Impact of family in-home quality time on person travel demand

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ABSTRACT

This paper introduces the concept of Primary Family Priority Time (PFPT), which represents a high priority household decision to spend time together for in-home activities. PFPT is incorporated into a fully specified and operational activity based (AB) discrete choice model system for Copenhagen, called COMPAS, using the DaySim software platform. Structural tests and estimation results identify two important findings. First, PFPT belongs high in the model hierarchy, and second, strong interactions exist between PFPT and the other day level activity components of the model system. Forecasts are generated for a road pricing and congestion scenario by COMPAS and a comparison version of the model system that excludes PFPT. COMPAS with PFPT exhibits less mode changing and time-of-day shifting in response to pricing and congestion than the comparison version.

1. INTRODUCTION

Although many activity and travel decisions relate to individual persons, anyone living in a household is affected by the presence of other household members, and the effects are likely to extend to activity and travel choices. Modelling of such activity and travel choices is at the heart of activity based (AB) models. However, AB models used for traffic forecasting have not thus far dealt with the impact that families have on individual activity and travel by choosing to spend time together at home, i.e. blocking out periods of time where out-of-home activities and travel cannot take place for members of the household.

In reality there can be important interactions between in-home activity and travel activity choices. Spending time together as a family is of high importance in Denmark. For instance, two parents, both working, usually have only a couple of hours at their disposal to spend with their children, especially if they are small. In that time period, child care is a high priority, as is planning of household activities for the next day.

The research reported in this paper addresses a notion that, for some households, spending time together at home as a family is of high importance, so high that even work schedules may be adjusted to accommodate it, where this is possible. This high priority in-home family time is called Primary Family Priority Time (PFPT). It is called "Primary" in contrast to "Secondary" Family Priority Time, which refers to family priority time that involves joint travel and activity away from home.

The objective of the research is to assess the validity and effectiveness of the concept of PFPT by implementing it within an advanced household AB demand model system of a discrete choice type. This model system, called COMPAS – COpenhagen Model for Person Activity Scheduling, is being developed for the Greater Copenhagen area under the ACTUM research project. The ACTUM project is funded by the Danish Strategic Research Council, in the period 2011-2016. COMPAS is the first operational discrete choice AB model within the Scandinavian countries.

The research yields an innovation with several important aspects. First, it introduces the idea of PFPT, formulates an unambiguous definition and estimates a model of PFPT participation. Second, it places PFPT within a fully specified discrete choice AB model system, identifying, on one hand, high placement of PFPT in the model hierarchy, and on the other hand, significant interactions of PFPT with other dimensions of the household's day activity choices. Third, it shows the importance of PFPT by generating predictions for the tested policy that differ in logical ways from a comparison model system lacking PFPT.

Section 2 reviews activity-based modelling efforts that have modelled intra-household interactions or in-home activities and discusses the theory related to the concept of PFPT. Section 3 relates to the data applied in the model, as well as the definition of PFPT applied in the model. The core of the paper is Section 4 where both the model structure and details of the estimation exercises are presented. Section 5 describes application of the model in the case study scenario involving road pricing and congestion. Concluding remarks and the future research needs are presented in Section 6. Section 7 is an appendix that describes the entire structure of the COMPAS model, providing the context of the current research for the interested reader.

2. BACKGROUND

2.1. Literature related to the modelling of intra-household interactions or in-home activities

A review by Bowman (1998) of the theoretical underpinnings of activity based models identifies elements that also apply to the concept of PFPT:

> *Chapin (1974) theorized that activity demand is motivated by basic human desires, such as survival, social encounters and ego gratification. Activity demand is also moderated by various factors, including, for example, commitments, ca-*

pabilities and health. A significant amount of research has been conducted on how household characteristics moderate activity demand. This research concludes that (a) households influence activity decisions, (b) the effects differ by household type, size, member relationships, age, gender and employment status and (c) children, in particular, impose significant demands and constraints on others in the household (Chapin, 1974; Jones, Dix, Clarke et al., 1983; Pas, 1984). Hagerstrand (1970) focused attention on constraints—among them coupling, authority, and capability—which limit the individual's available activity options. Coupling constraints require the presence of another person or some other resource in order to participate in the activity. Examples include participation in joint household activities or in those that require an automobile for access. Authority constraints are institutionally imposed restrictions, such as office or store hours, and regulations such as noise restrictions. Capability constraints are imposed by the limits of nature or technology. One very important example is the nearly universal human need to return daily to a home base for rest and personal maintenance. Another example Hagerstrand called the time-space prism: we live in a time-space continuum and can only function in different locations at different points in time by experiencing the time and cost of movement between the locations.

In recent decades activity based model systems have been developed that deal rigorously with Hagerstrand's time-space prism, such as PCATS (Kitamura and Fujii, 1997), Albatross (Arentze and Timmermans, 2004) and DaySim (Bradley, et al, 2010). Some of these also deal in various ways with constraints placed by the household on individual activity and travel. For example, in the United States some operational AB model systems condition individual activities and travel on modelled joint household activity pattern types (Bradley and Vovsha, 2005), a well as on joint travel arrangements for work and school commute and for joint non-mandatory tours (see section 7 Appendix). Some also model individual execution of household out-of-home maintenance activities (Vovsha et al, 2004a and 2004b).

Other intra-household interactions have been modelled in isolated fashion, outside the context of an operational AB model system. Gupta and Vovsha (2013) model schedule synchronization of the work tour for two workers. Srinivasan and Bhat (2006) present a discrete-continuous discretionary activity participation and duration model that captures trade-offs between in-home individual activity, out-of-home individual activity and out-of-home joint activity. Ho and Mulley (2013) review other research presenting models of intra-household interactions.

Most research on in-home activities in the activity-based modelling literature focuses on participation and duration of in-home activity, without attempting to model in-home activity as part of a travel demand model system. For example, Meloni, et al (2009) develop a mixed joint probit–Tobit (MJPT) model that uses a probit component to identify whether a woman conducts out-of-home discretionary activity in addition to in-home discretionary activity, and a Tobit component to estimate the duration of the out-of-home discretionary activities of various purposes. Konduri, et al (2010) develop a probit-based discrete-continuous model that jointly represents activity type choice and activity duration, in which in-home discretionary activity is one of the activity types, along with out-of-home discretionary and out-of-home maintenance.

A few aspects of in-home activities have been incorporated into operational AB model systems. Bowman (1998) models the decision to conduct maintenance activities at home as part of the person’s day activity pattern. CT-RAMP (Vovsha, et al 2011) and DaySim (Section 7 Appendix) include staying at home all day as one alternative in each person’s day activity pattern. DaySim (Bradley et al 2010) includes working at home as one of the usual work location choice alternatives, and also models participation in at-home work activity (Section 7 Appendix).

In summary, while some AB models explicitly model joint household decisions or intra-household interactions, and some incorporate in-home individual activities, none of them deals with the impact that families have on individual activity and travel by choosing to spend time together at home.

2.2. Behavioural theory behind the concept of PFPT

Researchers from Aalborg University under the ACTUM project present the results of in-depth household interviews that establish the importance of PFPT in Danish society (Aalborg University, 2012):

> *"... it is a wish or urge of the household and its members to spend time together. This is often referred to as quality time."* (p92)
>
> *"Especially households with younger children seem to have a high valuation of family time."* (p80)
>
> *"... most of the households seek to synchronise their personal schedules around dinner. However, this can both be seen in a functional perspective (one has to eat dinner) and in an emotional perspective (it is nice to spend time together with the family)."* (p92)
>
> *"The above-mentioned tactics are found in the empirical data and is something the households employ on a daily basis. A primary priority across the households in the sample is the synchronization of the household members for family quality time."* (p93)
>
> *"Even though quality time and togetherness between the household members is prioritised in all the households, there is a great variance in how the households are approaching this and to what degree togetherness is needed to fulfil the unity of the household. Each household has its own balance between, on one hand, synchronisation, togetherness and family quality time, and on the other hand, attending to individual activities and partaking in other social relations outside the household. For some, it is only necessary to meet occasionally during the daily life, such as at the prime meals, while for others, a significantly larger share of the time outside work and school is spent together. Nevertheless, synchronisation in the household is not something that occurs on its own. It*

needs to be induced, there is work involved, and it has to be taken into consideration during the planning and organisation in the daily life of the household. Just as the external rhythms are factors that affect the household's organisation, is the need and urge to synchronise the internal rhythms of the household members." (p93)

Summarizing the Aalborg research, the interviewed household members seek to arrange work and personal activities in order to fulfil high priority commitments to in-home quality family time, called PFPT in the current paper.

There have been frequent efforts in the social sciences, similar to the Aalborg work, to understand and describe causal links between work, children and leisure within Danish families. Bonke (2009) shows that Danish parents spend about 50% more time with their children than those in England, while parents in Canada and the USA fall in between them. Bonke (2002) concludes that for workdays, family quality time happens most often in the evening – about 50% of the investigated families had two pre-agreed evenings when the whole family was together. In 2005 the Danish Government established the Commission of Work-Life Balance. The Commission published a report, “Chance for balance” (2007), which provides 31 recommendations to the government in order to ease and improve everyday life, especially for young families. Recommendation number 28 urges taking the complexity of everyday life into consideration when planning and promoting future traffic policies—such as Wi-Fi access in busses and trains—and transport infrastructure—such as metro and light rail systems in cities.

3. SURVEY DATA AND DEFINITION OF PFPT

For more than twenty years Denmark has been collecting travel data across the whole country using a one-day person based survey with very limited information about other household members, the so-called TU-survey (DTU Transport, 2012). For the ACTUM project, additional households were added to the survey. A few new questions were added and all household members were included, so that household decisions and interactions among persons in the household could be modelled. One household adult answered questions related to the household (e.g. car ownership, household income), while every person completed an activity/travel diary for the same weekday. Diaries for children under age nine were completed by a parent. For the purpose of modelling PFPT, questions were asked about in-home activity participation. In particular, for each in-home episode, each respondent reported the amount of time they spent in each of several activity purposes and—importantly for modelling PFPT— for each purpose who joined them in the activity.

The households included in the survey were sampled across the Greater Copenhagen area, with a strong focus on the central municipalities of Copenhagen and Frederiksberg, an area in which one would expect some divergence from national averages for key socio-economic and demographic variables. The sample was taken from the internet panel of a survey company, and the sampling procedure was based on family structure, age and geography. In total, 903 households were interviewed. Of those, 801 provided complete enough information to be used, too few for implementing a system for real-world forecasts, but enough to test the PFPT concept and implement a complete working model system. Tables 1 and 2 show the distributions of sample households and persons by type.

Table 1: The household sample description

	Frequency	Percent
One adult no children	157	19.6
One adult with children	114	14.2
Two+ adults no children	145	18.1
Two+ adults with children	385	48.1
Total	801	100

Table 2: The person sample description

	Frequency	Percent
Full time worker	922	41.7
Part time worker	61	2.8
Retired	149	6.7
Nonworking adult	99	4.5
University student	115	5.2
Child age 16+	119	5.4
Child age 5 through 15	534	24.2
Child age under 5	210	9.5
Total	2,209	100

Because of concerns about increased respondent burden, efforts were made to reduce the number of questions, which, unfortunately, caused the loss of some information about in-home joint activity participation. In particular, households that stayed at home together all day have no reported shared in-home activities, there is no record of shared morning activity if everybody in the household left for work or school before 9am, and there is no record of late evening shared activity if everybody arrived home after 8pm. The result is that the survey data is biased downward in joint in-home activity participation.

Furthermore, since respondents were not asked directly whether they engage in high priority family in-home shared activities on a regular basis—for this the current research relies on the qualitative research from Aalborg University—and the survey covered only one day, it may not be possible to fully understand the nature of the observed behaviour. For example, in some cases an observed joint in-home activity might have occurred even without a family commitment to quality time together, and in other cases a family committed to regularly spending high priority quality time together might not have exercised that commitment on their survey day; such behaviour would not be captured in the data. In the light of intuition about Danish society and the results of the Aalborg study, the concept was tested in the models presented here, and they give plausible results.

PFPT participation was defined as a binary variable and deemed to have occurred if the household satisfied the following conditions:
- At least one person age 13 or older journeyed away from home during the day, returned home by 8pm, and reported shared at-home activities after returning home.
- The respondent explicitly reported participation in shared at-home activity for purposes other than work, school or commerce.
- The shared activity involved all members of the household and lasted at least 20 minutes.

In total, 644 households in the sample include two or more persons. With the above definition, 206 of those 644 households, i.e. 32%, participated in PFPT on their survey day.

This restrictive definition enables PFPT to be modelled simply and provides a high standard for statistically validating that it occurs. It leaves room for enhancement in future research using larger data sets with improved collection of information about in-home activities. For example, PFPT might be defined as a multinomial outcome, allowing for less than full household participation in some cases. Or, PFPT might be defined as a latent variable—representing the need to spend time at home with family members—whose indicators are participation in and duration of various in-home activities.

4. MODEL STRUCTURE AND MODEL ESTIMATION

4.1. Model overview

The household travel demand portion of the COMPAS model system consists of an integrated set of discrete choice models implemented on the DaySim software platform (Bradley, et al, 2010). As depicted on the left in Figure 1, the COMPAS household models consist of long-term choice models (i.e. usual work location, car ownership and public transport pass ownership), models at the day level that identify the tours and stop purposes, and tour and trip models that model the details of each tour, generating and modelling each trip.

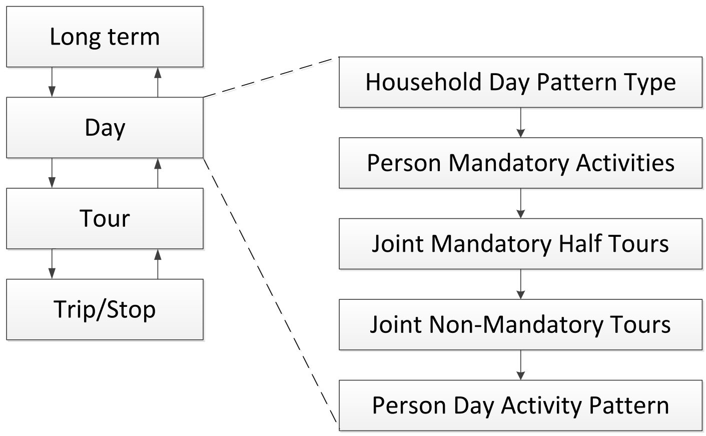

Figure 1: COMPAS model structure with details of the day level structure

According to the figure, the day level models consist of numerous models, placed in five main groups that operate in conditional sequence according to a priority hierarchy. Most of these models focus on modelling intra-household interactions explicitly. They constrain and condition the tour models, and are also impacted by accessibility arising from them. Also, in the course of the simulation, when a model at the day or tour & trip level determines that an activity or travel spans a particular period of time, that period becomes unavailable for other activities and travel. This method has already been implemented within DaySim for the Puget Sound Regional Council, the Metropolitan Planning Organization serving the Seattle region, and is currently being implemented also by the Delaware Valley Regional Planning Commission serving the Philadelphia region. Details of the entire COMPAS AB model system are presented in the Section 7 Appendix, to provide context for the research presented in this paper.

The innovative part of the current research is that PFPT participation is modelled and inserted into the hierarchy as a household choice at the level of the household day pattern type, conditioning the other dimensions of choice within the day. PFPT is modelled jointly with the household's choice of whether to conduct one or more joint tours for non-mandatory purposes. A joint tour is one in which two or more members of the household conduct a complete tour together, sharing purposes, destinations, and all travel. It can involve situations where one person escorts another to an activity, stays while that person carries out the activity, and then returns home together with them. Also, given that PFPT participation occurs, a PFPT schedule model determines the start time and duration of the PFPT activity. This time is then blocked out, making it unavailable for on-tour activities and travel. In this way, PFPT conditions the other models of the day in two ways: PFPT participation is used as an explanatory variable in the other choices, and the PFPT schedule serves as a hard time constraint. Details of the PFPT participation model within the COMPAS model system are presented in the rest of Section 4.

4.2. Structural tests

Alternative model structures are estimated to test the hypothesis that PFPT conditions Household Day Pattern Choice. The two model components are estimated jointly with three different structural assumptions: (1) MNL, (2) NL with household day pattern type conditioning PFPT, and (3) NL with PFPT conditioning household day pattern type. The key summary results are shown in Table 3. Structure 2's nesting parameter is outside the bounds of random utility theory, and Structure 3's likelihood is significantly better than either structure 1 or 2. This points to structure 3 as the superior structure, as hypothesized by the current research and underlined by the Aalborg qualitative research, in which households agreed to spend in-home quality time together and placed other day activities secondary to this. Importantly, however, as the structure 3 model converges, the nesting coefficient is driven to zero, indicating that the PFPT choice is not affected by the household pattern type logsum. In other words, these two models can be implemented in sequence, with PFPT conditioning household day pattern type, but without a logsum connection between them. The conditional order is important because, as will be shown in Section 4.4, the presence of PFPT significantly affects the conditional household day pattern type model.

Table 3: Estimation summary results of three alternative nesting structures for PFPT and household day pattern type

Model	**Log Likelihood**	**Rho Squared (relative to naïve model)**	**Nest Theta**	**Standard Error**
Naïve model with only a full set of alternative-specific constants	-1597.8	.000		
(1) MNL	-1194.5	.252	1.00	Fixed
(2) NL: Household Day Pattern Type conditions PFPT	-1192.5	.254	1.49	0.27
(3) NL: PFPT conditions Household Day Pattern Type	-1188.5	.256	0.03	0.06

Additional model structures are estimated to test the hypothesis that shared activity at home may be jointly determined with the presence of joint non-mandatory tours. In the context of the COMPAS model, all joint tours were understood as Secondary Family Priority Time (SFPT). Table 4 shows the incidence of these two binary outcomes using the 644 households with two or more members. A statistically significant Pearson correlation coefficient of 0.192 indicates that PFPT and joint tours tend to be present (or absent) together in a household's day. An example of joint incidence would be a day in which a child is accompanied by a parent for an afternoon activity, such as playing handball, with the household involved in PFPT at home in the evening.

Table 4: Presence of PFPT and joint tours in the estimation sample

	Frequency	Percent
No PFPT or joint tours	395	61.3
PFPT but no joint tours	156	24.2
Joint tours but no PFPT	43	6.7
PFPT and joint tours	50	7.8
Total	644	100

Four alternative model specifications are estimated: (4) an MNL model, (5) an NL model where presence of PFPT conditions joint non-mandatory tour presence, (6) an NL model where joint non-mandatory tour presence conditions PFPT, and (7) another MNL where an ASC is included for joint presence of PFPT and joint non-mandatory tours in the same day. The overall summary statistics of these four models are presented in Table 5.

Table 5: Estimation summary results of alternative nesting structures for PFPT and joint non-mandatory tour presence

Model	**Degrees of Freedom**	**Log Likelihood**	**Rho Squared (relative to naïve model)**	**Nest Theta**	**Standard Error**
Naïve model with only two constants	2	-810.5	0.000		
(4) MNL	16	-497.9	0.386	1.00	Fixed
(5) NL1 (PFPT presence conditions joint non-mandatory tour presence):	17	-485.1	0.401	0.04	0.02
(6) NL2 (joint non-mandatory tour presence conditions PFPT presence):	17	-486.2	0.400	9.88	4.8
(7) MNL with additional ASC for joint presence of PFPT and joint non-mandatory tour	17	-478.8	0.409	1.00	Fixed

Neither model 5 nor model 6 converges; model 5 fails as the nest theta approaches zero, and model 6 fails as theta approaches infinity. The results shown for models 5 and 6 are immediately prior to convergence failure. Among models 4, 5 and 6, model 5 is superior, suggesting a structure in which PFPT conditions joint non-mandatory tour presence, without a logsum connection. However, the ASC for joint presence of PFPT and joint non-mandatory tour presence cannot be empirically identified separately from the nest theta, so it is excluded from models 4 through 6. But model 7 includes this ASC instead of a nest theta, and yields a superior model fit, as indicated by the log-likelihood and rho squared values. Thus, the model 7 structure is selected, in which PFPT and joint non-mandatory tour presence are modelled jointly as an MNL and together condition the Household Day Pattern Type model, as shown in Figure 2.

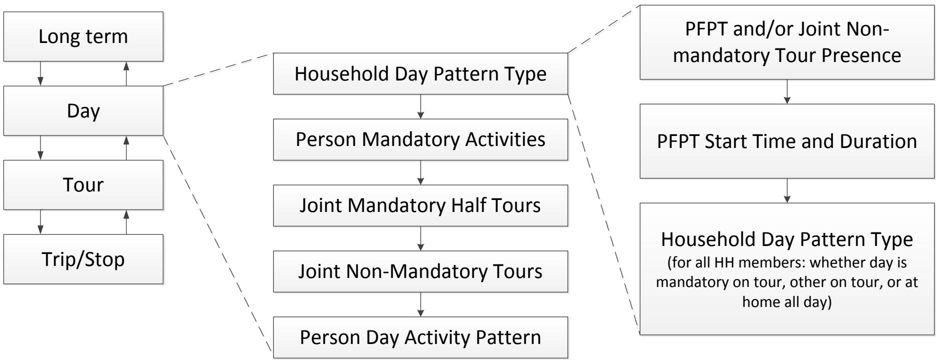

Figure 2: COMPAS model structure with details of the household day pattern structure

The above structural tests, which place PFPT and joint non-mandatory tour generation together (Model 7) at the top of the day's hierarchy, provide the most important finding of the current research. The estimation details of this model are discussed in detail in the next section.

4.3. Estimation results for a joint model of PFPT and presence of joint non-mandatory tours

Table 6 presents estimation results of a more refined version of the structure of model 7, an MNL with four alternatives: (i) neither PFPT nor a joint non-mandatory tour is present, (ii) PFPT is present without any joint non-mandatory tour, (iii) a joint non-mandatory tour is present without PFPT, and (iv) both are present.

The model consists of 26 coefficients: fourteen for the presence of PFPT, eleven for the presence of one or more joint non-mandatory tours, and one constant for the joint presence of both components.

PFPT is less likely in larger households, which is not surprising given the PFPT definition requiring participation of all members and the greater complexity of coordinating more schedules. It is also more likely in households with children but also when at least one adult (in the households with two adults) has higher education. As the number of cars increases the likelihood of PFPT drops. It may be that car ownership and PFPT are jointly determined, i.e. households with independent members may be more likely to own cars and less likely to engage in PFPT. Car ownership is rather low in Denmark compared to other European countries due to high taxation, so this finding might have an important impact in the future. Household income does not show a strong connection to PFPT. The model includes two logsums that make the PFPT model sensitive to changes in travel conditions. The work tour mode choice logsum indicates that PFPT is more likely if workplaces are more accessible. The at-home mode-destination logsum represents accessibility for non-mandatory activities. It uses a size function that includes effects of various magnitudes for all categories of employment, school enrollment and households, with food and retail employment being the strongest attractors. The small negative coefficient indicates that PFPT is slightly less likely in neighbourhoods where there is good non-auto access to out-of-home non-mandatory activities.

Joint non-mandatory tours are more likely to be present in larger households as the possibilities increase with the household size. Households with children are less likely to make this type of tour; these households are likely to have size three or greater, so this result partially offsets the effect of the larger household. A household of only two people, both adults, is more likely to make joint non-mandatory tours. The same goes for households where at least one adult has a high education and for single parent households. The effect of car availability on joint tours is very similar to its effect on PFPT participation. While it is not statistically strong in either case and needs to be tested with larger samples, it indicates that in this population, the presence of a car correlates with households doing less of both these things together as a family, not only less PFPT, but also—somewhat counterintuitively—less joint non-mandatory tours (SFPT). The income effects are very similar to the ones already presented on the PFPT part of the model.

The positive constant for the joint presence of PFPT and joint non-mandatory tours captures the tendency for these two outcomes to occur together.

Table 6: Estimation results of the joint model for PFPT and presence of joint non-mandatory tours

Summary statistics		
Number of observations	644	
Degrees of freedom	26	
Log-likelihood of naïve model with only a full set of three constants	-658.4	
Log-likelihood (final)	-464.2	
Rho squared (with respect to naïve model)	0.295	
Segmentation variables – PFPT	**Estimate**	**t-value**
Constant	-1.37	-3.4
HH size 3	-1.19	-3.4
HH size 4+	-1.52	-3.8
Pre-school children	1.15	3.6
One adult + school children	1.11	2.8
Two adults, both working	1.84	4.3
Two adults, 1+ with high education	3.47	10.4
Two adults, one car	-0.44	-1.6
Two adults, 2+ cars	-1.00	-2.2
HH income 300K-600K DKK (€40K-80K)	0.59	1.5
HH income 600K-900K DKK (€80K-120K)	0.29	0.7
HH income over 900K DKK (€120K)	-0.11	-0.2
Work tour mode choice logsum for up to 2 workers	0.13	1.6
At-home non-auto mode-destination logsum	-0.03	-2.4
Segmentation variables – joint non-mandatory tours		
Constant	-2.77	-5.5
HH size 3	1.18	2.0
HH size 4+	1.41	2.4
Children	-0.95	-1.9
HH size 2, both adults	0.57	1.1
Two adults, 1+ with high education	0.80	2.0
One adult + school children	0.85	2.5
HH with a car	-0.41	-1.6
HH income 300K-600K DKK (€40K-80K)	0.39	1.0
HH income 600K-900K DKK (€80K-120K)	0.52	1.3
HH income over 900K DKK (€120K)	-0.20	-0.5
Interactions		
PFPT + Joint non-mandatory tour alternative constant	0.66	2.0

4.4. Effects of PFPT on other model components

Incorporating PFPT in the COMPAS model system includes conditioning the models lower in the model hierarchy on the outcome of the PFPT model. Altogether there are 16 day level submodels (each of the five day-level parts shown in Figures 1 and 2 consists of more than one submodel). Conditioning these models involves restricting availability of alternatives. For example, given the definition of PFPT, then if PFPT is present the Household Day Pattern Type alternatives without at least one person over age 13 traveling away from home are not available and are excluded from the choice set.

Conditioning these models also involves using PFPT presence as an explanatory variable in the conditional submodels. Table 7 shows the estimation results for two selected day pattern sub-models, the Household Day Pattern Type model and the Joint Half Tour Generation Model. For persons other than full time and part time workers, the presence of PFPT is accompanied by a significantly increased likelihood of a person day pattern that involves at least one mandatory or non-mandatory tour.

Incidence of joint half tours (travel to and/or from work and/or school together) is positively influenced by the presence of PFPT. (To better understand the cases covered by these three coefficients see the Section 7 Appendix for detailed definitions and examples of the various types of half tours.) This result—along with the previously reported likelihood of co-incident PFPT and joint non-mandatory tour presence—is intuitively appealing; households that are more likely to do things together at home are also more likely to travel and do non-home activities together, in this case travel to and from work and school.

Table 7: Coefficients of the PFPT participation variable in day pattern models

Household Day Pattern Type model	Estimate	t-value
Mandatory; Full time worker	0.30	0.9
Mandatory; Part time worker	-0.07	-0.1
Mandatory; Gymnasium or university student	1.58	2.0
Mandatory; School child	1.36	2.2
Mandatory; Pre-school child	2.00	constrained (insufficient data)
Non-Mandatory; Full time worker	0.37	0.9
Non-mandatory; Part time worker	-0.27	-0.2
Non-Mandatory; Retired	2.54	2.7
Non-Mandatory; Non-working adult	2.59	2.3
Non-Mandatory; Gymnasium or university student	2.27	2.6
Non-Mandatory; School child	1.28	1.9
Non-Mandatory Pre-school child	0.79	1.2
Joint Half Tour Generation model		
Partially Joint Paired Half Tours (paired, to and from work/school)	1.59	3.0
Partially Joint Half Tour 1 (unpaired, to work/school)	1.80	2.9
Partially Joint Half Tour 2 (unpaired, from work/school)	0.54	1.3

4.5. Model fit to the observed data

The fully implemented model system, with all model coefficients estimated, is used to simulate activity schedules for the 801-household sample under the conditions that existed for model estimation. This is done without any calibration to match aggregate totals, which would normally be done in preparing an AB model system for use in forecasting. Tables 8 through 10 compare the results to those of the observed data itself. The simulation results are not expected to match the observed outcomes exactly, given the complexity of the model system, the fact that the simulation result is subject to random noise because of the small sample size, and the presence of travel time and cost coefficients that are borrowed from models estimated on the much larger TU data set. Overall, the similarity of the simulation results to the observed outcomes indicates a reasonably well-specified model system.

Table 8 gives overall fit of the COMPAS model to the observed data with respect to number of trips by travel purpose. The model produces in total slightly less trips (5%) than the observed. For the two most frequent purposes, i.e. work and education, the model fit is reasonably close, while for purposes like work-based trips, the difference tends to get larger.

Table 8: Number of trips per travel purpose

	Observed data	COMPAS	% difference
Work	1,829	1,712	-6.4%
Education	1,675	1,754	4.7%
Escorting	500	461	-7.8%
Shopping	530	433	-18.3%
Personal business	158	226	43.0%
Social	1,175	933	-20.6%
Business	114	120	5.3%
Work-based	37	58	56.8%
Total trips	6,018	5,697	-5.3%

The modal split, with respect to all trips in the day, is presented in Table 9. The overall observed car share is 34.7% while it is 32.5% in the model. The model slightly overestimates bicycle and public transport shares, and underestimates walk. The overall uncalibrated fit is however in an acceptable range.

Table 9: Mode shares with respect to total number of trips

	Observed data	COMPAS	% difference
Car drivers	29.4	26.2	-10.9%
Car passenger	5.3	6.3	18.9%
Public transport	10.6	12.0	13.2%
Bicycle	34.3	37.3	8.7%
Walk	20.4	18.2	-10.8%
Total	100%	100%	

It is also interesting to see the distribution of number of tours in Table 10. Apart from an over estimation of at-home person days, the model nicely fits the observed distribution of tour frequency.

Table 10: Shares of number of day tours

	Observed data	COMPAS	% difference
None	15.8	22.7	43.7%
One tour	56.5	53.8	-4.8%
Two tours	22.4	18.4	-17.9%
Three plus tours	5.3	5.1	-3.8%
Total	100%	100%	

5. POLICY FORECAST

This section tests the importance of PFPT in the COMPAS model system by comparing its predictions under a policy scenario to those of a version implemented without PFPT. The comparison version is implemented by removing the PFPT model from the structure and re-estimating all other model components without PFPT constraints and PFPT explanatory variables.

The two model versions are tested for a scenario with congestion and pricing in which travel times are increased and peak period road pricing is introduced. The portion of car travel time exceeding free flow time is increased from the 2010 base year values, resulting in peak period travel times in central Copenhagen that are doubled. The road pricing policy includes morning and afternoon peak charges of 3.00 DKK/km (approximately €0.40/km) with no pricing in the middle of the day or evening. The simulation is implemented using the 801-household estimation sample. To reduce the noise associated with simulation, each household's day is simulated ten times with a different set of random seeds each time.

Table 11 shows trip-percentage changes by mode and the total change in generation of trips. The dominant finding here is that the decrease in person car trips (the sum of car drivers and car passengers) in the COMPAS PFPT version of the model is significantly smaller than in the non-PFPT model. In other words, the PFPT model version is less sensitive to the tested policy scenario than the non-PFPT model. In response to the shift in person car trips, the trips by other modes go up, again with a smaller increase for the COMPAS PFPT version, except for walk mode. Finally, the COMPAS PFPT version's reduction in total number of trips is slightly smaller than that of the comparison non-PFPT model.

Table 11: Percentage change in trips by mode

	Comparison model without PFPT	COMPAS with PFPT	% difference
Car drivers	-9.97%	-9.32%	-6.5%
Car passenger	-8.77%	-6.16%	-29.8%
Public transport	6.63%	6.27%	-5.4%
Bicycle	3.64%	2.49%	-31.4%
Walk	1.54%	1.63%	6.0%
Total	-1.03%	-1.01%	-2.3%

Figure 3 shows the changes in work trips by car by time-of-day. This result is subject to higher noise-to-signal ratio than Table 11 because it includes a smaller sample of trips (work car trips only) and it spreads them out over an entire day. The two models show similar results, with the peak period pricing and congestion causing the car trips in the peak periods to drop, with some observed shifting, on average, to the other periods. The reduced sensitivity of the PFPT model (black line in the figure) is apparent in the afternoon peak, where the work car trips drop by a far smaller rate relative to the model version without PFPT (grey line in the figure).

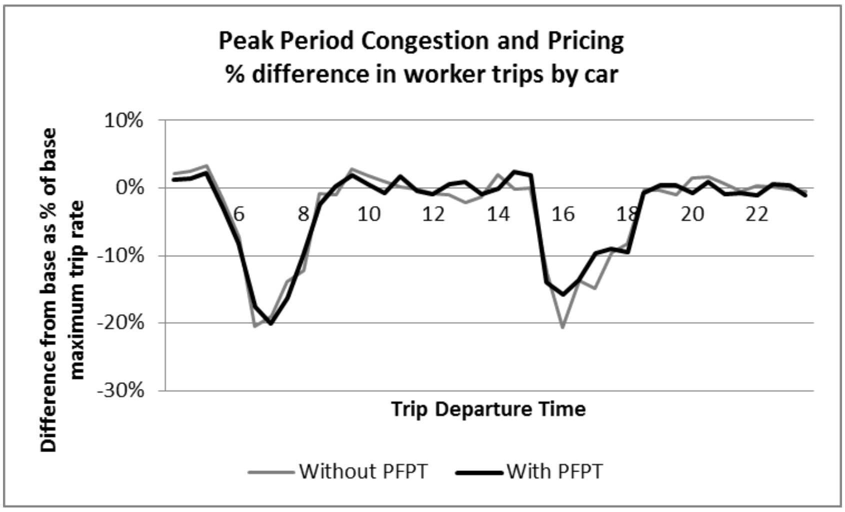

Figure 3: Scenario changes in time-of-day in the two model versions

The main reason that the model with PFPT is less sensitive than the comparison version without PFPT in its mode and time-of-day responses to the congestion and pricing policy lies in the fact that PFPT usually occurs during the evening peak period, which coincides with the dinner hour. PFPT households do not travel while they engage in PFPT, so those who engage in PFPT during the evening peak are substantially less affected by the policy than they otherwise would be. Overall, this causes the attractiveness of evening peak travel by car to be reduced less than in the comparison version without PFPT. As a result, there is less mode shifting away from car, and less shifting away from travel in the evening peak period.

The decreased mode sensitivity has been discussed with traffic planners in Copenhagen who find this result to be sensible. They have observed mode-change sensitivity that is less than predicted by their existing non-PFPT model. Also, car taxation in Denmark is the world's highest and car owners tend to stick to car usage even under the policies that directly support shift to public transport.

From the traffic planning point of view the observed time-of-day result also makes sense. Afternoon and evening are usually periods of the day rich in trip chaining; the after-work commute gets connected to activities such as shopping, personal business and leisure activities. As these activities, including PFPT, are time-constrained, the resulting time-of-day shifts are smaller.

The summary finding of the policy test scenario is that the PFPT version of the COMPAS model shows measurable, explainable and intuitively appealing lower price and congestion elasticities than the non-PFPT model version. These lower elasticities demonstrate the importance of PFPT from a policy perspective; ignoring PFPT in specifying an AB model system is likely to result in traffic forecasts that overestimate response to congestion and pricing.

6. CONCLUSIONS

This paper demonstrates how family in-home quality time, denoted as Primary Family Priority Time (PFPT) in the current research, can be integrated into a fully operational discrete choice AB model system and how this particular model component impacts travel demand of the family members. PFPT is implemented in the model system for Copenhagen, the COMPAS model, which is the first operational AB model in Scandinavia.

The most significant finding of the current research is that the undertaken structural tests provide empirical evidence in favour of a model structure in which PFPT resides at the top of the day level hierarchy, modelled jointly with the presence of joint non-mandatory tours. This finding corresponds well to the qualitative research from Aalborg University where households that agreed on spending in-home quality time together placed it above all other activities in the hierarchy of day activities. Estimation results show that PFPT is mildly affected by changes in travel conditions, and significantly affects the conditional models through explicit constraints and explanatory variables. The structural and estimation results indicate that a significant share of households in Copenhagen do indeed structure their activities and travel so as to accommodate a commitment to spending quality time at home together as a family.

But, does Primary Family Priority Time play any significant role in policy forecasts? The comparative forecasts provide strong evidence that it does. The COMPAS model system with PFPT is measurably less sensitive to a road pricing and congestion scenario than the comparison model system without PFPT. This is most evident in lower mode shift from car to other modes and smaller shift of car commutes away from the afternoon peak period. Explanation for such results can be found in the fact that, although PFPT itself is only mildly affected by travel conditions, it strongly constrains all conditional choices, via time constraints implemented throughout the COMPAS model structure, reducing their sensitivity to travel conditions. The scenario results show therefore that incorporating in-home activities into the AB model for Copenhagen is important. Not only does including PFPT improve the quality of the lower level models, but also if the COMPAS model ignored in-home activities it would overestimate response to changes in travel conditions.

With respect to data, this research demonstrates the value of collecting in-home activity data as a part of household surveys. Collecting—for each at-home episode of each person—the duration of and joint participation in activities by broadly defined purposes enables the modelling of PFPT. It is important to collect information about in-home activities for the entire day for all household members, and it would be valuable to ask directly whether the household engages in high priority family in-home activities on a regular basis. Further research with data that includes in-home activities could lead to a better understanding of which in-home data are most important, leading to collection methods that yield acceptable response rates, collection costs and quality.

Finally, it is important to acknowledge the limitations of the undertaken work that open up space for future improvements. This relates to a variety of PFPT definition tests, a larger sample, the collection of additional attitudinal data and detailed questioning to elicit the true existence of PFPT for a given household, and the use of multi-day data. Nevertheless, the current findings suggest that PFPT, even as specified in the current COMPAS model, could indeed be playing a strong role in household decision-making. They take a strong first step towards understanding and modelling the impact of family in-home quality time on person travel demand.

7. APPENDIX—AB MODEL SYSTEM CONTEXT

7.1. Overview

The household travel demand portion of the COMPAS model system consists of an integrated set of discrete choice models implemented on the DaySim software platform, an evolving and adaptable platform used for the development and application of practical AB microsimulation models (Bradley, et al, 2010).

As depicted on the left in Figure 1 (repeated here for ease of reference), the household models consist of long-term choice models, models at the day level that identify the tours and stop purposes for the day, and tour and trip models that model the details of each tour. The day level models constrain and condition the tour models, and are also impacted by accessibility arising from them. Also, in the course of the simulation, when a model at the day or tour & trip level determines that an activity or travel spans a particular period of time, that period becomes unavailable for other activities and travel.

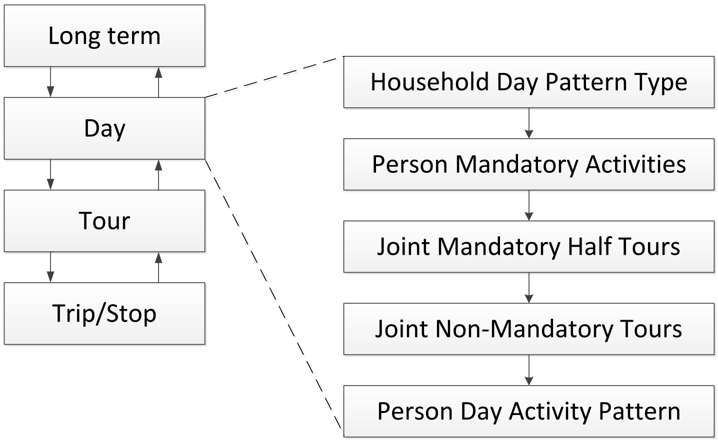

Figure 1: COMPAS model structure with details of the day level structure

7.2. Long term models

The COMPAS model includes three sub-models for long term decisions: usual work location, car ownership and public transport pass ownership. Eventually, it will also model school location, which is presently pre-determined when the synthetic population is generated.

7.3. Day level models

The day level models consist of numerous models in five main groups that operate in conditional sequence, according to a priority hierarchy, as shown in Figure 1 on the right. The household day pattern type model determines the highest priority aspects of the day from the perspective of the household, namely a pattern type for each person, determined simultaneously for all members. For each person, the pattern type identifies whether they travel for work, school or business (mandatory type), travel only for other purposes (non-mandatory type), or stay home all day (at-home type).

PFPT participation is inserted into the hierarchy as a household choice immediately above the household day pattern type, modelled jointly with the household's choice of whether to conduct one or more joint tours for non-mandatory purposes. Also, given that PFPT participation occurs, a PFPT schedule model determines the start time and duration of the PFPT activity.

Given the household's day pattern type, including PFPT, the next group of models determines the specific mandatory activities for each person in the household, including the participation in in-home work activity for each worker, the number of work, business and/or school tours for each person with a mandatory pattern type, and whether they have any intermediate stops for work or school in their day.

Given the needs within the household for travel to work and school, the next set of models determines joint travel to and/or from those mandatory activities. Joint travel to work and school is only modelled for persons travelling to their usual work or school location. It can take the form of half tours, either to (Half Tour 1) or from (Half Tour 2) work and/or school. These half tours can be either paired or unpaired, where paired half tours are symmetrical, involving the same participants traveling together in both directions. They can also be either partially joint, in which one person drops off one or more others on their way to work or school, or fully joint, in which the destination for all participants is the same place. In fully joint half tours it is possible that one participant serves as a chauffeur and returns home after dropping off the other(s). The following examples illustrate the half tour definitions. In example 1, the household includes 2 workers (A, B) and two school children (C, D). In the morning, worker A drops both children C&D. In the afternoon, worker B picks-up child C, while child D returns home on her own. This household's day includes two unpaired partially joint half tours; Half Tour 1 with A, C and D, and Half Tour 2 with B and C. In example 2, the children (C & D) travel to and from the same school together, while the parents go to and from work separately. In this case the household's day involves two paired fully joint half tours conducted jointly by C and D.

To model joint half tours, a generation model determines for the household whether a joint half tour occurs and what type it is. This is followed by a participation model that determines, simultaneously for all eligible household members, which ones participate. This pair of models is repeated until the generation model determines that no more joint half tours occur.

Once the joint travel for mandatory activities has been determined, the next set of models determines the number of joint tours for non-mandatory purposes conducted by members of the household, and the purpose of each one. This is modelled via a tour generation model followed by a participation model, repeating until the generation model determines that there are no more joint tours to be conducted.

The last of the day level models is the person day activity pattern. Constrained by all the prior model outcomes, this pair of models determines, for each person, the number of tours in the day, the purpose of each tour, and the purposes for which intermediate stops are to be made, if any. First, the pattern model determines the presence of tour and stop purposes. Second, the generation model determines the number of tours for each purpose that the pattern model determined to be present. The number of intermediate stops for each purpose is left to be determined subsequently as the tours determined here are being simulated.

7.4. Tours and trips

COMPAS simulates the details of each household's tours in the following priority order:

1. household's partially joint half tours

2. household's fully joint half tours
3. aspects of each person's mandatory tours that have not been determined by joint half tour simulation
4. household's joint non-mandatory tours
5. each person's remaining non-mandatory tours

As each tour and trip is simulated, the outcomes are recorded for each participant, including the updating of their available time windows, so that subsequent models are properly constrained. For partially joint half tours, the pickup and/or drop-off sequence is determined, the tour mode is modelled, and the timing of all work and school arrivals and departures is modelled. For fully joint half tours, the tour mode and timing are modelled, and intermediate stops are generated—and the location, mode and timing of each stop are modelled—iteratively for both half tours. For person mandatory tours, the destination is modelled if it is a business tour, work-based sub-tours are generated, the tour mode and timing are modelled, and intermediate stops are generated and modelled as described above. For the household's joint non-mandatory tours and each person's remaining non-mandatory tours, the destination is modelled, and intermediate stops are generated and modelled, as described above.

8. ACKNOWLEDGMENTS

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