ACTUM Project: Joint Activities and Travel of Household Members

Mikkel Thorhauge[1] (mt@transport.dtu.dk)
Goran Vuk[2] (gjv@vd.dk)
Sigal Kaplan[1] (siga@transport.dtu.dk)
[1] Technical University of Denmark, Department of Transport
[2] Danish Road Directorate

Abstract

The traditional approach for modeling transport-related choices refers to individual decision makers. However, in daily activities and travel choices individuals function according to the commitments as family members, and thus their choices are influenced by the welfare needs of other family members. Moreover, joint activities and travel occur in order to maximize family quality time, within a busy daily schedule. The current study unveils the joint activity and travel patterns of household members in the Copenhagen area, as part of the ACTUM research project, funded by the Danish Strategic research Council, for the development of a new generation of behaviorally realistic activity-based models.

1. Introduction

The traditional approach for forecasting the demand on the road network by using four-step models focuses mainly on utilitarian travel, basically commuting, during the morning and afternoon peak-hours. Because the traditional approach is based on origin-destination matrices by mode and by purpose, with emphasis on utilitarian purposes (e.g., work, education, shopping, errands), the basic data requirements include adult individual travel patterns. An important disadvantage of the traditional approach is that an individual's demand for travel in reality is derived from the daily activity pattern, and is subject to spatiotemporal constraints that derive from the need to include a set of activities within a period of one day. For example, in case that the activity pattern of a person comprises of work duration of 7 hours and shopping activities of 2 hours, this person may separate the two activities (i.e., Home-work-home-shop-home), and shop at a cheap location far from home. However, in case that a person has also a family dinner early in the evening, which constrains their time frame, they may choose instead to chain the work and the shopping activities (i.e., home-work-shopping-home) and shop near their home or workplace. This issue has been recognized already in the 1970's, but it was not until the 1990's that activity-based models and tour-based models were implemented instead of the traditional approach. Nowadays, there is a worldwide transition towards tour-based and activity-based models. Activity-based models were recently implemented in the United States for example in Sacramento (Bradley et al., 2009), Toronto (Roorda et al, 2008), New York (Vovsha et al. 2002), Dallas (Pinjari et al., 2008). A review of the progress in activity-based

models in the United States since the 1990's is provided by Vovsha et al. (2004), and a review of the application of activity-based models various cities in the United states and Canada, and their relative strengths compared with the four-step models is provided by Vovsha and Bradley(2006). In Europe activity based models have been implemented for example in Stockholm (Algers et al., 2001), The Netherlands (Arentze and Timmermans, 2000), and is currently being implemented in London (Sivakumar et al., 2010).

Another important issue is that the traditional four-step modeling approach focuses only on individual travelers, while neglecting family decision-making dynamics, and task allocation social interactions within the household that influence the daily activity-travel patterns of household members. In particular, both individual and joint activities and travel patterns are related to the role of the individual as a family member, defined by intra-household interactions in the attempt to satisfy the welfare needs of all household members and enhancing the unity of the family. A review of the literature (Kaplan and Vuk, 2012), shows that there are three main research streams. The first research stream is related to time and budget allocation, task allocation, and joint travel and activity participation. Time and budget allocation concerns mainly the representation of activity duration, travel times and trip frequency (Golob and McNally, 1997; Fujii et al., 1999; Golob, 2000; Zhang et al., 2005; Zhang and Fujiwara, 2006; Kato and Matsumoto, 2009; Mosa et al., 2009; Kang and Scott, 2011) but also for modeling personal expenditure of activities and travel (Kato and Matsumoto, 2009). Discrete choice models for task allocation include the studies of Vovsha et al (2004a,b), and Bradley and Vovsha (2005). The former models are embedded in the Mid-Ohio Regional Planning Commission (MORPC) tour-based model and the latter model is embedded in the activity-based model for Atlanta region. Decisions related to joint travel and activity participation consist of joint versus independent in-home and out-of-home activity patterns, mainly for leisure and maintenance (Scott and Kanaroglou, 2002; Gliebe and Koppelman, 2002; Gliebe and Koppelman, 2005; Přibyl and Goulias, 2005; Srinivasan and Bhat, 2006), joint versus independent travel (Chandrasekharan and Goulias, 1999), the decision to pre-plan joint activities or to engage in such activities impulsively (Kang et al., 2009), tour type, number of tours, and party composition (Vovsha et al., 2003), and parental escorting (Yarlagadda and Srinivasan, 2008). The results of the aforementioned studies establish the importance of intra-household interactions for activity-based models. Nevertheless, most of these studies were conducted in North America and hence their relevance to Denmark is yet to be explored. Moreover, only a few of the reviewed models are embedded in current tour-based / activity-based models.

While both the latest OTM version and the Danish National Traffic Model are taking a tour-based approach, intra-household interactions are currently not represented in Denmark. The current study takes a first step in closing this gap, by unveiling the joint activity and travel patterns of household members in the Copenhagen area, as part of the ACTUM research project, funded by the Danish Strategic Research Council, for the development of a new generation of behaviourally realistic activity-based models. In-depth analysis was conducted in order to understand the role of escort activities in individual travel, and the households' joint activities and joint travel patterns at a household level. In particular, the household coordination and constraints are considered as important, i.e. a mother escorting a child to school imposes time and spatial constraints on the mother, but this action also requires coordination with the father regarding the allocation of the car at the household level. Another important aspect is the concept of "primary family priority time", in which the entire household agrees on a daily level to spend time together in the household and engage in shared activities such as a family dinner. The activity and travel patterns are analyzed both with respect to the household characteristics and with respect to the activity purpose (i.e., mandatory and non-mandatory), and the characteristics of the tour or the trip.

The paper proceeds as follows. In section 2, the data collection process and the sample socio-economic characteristics are described. Following, section 3 provides an in-depth analysis of the activity and travel patterns at the individual level and at the household level. Section 4 gives an overview of the expected model structure in the ACTUM project. The analysis is conducted both at the tour level and at the trip level. Last, concluding remarks are offered.

2. Data

2.1 Data collection

The analysis of the activity and travel patterns of household members is based on data from the ACTUM survey. The ACTUM survey focused on collecting information from 24-hours travel-activity diaries, collected by means of a web-based survey. The ACTUM survey is similar to the current TU-survey and consists of both family-based and person-based interviews. Nevertheless, the ACTUM survey significantly differs from the TU-survey in two important aspects. Firstly, the TU-survey collects information from a single person in the household, while the ACTUM survey focuses on collecting information from all household members, including children. Specifically, household members older than 15 years old have completed the survey on their own, while for the children younger than 10 years the survey was completed by an adult. Children between 10-15 years of age could choose between completing the interview on their own or with an assistance of an adult. The travel diaries are completed by all household members simultaneously at the same travel day. Secondly, for each activity or travel episode, each household member is requested to specify whether it was conducted alone or jointly with other household members, and in the case that is was conducted jointly, with whom it was conducted. These two differences provide an important advantage to the ACTUM survey since it allows depicting a holistic picture of the travel and activity patterns of the household as a full unit. In addition, it allows conducting quality-control, in which individual travel-activities are compared, thus allowing completing under-reported trips that were conducted jointly with other household members. The survey structure is presented in Figure 1.
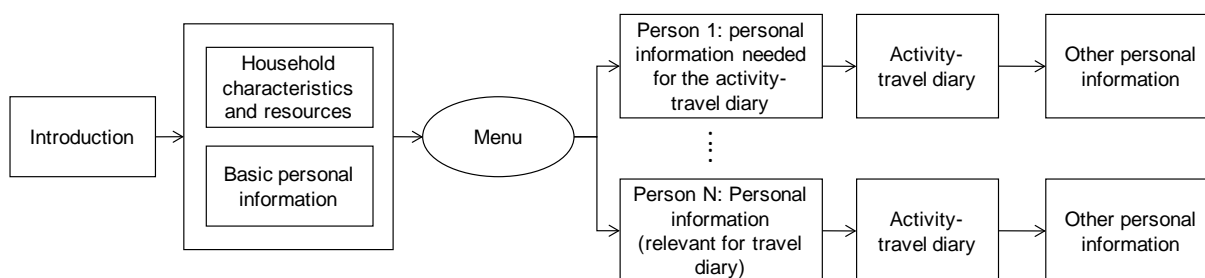

Figure 1 – data collection process

The households included in the survey were sampled from the Greater Copenhagen Area, mostly in the municipalities of Copenhagen and Frederiksberg, but also in other 35 municipalities in the greater Copenhagen area. The sample was taken from the Synnovate's internet panel, and the sampling procedure was based on family structure, age and geography. Table 1 shows the sample structure versus the initially proposed sample with respect to households, while table 2 shows the sample structure versus the proposed sample with respect to individuals within the households.

Table 1: Reproduction of household demographics in target population by the data sample

		Adults	Number of children				Total
			0	1	2	2+	
		0	1				1
	18-29 year	1	55 (50)				
	30-65 year	1	58 (50)	85 (50)	63 (50)		309 (250)
	65+ year	1	48 (50)				
	18-29 year	>1	40 (50)				
	30-65 year	>1	86 (50)	151 (100)	210 (200)	51 (50)	593 (500)
Adults	65+ year	>1	55 (50)				
	Total		342 (300)	237 (150)	273 (250)	51 (50)	903 (759)

Note: proposed sample is in parenthesis in blue.

Table 2: Reproduction of Individual demographics in target population by the data sample

		Adults	Number of children				Total
			0	1	2	2+	
		0	1				1
	18-29 year	1	55 (50)				
	30-65 year	1	58 (50)	170 (100)	192 (150)		523 (400)
	65+ year	1	48 (50)				
	18-29 year	>1	81 (100)				
	30-65 year	>1	184 (100)	462 (300)	846 (800)	260 (250)	1943 (1650)
Adults	65+ year	>1	110 (100)				
	Total		536 (450)	633 (400)	1038 (950)	260 (250)	2467 (2050)

Note: proposed sample is in parenthesis in blue.

The two tables show that the obtained results from the sample population are representative of the sample initially proposed in terms of their demographics and that the sample size is higher than initially expected.
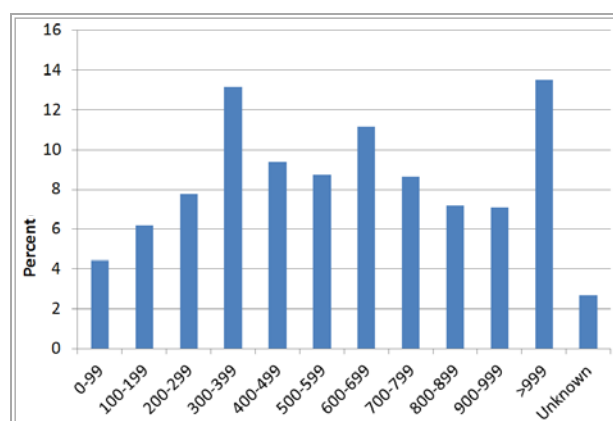
2.1 Sample characteristics

This section presents the socio-economic characteristics of the households and the adults comprising the sample.

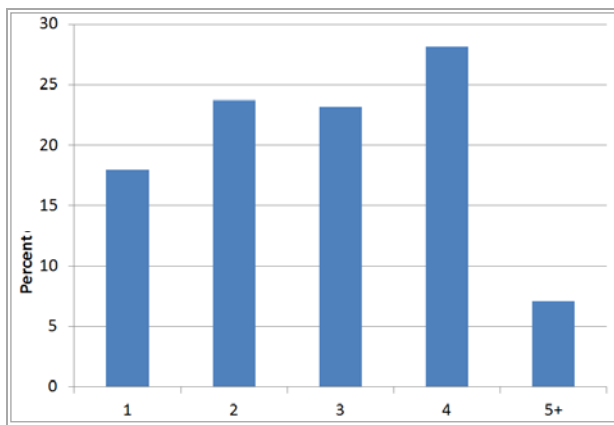### 2.1.1 Household socio-economic characteristics

The home ownership, household income, household size, and car ownership are presented in figure 2. The average household size is 2.83 persons per household. 48.9% of the sample consists of families with two adults and children, while 12.2% involve a single adult and children under the age of 18. A small share of the households (4.2%) consists of more than two adults, possibly grown-up children. About 55.7% are home owners, which is slightly lower than home ownership at the national level (63%). Home ownership is related to household size. As expected, a large percentage of small households prefer rented dwelling units, while large households prefer large owner occupied house. The share of cooperative dwelling also decreases as the household size increases. In terms of Income, 14% of the household sample earn up to 200,000, while 40% of the households in the sample have an income of up to 500,000 DKK, and 30% have a household income above 800, 000 DKK. Almost all the households (99.2%) have a high-speed internet connection, but they differ in terms of their payment method. The majority of the households (65.0%) pay a "flat" rate unlimited consumption, while the second most popular payment method is employer-paid connection (29.0%). The adopted payment methods actually allow unlimited possibilities to work from home or to shop and conduct errands through the Internet.
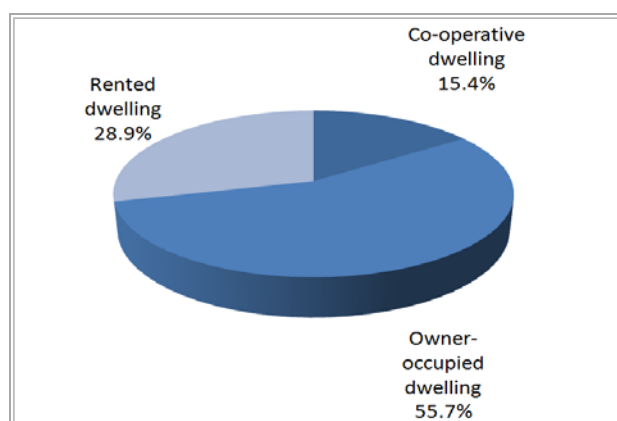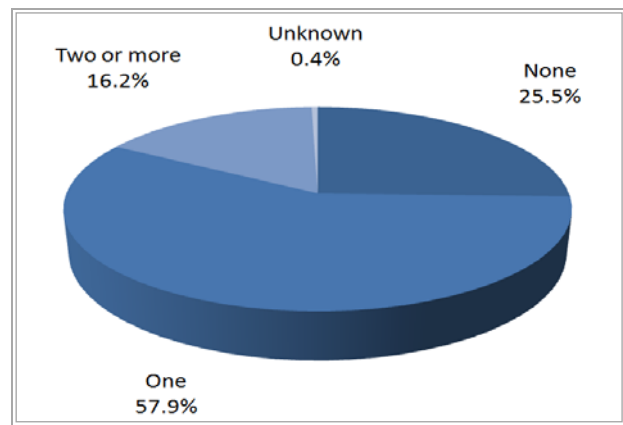

a. Home ownership

b. Household income in thousand DKK

c. Household size (number of persons)   d. Car ownership

Figure 2: Household socio-economic characteristics

In terms of mobility resources, in 92.7% of the households there is at least one person with a driver license, and 74.1% of the households have at least one car. This car ownership rate in the sample is much higher than the ownership rate at the national level (56%). Interestingly, only 11.7% have a parking place at home while 29.9% stated that they do not have a private parking at home, and 58.4% are unknown. Car ownership in the sample is related to household size as presented in table 3. As expected, car availability and number of cars dramatically increase with the increase of household size and presence of children in the household.

Table 3: Household car ownership by household size (percent)

	1	2	3	4	5	Unknown
No available car	58.6	30.4	19.6	9.1	9.4	58.6
One car	41.4	60.7	61.7	61.8	62.5	41.4
Two cars of more	0.0	8.9	17.7	28.3	28.1	0.0
Unknown	0.0	0.0	1.0	0.8	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Car ownership in the sample is related to also to income as presented in table 4. As expected, the share of households owning a car, as well as the number of cars per household, increase with the increase in the household income. In particular, there is a sharp decrease in the households without cars around the average income (300-399 thousand DKK), and there is a sharp increase in the ownership of two vehicles for households earning more than 500 thousand DKK.

Table 4: Household car ownership by household income (percent)

|	None	One	Two or more	Unknown	Total
0-99	67.5	22.5	10.0	0.0	100.0
100-199	62.5	33.9	3.6	0.0	100.0
200-299	52.9	41.4	5.7	0.0	100.0
300-399	38.7	56.3	4.2	0.8	100.0
400-499	29.4	70.6	0.0	0.0	100.0
500-599	17.7	62.0	19.0	1.3	100.0
600-699	13.9	67.3	18.8	0.0	100.0
700-799	14.1	71.8	12.8	1.3	100.0
800-899	7.7	66.2	26.2	0.0	100.0
900-999	4.7	59.4	34.4	1.6	100.0
>999	4.9	59.0	36.1	0.0	100.0
Unknown	29.2	54.2	16.7	0.0	100.0

2.1.1 Individual socio-economic characteristics for the adult respondents

There are 49.0% male respondents, and 61.8% of the respondents are adults over 17 years of age. Of the adults, 15% are in their twenties, 16.8% are in their thirties and 32.5% are in their forties. 13.5% of the sample consists of elderly over 60 years of age. 74.7% of the adults in the sample are involved in a relationship, while 19.2% are single, 3.5% are young adults (about 18 years of age) who still reside with

their parents and 2.6% of the respondents are divorced or widowed. In terms of education, more than two-thirds of the adult respondents (67.4%) have post-secondary higher education, while 29.1% of the respondents have secondary education (i.e., 10th form, higher preparatory certificate, technical, commercial and business education, vocational secondary education and other schooling), and only 3.5% have compulsory primary education. The employment status, income, working hours and working- hour flexibility are presented in Figure 3. In terms of employment status, 67.9% of the respondents are employees, while only 3.9% are self-employed. Only the employees and the self-employed (71.8%) among the adult respondents specified the number of working hours. As expected, the majority of the respondents work between 30-40 hours (74.6%), although a significant share of 19.9% have longer working hours. About 82.4% earn a personal yearly income of up to 500 thousand DKK. Interestingly, 49.8% of the respondents work fixed hours and there seems to be no specific dominant arrangement in terms of work-time flexibility. This percentage is much higher than the share of flexible working hours in Denmark at the national level which is around 25%.
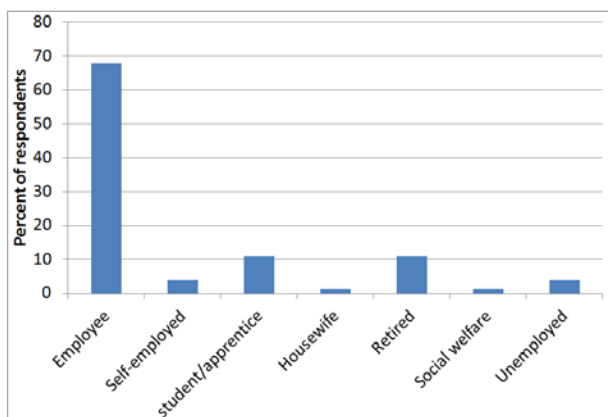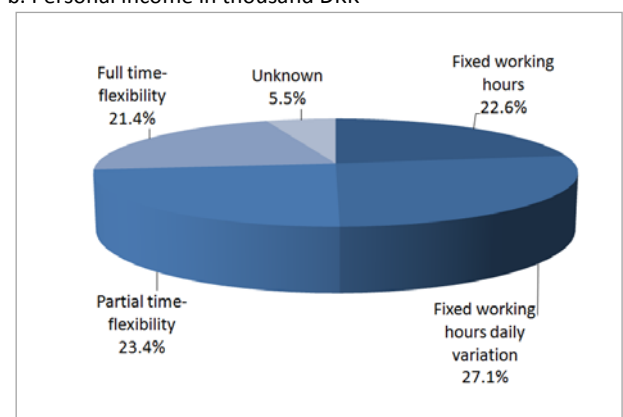

a. Employment status
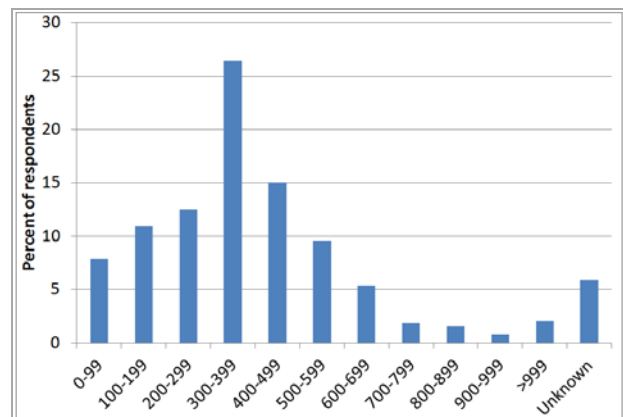
b. Personal income in thousand DKK
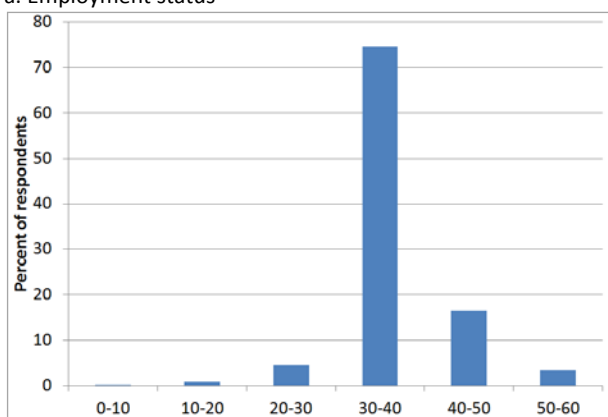
c. Number of weekly working hours

d. Work-hour flexibility

Figure 3: Individual socio-economic characteristics

3. Activities and travel patterns

3.1 individual activities and travel patterns

3.1.1 Person daily activity pattern

90.0% of the respondents start their daily activity pattern from home, another 5.0% start their activity pattern by working at home, and 1.4% start their daily activity pattern from the home of family and friends. The activity patterns were analyzed separately for children under 18 years old and adults. In the data set there are 547 activity patterns of adults and 200 activity patterns of children. The activity patterns differ in terms of the number of daily tours and activities included and their order of performance.

The share of adults who participate in out-of-home and in-home daily activities, and the number of activities is provided in figure 4. The average number of daily out-of-home home activities is 2.10 and the average number of in-home activities (including work at home, morning and evening) is 2.23. 67.8% of the survey respondents have one or two types of daily activities, and only 5.8% have more than three different activity types.
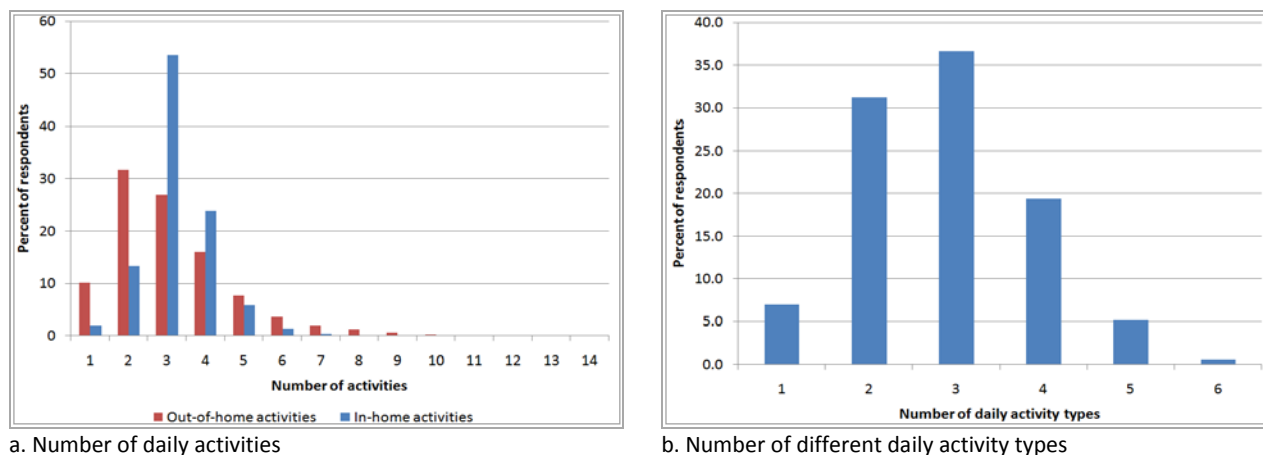

a. Number of daily activities

b. Number of different daily activity types

Figure 4: Number of activities and activity types for adults

The most common activity patterns regardless of the order of activities, performed by 54% of the sample population, include work out-of-home as a sole activity (13.4%), work out-of-home and escort activities (7.9%), stay home without working at home (7.0%), leisure as a sole activity (6.2%), work out-of-home and personal activities (5.5%), work and leisure (4.9%), personal errands as a sole activity (4.9%), and a combination of working and working at home (4.6%). Nevertheless, all other activity patterns that each corresponds to less than 1.0% of the survey population.

Regarding children activity patterns, 7.1% of the children stayed home the whole day. 44.2% of the children have a simple activity pattern comprising a single daily activity type, of which the most prominent are going to school (19.3%), going to a day care centre (17.6%), and leisure (3.8%). For the children who have two or more daily activity types, the most common combinations are education and leisure (10.7%), education, leisure and work/study at home (7.5%), education, personal activities and leisure (5.7%), education and personal activities (5.7%), education and escort activities (5.0%), education, day care and leisure (4.4%), education and work at home (4.4%) and escort and day care (4.4%). Notably, 31.8% of the children participate in leisure activities, which is possibly related to the relatively high household income and education level of survey respondents, but may also be related to an appropriate school and life balance ("playing is living").

Regarding "primary family priority time", 75% of the respondents are home between 19:00-24:00, which means that most of the households dedicate time to "family priority time" in the evening, which constrain their travel and out-of-home activity pattern.

2.4 Person daily tour analysis

In this paper a tour is defined as a trip-chain starting and ending at home in accordance with the Danish TU-data structure. 53.7% of the survey population has only one daily tour. The prevalence of various tour structures for home-based tours out-of-home with respect to the main activities (defined as work, education, the only out-of-home activity, or the longest activity) is provided in table 5. Duplicate activities of the same type were compressed, namely multiple secondary activities are grouped together. This tour type "Home-secondary-main-home" may include several secondary or main activities. As expected, the prominent tour type is by far performing a single (main) activity, and the most rare tour structure is a complex structure, consisting of secondary activities both before and after the main activity.

Table 6 describes the structure of the work tours that included escort activities (Chauffeuring) for the sub-sample of survey respondents who had only one daily journey. Most of the tours do not include escort

tours, and as expected more escort tours are conducted on the way to school than from school, also because in Denmark school children usually go from school to the youth club or day care with an accompanying teacher, where later on the parents pick them up.

Table 5: The distribution of tour structures in the whole survey population

Tour structure	Percent of respondents
Home-secondary-main-home	12.0
Home-secondary-main-secondary-home	5.3
Home-main-home	68.4
Home-main-secondary-home	14.3
Total	100.0

Table 6: The distribution of tour structures for respondents who had only one daily tour

Tour structure	Percent of respondents
Home-escort-work-home	12.2
Home-escort-work-escort-home	8.3
Home-work-home	71.9
Home-work-escort-home	7.5
Total	100.0

Differences in the general structure of the daily tour were investigated with respect to gender, education and employment status.

The distribution of tour structure by gender and the inclusion of escort activities in the tour are detailed in Table 7. According to Chi-square test, the null hypothesis that there is no significant difference between the two groups cannot be rejected at the 0.05 significance level (χ^2 =2.07<3.85). 20.9% of the female tours and 19.8% of the male tours include escort activities. The main gender difference is that male respondents have a higher tendency to perform the escort prior to the main activity (e.g., escort on the way to work), and female respondents have a higher tendency to perform complex tours including escort both before and after the main activity (e.g., escort before and after work). According to Chi-square test, the null hypothesis that there is no significant difference between the two groups can be rejected at the 0.05 significance level (χ^2 =5.67>3.85).

Table 7: The distribution of tour structures in the survey population by gender for all the tours and escort tours

Tour structure	All tours		Only tours including escort	
	Female (%)	Male (%)	Female (%)	Male (%)
Home-secondary-main-home	11.4	12.7	19.9	28.5
Home-secondary-main-secondary-home	6.0	4.6	22.4	15.7
Home-main-home	66.4	70.5	39.1	39.1
Home-main-secondary-home	16.2	12.3	18.6	16.7
Total	100.0	100.0	100.0	100.0

The distribution of tour structure for all the tours and for tours including escort according to education level for the adult population is portrayed in table 8. Respondents with higher education have less single-activity tours and more complex tours with secondary activities before and after the tours. Chi-square test results confirm that the null hypothesis that there is no significant difference between the groups can be rejected at the 0.05 significance level (χ^2 =16.37>3.85). Respondents with higher education also conduct more escort tours than respondents with secondary education. In particular, the share of escort tours for respondents with higher education is 30.1% in comparison with 16.9% among respondents with secondary education. The main difference between the groups with respect to escort tours is that people with higher education have a much higher probability to perform the escort activity prior to the main activity, while people with higher education perform the escort activity both before and after the main activity. The difference between the groups is significant at the 0.05 significance level (χ^2 =21.43>3.85).

Table 8: The distribution of tour structures in the survey population by education for all the tours and escort tours

| Tour structure	All tours		Only tours including escort	
	High-education (%)	Secondary education (%)	High-education (%)	Secondary education (%)
Home-secondary-main-home	13.8	15.1	20.8	39.3
Home-secondary-main-secondary-home	8.3	2.4	21.8	10.7
Home-main-home	64.4	72.2	40.4	35.4
Home-main-secondary-home	13.4	10.3	17.0	14.3
Total	100.0	100.0	100.0	100.0

The distribution of tour structure according to employment status for the adult population is portrayed in table 9. Employees and self-employed have a lower rates of simple single-activity tours, while housewives have the highest rate of such tours. Students, housewives and retired people rarely perform complex tours with secondary activities before and after the main activity. Self-employed people have a higher tendency then employees to conduct secondary activities prior to their main activities, while employees tend to conduct the secondary activities after the main activity. Possibly, this trend may be related to higher schedule flexibility in the morning for self-employed individuals.

Table 9: The distribution of tour structures according to employment status

	Home-secondary-Main-Home	Home-Secondary-Main-Secondary-Home	Home-Main-Home	Home-Main-Secondary-Home	Total
Employees	14.2	8.4	63.0	14.4	100.0
Self employed	21.1	9.2	60.5	9.2	100.0
Student/apprentice	9.0	1.7	77.3	11.9	100.0
Housewife	13.1	0.0	82.0	4.9	100.0
Retired	14.9	0.6	76.4	8.0	100.0
Social welfare	8.7	4.3	73.9	13.0	100.0
Unemployed	14.1	4.7	71.9	9.4	100.0

2.5 Person trip analysis

Figure 5 presents the time for trip departures and arrivals, as well as the distribution of the trip length (without the activity duration at the destination). The two peak periods are clearly represented in the figure, as about one fourth of the trips are conducted at the morning peak hour between 07:00-09:00 and about one third of the trips are conducted during the afternoon peak hour between 15:00-16:00. As expected, the trip departures and arrivals during the afternoon peak hour are spread over a greater time period in comparison with the morning peak hour. Most of the trips are local, as 66.8% of the trips are 15 minutes or less.
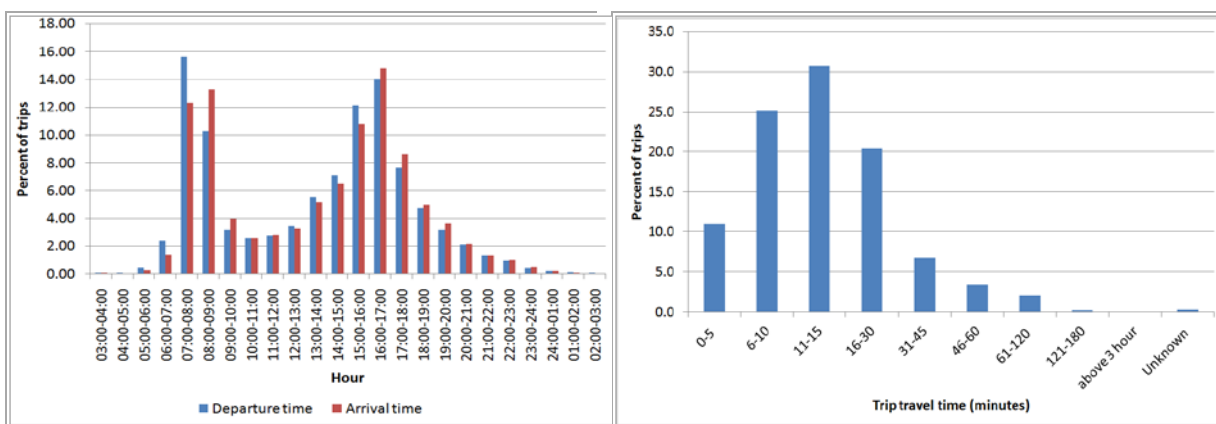
a. Trip departure and arrival times   b. Trip duration

Figure 5: The distribution of trip departure/arrival times and their duration

Table 10 details the trips by their origins and destinations. As expected in agreement with the sample residential distribution, 52.9% of the trips are conducted within Copenhagen municipality and Copenhagen county, which surrounds the metropolitan core. Also, it seems that most trips are short or medium distance trips or peripheral trips and there are not many radial trips from the suburbs to the metropolitan core. This result is in line with the trip duration that also shows that most trips are local trips.

Table 10: The distribution of trip origin and destination

	Copenhagen	Copenhagen county	Fredriksberg	Other	Total
Copenhagen	28.7	4.3	1.9	1.7	36.6
Copenhagen county	4.3	24.2	0.5	2.6	31.6
Fredriksberg	1.9	0.5	4.2	0.1	6.8
Other	1.8	2.5	0.2	20.5	25.0
Total	36.6	31.6	6.8	25.0	100.0

39.4% of the trips are home returning trips. For the remaining trips, 44.3% of the trips are conducted for mandatory activities (i.e., work, education and day care), 35.5% of the trips are conducted for maintenance (i.e., shopping, personal errands and escorting other household members), and 20.1% of the trips are for leisure activities. Table 11 presents the share of trips (including trips for returning home) by purpose and daily period. As expected, most mandatory trips (i.e., commuting, education and day care) are conducted during morning peak hour, while maintenance activities for shopping and errands are mainly conducted during non-peak hours. Interestingly, trips for shopping and errands split between the middle of the day (09:00-15:00) and the evening (after 18:00), possibly due to reasons of opening hours, since services (e.g., banks, medical care and personal care) are open only until early afternoon.

Table 11: Share of trips by purpose and time period

Trip purpose	07:00:09:00	09:00-15:00	15:00-18:00	18:00-07:00	Total
Workplace	66.8	12.7	17.4	3.1	100.0
Business/ work	28.4	52.1	15.4	4.1	100.0
Education	85.4	9.2	2.8	2.6	100.0
Day care/ youth club	58.0	34.7	3.1	4.2	100.0
Shopping and errands	5.9	48.7	7.4	37.9	100.0
Leisure	5.5	30.2	23.2	41.1	100.0
Escorting	35.6	17.5	8.4	38.6	100.0
Returning Home	3.4	23.0	22.6	50.9	100.0

The vast majority of trips (88.6%) were conducted by a single mode, and another 7.4% of the trips were conducted by two modes. Trips with more than two modes (e.g., bicycle + train + walk, bus + metro + walk) are relatively rare, although possible in certain occasions. The most common transport modes are the car (38.5%), the bicycle (30.2%) and walk (18.7%), while only 9.6% use public transport. Regarding the secondary transport mode, 58.6% of the respondents who have secondary transport mode walk, 18.8% use public transport, 16.5% cycle, 4.7% use the car and 1.4% use other transport modes (e.g., naval transport). Notably, the same trends for male and female respondents with respect to trip mode share. Nevertheless, car use is associated with age, although the share of car users in the survey population is around 40% and higher for most age groups, apart from children between 6 and 18 years of age and young adults in their twenties. High shares of car use (48%) are found also for trips of elderly people. The highest shares of public transport use (about 20%) are among teenagers and young adults up to 29 years old. After the age of 30 there is a sharp drop in the use of public transport, although the tendency to use public transport slightly increases for elderly above 70 years of age. The share of bicycle trips is the highest for children between the age of 6 and 17 (39.4-46.6%) and is the lowest (13.5%) for elderly people above the age of 70. The share of bicycle trips gradually decreases with age but remains over 20% until 70 years of age. The share of walking trips is highest for young children (27.0%) and decreases with age to 9.0% at the age of 50-59 and then increases again to 15.3% for respondents over the age of 70.

Table 12 presents the share of trips by mode and activity purpose. The main modes for commuting trips are the car (46.9%) and the bicycle (32.4%). The car is the dominant mode across trip purposes, apart for

education for which the bicycle is by far the dominant mode. This trend is in agreement with the trend observed for age since the highest share of bicycle users is observed among teenagers and young adults. The share of trips conducted by public transport is lower than the share of bicycle trips and is less than 10% for leisure, errands and work-related trips. Walk trips have a significant share for education, errands and leisure. Work-related and business trips have a significant share (31.4%) of other modes (e.g., heavy vehicles, air and naval modes).

Table 12: The share of trips by transport mode and trip purpose

Trip purpose	Car	Public Transport	Bicycle	Walk	Other or unkown	Grand Total
Workplace	46.9	15.2	32.4	2.7	2.7	100.0
Work-related/ business	43.2	7.1	11.2	3.0	35.6	100.0
Education	18.6	14.2	44.9	18.4	3.9	100.0
Errands	46.3	5.9	24.7	20.8	2.3	100.0
Leisure	37.1	8.5	29.9	21.2	3.2	100.0

3.2 Household joint activities and travel patterns

3.2.1 The importance of analyzing the household activity and travel patterns

An essential step for understanding the household coordination and the notion of the primary family priority time consists of investigating the activity pattern of the individual members at the household level. In order to illustrate the complexity within the household some examples are shown in Figure 6 for four family types: Young couple in their twenties, a married couple with children, a single-parent household, and a couple in their forties without children. The households were randomly selected from their respective household types. The figure illustrates the coordination required at a household level (mainly among the parents) and the constraints of the parents formed by the kids. It also shows the joined trips and activities among the household members.

Each spouse of the young couple has a mandatory daily tour – one for work and one for studying, possibly in a university. The two spouses leave home roughly at the same hour, and return in different daily periods, therefore they do not travel together. They meet at home only around 17:30 in the afternoon, after the working spouse has performed a personal errand.

As expected, the married couple with children has the most complicated activity and travel pattern of all the household types, since the two parents share the responsibility of escorting their children. The mother works half a day in the morning while the father works at night. Hence, in the morning the mother goes immediately to work, while the father escorts the younger child to school while the older child, who is already 10 years old goes to school alone. The father returns home to sleep immediately after bringing the child to school. In the afternoon, the father picks up the younger child, while the older child returns home by himself. After returning home, the older child and the mother travel together for a combination of personal errands (e.g., doctors appointment, shopping) followed by a joint leisure activity in which the child and his mother have quality time together. When they return to the home, the mother works from home at some point during the evening (the precise time is not known). In the evening, the father escorts the two children to a leisure activity in which only the children participate and the father waits for them (e.g., soccer game or a ballet class), and it is likely that the mother uses this time interval to work at home. Then the family spends time together at home starting from 19:00 and until the father needs to go to work. This is a good example of a family that prioritize the family togetherness both in in-home and out-of-home activities.

In the single-parent household, the mother stays at home in the morning, while the children go to school at the same hour although they do not seem to travel together. Then, at noon, the mother has a joint tour with her youngest child (who have already returned home from school), where they pick up the oldest son when he sons, and together all of them are having an escort trip. The mom's main occupation is studying, and it seems like she is bringing her kids along, possibly because they cannot be at home alone and she cannot afford daycare. This is most likely an unusual family pattern.

The couple in their forties has a different daily arrangement. One spouse chooses to stay home the whole day, while the other travels to work. As in the case of the young couple, the spouse who travels to work also conducts some personal errands. The working spouse returns roughly at 18:00 in order to have a family quality time.

Notably for all the household types, the entire household is at home early in the evening possibly for dinner. Nevertheless, the hour in which the household members gather differs across the households, because the households with children have the gathering roughly 1-2 hours later.
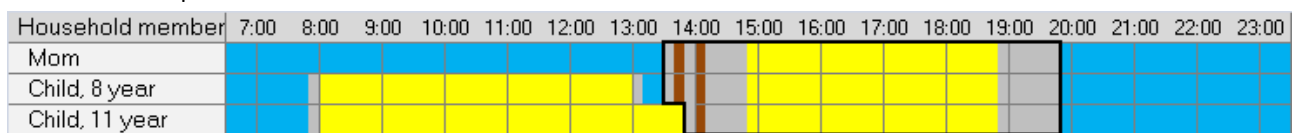
Figure 6 – activity pattern of a single household
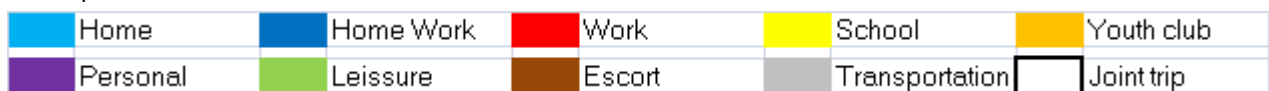

a. Two-persons young household
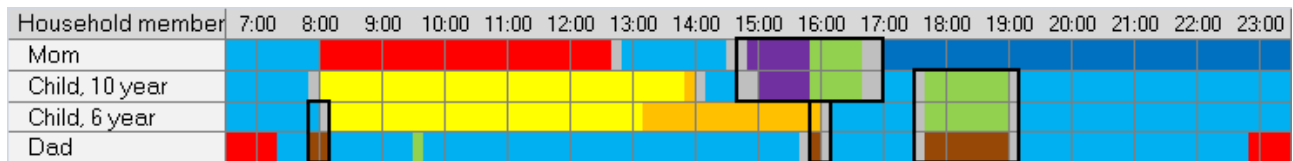
a. A married couple with children

c. Single parent with children

d. Two persons household without children

Home	Home Work	Work	School	Youth club
Personal	Leissure	Escort	Transportation	Joint trip

3.2.2 Tour level analysis

The share of joint versus solo tours by income groups is depicted in figure 7. For mandatory tours, is seems that the share of solo and joint tours is rather steady across income categories with slight fluctuations. This is reasonable since mandatory tours are mainly for work and education, which are conducted typically as solo tours. However, for non-mandatory tours, there is a clear trend of having less solo tours and more fully joint tours in middle income categories, while there are more solo tours for very low and very high income households. This is possibly related to the car ownership car allocation within the household, as well as to the nature of the activity pattern.
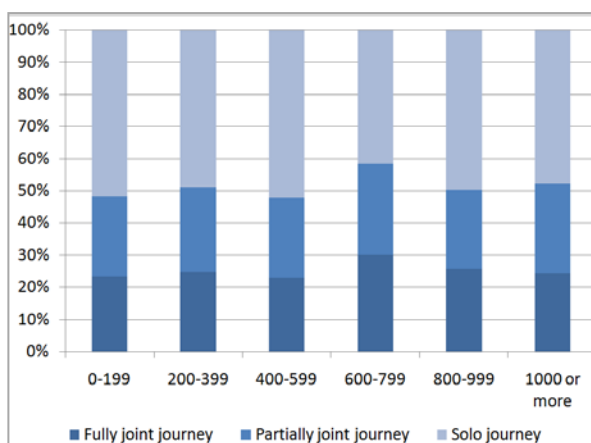
a. Mandatory tours
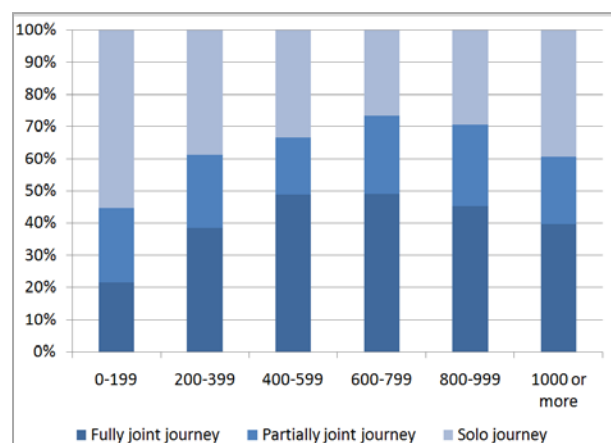
b. Non-mandatory tours

The share of joint versus solo tours by household size (for households with multiple members) for mandatory tours (i.e., work, education) and non-mandatory tours is provide in table 13 below. For mandatory tours, with the increase in the number of household members the number of solo tours decreases sharply and the number of partially and fully joint tours mildly increases. For non-mandatory tours, the share of solo tours decreases with the increase in household size, while the share of partially joint tours increases with household size, and the number of fully joint tours is the highest in three-member households. Namely, in two-person households, in which most likely there are two adults, there is a tendency to conduct the non-mandatory trips individually, possibly to save time or due to a different social activities. When children are involved there is a higher tendency to conduct joint trips and activities. Notably, when there is only one child there is a higher tendency for fully joint tours since the child accompanies the parents, however, when there are several children in different ages, the fully joint tours are replaced by escort tours of children to their activities.

Table 13: The share of joint and solo tours by household size (number of persons)

	Mandatory tours			Non-mandatory tours		
	Two household members	Three household members	Four or more household members	Two household members	Three household members	Four or more household members
Fully joint tour	14.3	22.1	31.7	40.2	50.8	32.7
Partially joint tour	22.8	23.9	29.7	25.5	24.3	51.7
Solo tour	62.9	54.0	38.7	34.2	24.9	15.6
	100.0	100.0	100.0	100.0	100.0	100.0

The share of joint versus solo tours by car ownership for mandatory tours and non-mandatory tours is provided in table 14 below. The decision to conduct a partially or fully joint tour is related to car ownership. For mandatory tours, the share of solo tours decreases dramatically with car ownership, in favor of an almost even split between partially and fully joint tours. For non-mandatory tours, with the increase in car ownership the share of solo tours decreases dramatically and the share of fully joint tours sharply increases. The share of partially joint tours remains almost the same, although there is a slight increase with car ownership.

Table 14: The share of joint and solo tours by car ownership

	Mandatory tours			Non-mandatory tours		
	No cars	One car	Two cars or more	No car	One car	Two cars or more
Fully joint tour	22.3	26.4	25.6	36.6	45.4	42.0
Partially joint tour	21.9	28.1	26.3	20.4	22.5	23.5
Solo tour	55.8	45.5	48.0	43.0	32.1	34.5
	100.0	100.0	100.0	100.0	100.0	100.0

Table 15 details fully joint, partially joint and solo tours by daily period. During morning peak hours, most tours are either solo tours or partially joint tours. During mid-day the tours are split between fully joint tours and solo tours. During the afternoon peak hour, more than half of the tours are fully joint tours and less than a third of the tours are conducted alone. During evening hours more than half of the trips are conducted alone and there are more fully joint tours than partially joint tours.

65.2% of the partially joint tours are conducted during morning peak hours, which is reasonable since these are mainly escort tours. On the fully joint tours, 42.7% depart during the morning peak hours, while 20.4% depart during mid-day and another 25.9% is conducted during afternoon peak hours. Interestingly, only 10.8% of the solo tours are conducted during the afternoon peak hours.

Table 16 presents the share of tours by tour type, tour duration (including the activity duration) and purpose. The tours for the purpose of work and school are naturally long tours due to the length of the activity, regardless of the number of participants (i.e. joint or solo). More than a third of the partially joint

tours are relatively short (less than 30 minutes) and 57.7% of these trips take less than an hour. Almost half of the joint tours are relatively long, as 72.6% have duration of at least one hour and 44.2% of the tours are more than three hours long. Solo tours are rather evenly distributed with respect to their duration.

Table 15: The share of tours by tour type and daily period

Tour type	AM Peak hour (07:00-09:00)	Mid-day off-peak 09:00-15:00	PM peak-hour (15:00-18:00)	Evening (after 18:00)
Fully joint tour	27.9	37.5	52.7	24.8
Partially joint tour	31.8	14.9	19.5	18.5
Solo tour	40.4	47.6	27.9	56.5
Grand Total	100.0	100.0	100.0	100.0

Table 16: The share of tours by tour type, purpose and duration

	0-30 minutes	31-60 minutes	61-120 minutes	121-180 minutes	>180 minutes	Total
Work or school						
Fully joint tours	0.8	0.8	0.8	3.7	93.8	100.0
Partially joint tour	0.4	0.4	0.2	0.9	98.1	100.0
Solo tour	1.8	1.1	1.4	2.0	93.8	100.0
Other purposes						
Fully joint tour	11.9	15.5	17.0	11.4	44.2	100.0
Partially joint tour	35.0	22.7	11.0	6.5	24.9	100.0
Solo tour	21.0	18.1	23.5	17.7	19.7	100.0

2.6.2 Trip level analysis

In terms of the trip participants, 88.0% of the trips are conducted solely by household members, while non-household members join the trip in 12.0% of the trips. The share of trips by participating individuals is detailed in table 17. 62.5% are solo trips. The most common trips are performed by a single adult (46.1%), an adult with one child (16.9%) and a single child alone (16.4%).

Table 17: The share of trips by participating individuals

Adults/ children	None	One	Two or more	Total
None	0.0	16.4	2.4	18.7
One	46.1	16.9	9.4	72.3
Two	5.1	2.2	1.6	8.9
Three of more	0.1	0.0	0.0	0.1
Total	51.3	35.4	13.3	100.0

The share of joint trips by participating individuals and the trip type is provided in table 18. Over 90% of the joint trips include joint activities, and this result is rather stable across trip participant categories (i.e., 2 adults, 2 adults with children, etc.)

Table 18: The share of joint trips by participating individuals

Trip type	2 adults	2 adults with children	Female with children	Male with Children	Other
Joint activities	92.9	98.6	93.8	93.0	92.9
Solo activities with Joint travel	7.1	1.4	6.2	7.0	7.1

The share of trips by participating individuals and purpose is detailed in table 19. Mandatory trips for adults are mostly conducted as solo trips, while the parents share equal responsibility for bringing children to day care facilities and schools. Usually, the escort activities are conducted by a single parent rather than by both parents. Naturally, the need for parental escort decreases with the child age, so while 56.8% of the children in day care are escorted by an adult to/from the day care facility, only 27.4% of the children in school are escorted by an adult to/from school. The parents seem also to split the responsibility regarding leisure activities with children, as only 5.6% of the leisure activities are conducted with two adults present, and in 20.2% of the leisure trips only one adult is present. Notably, two thirds of the leisure trips are conducted either alone or with non-household members. Trips with non-family members are also common

to/from day care facilities, and for business trips. While 60% of the trips for shopping and errands are conducted alone, some such maintenance trips are conducted with other family members, although such trips are rarely conducted by the male adult with the children.

Table 19: The share of trips by participating individuals and by trip purpose

Trip purpose	2 adults	2 adults with children	Female with children	Male with Children	Solo	Other	Total
Workplace	4.0	0.0	1.5	0.7	90.3	3.5	100.0
Business/ work	0.0	0.0	0.0	0.0	82.8	17.2	100.0
Education	0.8	0.8	14.8	12.6	51.2	19.8	100.0
Day care/ youth club	0.0	3.1	31.9	24.9	14.6	25.5	100.0
Shopping/ errands	9.0	9.4	12.3	4.0	58.7	6.5	100.0
Leisure	10.0	5.6	11.5	8.7	44.0	20.3	100.0
Escorting	4.1	4.5	32.9	22.1	32.5	3.9	100.0
Returning home	5.4	3.8	16.9	10.6	54.8	8.6	100.0

The share of trips by participating individuals and departure time is detailed in table 20. Most of the trips by a single adult with children take place during peak-hours, possibly due to chauffeuring activities. Trips involving a male adult with children rarely occur during the day between 09:00-15:00, possibly due to the task allocation between the male and female spouse within the household. For trips involving two adults (either with or without children) is rather low, the share of morning peak hour trips is the lowest and the share of afternoon peak hour trips is the highest. When children are involved in the trips, a higher share of trips is conducted during the day and fewer trips occur in the evening. Interestingly, a higher share of trips with non-household members occurs during daily off-peak hours rather than during the evening.

Table 20: The share of trips by participating individuals and by departure time

Departure time	2 adults	2 adults with children	Female with children	Male with Children	Solo	Other
07:00-09:00	14.1	13.1	29.1	36.0	25.5	22.8
09:00-15:00	29.2	30.2	17.4	7.4	27.0	33.8
15:00-18:00	32.2	39.5	42.4	40.9	30.8	26.9
18:00-07:00	24.4	17.2	11.2	15.8	16.7	16.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 21 presents the share of escorting trips by household size. The difference across household group size is significant at the 0.05 percent level. Notably, even a small share (4.9%) of single-person households engage in a joint travel escorting activities, possibly with elderly parents, friends or as part of a non-married couple. Naturally, the share of households that perform a higher number of escorting trips increases with the household size. Notably,23.3% of the households with four-people or more have three or more daily escorting trips.

Table 21: The share of escorting trips by number of escorting trips and household size

Number of daily escorting trips	Single person household	Two-persons household	Three-persons household	Four-persons household or larger
0	95.1	80.8	57.4	37.4
1	4.9	8.4	13.9	18.2
2	0.0	7.9	17.2	21.1
3	0.0	1.4	7.7	8.3
4 or more	0.0	1.4	3.8	15.0
Total	100	100	100	100

4. COMPAS; the ACTUM traffic model

A motivation behind the ACTUM household-based survey is to ensure the necessary data input for developing an activity based model for Copenhagen, the COMPAS model. Some of the pressing traffic

planning problems, causing the decision to build this model are increase in road congestion, increase in slow mode traffic, especially cycling, and a need for optimal strategy for infrastructure development in the region, e.g. Copenhagen Metro and the Harbour Tunnel project.

The proposed modelling approach rests upon the micro-economic theory, where each individual plans and executes daily activities by maximising his/her personal utility within the choice set and on different levels. A novelty here is an a priori assumption that family, or household (HH), puts time constraints on its members, so that the person day activity/travel demand has to be modelled as a function of HH characteristics. This is done by modelling periods of day where HH members spend time together at home - we call that for *Primary Family Priority Time*, and periods of the day where HH members are together on tour, e.g. escorting a child to school - we call that for *Secondary Family Priority Time*. That is to say that the HH plays a role when action regarding e.g. who will escort the child to school tomorrow, has to be put into the day schedule. However, it is the HH members that plan and execute day activities for the good of the HH, but also for their own sake (say playing tennis once a week) – in that way they maximise their own and the family overall activity pattern utility on a day level.

The COMPAS model includes three main model-packages: a) Longer term models, b) Day scheduling models, and c) Models for the tour and trip (Vuk and Bowman, 2012). In the first package we model work/school location for each HH-member, HH car ownership, as well as person transit pass ownership. In the second part we model HH time constraints upon its members, person main activity of the day, person full activity pattern of the day, person joint activities with other HH-members, and choice of working at home. Finally, for the each activity which demands travel, tours and trips are modelled taking into account modal split, choice of destination, and choice of time-of-day travel.

The core of the COMPAS model is the *Day scheduling models*. The reason for that is the notion of the activity based models saying that demand for travel is derived from the demand for activity participation, i.e. first when we know how a person plan and execute his/her activities we can model his/her travel demand. Based on that we need information on the person's family background, as well as his/her socio-economic background (e.g. education level, job type). Accordingly, forecasts in the COMPAS model are based on the model for synthetic population (and not on zonal data, which is done in the tour/trip based models).

In order to succeed in the complex task of estimating *Day scheduling models* for the HH-members it is an imperative that we obtain absolute accurate data, in time and space, for all activities and travels. For instance, if a parent states in his/her diary that he/she had a joint car trip with the child, the same information must occur in the child's trip diary – that including correct time window and place.

A second challenging issue in the estimation of the *Day scheduling models* is inclusion of the logsums. We want to bring logsums from the tour/trip models into the level of day scheduling models, but we also want that scheduling models on higher level are dependent of models on a lower level. For instance, we would like to model that parent's working pattern early in the day is influenced by the knowledge that in the evening he/she will escort the child to a sport activity.

5. Conclusions

The analysis, focusing on the household interactions and joint travel as an essential step towards estimating the activity-based model for the Copenhagen area, is unique in a Danish context. The analysis shows the importance of collecting data at the household level due to the large share of joint trips and shared activities within Danish household. In addition, it reveals the main role of everyday life coordination and interaction in Danish households on the travel patterns of family members. The results of the current study show that there are three manners of intra-household social interactions that influence the household activity and travel patterns.

Firstly, "primary family priority time" constrains the activity and travel pattern of the household by setting an hour in which all or some of the household members are at home. In fact, in the current sample,

75% of the respondents are home between 19:00-24:00, which means that most household members need to plan their travel and activity pattern for returning home at 19:00.

Secondly, household members engage in joint activities, resulting in fully joint tours. Interestingly, in houses were there are two spouses, they usually share the responsibility of joint activities with the children since most of the joint trips are conducted by one of the parents and the children. According to the results of the current study, the woman is dominant spouse in performing joint activities with the children.

Thirdly, household members engage in joint travel also in the case that the household members do not engage in the same activities. Hence the activity and travel patterns of some household members are related to and constrained by the activity and travel patterns of other household members. Hence, a significant share of the households engages in partially joint tours and escorting trips. The escorting activities dramatically increase with household size, which indicates that most of the escorting interactions are between parents and children.

Last, intra-household interactions are strongly related to household characteristics and to the tour and trip attributes. In particular, car ownership, income and household size significantly affect the tendency to perform partially and fully joint trips. In addition, trip purpose and departure time are also related to the decision to engage in joint versus solo tours.

The results obtained in the current study have an important meaning with respect to modeling the social interactions in the activity and travel patterns of the household, since such interactions can be explained and modeled as a function of the household and the tour characteristics.

References

Algers, S., J. Eliasson, and L.G Mattsson. 2001. Activity-based model development to support transport planning in the Stockholm region. Presented at the 5th Workshop of the TLE Network, Nynäshamn.

Arentze, T. , F. Hofman, H. van Mourik, and H. Timmermans, H. (2000). Albatross: multiagent, rule-based model of activity pattern decisions. Transportation Research Record 1706, pp. 136-144.

Bradley M., J. L. Bowman, and B. Griesenbeck. (2009). SACSIM: An applied activity-based model system with fine-level spatial and temporal resolution. Journal of Choice Modelling, 3(1), pp. 5-3.

Bradley, M., Vovsha, P. 2005. A model for joint choice of daily activity pattern types of household members. Transportation 32, 545-571.

Chandrasekharan, B., Goulias, K.G. 1999. Exploratory longitudinal analysis of solo and joint trip making using the Puget Sound transportation panel. Transportation Research Record 1676, 77-85.

Fujii, S., Kitamura, R., Kishizawa, K. 1999. Analysis of individuals' joint-activity engagement using a model system of activity-travel behavior and time use. Transportation Research Record 1676, 11-19.

Gliebe, J. P., Koppelman, F.S. 2002. A model of joint activity participation between household members. Transportation 29, 49-72.

Gliebe, J. P., Koppelman, F.S. 2005. Modeling household activity–travel interactions as parallel constrained choices. Transportation 32, 449-471.

Golob, T.F., Mcnally, M.G. 1997. A model of activity participation and travel interactions between household heads. Transportation Research part B 31, 177-194.

Golob, T.F. 2000. A simultaneous model of household activity participation and trip chain generation. Transportation Research Part B 34, 355-376.

Kang, H., Scott, D.M., Doherty, S.T. 2009. Investigation of planning priority of joint activities in household activity-scheduling process. Transportation Research Record 2134, 82-88.

Kang, H., Scott, D.M. 2011. Impact of different criteria for identifying intra-household interactions: a case study of household time allocation. Transportation 38, 81-99.

Kaplan S., G. Vuk (2012). Modeling interactions between household members. ACTUM WP3 Technical note, DTU-Transport.

Kato, H., Matsumoto, M. 2009. Intra-household interaction in a nuclear family: A utility-maximizing approach. Transportation Research Part B 43, 191-203.

Mosa, A.I., Harata, N., Ohmori, N. 2009. Simultaneous model for household interactions in daily activity, information and communication, and social behavior. Transportation Research Record 2135, 138-150.

Pinjari, A.R., N. Eluru, S. Srinivasan, J.Y. Guo, R.B. Copperman, I.N. Sener, and C.R. Bhat (2008). CEMDAP: Modeling and Microsimulation Frameworks, Software Development, and Verification. Proceedings of the Transportation Research Board 87th Annual Meeting, Washington D.C.

Přibyl, O., Goulias, K.G. 2005. Simulation of daily activity patterns incorporating interactions within households: algorithm overview and performance. Transportation Research Record1926, 135-141.

Roorda, M. J, E. J Miller, and K. M.N. Habib. (2008). Validation of TASHA: A 24-h activity scheduling microsimulation model. Transportation Research Part A: Policy and Practice 42 (2), PP. 360-375.,

Scott, D.M., Kanaroglou, P.S. 2002. An activity-episode generation model that captures interactions between household heads: development and empirical analysis. Transportation Research Part B 36, 875-896.

Sivakumar, A., Le Vine, S., Polak, J., 2010, An activity-based travel demand model for London, 38th Annual European Transport Conference. Glasgow, Scotland, 11-13 October

Srinivasan, S., Bhat, C.R. 2006. A multiple discrete-continuous model for independent and joint-discretionary-activity participation decisions. Transportation 33, 497-515.

Vovsha, P., Petersen, E., Donnelly, R. 2003. Explicit modeling of joint travel by household members: statistical evidence and applied approach. Transportation Research Record 1831, 1-10.

Vovsha, P., and M.Bradley. (2006). Advanced Activity-Based Models in Context of Planning Decisions. Transportation Research Record: Journal of the Transportation Research Board, 1981, pp. 34-41

Vovsha, P.,M. Bradley and J. L. Bowman. (2004). Activity-based travel forecasting models in the United States: Progress since 1995 and Prospects for the Future. Proceedings of the EIRASS Conference on Progress in Activity-Based Analysis, May 28-31, Maastricht, The Netherlands.

Vovsha P., E. Petersen and R. Donnelly (2002). Micro-Simulation in Travel Demand Modeling: Lessons Learned from the New York Best Practice Model. Transportation Research Record 1805, 68-77.

Vovsha, P., Petersen, E., Donnelly, R. 2004a. Model for allocation of maintenance activities to household members. Transportation Research Record 1894, 170-179.

Vovsha, P., Petersen, E., Donnelly, R. 2004b. Impact of intra-household interactions on individual daily activity-travel patterns. Transportation Research Record 1898, 87-97.

Vuk, G., Bowman, J. 2012. COMPAS model specification. ACTUM WP3 technical note.

Yarlagadda, A.K., Srinivasan, S. 2008. Modeling children's school travel mode and parental escort decisions. Transportation 35, 201-218.

Zhang, J., Fujiwara, A. 2006. Representing household time allocation behavior by endogenously incorporating diverse intra-household interactions: A case study in the context of elderly couples. Transportation Research Part B 40, 54-74.

Zhang, J., Timmermans, H.J.P., Borgers, A. 2005. A model of household task allocation and time use. Transportation Research Part B 39, 81-95.