Travel Survey (HTS) data.

2. Methodology

2.1 Creating trip chaining dataset from household travel surveys

The main data for analysis were created from the Sydney HTS which has been described elsewhere (Ho and Mulley 2013a; b). For the purpose of this chapter, we provide a general description of the survey. The Sydney HTS was first conducted in 1997/98 and the latest available wave was 2011/12. To date, the database includes 15 consecutive waves with each wave including a survey of household characteristics, person characteristics, vehicle characteristics, and a 24-hr travel diary for each participant. The collected information is organised into four separate tables which can be linked by key variables that are unique to each household, person, vehicle and trip. The trip table was restructured to create a trip chaining dataset where each row (or record) can be viewed as a round-trip journey, beginning and ending at the home. A small number of persons with a travel diary starting or ending outside the home were excluded from the analysis. This trip chaining dataset was used to examine the changing nature of trip chains.

The typology shown in Table 1 was the basis for classifying trip chains. This required the identification of primary and secondary activities and their sequences in trip chains with more than one out-of-home activities. Primary activities were assigned based on a hierarchical basis, with work/work-related business activities being the highest, followed by education, serving passenger (i.e., dropping off, picking up or accompanying someone), shopping, personal business, social and recreation activities. Secondary activities chained into each tour were then identified as activities other than the primary ones. Finally, a set of conditions was applied to classify trip chains into one of the six types shown in Table 1.

As with travel purpose, a trip chain may involve more than one travel mode. By mode, the trip chains were spread across car, bus, train, ferry, walking, cycling, other modes and the combination of these modes with the most popular multimodal tours being car and bus, car and train, and bus and train. By considering multimodal trip chains, this study is different from the existing literature which usually uses the concept of the main travel mode to deal with multimodal trip chains. The differentiation between single modal and multimodal chains is important for examining the effect of mode choice and trip chaining on CO_2 emission.

2.2 Approach to analysing the effect of trip chains on CO2 emission

CO_2 emission from each trip chain was calculated based on an average emission rate per passenger km and distance travelled by each of the modes involved in the trip chain. In Sydney, CO_2 emission rates per passenger km were 188 grams for an average car, 120 grams for bus, 105 grams for train and 171 grams for light rail (Demographia 2007). Distance and mode of travel were available in the Sydney HTS for each trip leg in a trip chain. Thus, CO_2 emission from each trip chain was approximated as the summation of emission across all trip legs.

The effect of trip chaining on CO_2 emission was examined using a daily activity arrangement framework. Specifically, given the number and locations of out-of-home activities one has to complete in a day, there are different ways of arranging them into trip chains. People with multiple daily activities can arrange them into one complex chain or multiple simple chains, and the way in which activities are chained will have impact on CO_2 emission, as does the travel mode to access these activities. As is common in the activity based modelling literature, we assume that activity generation and location precede mode choice and trip chaining decisions (Davidson et al. 2007; Bradley and Bowman 2006). The results are discussed in the next section.

3. Results

3.1 Descriptive analysis

The changing nature of trip chains was examined by looking at the average number of activities chained into a home-based tour over time, controlling for changes in household structure, car ownership and travel purpose. Fig. 1 shows the change in the complexity of trip chains in Sydney by household structure over a 15-year period from 1997/98 to 2011/12. Controlling for household structure, the complexity of trip chains appears to be stable over the studied period, with the average number of activities chained into a tour ranging from 1.58 to 1.87. One-way ANOVA tests conducted for each of the household structures suggest that there are significant differences in the complexity of trip chains across the 15 years but the estimated effect sizes, represented by eta^2, are very small. That is, controlling for changes in household structure, the time element explains less than 0.2% of the variation in the complexity of trip chains over the 15-year period. An investigation of changes in trip chain complexity by household car ownership and tour main travel purpose, shown in Fig. 2 and Fig. 3, suggests that the complexity of trip chains is also stable over time. This finding is not dissimilar to the findings in Melbourne of Currie and Delbosc (2011), although they did not control for changes in household structure, car ownership and travel purpose.

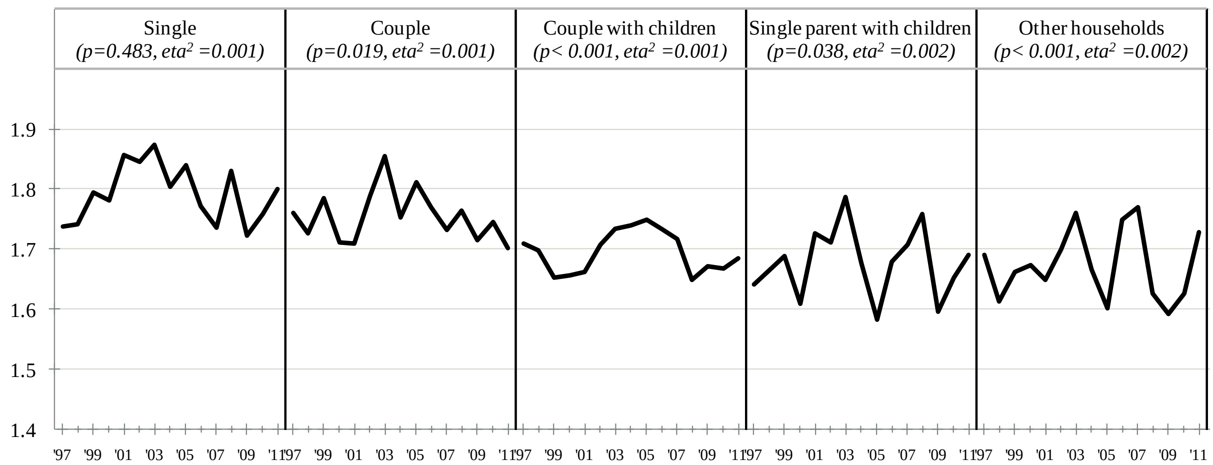

Fig. 1 Average number of activities per trip chain by household structure: changing nature over a 15-year period from 1997/98 to 2011/12 in Sydney

Notes: p-values are for one-way ANOVA tests. Data source: Sydney HTS 1997/98 – 2011/12.

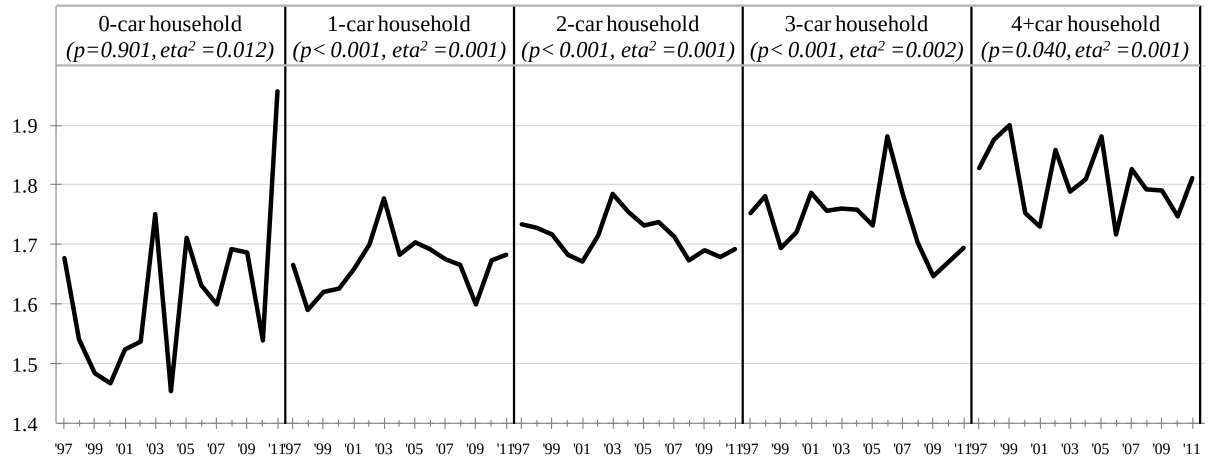

Fig. 2 Average number of activities per trip chain by household car ownership: changing nature over a 15-year period from 1997/98 to 2011/12 in Sydney

Notes: p-values are for one-way ANOVA tests. Data source: Sydney HTS 1997/98 – 2011/12.

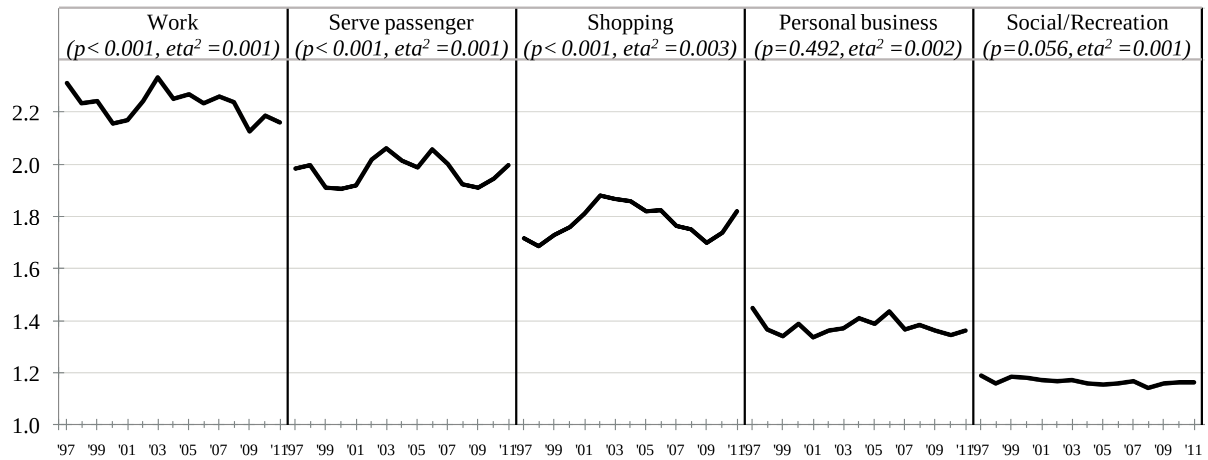

Fig. 3 Average number of activities per trip chain by tour main travel purpose: changing nature over a 15-year period from 1997/98 to 2011/12 in Sydney

Notes: p-values are for one-way ANOVA tests. Data source: Sydney HTS 1997/98 – 2011/12.

However, the finding of a stable trip chaining pattern in Australia is in sharp contrast to the results found in the US by McGuckin et al. (2005) who concluded that between 1995 and 2001 trip chains in the home-to-work journey increased by 20.74%. This contrast appears to arise from two sources. The first source relates to the different definitions of a trip chain used across studies. The second reason, which may be more pronounced, relates to the way in which changes in the population have (not) been controlled for. More specifically, McGuckin et al. (2005) adopted a definition that described a trip chain as a sequence of trips with intervening activities (i.e., not change mode) of 30 minutes or less while our study and Currie and Delbosc (2011) defined a trip chain as a round journey from home to home, including all intervening activities of any duration. Thus, an activity longer than 30 minutes defines the terminus of a trip chain in the former, but does not do so in the latter. This difference together with an increase in the worker population that was not controlled for by McGuckin et al. (2005) has misled them about a sharp increase in trip chaining amongst US workers between 1995 and 2001. This can be seen clearly from Table 2 that was created using data derived from Table 1 in McGuckin et al. (2005) and controlling for the change in the number of workers between 1995 and 2001. While Table 2 still supports the conclusions by McGuckin et al. (2005), an increase in the proportion of trip chains associated with work journeys is much less. Also, with the definition of a trip chain that takes all activities of any duration into consideration, it can be said that trip chains amongst US workers were stable between 1995 and 2001.

Table 2 Proportion of workers who trip chain on work journeys in the US between 1995 and 2001

	1995	**2001**
Sample size		
Number of weekday workers	68,760,000	68,990,000
Did not chain	31,290,000	31,660,000
Chained work trips	17,276,045	18,842,670
Chain home-to-work trip	5,929,237	7,158,844
Chain work-to-home trip	7,762,956	7,659,436
Chain both	3,583,852	4,024,390
Stopped longer than 30 minutes	20,193,955	18,487,330
Proportion of workers who chained…		
Work trips (stopped no longer than 30 minutes)	25%	27%
Home-to-work trip	9%	10%
Work-to-home trip	11%	11%
Both directions	5%	6%
Work trips (stopped longer than 30 minutes)	29%	27%
Work trips (stopped any duration)	54%	54%

Data source: Table 1 in McGuckin et al. (2005).

Fig. 4 shows the average CO_2 emission per activity by trip chain and selected mode of travel (active chains and other multimodal chains were not shown) in Sydney. More than three quarters (76%) of the trip chains were undertaken by car (17,450 chains to the total of 23,023 chains). Of the trip chains made by car, 41% were complex with two or more out-of-home activities. Holding travel mode constant, average CO_2 emission per activity decreases as the complexity of trip chain increases. This result is expected: given the number of activities, the fewer tours are made to chain activities (or the more complex the trip chains) the shorter the total distance travelled due to fewer 'return home' trip legs, and thus the lower the CO_2 emission. Fig. 4 also shows that CO_2 emission is strongly influenced by travel mode, given the trip chain type. Across all trip chain types, average CO_2 emission per activity is much higher for multimodal tours involving rail than for single modal tours or car and bus tours. Fig. 5 shows a breakdown of CO_2 emission per activity by travel mode for multimodal trip chains.

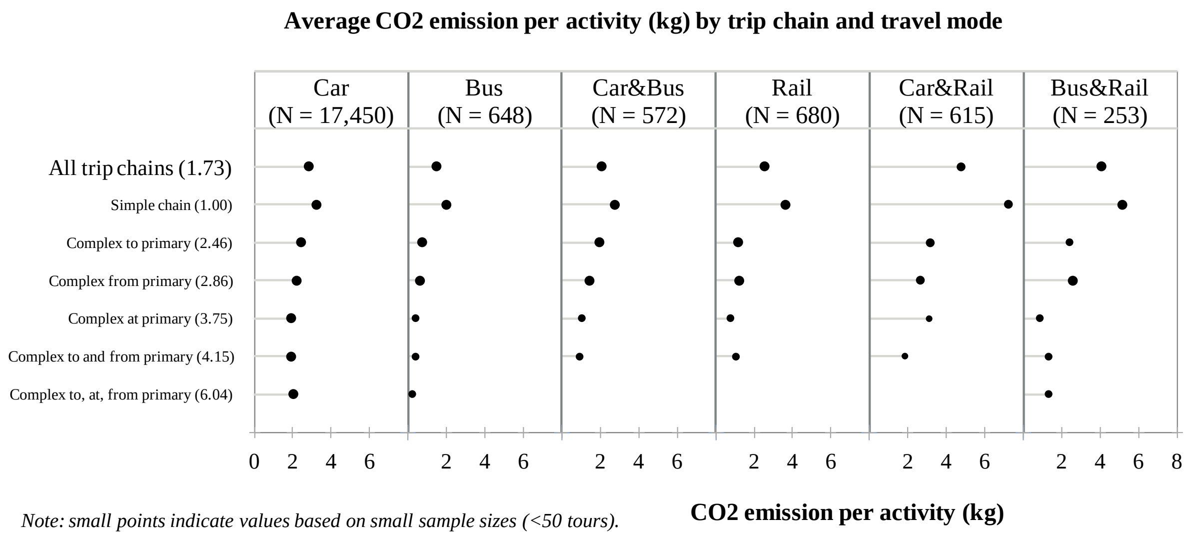

Fig. 4 Average CO2 emission per activity (kg) by trip chain and travel mode

Note: Values in parentheses after trip chain types are the average number of activities per chain. Data source: Sydney HTS 2007/08 – 2010/11.

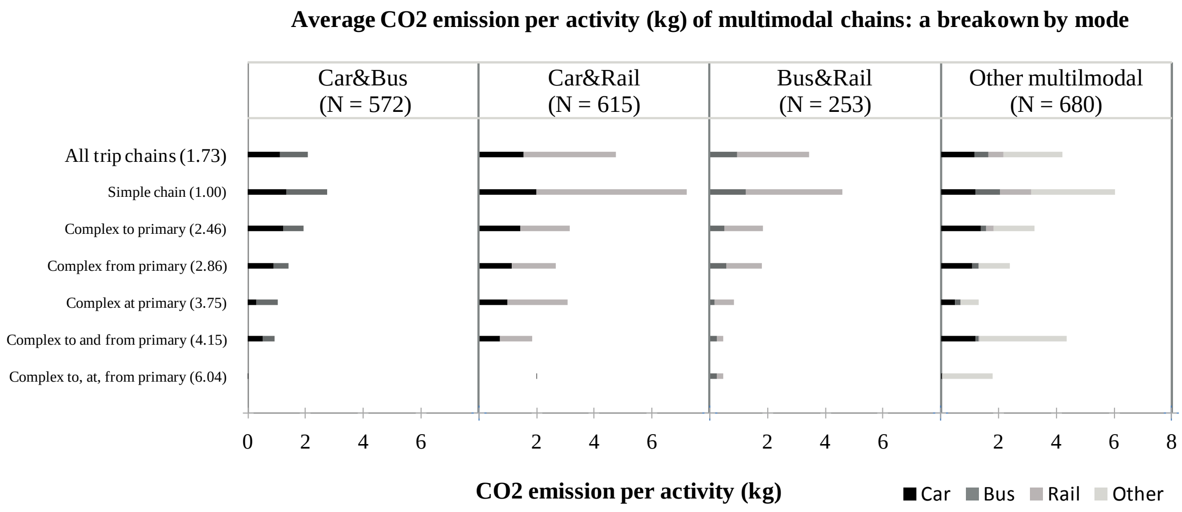

Fig. 5 Average CO2 emission per activity (kg) of multimodal chains: a breakdown by mode

Data source: Sydney HTS 2007/08 – 2010/11.

For multimodal chains by car and bus, the contribution to CO_2 emission is split equally between the two modes. This may be explained by a large proportion of trip chains involving bus on an outbound trip and car on an inbound trip or vice versa. Conversely, for multimodal trip chains by car and train or bus and train, the contribution of train legs to CO_2 emission is much larger than that of car legs or bus legs. As mentioned above, the emission rate of the train mode is lower than that of bus/car mode, and this result reflects the longer distance travelled by train than by car/bus mode for these multimodal tours. This shows the importance of controlling for distance travelled in modelling the influence of trip chaining behaviour on greening travel demand. The modelling results are presented next.

3.2 Modelling results

Separate regression models are estimated for people with different numbers of daily activities, given their locations. Table 3 shows different ways of arranging daily activities into trip chains and the average CO_2 emission corresponding to each way of arrangement. As shown in Table 3, people with one out-of-home activity can only arrange a simple chain to access the activity. They were excluded from modelling analysis as no alternative arrangements to a simple chain are available to evaluate the gain or loss in CO_2 emission resulting from different trip chaining behaviour. People with two daily activities can arrange the activities into two simple chains, or one complex chain to primary activity, or one complex chain from primary activity. Given the number of daily activities undertaken, the average CO_2 emission shown in the last column of Table 3 indicates that an arrangement of multiple simple chains does not necessarily produce higher CO_2 emission than one complex trip chain because travel mode and relative distances between activities, and between home and each of the activities also play an important role.

For a person with n daily activities, there are $n*(n+1)/2$ pair-wise relative distances between home and activities and between one activity to another. For example, for people with 2 daily activities, there are 2*3/2 = 3 pair-wise distances to be controlled for when examining the influence of trip chaining behaviour on CO_2 emission. These are distances between home and activity 1 (d_{01}), between home and activity 2 (d_{02}), and between activity 1 and activity 2 (d_{12}). The number of relative distances that have to be considered increases as the number of daily activities increases. A model for 4 daily activities has 4*(4+1)/2 = 10 distance variables. The empirical model considers 4 daily activities as a maximum number as the best trade-off between achieving population coverage (78.3% of the sample) and reducing potential multicolinearity.

Table 3 Alternative arrangements of daily activities into trip chains and their CO_2 emission

No. daily activities	Arrangement of activities	N	Average CO_2-e (kg)
1 activity	1S tour	5,015	3.75
2 activities	2S tours	1,660	5.27
	1C to primary	1,043	5.45
	1C from primary	822	5.18
3 activities	3S tours	464	5.93
	1C to primary	348	8.50
	1S + 1C to primary	620	6.31
	1C from primary	577	5.86
	1S + 1C from primary	346	6.13
	1C to and from primary	221	6.20
	1C at primary	139	6.20
4+ activities	4S tours	123	7.77
	1C to primary	197	11.43
	1S + 1C to primary	259	9.76
	2S + 1C to primary	293	7.53
	2C to primary	143	8.41
	1C from primary	419	9.24
	1S + 1C from primary	293	8.33
	2S + 1C from primary	157	7.68
	1C to + 1C from primary	160	9.65
	1C to and from primary	403	9.53
	1S + 1C to and from primary	203	8.02
	1S + 1C at primary	122	7.80
	Other arrangements	429	10.43

Note: S = simple, C = Complex. Data source: Sydney HTS 2007/08 – 2010/11.

Table 4 to Table 6 summarise the regression results of CO_2 emission on alternative arrangements of activities into trip chains, distances between home and each activity as well as between one activity to another, and the number of trip chains by mode for people with 2, 3 and 4 daily activities. Alternative arrangements of daily activities were effects coded to compare average CO_2 emission for each arrangement with the grand mean (average across all ways of arranging daily activities into trip chains). The coefficients associated with alternative arrangements of two activities shown in Table 4 indicate that, *ceteris paribus*, CO_2 emission per person per day will be 0.332 kg lower than average if the two activities can be chained into one complex tour to the primary activity, while it is 0.789 kg higher than average if these two activities are undertaken as two simple tours. The models for 3 and 4 daily activities (Table 5 and Table 6) also suggest that CO_2 emission is highest if activities are chained into multiple simple tours. In addition, the estimation results suggest that given the spatial distribution of daily activities, CO_2 emission can be cut by shifting away from the private car as a single mode. This is shown by the negative coefficients associated with alternative travel modes to the private car across all models. Most distance variables are significantly positive, as expected, except for two variables (d_{13} and d_{24}) that are negative. The counter-intuitive sign of these two variables are due to a high multicolinearity amongst distance variables as indicated in Table 6 by Variation Inflation Factor (VIF) values which are larger than a rule-of-thumb value of 5.0. As the distance variables are positively correlated, their coefficient estimates tend to be negatively correlated. This consequence, however, does not influence the effect of trip chaining and mode of travel on CO_2 emission, which is the focus of this chapter.

Table 4 Model of CO_2 emission for person with 2 daily activities, R^2= 0.906

Variable	Coefficient	t-stat	Sig.	VIF
Constant	0.879	5.97	***	-
2 simple tours (base) [a]	0.789	-	-	-
1 complex to primary (1/0/-1)	-0.332	-5.89	***	1.7
1 complex from primary (1/0/-1)	-0.456	-7.62	***	1.7
Distance between home and activity 1 (km)	0.185	16.10	***	1.4
Distance between home and activity 2 (km)	0.126	8.28	***	1.5
Distance between activities 1 and 2 (km)	0.184	12.58	***	1.5
Number of tours by walking	-1.236	-13.58	***	1.0
Number of tours by bus	-0.812	-6.13	***	1.0
Number of tours by train	-2.102	-10.81	***	1.0
Number of tours by car and bus	-0.533	-5.74	***	1.0
Number of tours by car and train	-1.707	-5.25	***	1.0
Number of tours by bus and train	-1.551	-4.80	***	1.0
Number of other multimodal tours	-0.922	-0.90		1.0

Note: [***] significant at 99% level.
[a] Coefficient is calculated as the negative sum of the coefficients associated with other trip chain types.

Table 5 Model of CO_2 emission for person with 3 daily activities, R^2= 0.930

Variable	Coefficient	t-stat	Sig.	VIF
Constant	1.015	8.60	***	-
3 simple tours (base) [a]	1.440	-	-	-
1 complex to primary (1/0/-1)	-0.575	-4.61	***	2.1
1 simple + 1 complex to primary (1/0/-1)	0.692	7.37	***	1.7
1 complex from primary (1/0/-1)	-0.751	-8.23	***	1.9
1 simple + 1 complex from primary (1/0/-1)	0.560	4.70	***	2.1
1 complex to and from primary (1/0/-1)	-0.676	-7.03	***	2.4
1 complex at primary (1/0/-1)	-0.690	-7.84	***	3.0
Distance between home and activity 1 (km)	0.191	12.11	***	2.4
Distance between home and activity 2 (km)	0.040	2.31	**	5.6
Distance between home and activity 3 (km)	0.120	8.30	***	2.8
Distance between activities 1 and 2 (km)	0.158	13.45	***	2.9
Distance between activities 1 and 3 (km)	-0.011	-0.98		2.9
Distance between activities 2 and 3 (km)	0.182	11.90	***	1.9
Number of tours by walking	-1.173	-14.29	***	1.1
Number of tours by bus	-1.259	-9.27	***	1.0
Number of tours by train	-2.750	-11.67	***	1.0
Number of tours by car and bus	-0.977	-7.75	***	1.0
Number of tours by car and train	-2.726	-7.83	***	1.1
Number of tours by bus and train	-1.382	-5.65	***	1.0
Number of other multimodal tours	-0.897	-1.96	*	1.0

Note: [***] significant at 99% level; [**] at 95%; [*] at 90%.
[a] Coefficient is calculated as the negative sum of the coefficients associated with other trip chain types.

Table 6 Model of CO_2 emission for person with 4 daily activities, R^2= 0.911

Variable	Coefficient	t-stat	Sig.	VIF
Constant	1.571	8.62	***	-
4 simple tours (base) [a]	1.664	-	-	-
1 complex to primary (1/0/-1)	-0.974	-5.23	***	1.8
1 simple + 1 complex to primary (1/0/-1)	0.143	0.79		1.5
2 simple + 1 complex to primary (1/0/-1)	0.843	4.45	***	1.5
2 complex to primary (1/0/-1)	-0.808	-2.55	**	2.2
1 complex from primary (1/0/-1)	-0.769	-4.09	***	1.6
1 simple + 1 complex from primary (1/0/-1)	0.524	2.57	**	1.6
2 simple + 1 complex from primary (1/0/-1)	0.575	3.15	***	1.9
1 complex to + 1 complex from primary (1/0/-1)	0.047	0.21		2.2
1 complex to and from primary (1/0/-1)	-0.816	-4.54	***	1.6
1 simple + 1 complex to and from primary (1/0/-1)	-0.098	-0.72		2.0
1 simple + 1 complex at primary (1/0/-1)	0.384	1.33		2.1
Other arrangements (1/0/-1)	-0.713	-1.68	*	7.7
Distance between home and activity 1 (km)	0.181	7.46	***	1.9
Distance between home and activity 2 (km)	0.010	0.31		8.2
Distance between home and activity 3 (km)	0.014	0.43		11.9
Distance between home and activity 4 (km)	0.102	5.22	***	4.0
Distance between activities 1 and 2 (km)	0.195	6.72	***	5.2
Distance between activities 1 and 3 (km)	-0.088	-2.91	***	10.1
Distance between activities 1 and 4 (km)	0.048	1.94	*	5.0
Distance between activities 2 and 3 (km)	0.237	9.85	***	2.2
Distance between activities 2 and 4 (km)	-0.071	-2.37	**	4.2
Distance between activities 3 and 4 (km)	0.200	8.34	***	3.3
Number of tours by walking	-0.928	-8.86	***	1.1
Number of tours by bus	-1.450	-11.01	***	1.0
Number of tours by train	-1.995	-4.96	***	1.0
Number of tours by car and bus	-0.500	-1.27		1.0
Number of tours by car and train	-1.985	-6.50	***	1.0
Number of tours by bus and train	-0.528	-0.43		1.0
Number of other multimodal tours	-1.352	-2.85	***	1.0

Note: [***] significant at 99% level; [**] at 95%; [*] at 90%.
[a] Coefficient is calculated as the negative sum of the coefficients associated with other trip chain types.

The estimated models are used to examine the gain or loss in CO_2 emission if multiple activities are chained into a single complex chain in contrast to multiple simple chains. The complex trip chain selected for this simulation is the complex chain from the primary activity due to its prevalence (see Table 3) and the smaller time pressure that travellers such as workers experience after undertaking the primary activity as compared to before doing it. The main question of interest is what are the gains in CO_2 emission if people undertaking multiple activities with multiple simple chains now do so with only one complex chain from the primary activity? As the literature suggests that travellers may require the use of a private car for complex trip chains, the simulation assumes that all newly complex chains are to be made by a single mode of car. However, bus and train as single modes are also simulated to provide a range of gains in CO_2 emission. The procedure for estimating the gains/losses in CO_2 includes three steps:

(1) The estimated coefficients and the estimation sample data are used to compute CO_2 emission for the base.

(2) Changes to trip chaining behaviour and travel mode of individuals with multiple simple tours are simulated by setting the effects coded variables associated with trip chain types to the appropriate values (1, 0 or – 1), and their numbers of tours by car to 1 and by other modes to 0 if the complex trip chain is made by car (similarly for the scenarios where the complex chain is made by bus or train).

(3) The estimated coefficients and the simulated sample data are used to compute CO_2 emission for the scenario, and the gains/losses in CO_2 emission are calculated as the percentage difference between the scenario and the base.

The simulation results suggest that if people with multiple simple chains can chain their daily activities into a single complex chain, this would reduce the CO_2 emission by 5.2% even if the complex chain is made by car. However, the level of CO_2 emission saving from chaining multiple activities is more significant if complex chains from the primary activity are made by bus (13.0%) or train (19.1%).

4. Conclusions and discussion

This chapter has explored the changing nature of trip chains over a 15-year period and the emissions saving from complex trip chains using the Sydney HTS. Results reveal that in Sydney the complexity of trip chains in terms of average activities per chain remain stable between 1997/98 and 2011/12. This appears to be contrary to previous evidence which suggests that trip chaining behaviour, especially in the home-to-work direction, has become more popular as people grow time-poor (McGuckin et al. 2005). However, a deeper investigation has suggested that this contrast is a result of the difference in the definition of trip chains adopted by different studies and the failure to account for changes in the population over time in previous studies. Controlling for changes in household structure, car ownership and travel purpose, this chapter found a stable trip chaining behaviour over a long period of 15 years. Consistent with evidence found elsewhere (Currie and Delbosc 2011), this finding suggests a less bleak outlook for public transport and its potential for greening the travel demand chains.

For people with multiple daily activities, there are different alternative arrangements of activities into trip chains and this has a significant impact on CO_2 emission, as does the travel mode to access these activities. This chapter has demonstrated, using both descriptive and modelling evidence, that CO_2 emission can be cut by a substantial amount if activities are chained to fewer complex tours and/or greener travel modes are used. With changes in trip chaining behaviour of people with all activities undertaken separately by multiple simple chains, the simulation suggested a 5% to 19% saving of CO_2 emission, depending on the travel mode selected to undertake the complex trip chains.

GHG emissions from urban passenger transport are usually studied through vehicle kilometres travelled (VKT), but this approach cannot be used to examine the potential of greening travel demand by encouraging more trip chains. This is because the VKT approach combines distance travelled by all trip chain types, and thus the information on the ways in which individuals chain their daily activities is lost. A modelling approach at the tour level cannot be used either because this does not allow activities that are chained into different tours to be rearranged into one tour, a critical character for studying the effect of trip chains on CO_2 emission. This chapter has developed a daily activity modelling framework to relate CO_2 emission to different arrangements of daily activities into trip chains, taking into consideration the opportunities of using multiple modes of travel to undertake trip chains. However, this approach also comes with certain limitations, most of which are considered necessary in the estimation of the empirical models used to examine the relationship between trip chains and CO_2 emission. In terms of modelling, we have considered the number of daily activities, their locations, and the travel modes to access them as exogenous variables. While these assumptions are fully consistent with activity-based modelling, this limitation means that the effect on CO_2 emission of changes in daily activities due to changes in land use patterns, which allow people to do the same activity at a different place, cannot be evaluated.

Another limitation relates to the way in which CO_2 emissions are computed as average emission rates of different modes identified in a trip chain. This means that some scenarios such as changes in fuel types and fuel consumption have to be analysed by re-aggregating the daily CO_2 emission from the trip level. These limitations can be overcome with a fully integrated activity based modelling framework that places an activity arrangement model after an activity generation model that generates the number of daily activities undertaken by each person. The mode choice and time of day model would then be applied for each trip chain. Subsequently, other models that form the rest of the activity-based framework (intermediate stop frequency, location, departure and arrival times, and trip mode models) could be applied to each trip chain, and the network assignments and skim matrices can then be performed. Outcomes from the trip mode model and network assignment model would then be aggregated to obtain CO_2 emission for each person per day.

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