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Time period choice modelling – review of practice

James Fox, Fay Dunkerley, Bhanu Patruni, Andrew Daly

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Preface

RAND Europe was commissioned by the Bureau of Transport Statistics (BTS) of Transport for NSW to undertake a review of the time period choice modelling literature.

The Sydney Strategic Transport Model (STM) was designed by Hague Consulting Group (1997). In Stage 1 of model development (1999–2000), Hague Consulting Group developed mode-destination and frequency models for commuting travel, as well as models of licence ownership and car ownership. In addition a forecasting system was developed incorporating these components. In Stage 2 of model development (2001–2002), RAND Europe, incorporating Hague Consulting Group, developed mode and destination and frequency models for the remaining home-based purposes, as well as for non-home-based business travel. Then, during 2003 and 2004, RAND Europe undertook a detailed validation of the performance of the Stage 1 and 2 models. Finally, Halcrow undertook Stage 3 of model development (2007), re-estimating the home–work mode-destination models, and at the same time developing models of access mode choice to train for home–work travel.

By 2009, some model parameters dated back to 1999, raising concerns that the model may no longer reflect with sufficient accuracy the current behaviour of residents of Sydney. Furthermore, changes to the zone structure of the model occurred with the number of zones approximately trebling in number and the area of coverage increased to include Newcastle and Wollongong. Therefore, the BTS commissioned RAND Europe to re-estimate the STM models using more recent information on the travel behaviour of Sydney residents, and implement those updated models. The updated version of the model system is referred to as STM3.

This report presents a review of time period modelling literature that was undertaken with two objectives. First was to undertake a broad review of the time period choice literature to understand how researchers and practitioners have modelling time period choice, and the practical lessons learnt from those studies that have implemented time period choice in a strategic model. The second more targeted objective was to provide recommendations on how to incorporate time period choice within the current STM3 model.

This document is intended for a technical audience familiar with transport modelling terminology.

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For more information about RAND Europe or this document, please contact James Fox:

RAND Europe
Westbrook Centre
Milton Road
Cambridge CB4 1YG
United Kingdom
Tel. +44 (1223) 353 329
jfox@rand.org

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1. Introduction

Version 3 of the Sydney Strategic Travel Model (STM3) incorporates a wide range of behavioural choices:

- Licence holding
- Car ownership
- Travel frequency
- Mode and destination choice (modelled simultaneously), incorporating:
    - Choice between tolled and non-tolled alternatives for car driver
    - Choice between park-and-ride (P&R), kiss-and-ride (K&R), bus and walk access modes for train
    - Choice of access station for P&R and K&R access to train.

However, the mode-destination models do not explicitly represent time period (TP) choice. Instead, average level-of-service is calculated by taking a weighted average across the modelled TPs using the time period proportions observed in the estimation sample (separately by journey purpose).

BTS are considering whether the STM3 mode-destination models should be extended to model macro time period choice. Over the next 20 years, the population of Sydney is expected to grow by 35 per cent and this will result in increased congestion in the peak periods, which will result in some travellers who currently travel in the peaks choosing to travel at less congested times.

This review has two objectives. First is to undertake a broad review of the TP choice literature to understand how researchers and practitioners have modelled TP choice, and the practical lessons learnt from studies that have implemented TP choice models in a strategic model. This will allow an understanding of the state of practice, and will also provide useful material if, over the longer term, the STM3 were to migrate to an activity-based framework. The second more targeted objective is to provide recommendations on how to incorporate TP choice within the current STM3 model.

Two sets of material have been reviewed: journal and conference publications that have been identified using a systematic search process, and ‘grey literature’ identified by the study team (including reports on RAND Europe studies) and BTS.

The remainder of this report is structured as follows. Chapter 2 summarises the methodology and findings from review of journal and conference papers. Chapter 3 describes the review of the identified grey literature. The note concludes in Chapter 4 with a summary of the broader review, and a set of specific recommendations for the incorporation of time period choice into STM3.

2. Review of journal and conference papers

2.1. Search process

2.1.1. Databases

In this study we searched the following databases for journal articles and conference papers:

- The Transport Research International Documentation (TRID) database
- Scopus
- Web of Science.

These databases provide extensive coverage of transport-related publications, and are described briefly below.

The TRID database

The TRID database integrates the content of two major databases, the Organisation for Economic Co-operation and Development's (OECD's) Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database and the US Transportation Research Board's (TRB's) Transportation Research Information Services (TRIS) Database. The TRID indexes over 900,000 records of transportation research worldwide, and is arguably the most comprehensive database for transport research. It contains peer-reviewed journals, reports and conference proceedings.

Scopus

Scopus is a large abstract and citation-based database of peer-reviewed literature with over 53 million records in the fields of science, technology, medicine, social sciences, arts and humanities.

Web of Science

Web of Science is a citation index. The database covers 5,294 publications in 55 disciplines as well as 160,000 conference proceedings.

2.1.2. Search terms

The search terms used are detailed in Table 1. Truncation and wildcard characters are used in order to capture a range of terms, e.g. 'model*' to capture 'model', 'modelling' and 'modeling'. Search terms in separate columns are connected together in a search string using 'AND' and terms in separate lists within a column are connected together in a search string using 'OR'.

Table 1: Search terms

model*	A N D	time of day OR time-of-day OR time of travel OR time-of-travel OR time period OR departure time OR trip timing OR trip-timing OR activity schedule

The Scopus and Web of Science databases cover journals in a wide range of subjects from physical sciences and engineering to social sciences and humanities. For this reason, the searches for these two databases were restricted to journals related to transportation only.

2.1.3. Inclusion and exclusion criteria

The inclusion and exclusion criteria applied to obtain papers of interest are summarised in Table 2.

Table 2: Inclusion and exclusion criteria

Criterion	Condition
location	a breadth of relevant international evidence was seen as an advantage and as such no boundaries were set on the countries to be included
language	English keywords were used for the search process, but the results from the search with English keywords were not restricted to English language material
time period	only papers published since 1990 were included[1]
demand type	passenger demand only – results from freight models were excluded
modes	results were restricted to surface transport modes

2.1.4. Selecting the studies to be reviewed

The database searches were undertaken by a trained librarian. The database searches identified:

- 1,816 hits from the TRID database
- 345 hits from the Scopus and Web of Science databases.

The abstracts of these 2,161 hits were then screened to identify a list of 144 candidate papers, which were supplemented by adding four further references cited in a recent PhD thesis on departure time choice

[1] With the exception of one key paper by Kenneth Small, published in 1982.

modelling that were not identified by the database searches. This 'long list' of 148 papers was reviewed by senior RAND Europe staff, and then a draft shortlist was proposed to BTS. A few changes were made as a result of BTS's review, resulting in a shortlist of 22 papers selected for review. References of the 148 papers that constitute the long list are provided in Appendix B.

2.2. Overview of studies

Table 6 summarises the 22 journal and conference papers selected for review. As well as listing the author(s), year and title, Table 6 summarises the geographical area of the research, whether stated preference (SP) or revealed preference (RP) was used and whether the models incorporated any segmentation other than segmentation by journey purpose.

Full references and abstracts for the 22 papers selected for review are provided in Appendix A.[2]

Geographical area

The continents in which the 21 of the 22 shortlisted studies were undertaken are summarised in Table 3 (one of the shortlisted studies was a theoretical paper that did not use data from a specific geographical area).

Table 3: Continent of shortlisted studies

Continent	Studies
Australasia	1
Asia	2
Europe	7
North America	10
South America	1

All but four of the studies were undertaken in Europe or North America, with just one from Australasia. No African studies were identified by the search process. The Australasian study uses data collected in Sydney.

Data type

The types of data that have been used in the 22 shortlisted studies are listed in Table 4.

[2] For some papers, the abstract does not appear in the EndNote database and so only the reference is provided.

Table 4: Data type used for shortlisted studies

Data type	Studies
SP	7
RP	10
joint SP-RP	3
n/a	2

The balance between SP and RP evidence is fairly even, and three studies have combined SP and RP data.

Segmentation

Eight of the 22 studies, i.e. just over one-third, incorporated segmentations in the models other than by journey purpose. These eight segmentations were:

- Occupation type in two of the studies
- Part-time workers, females with children, high income, no work flexibility
- Flexible/non-flexible working
- Part-time worker/full-time worker/retired
- Work flexibility
- Cost variable adjusted by income
- Income (sometimes expressed as cost/income), travel subsidy, car ownership, availability of parking

A key factor for modelling time period choice for commuters is flexibility in working hours. While SP data may record whether workers have flexible working hours, this information is not always recorded in the household travel surveys used to develop RP model systems. Segmentation by occupation type and full-/part-time working may proxy the same effect, for example different occupation types will have different levels of flexibility in working hours, and household travel surveys usually record whether workers work full- or part-time. An issue is that flexibility has increased considerably over recent decades, and forecasting shifts in the level of flexibility in the future is difficult. However, including such parameters allows testing of the impacts of changes in worker flexibility in different future scenarios.

Given that a number of studies have identified flexibility in working hours as having an important impact upon TP choice sensitivity, the information available in the HTS data was reviewed to assess what type of segmentation the HTS data could define. The HTS data records a ‘work schedule’ variable for workers, the codes recorded are summarised in Table 5.

Table 5: Work schedule codes recorded in HTS

1	fixed start and finish times - same each day
2	Flexitime
3	fixed start and finish times - each day can vary
4	rostered shifts
5	rotating shifts
6	variable hours
8	other (specify)

These codes could be used to segment the workers in the HTS data into flexible and inflexible categories, though as noted above to implement a model of this type it would be necessary to either make forecasts of future changes in flexibility in working hours, or to assume there are no future changes in flexibility in working hours. That said, the inclusion of such a variable is likely to be important in traveller behaviour and will allow explicit testing of differing scenarios around work flexibility.

Table 6: Journal and conference papers, study overviews

No.	Author(s)	Year	Title	Geographical area	Data type	Segmentation (other than purpose)
1	Bajwa, S.	2008	Discrete choice modeling of combined mode and departure time	Tokyo metropolitan area	SP	none reported
2	Ben-Akiva, M. and M. Abou-Zeid	2013	Methodological issues in modeling time-of-travel preferences	San Francisco Bay area	RP	PT workers, females with children, high income, no work flexibility
3	Bhat, C.	1998	Accommodating flexible substitution patterns in multi-dimensional choice modeling: formulation and application to travel mode and departure time choice	San Francisco Bay area	RP	none reported
4	Bowman, J. and M. Ben-Akiva	2001	Activity-based disaggregate travel demand model system with activity schedules	Boston	RP	none reported
5	Day, N.	2010	Analysis of work trip timing and mode choice in the Greater Toronto Area	Greater Toronto area	RP	occupation type
6	de Jong, G., A. Daly, M. Pieters, C. Vellay, M. Bradley and F. Hofman	2003	A model for time of day and mode choice using error components logit	The Netherlands, but with a focus on the Randstad	SP	none reported
7	Ettema, D., F. Bastin, J. Polak, and O. Ashiru	2007	Modelling the joint choice of activity timing and duration	The Netherlands	SP	none reported
8	Hess, S., A. Daly, C. Rohr and G. Hyman	2007	On the development of time period and mode choice models for use in large scale modelling forecasting systems	London, West Midlands region of the UK, the Netherlands	SP	flexible / non-flexible working (PRISM and the Netherlands)
9	Holguín-Veras, J. and B. Allen	2013	Time of day pricing and its multi-dimensional impacts: a stated preference analysis	New Jersey	SP	PT worker / FT worker / retired
10	Holyoak, N.	2007	Modelling the trip departure timing decision and	Sydney	RP	none reported

No.	Author(s)	Year	Title	Geographical area	Data type	Segmentation (other than purpose)
			peak spreading policies			
11	Knockaert, J.	1995	The Spitsmijden experiment: a reward to battle congestion	Zoetermeer to the Hague area of the Netherlands	RP	none reported
12	Lizana, P.	2014	Modeling mode and time-of-day choice with joint RP and SC data	Santiago Metropolitan area	joint RP-SP	none reported
13	Noland, B. and K. Small	1995	Travel-time uncertainty, departure time choice, and the cost of morning commutes	n/a	n/a	n/a
14	Nurul Habib, K.	2012	Modeling commuting mode choice jointly with work start time and work duration	Greater Toronto area	RP	commute segmented by occupation type
15	Paleti, R., P. Vovsha, and D. Givon	2014	Joint modeling of trip mode and departure time choices using revealed and stated preference data	Jerusalem	joint RP-SP	none reported
16	Saleh, W. and S. Farrell	2005	Implications of congestion charging for departure time choice: work and non-work schedule flexibility	Edinburgh	SP	flexibility(represented by terms in the utilities)
17	Sikder, S., B. Augustina, A. Pinjaria and N. Elurub	2014	Spatial transferability of tour-based time-of-day choice models: an empirical assessment	San Francisco Bay area	RP	n/a
18	Small, K.	1982	The scheduling of consumer activities: work trips	San Francisco Bay area	RP	none reported
19	Tringides, C. and R. Pendyala	2004	Departure-time choice and mode choice for non-work trips: alternative formulations of joint model systems	South-east Florida	RP	none reported
20	Vovsha, P. and M. Bradley	2004	Hybrid discrete choice departure-time and duration model for scheduling travel tours	Mid-Ohio	RP	none reported
21	Willigers, J. and M. de Bok	2009	Updating and Extending the Disaggregate Choice Models in the Dutch National Model	The Netherlands	both SP and RP	cost variable adjusted by income
22	Williams, I. and J. Bates	1993	APRIL – a strategic model for road pricing	London	n/a	income, travel subsidy, car ownership, availability of parking

2.3. Model structure

Table 8 highlights the model structure used in the 22 shortlisted studies, detailing the choice responses modelled, the modes for which time period choice is modelled, the model type and, for studies where nested logit is used, the resulting ordering of the different choices represented. In the 'Model type' column the following abbreviations are used: MNL for multinomial, NL for nested logit and MxL for mixed logit. In the 'Ordering of modelled choices where NL is used' column M denotes modes, TP denotes time periods and D denotes destinations.

Modes for which time period choice is modelled

Table 7 summarises the modes for which time period choice is modelled, segmenting the data into SP and RP data (as often SP data is only collected for a restricted set of modes). Note that Table 7 excludes those North American studies reviewed where TP choice is modelled above mode choice, because with this structure it is not possible to model TP choice for a subset of the modes.

Table 7: Modes for which time period choice is modelled in the shortlisted studies

Modes	SP	RP	SP & RP	Total
car	3	2	1	6
car and PT	4	1		7
car, PT, walk/cycle		3	2	5
unknown		2		2

The SP-only studies model either car only, or both car and PT, but not walk/cycle modes. This is likely to be because there is a belief that changes in TP choice are unlikely for these modes as congestion does not prevent individuals walking or cycling at peak times. Furthermore, there are fewer policies focused on these modes. The fully multi-modal models, i.e. including both motorised and non-motorised modes, all use RP data. It is noted that the current STM3 mode-destination models incorporate walk and cycle as well as car and PT modes.

Model type and ordering of modelled choices where nested logit is used

The majority of time period choice only studies use multinomial logit models, and the majority of studies that model both TP and mode choice use nested logit formulations.

For studies that model TP and mode choices in a nested logit structure, the most frequent structure is one with mode choice (M) above (i.e. less sensitive than) time period (TP) choice. However, an important and intuitive finding of Hess et al. (2007) is that 'the sensitivity of time period choice is higher when shorter time periods are used, so the relative sensitivity of time period and mode choices depends upon the length of the time periods modelled'.

Table 8: Journal and conference papers, model structure

No.	Author(s)	Year	Choices modelled	Modes with TP choice modelled	Model type	Ordering of modelled choices where NL is used
1	Bajwa, S.	2008	mode and departure time	car	MNL, NL, MxL	NL: M > TP
2	Ben-Akiva, M. and M. Abou-Zeid	2013	departure and arrival time	n/a	probably MNL (not explicitly stated)	n/a
3	Bhat, C.	1998	mode and departure time	drive alone, shared ride, transit	MNL and MxL	n/a
4	Bowman, J. and M. Ben-Akiva	2001	daily activity pattern	n/a - activity pattern modelled above mode choice	MNL	n/a
5	Day, N.	2008	mode and departure time	car driver, car passenger, transit modes, walk/bike	MNL for mode choice, hazard model for trip timing	n/a
6	de Jong, G., A. Daly, M. Pieters, C. Vellay, M. Bradley and F. Hofman	2003	mode and departure time choice	car driver, train	MxL	ordering of M & TP choices?
7	Ettema, D., F. Bastin, J. Polak, and O. Ashiru	2007	activity timing and duration	car driver and PT	MNL, MxL	n/a
8	Hess, S., A. Daly, C. Rohr and G. Hyman	2007	mode and departure time	car driver only (London, W. Mid.s) car driver and PT (Netherlands)	continuous time: MNL discrete time: MNL and NL	structure varied according to length of TPs
9	Holguín-Veras, J. and B. Allen	2013	frequency, mode, route and time period choice	car and PT	MNL	was not possible to estimate valid NL models
10	Holyoak, N.	2007	departure time choice	car	MxL	n/a

No.	Author(s)	Year	Choices modelled	Modes with TP choice modelled	Model type	Ordering of modelled choices where NL is used
11	Knockaert, J.	1995	mode and departure time	car, PT, bike	MNL, NL, MxL	NL: M > TP
12	Lizana, P.	2014	mode and departure time	car driver, car passenger, PT modes, walk, taxi	MNL, MxL	NL: M > TP
13	Noland, B. and K. Small	1995	departure time choice	car	n/a	n/a
14	Nurul Habib, K.	2012	mode choice, work start time, work duration	car driver, car passenger, transit modes, walk	mode choice – discrete start time and duration – continuous	n/a
15	Paleti, R., P. Vovsha, and D. Givon	2014	mode and departure time	car driver, car passenger, walk, bike, PT modes, school bus, taxi	joint mode and TOD choice using hybrid choice-duration model	M > TP
16	Saleh, W. and S. Farrell	2005	departure time	car only	MNL	n/a
17	Sikder, S., B. Augustina, A. Pinjaria and N. Elurub	2014	time of day	n/a	MNL	n/a
18	Small, K.	1982	work arrival time	car only	MNL	n/a
19	Tringides, C. and R. Pendyala	2004	mode and departure time	car single occupancy, car multiple occupancy	bivariate probit model, departure time and mode represented as binary choices	workers: TP > M non-workers: M > TP
20	Vovsha, P. and M. Bradley	2004	tour scheduling	n/a	MNL	n/a
21	Willigers, J. and M. de Bok	2009	mode, time period and destination	car driver	NL	M > TP > D for some purp.s one or more θ=1
22	Williams, I. and J. Bates	1993	mode and time period	car driver, car passenger, bus, rail and walk/cycle	incremental NL	not stated

2.4. Treatment of time period choice

Table 11 summarises how time period choice is represented in models in the 22 studies reviewed. Specifically, the table presents information on the time periods used, indicating the number and length of periods and recording whether continuous time is represented rather than discrete time periods, notes whether separate network assignments were made by time period to provide inputs to the time period models, flags whether the models represent the linkage between the outward and return legs of a tour and details the terms used in the utilities to differentiate the different time period alternatives other than travel cost and travel time.

Time period duration

Table 9 summarises the level of detail used to model peak time periods (in the majority of studies shorter time periods are used to cover the peak periods to account for variation in congestion levels at different points in the broader peak period).

Table 9: Time period duration in the peak periods

Duration	Studies
continuous time	4
< 1 hour periods	8
1 hour periods	4
> 1 hour periods	8

A substantial number of studies have used time periods of one hour or shorter, whereas the current STM3 uses longer peak periods. Given the Hess et al. (2007) finding that the sensitivity of time period choice depends on the length of the time period, an important consideration is the number and proposed length of TPs that are used. This will depend on proposed assignment procedures and have implications for run times.

It is noted that none of the four studies that represented time as a continuous variable were studies that fed into operational strategic models.

Separate assignments by time period

Not all of the studies used separate highway assignments by TP. In the case of models developed from SP data, the TPs may be based around self-reported journey times. However, to develop and implement a TP choice model within a strategic model such as STM3, the developer must answer two related questions:

1. What TPs should be used as alternatives in the demand model?
2. What TPs should be used for assignment?

It is not necessary that the TPs used in each be the same, although to allow the demand to be assigned it is important that the TPs used in the demand models nest within those used for assignment. An example of using differing resolutions for the demand and assignment models is given by Vovsha and Bradley (2004), which uses hourly resolution for the TP choice model, but assigns the trips in four, more aggregate, TPs

(AM peak, midday, PM peak, night). An advantage of this structure is that rather than tie the model closely to the assignment TP definitions, it offers the modeller a great deal of flexibility to change the way in which level-of-service is fed to the demand models, whether it be by using uniform level-of-service within each assignment period, using more detailed assignment periods or applying some form of a factoring approach. The current version of STM3 assigns highway demand separately by four TPs:

- AM peak: 07:00 to 08:59
- Inter-peak: 09:00 to 14:59
- PM peak: 15:00 to 17:59
- Off-peak: 18:00 to 06:59

In model estimation, level of service for one-hour 'shoulder' periods around the two peak periods has been approximated by taking a simple average of the LOS for the relevant peak and the inter-peak periods.

Outward and return tour leg linkage

A key aspect of TP choice is that it is made based on travel conditions on both the outward and return legs, and therefore better quality models are identified by modelling outward and return TP choice simultaneously. This is achieved by defining a separate TP choice alternative for each possible combination of outward and return TP. Moreover, including TP choice alternatives by combinations of outward and return TPs ensures some level of congruence of activity times.

Table 10 presents a count of the studies that represent the linkage between the outward and return tour legs, as the current STM3 mode-destination models do.

Table 10: Linkage of outward and return time periods

Duration	Studies
yes	10
no	11
n/a	1

It can be seen that around half the studies represent the linkage, i.e. use a fundamentally tour-based approach, and half do not, i.e. use a trip-based approach. We would recommend that STM3 retains a tour-based approach.

Terms in the utilities other than cost and time

A number of the studies that have developed time period choice models using SP data have incorporated terms for early and late penalties relative to the preferred arrival or departure time (referred to as 'schedule delay'). This approach is best suited for SP data where the preferred arrival and/or departure time can be recorded from the respondent.

For RP modelling a mechanism is needed for forecasting future arrival and/or departure times. Ben-Akiva and Abou-Zeid (2013) describe an approach that can be used in RP models that approximates schedule delay, when information on desired travel times is not available. In their approach they assume that for a given market segment preferred arrival times for arrival time sensitive trips, and the departure times for departure time sensitive trips, are constant. This suggests the mean schedule delays for a given market segment are constant, and the schedule delay effect can be captured in the alternative specific constants.

The RP models that RAND Europe have developed are described in Chapter 3; all incorporate alternative specific constants that effectively capture mean schedule delay effects for each market segment (the market segments are travel purposes in these models). For this approach to work well, the market segments should have similar characteristics in terms of preferred arrival and departure times. This is an argument for introducing segmentation into the models to reflect this, for example splitting workers into those with flexible and those with non-flexible working hours.

Table 11: Journal and conference papers, treatment of time period choice

No.	Author(s)	Year	Time periods	Assign by TP?	Linkage out & return?	Terms in utilities other than cost & time
1	Bajwa, S.	2008	dep. time in 15 min intervals	n/a	no	early arrival, late arrival, car avail., age, income, live in suburbs
2	Ben-Akiva, M. and M. Abou-Zeid	2013	35: 33 of ½ hour duration, plus early and late	not clear	yes	arrival time, departure time, activity duration, size variable for period length
3	Bhat, C.	1998	6: early AM, AM-peak, AM inter-peak, PM inter-peak, PM-peak, evening	yes	no	trip destination attributes, employment status, age, gender, income and car availability terms
4	Bowman, J. and M. Ben-Akiva	2001	4: AM-peak, inter-peak, PM-peak, off-peak	yes	yes	dummy variables for different activity pattern types
5	Day, N.	2008	continuous time	by 24 1-hr periods	yes	age, gender, income, number of stops
6	de Jong, G., A. Daly, M. Pieters, C. Vellay, M. Bradley and F. Hofman	2003	continuous time	n/a	yes	early penalty, late penalty, separately for outward and return, increased & reduced activity participation for non-flexible workers, age part-time workers, low education level, work at home regularly
7	Ettema, D., F. Bastin, J. Polak, and O. Ashiru	2007	continuous time	n/a	no	time of day dependent utility, duration, schedule delay
8	Hess, S., A. Daly, C. Rohr and G. Hyman	2007	tested continuous time, and time periods of different durations	n/a	yes	continuous time specification includes schedule delay, discrete time period specification includes activity duration
9	Holguín-Veras, J. and B. Allen	2013	peak, off-peak	n/a	no	schedule delay terms interacted with race, country of origin, employment, education level; total travel time with PT worker
10	Holyoak, N.	2007	AM and PM-peaks split into 1 hour periods	no	no	journey time as a random parameter, HH white collar worker as a random parameter, HH FT worker, HH cars / resident, HH children

No.	Author(s)	Year	Time periods	Assign by TP?	Linkage out & return?	Terms in utilities other than cost & time
11	Knockaert, J.	1995	AM peak only, for cars 7–10 am period split into 15 min periods	no	no	constants for schedule delay, linear and quadratic schedule delay
12	Lizana, P.	2014	three sets of time periods tested: 15 mins, 30 mins, 1 hour	no	no	schedule delay early, schedule delay late, late for work dummy, car availability, cost / wage rate, medium and high flexibility for SDE & SDL
13	Noland, B. & K. Small	1995	n/a	n/a	no	SDE, SDL, constant for late arrival, 'head start' term as a function of departure, arrival and travel times
14	Nurul Habib, K.	2012	continuous time	yes	yes	start time model: FT worker work duration, total travel time, distance, dwelling type, HH size, age, gender, O & D density, free parking, work duration
15	Paleti, R., P. Vovsha, and D. Givon	2014	48 ½ hour periods	not clear	yes	early and late shift variables interacted with part-time worker, gender, age, household income, distance, presence of children
16	Saleh, W. and S. Farrell	2005	AM-peak split into 5 ½ hour periods, sixth period for arrivals after 09:30	n/a	no	basic: arrival (categorical), distance, car delay dummy, early departure, schedule delay, senior management, marital status flexibility: start work 30 mins early, start work 30 mins late, have children and all adults working, activities before work, income
17	Sikder, S., B. Augustina, A. Pinjaria and N. Elurub	2014	48 ½ hour periods	n/a	yes	as per paper 2
18	Small, K.	1982	12 5-minute intervals of arrival time	n/a	no	schedule delay variables, HH type, occupation, work time flexibility
19	Tringides, C. and R. Pendyala	2004	3: AM-peak, off-peak, PM-peak	yes	no	age, presence of children, high income, employment status
20	Vovsha, P. and M. Bradley	2004	19 1-hour periods from 05:00 to 24:00	yes	yes (4 TPs)	departure and arrival time components, activity duration, worker status
21	Willigers, J. and M. de Bok	2009	7: 2 peaks, 4 shoulders, 1 off-peak	yes	yes	none reported
22	Williams, I. and J. Bates	1993	8: 2 3-hour peaks, 4 1-hour shoulders, inter-peak, off-peak	yes	yes	time includes parking search time

3. Grey literature

3.1. Identifying material for review

The approach used to identity grey literature was less systematic than that employed for the review of journal and conference papers. The first group of studies reviewed were modelling studies undertaken by RAND Europe that incorporate time period choice models, namely:

- The PRISM model for the West Midlands region of the UK
- The Manchester Motorway Box study
- The OTM model for the Greater Copenhagen area.

Reports for all three of these models are available online.

Next, were two studies identified by BTS that had an Australasian connection:

- A review by Sinclair Knight Mertz of transport modelling tools that includes documentation of a model in Auckland
- Documentation of a model for Edmonton Canada, relevant because a city region in Australia is considering adopting the Edmonton modelling approach.

Finally, three more studies that the study team were aware of were reviewed:

- Work from London in the 1990s that pioneered the outward and return linkage present in tour-based approaches
- The Dutch National Model, which was the first large-scale time period choice model (in its initial version developed by Hague Consulting Group
- A review of activity-based models in the US.

In total this gave eight different studies that have developed model systems capable of predicting time period choice, seven of which have been widely used for policy analysis. Thus the focus of the review of grey literature was on model systems that are similar in scope to STM and that have implemented TP choice.

3.2. Overview of studies

Table 12 summarises the eight studies that have been reviewed, listing the authors, the year and title of the report, the geographical area covered, the type data used to develop the time period choice models and any segmentation present in the models other than journey purpose.

Table 12: Grey literature, study overviews

No.	Author(s)	Year	Title	Geographical area	Data type	Segmentation (other than purpose)
G1	RAND Europe	2014	PRISM 2011 Base: Mode-Destination Model Estimation	West Midlands region of UK	RP/SP	none in implemented models
G2	Fox, J., A. Daly	2009	Manchester Motorway Box: Post Survey Research of Induced Traffic Effects. Model Estimation	Greater Manchester area	RP	none
G3	Fox, J., B. Patruni & A. Daly	2013	OTM6 Demand Model Estimation: Mode Destination and Frequency Models	Greater Copenhagen area	RP/SP	none
G4	Sinclair Knight Mertz	2009	Critical Review of Transport Modelling Tools	various, Auckland model reviewed	not clear	not stated
G5	Transportation Department, City of Edmonton	2007	City of Edmonton Regional Travel Model	Edmonton	RP	2 worker segments (need car at work, do not need car at work), 3 education segments (primary, secondary, tertiary), for discretionary purposes segmentation into working age adults and seniors (65–74), older seniors (75+)
G6	Williams, I. & J. Bates	1993	APRIL – A Strategic Model for Road Pricing	Central and Inner London	SP	none
	Polak, J. & P. Jones	1994	A Tour-Based Model of Journey Scheduling under Road Pricing			
G7	Significance	2014	*Actualisatie van keuzemodellen voor het NRM/LMS* [Updating choice models for national and regional model systems]	The Netherlands	RP/SP	income segmentation impacts time period choice
G8	Transportation Research Board	2014	Activity-Based Travel Models: A Primer	United States	varies	varies between models

Note: Study G1 used information on the placement of TP choice relative to mode choice that is given in the UK Department for Transport's WebTAG guidance and that is based upon SP evidence. Study G3 used information on the placement of TP choice relative to mode choice drawn from the Hess et al. (2007) paper reviewed in Section 2.

It can be seen from Table 12 that most model systems that have implemented TP choice have used RP data. In contrast, a sizeable proportion of the journal and conference papers rely on SP data. This discrepancy probably reflects the fact that SP data allows more detailed model specifications to be developed, specifically incorporating schedule delay terms for differences relative to the preferred departure or arrival times, and increased heterogeneity in responses. However, these specifications are difficult to implement in large-scale model systems. So more academic papers can develop more complex specifications from SP data without needing to consider how these specifications would be implemented within an operational model system. A further consideration is that large-scale models as a whole tend to be developed from RP surveys.

As discussed in the previous section, the difficulty with the schedule delay approach arises because preferred arrival and departure times are not typically recorded in RP data, and even if they are recorded for the base year there is a need to forecast preferred arrival and departure times in the future. Moreover, Ben-Akiva and Abou-Zeid (2013) showed that, under an assumption of constant preferred arrival or departure times for a given market segment, the time period constants that are typically used in RP implementations are equivalent to the schedule delay approach.

In terms of the relative strengths of RP and SP data for modelling TP choice, RAND Europe have relevant experience from a number of studies. Work to examine the impacts of a motorway extension in Manchester found that it is difficult to estimate the sensitivity of time period choice relative to mode and destination choice from RP data alone for mandatory travel purposes. We also struggled to identify the relative sensitivity of TP choice from RP data alone in the PRISM and OTM6 studies (studies G1 and G3 in Table 12).

One hypothesis is that these problems arise because the demands on an assignment to give variation in congestion for different origin-destination pairs that can explain different levels of peaking are quite severe; another is that the TP constants are highly correlated with the TP nesting parameter.

It is noteworthy that in the Edmonton study it has been possible to estimate the relative sensitivity of TP choice for home–work travel, and the results presented in the Edmonton study modelling report appendix suggest that it has also been possible to identify the sensitivity of TP choice for other travel purposes. However, it is not clear from the report what the significance of the TP nesting parameters was, and so it is not possible for us to draw any wider conclusions from this study as we do not know whether the TP nesting parameters identified were statistically significant.

The issues in identifying TP choice from RP data alone can be overcome by the use of joint SP and RP data. Information on the placement of TP choice relative to mode choice can be drawn from SP data, while the RP data can be used to estimate time and cost sensitivity, as well as outward-return TP combination constants.

3.3. Model structure

Table 13 summarises the model structure used in the 22 shortlisted studies, detailing the choice responses modelled, the modes for which time period choice is modelled, the model type and, for studies where nested logit is used, the ordering of the different choices represented. Note that in a number of these models the mode-destination–time period choice models are linked to a higher level frequency choice using logsums, and some of these models include access mode and station choice sub-models for PT. Table 13 only details whether or not mode and destination choices are modelled simultaneously with TP choice.

Table 13: Grey literature, model structure

No.	Year	Geographical area	Choices modelled	Modes with TP choice modelled	Model type	Ordering of modelled choices where NL is used
G1	2014	West Midlands region of UK	mode, time period and destination	car driver	NL	commute: M=TP>D business: M>TP=D shopping: M>TP=D escort: M>TP=D other travel: M>TP=D
G2	2009	Greater Manchester area	mode, time period and destination	car driver	NL	commute: D>M=TP business: M=D>TP education: M=TP=D shopping: M>TP=D leisure: M>TP=D NHB business: M=TP=D NHB other: M=TP=D
G3	2013	Greater Copenhagen area	mode, time period and destination	all – car driver, car passenger, PT, cycle, walk	NL	commute: M>D business: M>D education: M>D shopping: M>TP>D other: M>TP>D
G4	2009	various, Auckland model reviewed	distribution and mode choice, followed by separate time period choice model	car, PT	MNL for time period choice	n/a
G5	2007	Edmonton	sequential choices of frequency, destination, time of day, mode and peak crown/shoulder choice	all – car, PT, P&R, walk, bike, school bus	MNL for time period and peak crown/shoulder choices	n/a
G6	1993/ 1994	Central and Inner London	incremental nested logit with 5 levels: frequency, destination, mode, time periods, route	car driver	incremental logit	destination choice assumed above mode and TP choice for HBW mode and TP choice at same level, for

No.	Year	Geographical area	Choices modelled	Modes with TP choice modelled	Model type	Ordering of modelled choices where NL is used
						HBO, mode above TP choice, these based on research by TSU Oxford; hierarchy coefficients not given
G7	2014	The Netherlands	mode, time period and destination	car driver	NL	not reported[3]
G8	2014	United States	varies	varies	varies	varies

[3] However, see published paper 21, which refers to earlier analyses of the same data.

The RAND Europe / Hague Consulting Group studies (G1, G2, G3, G7) follow a common design, with the simultaneous estimation of mode, TP and destination choices rather than sequence estimation. In terms of structure, it can be seen that TP choice has often been constrained to be at the same level as mode or destination choice. This is due to limitations in using RP data alone, rather than an indication that the sensitivities are actually equal. This issue is discussed further in the 'overview of studies' sub-section above.

Study G6 employs an incremental logit approach, that is to say the models are applied based on the change on generalised cost relative to the base year to calculate changes in trips relative to observed base matrices. A limitation of this approach is that it requires base matrices to be defined for each model segment, so for example if a segmentation of workers into flexible and non-flexible were to be used then this would necessitate the development of base matrices with the same segmentation. A key advantage of applying models absolutely then pivoting around base matrices – which is the approach currently used in the STM – is that the base matrices do not need to incorporate the detailed segments used by the demand model.

Table 14 overleaf summarises how TP choice has been treated in the eight grey literature reports that have been reviewed. It can be seen that the majority explicitly represent the linkage between outward and return tour legs, and represent between three and five TPs. Study G3 is the exception, incorporating more detail in the peak periods leading to a total of ten TPs. As discussed in Section 2.4, an important finding from the academic literature is that the sensitivity of TP choice relative to mode choice depends on the length of TP that is modelled.

Table 14: Grey literature, treatment of time period choice

No.	Year	Geographical area	Time periods	Assign by TP?	Linkage out & return?	Terms in utilities other than cost & time
G1	2014	West Midlands region of UK	Four TPs: AM 07:00–09:30; IP 09:30–15:30; PM 15:30–19:00; OP 19:00–07:00	yes	yes	out-return TP combination constants
G2	2009	Greater Manchester area	Four TPs: AM 08:00–09:00; IP 07:00–08:30, 09:00–16:00, 18:00–20:00; PM 16:00–18:00; OP 20:00–07:00	yes	yes	out-return TP combination constants
G3	2013	Greater Copenhagen area	Ten TPs: AM(1) 07:00–08:00, AM(2) 08:00–09:00; IP(1) 05:00–07:00, IP(2) 09:00–15:00, IP(3) 18:00–21:00; PM(1) 15:00–16:00, PM(2) 16:00–17:00, PM(3) 17:00–18:00; OP(1) 03:00–06:00, OP(2) 21:00–03:00	yes	yes	out-return TP combination constants
G4	2009	various, Auckland model reviewed	Three TPs: AM, PM, other (definitions not given)	yes	yes	none (implemented as incremental model using on generalised cost changes)
G5	2007	Edmonton	Three TPs: AM 07:00–09:00, PM 16:00–18:00, rest of day	yes	no	TP constants, TP-region constants
G6	1993/ 1994	Central and Inner London	time effectively continuous but 3-hour peaks are recognised	n/a	yes	early and late schedule delay (linear and quadratic), activity time participation
G7	2014	The Netherlands	Five TPs: 2 peaks, 2 shoulders, off-peak (detailed definitions not reported)	yes	yes	no additional terms
G8	2014	United States	varies between models	varies	varies	varies between models

4. Recommendations for development of STM

Our recommendation is that the tour-based approach currently used in STM is retained, allowing explicitly linkage between outward and return tour legs, which is important when modelling TP choice. We further recommend that in application, the model is applied in absolute form (as opposed to incrementally) and pivoted around observed base matrices as per the current STM. This allows for further segmentation.

It is recommended that the TP definitions be revisited by BTS in the light of data showing how demand and congestion vary across the day in the current model base year.

A number of studies have incorporated segmentation in the TP choice models on top of segmentation by journey purpose. Many of these segmentations represent differences in TP sensitivity between workers with flexible and those with non-flexible working hours, either directly, or indirectly through segmentation into full-time and part-time workers or by occupation type. Our recommendation is that TP choice models be developed for all of the model purposes represented in STM. We further recommend that in the longer term, for commuter and business travel, the STM should reflect differences in TP sensitivity between workers with flexible and those with non-flexible working hours.

Our recommendation on the issue of for what modes TP choice should be modelled, are that in the short term models should be developed for car only, and that in the medium term that TP choice models should either remain car only or should be extended to cover PT modes, depending on whether BTS plan to develop separate PT networks for peak and off-peak periods.

As discussed in Section 3.2, our experience of trying to identify the sensitivity of TP choice relative to mode and destination choice from RP data alone is not positive. Therefore our medium-term recommendation is to collect new SP data in Sydney, and then to estimate simultaneous models of mode, destination and TP choice data by pooling the RP and SP data. It would be important that any new SP data used a definition of flexible and non-flexible working that was consistent with the RP data, i.e. the HTS data.

Drawing these recommendations together, we suggest a two-stage development plan for incorporating TP choice within STM:

- In the short term, import TP choice into the mode-destination model structure for car only, using Hess et al. (2007) to provide structural parameters appropriate to the length of TP modelled. This is the approach we used successfully to import TP choice models into the OTM models for the Greater Copenhagen area (study G3 in Table 12, Table 13 and Table 14). It is noted that this approach requires the mode-destination models to be re-estimated

- In the medium term, to collect new SP data across the STM model area to develop joint RP-SP models that incorporate TP choice within the mode-destination model structure, and reflect differences in sensitivity between workers with flexible and those with non-flexible working hours. The issue of what modes TP choice should be modelled for is discussed further below.

The two-stage approach allows users of STM to benefit from a capability to model the impact of policy on TP choice in the short term while an SP survey on TP choice is being commissioned, collected, analysed and implemented. If BTS were to later decide to develop an activity-based model, the SP data could be readily incorporated into models of TP choice that fit within an activity-based model.

An important issue for consideration if workers are segmented into flexible and non-flexible groups is that it will then be necessary to forecast changes in that split when undertaking analysis of future scenarios. The HTS data has been collected since 1997, and so analysis of the changes in the proportion of workers with flexible hours from 1997 to the present could be used to inform predictions of any future changes in the flexible/non-flexible worker split. We suggest that predicted changes in the flexible/non-flexible should be made with consideration of the predicted split between full- and part-time working.

Issues that would need to be agreed with BTS if these recommendations were to be followed are:

- Whether following analysis of current demand and congestion profiles, the number and definition of the TPs needs to be revised
- Once the TP definitions had been agreed with BTS, the appropriate sensitivity for TP choice could be specified based on the Hess at al. (2007) work and other RAND Europe experience
- Whether BTS intend to develop off-peak PT networks over the medium term, and if so whether the joint RP-SP models should represent TP choice for public transport as well as for car.

Appendix A – References and abstracts for reviewed papers

Bajwa, S. 2008. Discrete choice modeling of combined mode and departure time. *Transportmetrica* 4(2): 155–177.

Ben-Akiva, M. and M. Abou-Zeid. 2013. Methodological issues in modelling time-of-travel preferences. *Transportmetrica A: Transport Science* 9(9): 846–859.

The authors address three methodological issues that arise when modelling time-of-travel preferences: unequal period lengths, schedule delay in the absence of desired time-of-travel data and the 24-hour cycle. Varying period length is addressed by using size variables. Schedule delay is treated by assuming either arrival or departure time sensitivity and using market segment specific utility functions of time-of-travel, or using distributions of the desired times-of-travel. The 24-hour cycle is modelled by using a trigonometric utility functional form. These methodologies are demonstrated in the context of a tour-based travel demand model using the 2000 Bay Area travel survey.

Bhat, C. R. 1998. Accommodating flexible substitution patterns in multi-dimensional choice modeling: formulation and application to travel mode and departure time choice. *Transportation Research Part B: Methodological* 32(7): 455–466.

The nested logit model has been used extensively to model multi-dimensional choice situations. A drawback of the nested logit model is that it does not allow choice alternatives to share common unobserved attributes along all the dimensions characterising the multidimensional choice context. This paper formulates a mixed multinomial logit structure that accommodates unobserved correlations across both dimensions in a two-dimensional choice context. The mixed multinomial logit structure is parsimonious in the number of parameters to be estimated and is also relatively easy to estimate using simulation methods. The mixed multinomial logit model is applied to an analysis of travel mode and departure time choice for home-based social-recreational trips using data drawn from the 1990 San Francisco Bay Area household survey.

Bowman, J. L. and M. E. Ben-Akiva. 2001. Activity-based disaggregate travel demand model system with activity schedules. *Transportation Research Part A: Policy and Practice* 35(1): 1–28.

The article discusses an integrated activity-based discrete choice model system of an individual's activity and travel schedule, for predicting urban passenger travel demand. A prototype demonstrates the system concept using a 1991 Boston travel survey and transportation system level of service data. The model system represents a person's choice of activities and associated travel as an activity pattern overarching a set of tours. A tour is defined as the travel from home to one or more activity locations

and back home again. The activity pattern consists of important decisions that provide overall structure for the day's activities and travel. In the prototype, the activity pattern includes (a) the primary activity of the day, with one alternative being to remain at home for all the day's activities; (b) the type of tour for the primary activity, including the number, purpose and sequence of activity stops; and (c) the number and purpose of secondary tours. Tour models include the choice of time of day, destination and mode of travel, and are conditioned by the choice of activity pattern. The choice of activity pattern is influenced by the expected maximum utility derived from the available tour alternatives.

Day, N. 2008. The joint modelling of trip timing and mode choice, Master's Thesis, Department of Civil Engineering, University of Toronto.

de Jong, G. et al. 2003. A model for time of day and mode choice using error components logit. *Transportation Research Part E: Logistics and Transportation Review* 39(3): 245–268.

The Dutch National Model System has been used for over ten years to predict the response of travellers to a wide range of developments, including changing travel times or the imposition of time-dependent road user charging. One of the results of these simulations has been that the choice of when to travel greatly affects the amount of congestion on the road network and that policies aimed at spreading out peak travel can be effective instruments to relieve congestion. This paper presents a new error components logit model for the joint choice of time of day and mode, using data from a stated preference survey into the time of day choice of travellers by car and train in The Netherlands. Findings suggest that time of day choice is sensitive to changes in peak travel time and cost, and that policies that increase these peak attributes will lead to peak spreading. However, in general, the time of day sensitivities to travel time and cost changes in the sample appear to be lower than ten years ago.

Ettema, D. et al. 2004. Modeling timing and duration of activities and trips in response to road-pricing policies. *Transportation Research Record, 1894*: 1–10.

This paper develops a model of activity and trip scheduling that combines three elements that have to date mostly been investigated in isolation: the duration of activities, the time-of-day preference for activity participation and the effect of schedule delays on the valuation of activities. The model is an error component discrete choice model, describing individuals' choice between alternative workday activity patterns. The utility function is formulated in a flexible way, applying a bell-shaped component to represent time-of-day preferences for activities. The model was tested using a 2001 data set from the Netherlands. The estimation results suggest that time-of-day preferences and schedule delays associated with the work activity are the most important factors influencing the scheduling of the work tour. Error components included in the model suggest that there is considerable unobserved heterogeneity with respect to mode preferences and schedule delay. A model of timing and duration of activities and travel is outlined. The model assumes that marginal utility derived from activities encompasses two distinct components, one derived from duration of activity involvement and the other derived from activity participation at a particular time of day. To test travellers' responses to road-pricing schemes, an operational model is developed and calibrated on a stated-preference data set collected in a previous study in London. The estimation results suggest that

utility derived from work is partly duration dependent and partly time-of-day dependent. A model in which the duration-dependent marginal utility is described by a logarithmic function and the time-of-day-dependent marginal utility is described by a Cauchy function provides the best description of trip and activity timing. The model is used to evaluate the effect of various pricing schemes for the estimation sample. The predictions suggest that pricing policies have a considerable impact on commuters' trip and activity scheduling, involving shifts to earlier and later departure times. Also discussed are the implications of the model for value-of-time estimates. The results indicate that the value of time changes through the day depending on the utility profiles of the activities.

Hess, S., et al. 2007. On the development of time period and mode choice models for use in large scale modelling forecasting systems. *Transportation Research Part A: Policy and Practice* 41(9): 802–826.

A substantial amount of research is presently being carried out to understand the complexities involved in modelling the choice of departure time and mode of travel. Many of these models tend to be far too complex and far too data intensive to be of use for application in large scale model forecasting systems, where socio-economic detail is limited and detailed scheduling information is rarely available in the model implementation structure. Therefore, these models generally work on the basis of a set of mutually exclusive time periods, rather than making use of continuous departure time information. Two important questions need to be addressed in the use of such models, namely the specification used for the time periods (in terms of length), and the ordering of the levels of nesting, representing the difference in the sensitivities to shifts in departure time and changes in the mode of travel. This paper aims to provide some answers to these two questions on the basis of an extensive analysis making use of three separate Stated Preference (SP) datasets, collected in the United Kingdom and in the Netherlands. In the analysis, it has proved possible to develop models that allow reasonably sound predictions to be made of these choices. With a few exceptions, the results show higher substitution between alternative time periods than between alternative modes. Furthermore, the results show that the degree of substitution between time periods is reduced when making use of a more coarse specification of the time periods. These results are intended for use by practitioners, and form an important part of the evidence base supporting the UK Department for Transport's advice for practical UK studies in the WebTAG system.

Holguín-Veras, J. and B. Allen. 2013. Time of day pricing and its multi-dimensional impacts: A stated preference analysis. *Transportation Research Part A: Policy and Practice* 55: 12–26.

Time of day pricing uses higher tolls in the peak-hours to induce passenger car traffic to consider a switch to more sustainable alternatives in terms of time of travel, mode, route and payment method. In designing such programmes, special attention must be paid to ensure that the drivers' behavioural responses to pricing are well understood. This is important because, if the analysts do not correctly predict users' reactions, policies and programmes may fail to achieve their objectives. Knowledge of users' responses to pricing assists policymakers to design effective pricing programmes. This paper investigates the behavioural impacts of time of day pricing using stated preference data collected from regular users of the New Jersey Turnpike. As part of the data collection process, the respondents were presented with hypothetical toll scenarios and asked how they would change behaviour. Using these data, discrete choice models were estimated as a function of policy variables

and respondents' socio-economic attributes. The final model shows that time of day pricing could induce changes in the payment method used to pay the tolls, route choice, and time of travel. It was found that the amount of the toll, total travel time and schedule delay – together with other socio-economic variables – were important factors in determining which alternative a user would select. Market share analyses for basic toll scenarios were conducted to assess the overall impacts of alternative toll scenarios. Elasticities were computed for the key variables in the model. In its final sections, the paper discusses policy implications and chief conclusions.

Holyoak, N. and M. A. P. Taylor. 2007. Modelling the Trip Timing Decision and Peak Spreading Policies. European Transport Conference, Noordwijkerhout, the Netherlands.

As the supply of transport infrastructure struggles to keep pace with ever-increasing transport demands from the community, peak period traffic congestion is a problem faced by many urban areas around the world. Australia's largest capital city, Sydney is no exception, with a population of over four million generating approximately 15.5 million trips each weekday, much of which occurs during morning and afternoon peak periods. It is for this reason that planners often focus on peak time periods for network provisions and operational management. This can lead to an inefficient allocation of resources, which could be unsustainable for future transport network operations. Peak spreading may be seen as having two broad dimensions. The first may be described as 'passive' peak spreading, which is a natural increase in the duration of a peak period as travel demand tests the capacity of a facility so that the levels of peak travel activity persist for a longer period. The second dimension is 'active' peak spreading, in which individual travellers deliberately change their travel behaviour to avoid peak periods, or transport policies are enacted to encourage people to travel outside of the peak periods. The concept of peak spreading thus introduces strategies and management techniques to manage the peak traffic demand as it allows for the spreading of peak period traffic flow profiles in congested areas. It is therefore important to represent the effects of such strategies in a modelling environment for evaluation. After a critical analysis of current international practice for representing trip timing behaviour in current travel demand models, this paper provides a summary of observed trip timing behaviour in Australian capital cities. It also focuses on the requirements for a travel time model with abilities in the representation of peak spreading strategies suggestions for future research directions.

Knockaert, J. et al. 2012. The Spitsmijden experiment: A reward to battle congestion. *Transport Policy* 24: 260–272.

It can be imagined that a reward may be a far more popular policy instrument than the traditional taxation approach towards containing externalities, usually presented in public economics literature. Given the implied policy potential, the authors conducted an extensive reward experiment in real-world conditions on a congested motorway corridor in the Netherlands. In this paper the data collected in the experiment are used to estimate a number of discrete choice models that describe the commuter's behaviour with respect to departure time choice as well as transport mode choice. The authors apply the traditional scheduling approach where rush-hour travellers trade off travel time for schedule delay disutility, and study how this equilibrium shifts upon the introduction of a reward. The results of the analysis provide a clear indication that a reward can be used as an effective policy

instrument. The participant's behaviour implies that the shadow prices of schedule delay are close to constant over time, a finding that is in line with the classic assumptions in the literature. Preferences for different departure times for car trips within the rush hour are found to be correlated. This indicates that shifting departure time is likely to be a more important behavioural response to policies for congestion relief than a modal shift or teleworking. Comparing the relative as well as the absolute sizes of the different valuations of schedule delay early, schedule delay late and travel time shows that they are comparable to past findings in the literature.

Lizana, P. et al. 2014. Modeling Mode and Time-of-Day Choice with Joint RP and SC Data. 93rd Annual Meeting of the Transportation Research Board, Washington D.C.

Trip departure time has become a more important theme in practice as urban congestion problems are increasingly addressed by travel demand management (TDM) strategies. In this paper, the authors formulate and estimate a joint mode-departure time choice model using combining revealed preference (RP) and stated choice (SC) data about commuting trips in Santiago. The information was gathered through a series of surveys (RP, SC and attitudinal survey) applied to some 500 commuters in the Santiago Metropolitan Area. The travel time, cost and cost divided by wage rate coefficients were fairly similar in both environments (RP and SC), while schedule delay (SD) penalties associated with early or late arrival to work differed between each data. The degree of flexibility that workers have to adjust their arrival time to work resulted to be statistically significant when interacted with SD terms, suggesting that the level of work flexibility indeed influences temporal choices. The use of different time-resolution intervals showed that goodness of fit of the estimated models increased when higher time resolutions (i.e. length of departure time intervals) were considered, but values of time could differ when using distinct aggregation of trip departure time alternatives.

Noland, R. B. and K. A. Small. 1995. Travel-time uncertainty, departure time choice, and the cost of morning commutes. *Transportation Research Record* 1493: 150–158.

Existing models of the commuting time-of-day choice were used to analyse the effect of uncertain travel times. Travel time included a time-varying congestion component and a random element specified by a probability distribution. The results from the uniform and exponential probability distributions were compared and the optimal 'head-start' time that the commuter chooses to account for travel time variability, that is, a safety margin that determines the probability of arriving late for work, was derived. The model includes a one-time lateness penalty for arriving late as well as the per-minute penalties for early and late arrival that are included by other investigators. It also generalises earlier work by accounting for the time variation in the predictable component of congestion, which interacts with uncertainty in interesting ways. A brief numerical analysis of the model reveals that uncertainty can account for a large proportion of the costs of the morning commute.

Nurul Habib, K. M. 2012. Modeling commuting mode choice jointly with work start time and work duration. *Transportation Research Part A: Policy and Practice* 46(1): 33–47.

This paper presents a joint trivariate discrete-continuous-continuous model for commuters' mode choice, work start time and work duration. The model is designed to capture correlations among random components influencing these decisions. For empirical investigation, the model is estimated using a data set collected in the Greater Toronto Area (GTA) in 2001. Considering the fact that work duration involves medium- to long-term decision making compared with short-term activity scheduling decisions, work duration is considered endogenous to work start time decisions. The empirical model reveals many behavioural details of commuters' mode choice, work start time and duration decisions. The primary objective of the model is to predict workers' work schedules according to mode choice, which is considered a skeletal activity schedule in activity-based travel demand models. However, the empirical model reveals many behavioural details of workers' mode choices and work scheduling. Independent application of the model for travel demand management policy evaluations is also promising, as it provides better value in terms of travel time estimates.

Paleti, R. et al. 2014. Joint Modeling of Trip Mode and Departure Time Choices Using Revealed and Stated Preference Data. 93rd Annual Meeting of the Transportation Research Board, Washington D.C.

Travel choices of mode and trip departure time are closely intertwined since the Level-of-Service (LOS) attributes for each mode vary substantially across time-of-day (TOD) periods. Most congestion mitigation strategies are intended to alter mode as well as trip departure time choices of travellers. Thus, these two travel dimensions have to be analysed and modelled jointly. However, it is usually difficult to uncover the trade-offs between different LOS attributes using Revealed Preference (RP) data, particularly in the context of TOD choice modelling. The objective of the current study is to develop an integrated model of mode and trip departure time-of-day choices using both RP and Stated Preference (SP) data from the large-scale Household Travel Survey undertaken in Jerusalem in 2010. The SP component was specifically designed to compensate for the RP limitations and provide mode and departure time switches as the result of policies such as pricing. The developed model captures the impact of a rich set of socioeconomic factors and is also sensitive to a wide range of policy variables such as toll, parking cost, etc. The developed model also accounts for several important econometric aspects and associated problems that arise during the joint RP-SP analysis while maintaining a model structure that is manageable in model estimation and subsequent application.

Saleh, W. and S. Farrell. 2005. Implications of Congestion Charging for Departure Time Choice: Work and Non-Work Schedule Flexibility. *Transportation Research Part A: Policy and Practice* 39 (7-9): 773–791.

This study investigates the potential impacts of implementing variable congestion charging on the peak spreading of departure time choices. The study addresses non-work activities as well as socioeconomic characteristics and their influence on scheduling flexibility for work trips. Departure time choice models were calibrated using data collected as part of a larger survey on the consequences of congestion charging on travel choices in the city of Edinburgh. The inclusion of variables related to work and non-work scheduling, as well as socioeconomic variables have improved the performance of the models. This suggests that non-work activities, as well as work schedule flexibility, have an impact on departure time choice for the journey to work. This means that even for those with flexible work schedules, but with other non-work commitments, the timing of their work trip may not be so flexible. These findings suggest that other complementary measures, such as

childcare provision at work and different operating hours of shopping and leisure facilities, should be introduced in parallel with variable congestion charging schemes.

Sikder, S. et al. 2014. Spatial Transferability of Tour-Based Time-of-Day Choice Models: An Empirical Assessment. 2nd Conference of Transportation Research Group of India.

An empirical assessment is presented on the transferability of tour-based time-of-day choice models across different counties in the San Francisco Bay Area. Transferability is assessed using two different approaches: (1) application-based approach, and (2) estimation-based approach. The former approach tests the transferability of a model as a whole while the latter approach allows the analyst to test which specific parameters in the model are transferable. In addition, the hypothesis that pooling data from multiple geographical contexts helps in developing better transferable models than those estimated from a single context was tested. The estimation-based approach yields encouraging results in favour of time-of-day choice model transferability, with a majority of parameter estimates in a pooled model found to be transferrable. Pooling data from multiple geographical contexts appears to help in developing better transferable models. However, attention is needed in selecting the geographical contexts to pool data from. Specifically, the pooled data should exhibit the same demographic characteristics and travel level-of-service conditions as in the application context.

Small, K. 1982. The scheduling of consumer activities: work trips. *The American Economic Review* 72: 467–479.

Tringides, C. A. et al. 2004. Departure-time choice and mode choice for nonwork trips: alternative formulations of joint model systems. *Transportation Research Record* 1898: 1–9.

Modelling travel demand by time of day is gaining increasing attention in the practice of travel demand forecasting. The relationship between time-of-day (departure-time) choice and mode choice for non-work trips is investigated. Two alternative causal structures are considered: one in which departure-time choice precedes mode choice and a second in which mode choice precedes departure-time choice. These two causal structures are analysed in a recursive bivariate probit modelling framework that allows random error covariance. The estimation is performed separately for worker and non-worker samples drawn from the 1999 Southeast Florida Regional Household Travel Survey. For workers, model estimation results show that the causal structure in which departure-time choice precedes mode choice performs significantly better. For non-workers, the reverse causal relationship, in which mode choice precedes departure-time choice, is found to be a more suitable joint modelling structure. These two findings can be reasonably explained from a travel behaviour perspective and have important implications for advanced travel demand model development and application.

Vovsha, P. and M. Bradley. 2004. Hybrid discrete choice departure-time and duration model for scheduling travel tours. *Transportation Research Record* 1894: 46–56.

A new model for scheduling travel tours is described. The model is essentially a discrete choice construct that operates with tour departure-from-home and arrival-back-home time combinations as alternatives. The proposed utility structure, based on continuous-shift variables, represents an analytical hybrid that combines the advantages of a discrete choice structure (flexible and easy to estimate and apply) with the advantages of a duration model (parsimonious structure with a few parameters that support any level of temporal resolution including continuous time). The hybrid model currently has a temporal resolution of 1 h, which is expressed in 190 hour-by-hour departure- and arrival-time alternatives. The model is applied sequentially for all tours in the individual daily activity-travel pattern according to a predetermined priority of each activity type. The enhanced temporal resolution allows for the application of direct availability rules for each subsequently scheduled tour to be placed in the residual time window left after the tours of higher priority are scheduled. This feature ensures a full consistency for the whole individual daily schedule. The model has been estimated and applied as a part of the new regional travel demand model developed recently for the Mid-Ohio Regional Planning Commission.

Willigers, J. and M. de Bok. 2009. Updating and Extending the Disaggregate Choice Models in the Dutch National Model. European Transport Conference, Noordwijkerhout, the Netherlands.

The Netherlands National Model System (NMS) is known as one of the first disaggregate national travel demand forecasting systems used in practice. The model system has been in use since 1986, and has been extensively updated and extended through its lifetime. Disaggregate discrete choice models are applied in the various modules of the modelling system. These modules simulate the different choices in travel behaviour: tour frequencies, mode and destination choice, time of day choice, secondary and lower level destinations and the choice of a train route. This paper presents the re-estimation and improvements of the Netherlands National Model System (LMS). These include integration of logsums from subsequent choices and combined revealed preference/stated preference estimations for the mode/destination models.

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Ben-Elia, E. and D. Ettema. 2010. Commuters' Choice-Behavior with Rewards for Avoiding Peak-Hour Driving. 89th Annual Meeting of the Transportation Research Board, Washington D.C.

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