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Defining and understanding trip chaining behaviour

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Abstract Trip chaining is a phenomenon that we know exists but rarely investigate. This could be attributed to either the difficulty in defining trip chains, extracting such information from travel diary surveys, the difficulty in analysing all the possible trip chain types, or all of the above. Household travel diary surveys provide a wealth of information on the travel patterns of individuals and households. Since such surveys collect all information related to travel undertaken, in theory it should be possible to extract trip-chaining characteristics of travel from them. Due to the difficulty in establishing and analysing all of the possible trip chain types, the majority of research on trip chaining has appeared to focus on work travel only. However, work related travel in many cities does not represent the majority of activities undertaken and, for some age groups, does not represent any travel at all. This paper begins by reviewing existing research in the field of trip chaining. In particular, investigations into the definitions of trip chaining, the defined typologies of trip chains and the research questions that have been addressed are explored. This review of previous research into trip chaining facilitates the following tasks: the identification of the most useful questions to be addressed by this research; defining trip chaining and associated typologies and defining data structures to extract trip chaining information from the household travel surveys conducted in metropolitan Adelaide, South Australia. The definition and typology developed in our research was then used to extract trip-chaining information from the household travel diary survey (MAHTS99) conducted in Adelaide in 1999. The extracted trip chaining information was then used to investigate trip-chaining behaviour by households. The paper reports the results of this analysis and concludes with a summary of the findings and recommendations for further investigations.

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Introduction

This paper seeks to add to the understanding of trip chaining behaviour and its occurrence in everyday travel in an urban area. It does this by reviewing the previous research in the field and the definitions and descriptions offered for trip chaining from that research, and then suggesting a working definition of trip chaining and definition of the typology of trip chains. It then uses these conceptual results in a study of trip chaining behaviour in metropolitan Adelaide, South Australia, using a detailed database (MAHTS99) of household travel for that city which is based on the collection of comprehensive activity-travel diary data for the individuals in the surveyed households.

For the initial purposes of the paper, consider a *trip* to be a tour that may involve several activities and a *trip segment* to be the travel between a particular pair of activities. Individuals are assumed to make trips for some purpose and that the specific purpose is to engage in a set of activities. Thus the activities drive the trip making process. Stopher et al. (1996) classified activities into three categories:

- *mandatory* activities, which have frequency (typically daily), location and timing that are all fixed (e.g., work and school)
- *flexible* activities, which are performed on a regular basis but have some characteristics (e.g., timing or location) that can vary (e.g., shopping for convenience goods or banking)
- *optional* activities, which are discretionary and for which all characteristics may vary. In particular, frequency may be zero in a given time period (e.g., social and recreational activities).

Typically the activities undertaken by an individual will generate a primary trip each day, which usually will be the journey to work or school, or some other mandatory activities. Most people will have one primary trip per day, most of the time. However, each traveller may also have one or more secondary trips that are flexible and/or optional, with a wide range of possible trip purposes. Each trip may involve a single activity, or several activities may be linked together to form a trip chain. If the basic planning unit is the trip chain instead of individual trip segments then the individual's home can be considered to be the origin and destination of all trips in the study area. In other words, all trips could then be considered as home-based trips, irrespective of how many intermediate destinations are visited.

Definitions of trip chaining

A consideration of the research literature on trip chaining reveals that there is no commonly accepted definition of a trip chain, although the concept is widely recognised amongst transport planners. McGuckin and Murakami (1995) illustrated the alternative approaches to defining trip chains. The three distinct categorisations of a multi-segmented trip originating and ending at the home and containing primary and secondary activities in between include:

- a set of separate trip segments
- two trip chains, one from home to a primary activity and one from the primary activity to home, or
- one home-based trip chain (i.e., the definition suggested above).

McGuckin and Murakami used the second of these patterns to define trip chains. Their definition was that a trip chain was a set of trip segments between the anchor points of home and work. A McGurkin–Murakami trip chain thus consists of a connected set of trip segments from home to work, from home to home, from work to home, or from work to work. Given the previous discussion, 'school' may be taken as an alternative anchor activity to 'work'.

Holzapfel (1986) proposed an alternative definition, in which the individual's home is again the sole anchor. Trip chain was defined as 'a sequence of changes of place which do not take the form of <home–activity–home>'. Under this definition the trip chain must comprise at least three trip segments, i.e., <home–activity1–activity2–home>, or more generally <home–activity1– … – activityN–home>. Thus Holzapfel treats simple trip structures (<home–activity–home>) as different from trip chain structures (<home–activity1– … – activityN–home>).

Goulias and Kitamura (1989) proposed a definition of trip chaining as a function of the numbers of trip segments by purpose, including the following factors:

- spatial distribution of trip ends
- trip timing
- total number of trip segments.

They assumed that the number of mandatory activities influences the number of flexible and optional activities. The anchor activities are home, school or work, and the basic definition of a trip chain is then the set of trip segments between two anchor activities.

Thill and Thomas (1987) proposed a more abstract definition of trip chaining, based on Hagerstrand's space-time prism theory (Hagerstrand 1970). Their definition is that a trip chain is a series of movements between successive destination choices over some period of time, i.e., a trip-segment sequence of activities. They used this definition to consider complex relationships between activity sets and the interdependence of timing, duration, location, frequency and sequencing of activities, the nature and number of stops, and trip length. The implication of the Thill-Thomas study was that trip chains could be terminated at any given activity, if the duration of that activity exceeded some pre-determined time.

Srinivasan (1998) proposed a more generalised definition of trip chains. Under this definition, a trip chain is a scheduling of activities in time and space, made by linking together work and non-work trips or two or more non-work trips. This definition enables the identification of different types of trip chains. Srinivasan identified four specific types:

- work-based trip chains (<home–work–chain–work–home>)
- trip chains taking place on the journey to or from work (<home–chain–work–home> or <home–work–chain–home>)
- home-based trip chains (<home–chain–home>), which do not include any work activities or work-based trip chains
- mode chaining or the combination of two or more travel modes for a trip chain, regardless of whether the chain involves home or work anchor activities.

An appraisal of the alternative definitions presented above suggests that the two most commonly accepted definitions of trip chains are:

1. a sequence of trip segments beginning at the 'home' activity and continuing until the traveller returns 'home'
2. a sequence of trip segments between a pair of anchor activities 'home' and 'work' or 'school'.

In these definitions the anchor activity is undertaken by the specific individual traveller whose trip chain is under investigation.

Trip chain methodologies

This section reviews the trip chain typologies defined and used in the research field. Strathman and Dueker (1995) derived seven types of trip chains. Two main groups of chains were defined, namely simple and complex. All trips start and end at home with trip chains revolved around work and non-work trip segments. The same typology was also used in Hensher and Reyes (2000) to determine the effect of trip chaining behaviour on the choice of travelling by public transport in Sydney. The advantage of this method was that the ordering of activities (i.e., whether additional trip segments were undertaken on the way to work or on the way back from work) was included in the configurations. The rules followed by Strathman and Dueker (1995) and Hensher and Reyes (2000) to link trips segments to form trip chains were:

- trip chains start and end at home
- information on every trip segment of a trip chain had to be complete
- changing mode stops were not considered as a trip segment in a trip chain.

By following these rules, the first/last trip of the travel diary survey that did not commence/end at home were excluded (which was also done in Strathman et al. 1994).

Strathman et al. (1994) compared the trip chaining behaviour of travellers in Portland, Oregon with findings from a study by Golob (1986) from The Netherlands. Strathman et al. adopted the typology used in the study by Golob where Trip chains were split into simple and complex chains, where the complex chains were derived by the first two destinations.

Bowman and Ben-Akiva (2001) derived an activity-based disaggregate travel demand model system that incorporated activity scheduling. They defined a set of activity patterns called tours (trip chains). Activity patterns contained a primary tour (travel related to primary activities) and secondary tours (involving travel for activities of lower priority to the activity in the primary tour). Their survey data for Boston did not collect information on which activity was a primary activity, so deterministic rules were used to identify primary and secondary activities. All activities were ranked in order of work related, school and all other purposes. Assigning higher priorities to activities of longer duration broke any ties. The advantage with this method was that it defined the number of secondary trips involved however the disadvantage was that it did not indicate when additional stops occur.

The studies by Davidson (1991) and Jou and Mahmassani (1998) focused on the home to work commute. The investigations involved determining how many trips occurred and for what purpose during morning and afternoon periods between home and work.

Space-time theory has also been used to derive trip chaining (Thill and Thomas 1987; Kondo and Kitamura 1987; Nishii et al. 1988). Space-time theory takes into consideration that people are not only constrained by space but by time as well. In relation to trip

chaining, Kondo and Kitamura (1987) and Nishii et al. (1988) assume that home and work are fixed in terms of location and time. This led to all other trips to revolve around the home and work locations and the working time period. Three-dimensional prisms are created which show the area in space and time that captures all the activities a person can participate in urban space. Kondo and Kitamura define the space available between the earliest possible time to depart and the commencement time of work. The space-time prism for work activities was bounded by the time to depart for travel, the time of the commencement of work and between the locations of home and work. Similarly prisms for during work and after work were also defined resulting in three prisms that defined the trip chain types. Nishi et al. (1988) extended the work by Kondo and Kitamura further by defining *multi-chains* for when additional activities were pursued in separate home-based trip chains and *single-chains* for when the activity was linked to a commute trip. This allowed for five trip chain types:

1. *multi* or *single*-chain for activities pursued before work
2. activities pursued during work, and
3. *multi* or *single*-chain for activities pursued after work.

Research by D'Este (1997) proposed a model using Markov chains to model trip chaining behaviour to extend the utility of the traditional four-step travel demand models. The steps involved in modelling trip chaining behaviour using Markov chains are as follows:

1. create the Markov Transition Matrix. This matrix represents the probabilities of travelling from one activity to another. The 'Home' activity is defined twice: once as an origin and once as a destination
2. calculate a sequence of system states. Each state represents the likelihood of an individual participating in an activity at a particular segment of a trip chain. The probability of being at an activity at a particular state is calculated by the summation of the products of the probabilities of being at an activity in the previous segment and the probability of travelling from each activity to the current activity. The first state assumes the individual to be home and the final state results in the individual returning home
3. calculate the matrix of cumulative transition probabilities. Using the sequence of systems states, the cumulative probability of travelling from one activity to another is the sum of all probabilities of being at the origin activity at each state multiplied by the probability of travelling from the origin to the destination activities from the Markov Transition Matrix.

The cumulative transition probabilities provide the probabilities of activities being followed by another activity within a trip chain. D'Este discussed how the matrix of cumulative transition probabilities is equivalent to a traditional trip table that shows the number of trips between activity types. A criticism of the Markov chain method is that it does not consider memory or forward planning (D'Este 1997).

A proposed definition and typology set

A number of the various typologies defined and used within studies related to trip chaining were reviewed in the preceding section. The common themes from these typologies are:

- trip chains start and end at home;
- the majority of trip chains revolve around an activity that is important and is fixed in location and time (work most common activity);
- secondary trip segments are made before, during and after the primary activity.

Thus we define the trip chain (which could also be referred to as an *activity schedule*) to be the linking of secondary activities to a primary activity through travel that is made from when an individual leaves home to when they return home. It is a schedule that individuals will follow (or create as they proceed through the day) from the moment they leave home to the moment they return home.

There were a number of reasons why the home-to-home type of definition of trip chains was adopted. Firstly, from analysis performed on the 1999 Metropolitan Adelaide Household Travel Survey (MAHTS99) data used in this paper, it was found that the majority of travel commenced (98.6 per cent of initial trips) and ended (97.7 per cent of final trips) at home. Secondly, travel in some respects requires the traveller to make some preliminary decisions as to what activities to undertake, where to participate in those activities, when to undertake travel and how to undertake travel to achieve ones objectives. Once away from the home, the set of options available will change (and probably reduce, particularly related to choice of transport mode and any choices influenced by time availability) so in order for a traveller to achieve their objectives, they need to have an idea of how their travel patterns will unfold. For this reason, the entire journey of when the person left home to their return should be considered in its entirety rather than just considering travel between home and a primary activity. The final reason for choosing this approach is that the proposed definition lends itself to being adopted within an activity-based framework, where more importance is placed on the activities visited (which are the reasons for travel being undertaken) rather than on the trips undertaken, making the definition adopted consistent with the assumption that travel is a derived demand.

The trip chain typology thus defined in this research is shown in Table 1. The typology considers the linking of the home activity (H) with other primary activities (P) and secondary activities (S). For each chain there is one primary purpose, however there could be a number of secondary activities (hence {S} ≡ the set of secondary activities). It is proposed that each secondary activity type be identified and in the case where secondary activities are the same type of activity (e.g., social/recreation) then information associated with those activities will be aggregated (similar to the typology by Bowman and Ben-Akiva 2001). The typology proposed provides a template that will form many trip chaining types depending on the combination of primary and secondary activity types. As shown in Table 1, there are two ways of grouping trip chains: simple trip chains that involve a single activity and complex trip chains that involve many activities being visited.

Table 1 Proposed trip chain typology

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

[H = home activity (H), P = other primary activities (P), S = secondary activities]

Extracting trip chaining information from travel diary surveys

The definition and typology defined above was the basis for extracting trip chaining information from a household travel diary survey. As mentioned above, the survey data used in this paper was derived from MAHTS99. The survey gathered information based around people's day-to-day activities over two consecutive days within the metropolitan region as defined by the Adelaide Statistical Division. A sample of approximately 9,000 homes, representing two per cent of all private dwellings in the region, was randomly selected. Particular attention in the survey was given to the accuracy and reliability of the travel diaries, so that the final database has a good representation of walking trips and transfers between modes. This hallmark of MAHTS99 should permit the detailed study of trip chaining behaviour. The final information gathered also included household and personal characteristics of participants.

In our analysis of the MAHTS99 data, trip chains from home to home were extracted. Within each chain, there would be one or more intermediate activities. The following conditions were used to determine and construct the trip chains:

- trip chains were excluded for cases where the travel for a surveyed day did not start and end at home.
- trip chains that extend from the end of day one to the start of day two were excluded.
- change-mode stops were not included as activities in a chain.
- trip chains were constructed for travel from a properly constructed hierarchy of household/person/day/stop (stop being equivalent to a trip segment) records only.
- the information gathered for each household was complete.
- for all except the last chain segment, a trip chain's end point is the start point for the next chain. This condition ensures a continuous flow of travel is recorded for every individual.

Trip chaining analysis

Two tables were derived from the MAHTS99 database, one representing every trip chain undertaken during the survey and the second representing every activity (or trip segment) undertaken within each trip chain. Each activity type is allocated a priority and category level, with more than one type permitted per level. The order of priority is determined from the hierarchy of activity types as defined by Stopher et al. (1996), i.e., mandatory, flexible or optional activities. Activities within each chain are then ranked in order of importance, determined firstly in order of category level, then on the basis of longest duration for activities with the same category. If activities still have the same priority, then the first activity visited obtains the higher rank. For each chain, the activity with the highest importance rank is considered to be the 'primary activity'.

Travel choices

This section investigates the relationship between the travel choices people make with respect to trip chaining. The travel choices to be investigated are mode, activity and time of travel.

Table 2 f chains and the proportion of complex trip chains made by each dominant mode type during an average weekday in metropolitan Adelaide in 1999

Dominant mode	Simple trip chains	All trip chains	Percentage of complex trip chains
Truck	6,199	13,439	54
Tram	2,249	4,285	48
Train	7,687	14,608	47
Bus	38,696	67,726	43
Car Driver	433,983	754,403	42
Car Passenger	201,075	334,350	40
Taxi Passenger	4,422	6,135	28
Motor Cycle	2,725	3,700	26
Bicycle	15,164	18,606	18
Walk, Wheelchair	120,681	136,556	12
Other	1,043	1,135	8

Mode choice

The data in Table 2 shows the number of simple and total trip chains undertaken by each mode of travel during an average weekday in metropolitan Adelaide in 1999. The table also shows the proportion of trip chains that are complex to determine which modes of transport individuals will use to undertake more than one activity within a trip. The use of commercial vehicles (truck) *for personal travel* is associated with the highest proportion of complex trip chains. All forms of mass public transport are also associated with a high number of activities being undertaken within a single journey with the private car being slightly less. There is a large gap between the proportion of complex trip chains undertaken by the private car and the other modes. Non-motorised forms of transport such as the bicycle and walking exhibit the least proportion of complex trip chains amongst the modes.

An interesting result is that on average a higher number of activities are undertaken during a journey by mass public transport than by private car. This result does not fully support the conclusions derived by Hensher and Reyes (2000) that the more complex the trip the less likely public transport would be used. To investigate further, Table 3 was created to compare the proportion of simple and complex trip chains by car and by public transport for Adelaide (as derived in this report) and for Sydney (as derived from the Random Parameter Logit (RPL) models developed by Hensher and

Table 3 Proportion of trip chains by complexity and mode for Adelaide and Sydney

	Proportions for Adelaide in 1999 during a weekday (%)	Proportions for Sydney in 1991/92 (%)
Simple—public transport	3.6	10.1
Simple—car	46.9	45.0
Complex—public transport	2.8	6.0
Complex—car	33.5	35.1

Reyes 2000). An argument by Hensher and Reyes (2000), for their hypothesis that trip chaining is a barrier to the propensity to use public transport, is supported by the differences between simple and complex trip chains for both car and public transport where for public transport, the proportional decrease in its use for complex trip chains is far greater than the proportional decrease for the car. In Adelaide, the decrease from simple to complex by car was similar to that of Sydney but the decrease for public transport was small.

It is interesting to further note that although all three trip chain models (based on a sample of 791 trip chains) derived by Hensher and Reyes show that the barrier to public transport is strongly linked to the presence of household vehicles, the number of vehicles is least impacting for complex non-work trip chains than for simple non-work trip chains which is *'counter to the hypothesis that complexity in trip chaining is a generic barrier to public transport use.'* (Hensher and Reyes 2000).

It is believed (and possibly subject to further research) that trip chaining via the two types of transport mode are quite different. With mass public transport, a traveller may choose a destination with mixed land-uses containing a variety of activities in close proximity to one another that are reachable by non-motorised forms of transport. On the other hand the type of trip chaining undertaken by the private car could involve visiting a number of locations that are not necessarily in close proximity to each other requiring a more flexible mode of transport than that offered by mass public transport.

Activities

Initially the analysis investigated the kinds of primary activities people would tend to attach other activities to within a trip chain. The data in Table 4 show the average number of activities contained within trip chains relative to a primary activity. Employer's business tends to have the higher number of activities associated with them within a trip chain with the lowest being social and recreation related travel. Work travel is the second highest

Table 4 For each activity type, the average number of activities undertaken while the primary activity, the number of times an activity is secondary and as a proportion of all trips that involves the activity type in metropolitan Adelaide in 1999

Activity	Activities per chain	As secondary activity	All occurrences	Percentage of secondary activities
Drop-off/pick-up	2.10	108,028	264,153	41
Education	1.62	9,360	162,695	6
Employer's business	3.36	105,971	140,702	75
Personal business	1.78	123,056	219,708	56
Serve passenger/accompanying	1.88	131,379	239,523	55
Shopping	1.69	209,260	443,285	47
Social and recreation	1.19	279,522	511,340	55
Social welfare/medical	1.75	20,057	49,729	40
Work	2.18	131,677	442,119	30

suggesting that people chaining activities together will tend to attach them to work-related travel and least likely to social and recreation purposes.

For each activity, Table 4 shows the number of occasions when the activity was secondary within a trip chain, when it was either secondary or primary, and the proportion of these occasions when the activity was secondary within trip chains. The table shows that employer's business is the most likely to be undertaken as a secondary activity within a complex trip chain with education being the least likely. Work and social welfare/medical are also least likely to be undertaken as a secondary activity. Those likely to be undertaken as a secondary activity within a trip chain include personal business, serve passenger/accompany someone, and social/recreation.

The tendency for an activity, when being undertaken as a primary activity, to have a number of secondary activities pursued within the same trip chain was investigated. When employer's business is undertaken, there is likely to be a multiple number of activities being undertaken (including other employer's business). On the other hand, social/recreation trips are more likely to be pursued alone. In general, the graphs suggest that the majority of trip chains are simple, containing only a single activity.

From investigating the occurrence of various trip chain types it was found that of the complex trip chains with multiple activities, shopping appeared to be trip chained the most with activities that include social/recreation, work, drop-off/pick-up and personal business. There are also a number of work activities chained with other activities that include shopping (already mentioned) and social/recreation.

Time of travel

This section aims to determine when activities are pursued secondary to another activity to form complex trip chains. From our analysis, chaining of many trip segments is not necessarily a peak period phenomenon but rather depends on the activity. To address the travel associated with each activity type in turn, as a secondary activity:

- drop-off/pick-up activities appear to occur mainly during peak periods of 8 am to 9 am, 3 pm to 4 pm, and 5 pm to 6 pm
- personal business occurs mainly during the off-peak of 9 am to 4 pm
- social/recreation peaks between 12 noon and 1 pm however it appears to be pursued actively from 9 am to 8 pm
- education, as indicated by Table 4, is not commonly pursued as a secondary activity and does not show any distinct peaks except for the spike from 8 am to 9 am
- serve passenger/accompanying someone has two distinct peaks from 8 am to 9 am and 3 pm to 4 pm however such activities are actively pursued between these time periods
- social welfare/medical appears to occur during the off-peak from 9 am to 5 pm
- employer's business tends to be most actively pursued during the off-peak between the times of 9 am to 5 pm
- shopping is actively undertaken from 9 am to 6 pm with a drop in the middle of the day between 2 pm and 3 pm
- work shows two distinct peaks from 8 am to 9 am and 1 pm to 3 pm, however it is actively undertaken throughout the middle of the day and the late afternoon.

Individuals

This section discusses how much and what kinds of trip chaining is undertaken by households and individuals (in terms of age and gender).

Age groups

This section investigates the different trip chaining characteristics undertaken by individuals of various age groups. An analysis of trip chaining patterns across age groups clearly suggests that individuals of various age groups have very different travel patterns in terms of the kinds of trip chains they can make. The analysis also illustrates the progression of individuals' travel patterns as they age. The investigations suggest the following trip chaining characteristics to be inherent across the age groups:

- for 0–4 years of age, individuals tend to accompany someone else, with simple social/recreation, personal business (child care) and education trip chains predominating
- for ages 5–9 years simple education trip chains are undertaken the most with social recreation and accompanying travel still being undertaken. Simple personal business trip chains are no longer major with shopping starting to become important
- ages 10–14 years are similar to the previous age group with multiple accompanying trip chains occurring less and increased simple shopping and complex social/recreation related travel
- at ages 15–19 years simple accompanying trips occur less, simple personal business becomes important again with increases in simple social/recreation travel. This age group marks the beginning of work related travel with drop-off/pick-up simple trip chains also occurring
- from 20 years to 24 years of age, simple work travel becomes the highest trip chain undertaken with simple social/recreation and shopping travel. This age group is the last to significantly undertake travel related to education
- the 25–29 age group is similar to the previous age group except the increasing trend of simple drop-off/pick-up travel continues with complex social/recreation and shopping travel increasing
- the 30–39-year age group is interesting in that simple drop-off/pick-up trip chaining is the second most trip chain undertaken and is the only age group where travel related to social/recreation and shopping decreases
- the 40–49-year age group marks the beginning of the declining trend of simple drop-off/pick-up related travel. Simple social/recreation and complex shopping travel increases
- similar to the previous age group, the 50–54-year age group shows simple drop-off/pick up trip chains decreasing and multiple social/recreation trip chains increasing
- the 55–59-year age group marks a transitional period where simple social/recreation trip chains are the most common and simple work trip chains start declining. Both simple and complex shopping trip chains commence their incline with simple serve passenger/accompanying trip chain being significant. Simple personal business trip chains continue their upward trend
- the 60–64-year age group show the trends from the previous age group continue

- from 65 years and onwards, simple social/recreation, shopping and personal business trips remain as the top three trip chain types with multiple social/recreation and shopping trip chains also being significant.

Gender

This section investigates the kinds of trip chains undertaken by males and females. Table 5 shows the top 20 trip chains undertaken during an average weekday in metropolitan Adelaide in 1999. For each gender type, the table shows the number of trip chains undertaken and a rank value indicating the number of trip chains of that nature made in descending order. Differences in trip chaining characteristics by males and females include:

- males undertake significantly more simple work and education trip chains
- females undertake significantly more simple shopping, drop-off/pick-up, and serve passenger/accompanying trip chains
- females undertake significantly more complex trip chains involving shopping and social/recreation
- males undertake more complex trip chains involving work.

Table 5 Top 20 trip chains types ranked by the number of trip chains made by females and males in metropolitan Adelaide in 1999 during an average weekday

Trip chain type—detailed	Female		Male	
	Trip chains	Rank	Trip chains	Rank
Home–Social/Recreation*–Home	103,497	1	102,164	1
Home–Work*–Home	64,200	3	101,119	2
Home–Shopping*–Home	79,560	2	59,539	3
Home–Education*–Home	46,429	5	52,167	4
Home–DropOff/PickUp*–Home	53,047	4	27,525	6
Home–Serve Passenger/Accompanying*–Home	31,906	6	26,635	7
Home–Personal Business*–Home	28,010	7	27,619	5
Home–Serve Passenger/Accompanying*– ... –Serve Passenger/Accompanying*–Home	15,816	8	14,076	8
Home–Social/Recreation*– ... –Social/Recreation*–Home	13,497	9	11,907	9
Home–Shopping*– ... –Shopping*–Home	13,418	10	9,450	10
Home–Social Welfare/Medical*–Home	9,948	12	7,374	13
Home-Social/Recreation-Shopping*-Home	10,170	11	5,949	15
Home–Work*–Shopping–Home	7,566	15	5,153	16
Home–Shopping*–Social/Recreation–Home	7,961	14	4,617	19
Home–DropOff/PickUp*–Shopping–Home	8,591	13	3,070	26
Home–Employer's Business*–Home	3,145	27	8,017	12
Home–Personal Business-Shopping*–Home	7,295	16	3,700	22
Home–Work*–Social/Recreation–Home	4,623	21	6,186	14
Home–Work*– ... –Work*–Home	2,397	32	8,250	11

Table 6 Amount of trip chaining undertaken by households with a specific number of vehicles in metropolitan Adelaide in 1999

	Weekday			Saturday			Sunday		
No of household vehicles	Avg no of activities	Number of trip chains	% Simple trip chains	Avg no of activities	No of trip chains	% Simple trip chains	Avg no of activities	No of trip chains	% Simple trip chains
0	1.57	44,844	69	1.47	36,445	77	1.17	29,373	84
1	1.79	447,227	62	1.63	399,428	66	1.58	320,745	68
2	1.87	609,546	60	1.62	613,055	67	1.57	530,907	65
3	1.88	170,245	62	1.56	171,330	70	1.65	110,710	66
4	1.90	50,093	60	1.62	74,699	69	1.38	55,662	73
5	1.61	13,311	67	1.69	17,100	64	1.57	8,893	63
6	1.68	6,268	67	0.00	0		1.50	3,568	58
7	1.69	2,478	71	0.00	0		3.50	466	44

Households

Vehicle ownership

This section investigates the amount of trip chaining and the average number of activities per trip chain undertaken by households relative to the number of vehicles owned. Table 6 shows for an average weekday, Saturday and Sunday in metropolitan Adelaide in 1999, the average number of activities per trip chain, the number of trip chains and the proportion of single activity trip chains undertaken by households characterised by varied car ownership. Households with no vehicles have the lowest average number of activities within their trip chains and undertake the highest proportion of single activity trip chains.

When compared with households with one vehicle, households with two to four vehicles will tend to trip chain more over an average weekday. Those with five or more vehicles will tend to chain activities less than households with one vehicle. Households with one to four cars will tend to undertaken a similar proportion of single activity trips. On Saturdays, among households of varied vehicle ownership there appears to be little variation in the propensity to chain a number of activities together within a trip chain. On Sundays, with the exception of households with seven vehicles, households with three vehicles tend to chain the greatest number of activities within a trip chain with little variation among other household vehicle ownership types.

Household types

The data in Table 7 shows the average number of activities undertaken within trip chains by each household type over an average weekday, Saturdays and Sundays. During an average weekday, households containing a single adult with children between the age of 0–4 years only, tend to chain their activities within a journey more so than any other household type with the least being households with a single adult with children 5–11 years only. In general, it appears that the majority of household types on an average weekday

Table 7 For each household type, the average number of activities per trip chain by day of the week and trip chaining characteristics in metropolitan Adelaide in 1999

Household type	Average no of activities			Simple trip chains	Complex trip chains
	Weekday	Saturday	Sunday		
Adults	1.88	1.60	1.53	Majority of trip chains are simple with social/recreation exceeding other travel. Significant travel devoted to shopping and work.	A significant chaining of social/recreation, shopping, and work. Personal business also being undertaken.
Family with young children	1.86	1.66	1.56	Trip chaining if social/recreation, serve passenger/accompanying someone, and work. Drop-off/pick-up greater for households with children 5 years and above.	Multiple serve passenger/accompanying someone undertaken the most with mixing of social/recreation and shopping. Education and drop-off/pick-up greater for older households.
Family with older Children	1.77	1.57	1.57	Simple trip chains dominant with the greater number involving education. Other activities pursued include social/recreation, drop-off/pick-up, and work.	Trip chains involving education, work and social/recreation. For younger households multiple drop-off/pick-up and serve passenger/accompanying someone significant.
Single adult with young children	1.91	1.72	1.84	Dominated by serve passenger/accompanying someone with some social/recreation. Education and drop-off/pick-up greater for households with children 5 years and above.	Dominated by multiple serve passenger/accompanying someone with some drop-off/pick-up.
Single adult with older children	1.75	1.75	1.64	Education the greatest for younger households. Those with adults undertaking more work, social/recreation and shopping.	Few undertaken, mainly social/recreation with some serve passenger/accompanying someone mixed in with education.

tend to undertake between 1.75 and 1.90 activities per trip chain. On Saturdays, households containing a single adult with children 0–17 years and adult children, tend to undertake on average more activities within a trip chain with households containing a single adult with children 5–11 years only undertake on average less activities within a trip chain. With the exception of households with other adults only, households containing all adults tend to undertake less-activities during a trip chain (with an average ranging from 1.50 to 1.59) than the majority of households with dependents (with an average ranging from 1.54 to 1.87, excluding the two extreme cases mentioned earlier). On Sundays, the most significant finding is that households of a family type tend to undertake less-activities during a trip chain (with averages ranging from 1.42 and 1.59) than households with a single adult (with averages ranging from 1.60 to 2.47), with fewer activities also being undertaken by households with adults only. Comparing across the days of the week, the greatest amount of chaining of activities within a single journey occurs during an average weekday decreasing on Saturdays and further on Sundays.

Table 7 also provides an overall descriptive summary of the major trip chaining characteristics of different types of households as revealed in the Adelaide household travel survey data. Simple and complex trip chains are discussed separately in this table since in most instances the travel activity was dominated by simple trip chains. It is evident that the travel characteristics of households can vary significantly depending on the household structure.

Conclusions

A literature search and review of trip chain research was undertaken to devise a definition of trip chaining that was suitable for a detailed study of trip chaining behaviour using travel-activity diary data from households. The resulting definition was that a trip chain (which could also be referred to as an *activity schedule*) is the linking of secondary activities to a primary activity through travel that is made from when an individual leaves home to when they return home. It is a schedule that individuals will follow (or create as they proceed through the day) from the moment they leave home to the moment they return home. This definition was then used in an analysis of the 1999 Adelaide Household Travel Survey (MAHTS99) database to extract and analyse trip-chaining information from the household activity-travel diary data in the database.

Travel choices such as mode, activity and time of travel choice in relation to trip chaining were investigated. In metropolitan Adelaide in 1999, it was found that:

- most trip chains were simple (entire week)
- more than half of all trip chains for personal travel undertaken by commercial vehicles were complex. Overall, it was found that the proportion of complex trip chains undertaken by motorised forms of transport was significantly greater than the proportion undertaken by non-motorised forms
- employer's business is the most chained activity with 75 per cent of trip chains being complex. More than half of all trip chains were also complex for personal business, accompanying someone and social and recreation activities
- only 94 per cent of trip chains involving education were simple. Work (70 per cent) and social welfare/medical (60 per cent) trip chains were also mainly pursued as simple trip chains

- the time of day where secondary activities were chained within a journey depended on the activity rather than being a peak phenomena. Activities that are truly pursued during the peak periods are serve-passenger related activities such as drop-off/pick-up and accompanying someone. The rest of the activities, although some peaking during certain periods of the day, tend to be pursued throughout the day
- a greater proportion of trip chains are undertaken during weekdays than weekends.

The relationships between the characteristics of individuals and households with respect to trip chaining behaviour were also explored. The findings of this analysis include:

- the type of trip chaining undertaken across age groups varies significantly which is influenced by the stage at which people are in their lives. It was found that:
  - dependents tend to be serve-passenger and undertake education activities
  - those within the working age undertake majority work, social and recreation, shopping and personal business activities. The activity drop-off/pick-up peaks at the 30–39-year age group
  - from the age of 55 years onwards, work declines and trip chaining associated with social/recreation and shopping activities starts to become undertaken the most
- males tended to undertake more work and education related trip chains. Females will undertake trip chains containing shopping, social/recreation and serve-passenger activities. This supports the notion of gender division of household and social labour as a factor in travel behaviour, as found in recent studies such as Kwan (1999)
- households with no vehicle undertake less complex trip chains than those with a car, particularly on weekends
- the amount of complex trip chaining undertaken by households varies among household structure types and across days of the week, with characteristics such as whether there are dependants or only adults and whether the household is single parent or family
- the type of trip chaining undertaken by households also varies across household structure types.

Further research

Detailed trip chain types were examined in this research to show how trip chains are formed, particularly in terms of when secondary activities are pursued with respect to primary activities. What the trip chain types do not show is the interaction of household members in conducting trips. In essence, this research only investigated trip chains in isolation but in no way shows how some of the trip segments link in together to show household interactions. The household and individual activity-travel data available in MAHTS99 could be used to examine these interactions. Clarke (1987) discussed a software tool called PISA used to explore and extract information from transport survey databases to allow for both trip and activity-based analysis and representation. Adams (2000) reported on a tool developed to represent both physical and virtual activities undertaken by individuals within and away from the home and how these activities interrelate with the activities of others. Such research, along with research efforts around the field of space-time mapping (e.g., Forer and Huisman 2000; Kwan 2000) could be adapted to the research described in this paper. Such developments could allow more

transport policies to be evaluated effectively on the basis of the actual travel behaviour exhibited by individuals in a household.

The aim of the analysis undertaken in this paper was to identify the relationships between trip chaining behaviour with various factors. Making conjecture as to the reasons why such relationships exist was avoided. For future work, important results from this research should be identified and further explored to identify the reasons behind these results and the implications for transport policy development.

Trip chaining behaviour was analysed with each individual factor in isolation. Although relationships may exist, there is no indication of the significance or strength of the relationships. Conducting multivariate analysis would allow all factors to be combined together with results providing an indication of the role each factor plays in influencing trip-chaining behaviour.

One step further to the multivariate analysis could be the development of behavioural models that allow a number of these factors to be combined within utility functions. Developing the relevant utility functions will yield coefficients that would show the strength and relationships among attributes with a trip chaining option. The added benefit of developing such models is that elasticities may be derived providing insight into the relationship between opportunity and time particularly in relation to the types of activities pursued. A further benefit to developing a trip chain behavioural model is that it may then be incorporated within travel demand models.

For the purpose of policy evaluation and planning, trip chaining behaviour needs to be appropriately incorporated into travel demand models. The extent to which trip chaining is usually incorporated within travel demand model is by defining non-home based travel as another activity type. By extracting tour and activity-based information from what was effectively a trip based database derived from a trip based survey, there is now an opportunity to incorporate such behaviour in travel demand models more effectively. Tour and activity based models need to be developed that acknowledge the relationships of trips between family members and between trip segments themselves which results in the trip chains investigated in this research.

There are a number of possible ways forward. The most effective in the short term may be a hybrid tour/trip based travel demand model where trip chaining is incorporated. At the trip generation step, a third type of zone should be created along with the production and attraction zones to include transitional zones where trip chain could be facilitated. This will then require an enhancement of the trip distribution step by incorporating a high level version of the assignment step where tours are assigned to groups of zones. Mode split could operate as per usual for each individual trip segment except within the utility functions there would need to be scope to acknowledge the relationships between trip segments. This has been attempted in previous modelling efforts by incorporating the mode chosen in the previous trip segment (Primerano and Taylor 2005; Bowman and Ben-Akiva 2001).

Markov chains could be adopted to model trip chaining behaviour as described by D'Este (1997) and incorporate within a travel demand model as implemented by Holyoak (2001) through using the cumulative transition probabilities to create an origin-destination trip matrix. In the longer term, trip chaining could be incorporated in a similar fashion, with the transition probabilities derived from discrete choice models which can incorporate household activity methodology used in PISA discussed in the beginning of this section and/or the latest advancements in space-time modelling.

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