CONSIDERING JOINT TRIPS AND ACTIVITIES IN WEEK ACTIVITY SCHEDULES

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ABSTRACT

People undertake trips and activities either alone or jointly with others. Including such joint actions in travel demand models increase behavioral realism, but it would also add complexity to the modeling process. To understand the importance of joint actions, it is first necessary to investigate their specific characteristics such as purposes or timing. So far, these characteristics are under-represented in travel demand models, particularly in those dealing with simulation periods exceeding one day. Here, we introduce a method to extract joint actions from household one-week-survey data and investigate their characteristics. We show that about 20% of all trips and 18% of all activities are undertaken jointly. Moreover, we find significant differences in the proportion of joint actions for different activity types and categories of people. For example, leisure and shopping actions are more often undertaken jointly, and pensioners undertake more joint actions than employed persons or students. Because the characteristics of joint actions differ from those of actions undertaken alone, modeling these actions explicitly and integrating their characteristics into travel demand models increases behavioral realism and improves results.

INTRODUCTION

A travel demand model always tries to model travel behavior as realistically as possible. At the same time, it must remain simple enough to be practicable and keep complexity under control. One factor that increases both realism and complexity is including joint trips and activities (i.e., actions undertaken together by more than one person in the household) in the model. There are two reasons why this is important. First, it enables travel demand models to simulate more accurate and realistic behavior, in general. Taking a joint trip reduces both temporal and spatial flexibility, since decisions about timing and destination are also dependent on the other parties. The same reduced flexibility occurs when undertaking joint activities. In planning such trips and activities, the additional coordination tasks must then be considered. Second, joint trips are also relevant for modeling car-passenger trips accurately, since all trips taken as a car-passenger require a car-driver and thus represent a joint trip with at least two people.

Bradley and Bowman (*1*) in 2006 and Davidson et al. (*2*) in 2007 reviewed activity-based travel demand models and identified the linkages between household members (e.g., joint actions) as one key for model implementation. Nonetheless, joint trips, activities, and the related decisions are generally underestimated for simulation periods exceeding one day. There are only a few travel demand models simulating periods longer than one day. This is often caused by data requirements and the goals of these models. If the goal is to investigate infrastructure needs, then one-day models are sufficient. However, to study the stability and variability of personal behavior, longer simulating periods are needed (*3*). A one-week simulation period, for example, provides valuable insights into transportation modes and activities that vary from day to day throughout the week.

In this paper, we look closely at the topic of joint trips and activities. First, we present relevant research from the literature. Second, using datasets from two German surveys, we show how to detect the joint trips and activities of household members. We then describe the characteristics of these trips and activities and illustrate how they are integrated into people's daily travel behavior. Unlike most survey data used for travel demand modeling, our two data sources cover one complete week. Thus, we can analyze characteristics across several days and discover whether the same household member takes joint trips each time or not – information that may be useful when analyzing stability in travel behavior. For example, does the same parent always take the child to school in the morning? One-day travel surveys cannot examine these features. We next investigate joint trips and activities using a logistic regression model. Here, we identify contexts and situations in activity schedules that lead to a joint activity or trip. Finally, we examine how joint activities and trips might be integrated into the activity generation module (*actiTopp)* of *mobiTopp,* a travel demand model developed at the Institute for Transport Studies at the Karlsruhe Institute of Technology (KIT) (*3; 4*). Towards this end, we present our own thoughts and ideas, along with a framework of how we can further include joint actions in future work in our model.

LITERATURE REVIEW

The research in this field falls into two main categories. Some focuses on the allocation of activities to different household members. Activities may be shared (e.g., maintenance tasks) and thus members "consume" a joint time budget. Other research focuses on trips and activities undertaken jointly by two or more household members. These two aspects may be connected, but they can also be studied separately, since the data needed for investigation is also different. Investigating the allocation of household activities requires information about these activities. Depending on the travel survey data, this information may not be available. In this paper, we focus solely on joint trips and activities.

One of the first studies in this field was carried out by van Wissen (*5*), who highlighted the importance of joint activities – especially for home, leisure, and shopping purposes. Other researchers (*6*–*9*) focused on empirical evidence and models to investigate relevant decision factors. Vovsha et al. (*10; 11*) investigated the topic with a study done in Ohio, USA. They differentiated between three joint categories and formulated regression models to integrate joint actions in their existing tour-based modeling system. They found full-time workers and students to be the most "individual" types – least likely to undertake joint activities. In 2005, several approaches were published in a special issue of the journal *Transportation* (*12*). Pribyl & Goulias (*13*) and Lee et al. (*14*) investigated the topic using cluster analysis methods. This group estimated the importance of day-of-week and life cycle stage for maintaining interpersonal contacts, i.e., undertaking joint activities.

In addition to descriptive analyses and models investigating important factors and parameters for joint trips and activities, work has also been done to integrate this knowledge into activity-based travel demand models (ABM). Bradley and Bowman (*1*) name models featuring joint actions. Bradley and Vovsha (*15*) continued their studies on joint modeling of daily activity patterns and presented further details on intra-household interactions. Their approaches later became part of the CT-RAMP models (*16*). This is one example of a possible integration. Today, most ABM integrate joint activities and trips.

As shown, there is a variety of approaches for examining joint trips and activities. Unfortunately, they are generally limited to one-day schedules. Modeling approaches of longer periods, such as one week, are generally limited, independent of joint actions. Since modeling of longer periods allows one to capture more detailed behavior (see *3* or *17* for more details), however, the role of joint activities and trips is indeed relevant and actually underestimated. Moreover, since most of the existing studies draw on data surveys conducted in the USA, it would also be interesting to learn whether the same characteristics and results hold true for Germany.

DATA

We used two data sources for this study: the German Mobility Panel – a nationwide travel behavior survey – and a survey conducted in the greater Stuttgart region. The similar design of these surveys allows us to directly test and verify our methods on two different datasets and, hence, to compare and interpret the results.

The German Mobility Panel (MOP)

Since 1994, the MOP has collected data every year about the travel behavior of the German population. Here, 1,000-1,500 households with 2,000-2,400 persons aged 10 years and older contribute to the MOP survey by recording a trip diary for one week. The MOP survey is carried out in the autumn and, to capture "average daily travel", the week is chosen to exclude holidays. The survey is funded by the German Federal Ministry of Transport and Digital Infrastructure and the Institute for Transport Studies at the Karlsruhe Institute of Technology (KIT) is responsible for the design and scientific supervision of the survey (*18; 19*). Survey participants provide a complete trip diary containing information on all their trips over a whole week. This information includes distances traveled, modes of transportation, purposes for traveling, and departure and arrival times. Moreover, participants also provide socio-demographic information (e.g., employment status, gender, age …) and further information (e.g., car parking availability at home and at work, transit service quality for commuting …). Unfortunately, no geocodes for departure and arrival are recorded. Participants report whether each day within the survey was normal or special: whether the participant was ill or on vacation or whether the car was out of service.

The data set used for our analyses was collected between 2010 and 2015. Data from repeated survey participation, which occurs due to the survey's panel character, was regarded as independent.

Travel Survey in the Greater Stuttgart Region

In 2009/2010, a large multiday household travel survey was conducted in the greater Stuttgart region (population = 2.7 million). Here, participants were polled on their travel behavior for a period of seven consecutive days (one-week travel survey). This household survey was very similar in design to the MOP survey. It did not have the panel approach of repeated participation, but did include geocoding of the trips. It was carried out between September 2009 and April 2010, and the main survey times fell outside of the holiday seasons (mid-September to mid-December 2009 and mid-January to mid-April 2010). All household members aged 6 years and older were asked to complete a trip diary for one week, containing all relevant information about their trips, such as distances, modes and durations. Place of destination and arrival is reported on traffic zone level (i.e., the region is divided into 1,074 traffic zones). Altogether, 10,744 persons in 4,709 households contributed to the survey.

Data Preparation

We selected several households from the sample only. All household members had to fill in their trip diary and the reporting needed to be in the same period. To improve comparability of the two data sets, we limited the data of the Stuttgart survey to those persons aged 10 years and older. Ultimately, the MOP survey data included 9,843 persons taking more than 218,000 reported trips and the Stuttgart survey data contained 9,547 persons taking more than 200,000 trips. Since both datasets recorded the unit of trips, activities were only an indirect outcome and needed to be determined from given data. Therefore, we transformed the trip data into corresponding activity data (see also *17*).

MATCHING METHODOLOGY

Travel survey data can be used to estimate joint trips and activities. Unfortunately, these two datasets did not directly collect information about the presence or absence of travel companions. Consequently, we needed to identify and estimate trips and activities made jointly. Since both surveys use the household as their basis, this is the only unit where joint trips and activities can be identified. Although there are trips and activities that are undertaken with non-household members, we cannot identify them. Due to this fact and other matching limitations, one has to regard the amount of joint trips and activities as lower bounds. However, since we also use the household as the modeling unit for our travel demand model, this is an acceptable restriction for us.

We aggregated purposes of activities and transportation modes in order to simplify matching algorithms. We ultimately distinguished the purposes work, education, leisure, shopping, and transport (i.e., picking someone up or dropping someone off) and the transportation modes walking, bicycle, motorbike, car-driver, car-passenger, and transit.

Joint Trips

To identify joint trips, we investigated all trips of every household in the sample. Ordering them by their starting time within the week, we matched trips of different household members according to their starting and ending times. For example, in a two-person household, we compared each trip of person 1 to each trip of person 2. On the assumption that participants might not always report times to the exact minute, we permitted matching within a 5-minute range of given starting and ending times. Besides timing, “joint trips” had to meet other criteria:

1. The mode combination needed to be compatible. For example, same mode or car-driver paired with car-passenger.
2. The purpose combination needed to be compatible. For example, same purpose or any purpose paired with a transport trip.
3. The starting and ending areas needed to be the same (only applicable to the Stuttgart survey data, since the MOP survey provided no geocodes).

4. The reported distances needed to be in the same range. Here, we allowed a maximum deviation of 10%. We considered this distance parameter to compensate for missing geocodes in the MOP data.

If a trip met all these criteria, we considered it a joint trip. Because we used starting and ending times for the matching process, we did not get matchings when people started, but did not end, a trip together. Only trips made together for the whole duration were detected. As geocodes were available for the Stuttgart data and on traffic zone level only, we limited the temporal range to 5 minutes to avoid mismatching of joint trips.

Joint Activities

Joint activities were identified analogously to joint trips. We also matched activities of different household members by starting and ending times – with the same 5-minute grace period. However, since there was no information about modes or distances, we eliminated these criteria. Ultimately, we used the following two criteria to complement timing:

1. The purpose needed to be the same.
2. The starting and ending areas needed to be the same (Stuttgart data only).

If an activity met these criteria, we considered it a joint activity. Joint activities were only detected if people stayed together during the whole activity duration. If someone left earlier or came later than the 5-minute range, no joint activity was detected.

RESULTS

The following section presents descriptive results using our presented methodology to identify joint trips and activities. TABLE 1 shows descriptive information for the two data sources, along with joint trips and activities. Since, by definition, people in single-households cannot have joint actions, we show matching results only for people living in at least two-person households.

Results are comparable for both data sources. About 25% of all trips were taken together with another household member. Most of them took place at exactly the same time, i.e., using the five-minute range did not significantly increase the share. The share of joint activities was about 16% to 18% – slightly less than the share of joint trips. This seems reasonable, however, since one joint activity might cause two joint trips (e.g., trip to the start of the activity and trip leaving the activity). The finding are in line with other studies. Analyzing data from the Puget Sound Transportation Panel (*6*) also shows between 23% and 28% of joint trips, depending on the survey wave.

TABLE 1 Descriptive Information

Socio-demographic information	MOP data		Stuttgart data	
male	4,641	48.94%	4,642	48.70%
female	4,842	51.06%	4,889	51.30%
persons living in worker-households (1-2 persons)	3,538	37.31%	2,270	23.78%
persons living in non-worker-households (1-2 persons)	3,147	33.19%	2,745	28.75%
persons living in households with children under 18	2,116	22.31%	3,263	34.18%
persons living in households with no children (>2 persons)	682	7.19%	1,269	13.29%
persons living in single-households	2,476	18.77%	991	10.38%
persons living in at least two-person households	10,716	81.23%	8,556	89.62%
full-time workers	3,051	32.17%	2,899	30.37%
part-time workers	1,361	14.35%	1,241	13.00%
students	1,026	10.82%	1,864	19.52%
pensioners	3,365	35.48%	2,824	29.58%
others	680	7.18%	719	7.53%
Joint trips (only for persons living in at least two-person households)				
no joint trip	126,095	77.11%	136,285	75.80%
direct matching	34,973	21.39%	41,833	23.27%
matching in 1-minute range	546	0.33%	260	0.14%
matching in 2-minute range	323	0.20%	179	0.10%
matching in 3-minute range	280	0.17%	122	0.07%
matching in 4-minute range	144	0.09%	63	0.04%
matching in 5-minute range	1,158	0.71%	1,049	0.58%
Joint activities (only for persons living in at least two-person households)				
no joint activity	145,976	82.69%	158,942	81.13%
direct matching	28,371	16.07%	35,342	18.04%
matching in 1-minute range	338	0.19%	131	0.07%
matching in 2-minute range	268	0.15%	123	0.06%
matching in 3-minute range	246	0.14%	131	0.07%
matching in 4-minute range	149	0.08%	62	0.03%
matching in 5-minute range	1,178	0.67%	1,181	0.60%

Characteristics of Joint Trips

We investigated all trips taken by persons living in at least two-person households for our analyses. Relatively more joint trips were made on weekends than on weekdays. Whereas the share of joint trips was about 17% (MOP data) and 18% (Stuttgart Data) of all trips on weekdays, the share increased to 21% and 22% on Friday, to 35% and 38% on Saturday, and to 46% and 48% on Sunday. It also varied according to the time of day, rising in the morning to about 30% of all trips starting within a given hour, remaining relatively stable throughout the day, and then rising slightly again in the evening hours, when also many trips home occurred.

In the following analysis, we examine joint trips by itself to determine their characteristics. Most joint trips were taken as a combination of the modes car-driver and car-passenger (MOP: 73%, Stuttgart: 72%). Walking trips were about 14% (both MOP and Stuttgart) and joint transit trips about 4% (MOP) and 8% (Stuttgart). The mode share for transit was higher in Stuttgart than in MOP due to this survey region’s more extensive transit supply and metropolitan character. All other modes were under 5%. Neglecting trips returning home – which were about half of all joint trips – and focusing on out-of-home-trips, joint trips were taken mainly for leisure (MOP: 48%, Stuttgart: 44%) and shopping (MOP: 35%, Stuttgart: 36%). Transport trips were only around 15%. The importance of shopping and leisure activities has also been shown by others (see section “Multinomial Logistic Regression Model”).

TABLE 2 Joint Trips – Characteristics

Combination of household members by employment status	**share of joint trips [%]**	
	MOP data	**Stuttgart data**
all full-time workers	10.65%	8.75%
all pensioners	37.64%	36.31%
full-time worker & part-time worker	8.68%	10.92%
full-time worker & student	4.20%	4.73%
part-time worker & student	4.21%	5.32%
other	34.62%	33.97%

Combination of household members by age	**share of joint trips [%]**	
	MOP data	**Stuttgart data**
all persons aged 36 to 50	7.72%	8.22%
all persons aged 51 to 60	9.22%	7.69%
all persons aged 61 to 70	19.62%	17.60%
all persons aged over 70	17.97%	13.47%
persons aged 36 to 50 and 10 to 17	5.42%	9.09%
persons aged 61 to 70 and 51 to 60	7.07%	3.88%
persons aged 61 to 70 and over 70	8.08%	6.80%
other	24.89%	33.26%

Share of joint trips related to all trips of a person [%] (only for persons living in at least two-person households)	**MOP data**			**Stuttgart data**		
	MEAN	**Q1**	**Q3**	**MEAN**	**Q1**	**Q3**
full-time workers	16.94	0	25	18.19	5	27
part-time workers	18.58	4	28	18.63	7	26
students	16.52	0	25	20.50	3	31
pensioners	39.83	18	58	40.99	19	61
others	26.81	8	42	26.78	8	40

Number of days taking joint trips in a week (only for persons living in at least two-person households)	**MOP data**			**Stuttgart data**		
	MEAN	**Q1**	**Q3**	**MEAN**	**Q1**	**Q3**
full-time workers	1.85	0	3	1.86	1	3
part-time workers	2.16	1	3	2.19	1	3
students	1.93	0	3	2.14	1	3
pensioners	3.17	2	5	3.02	2	4
others	2.36	1	4	2.28	1	3

More than 90% of joint trips were taken by two household members only. TABLE 2 shows the most frequent combinations of household members by employment status and age. Pensioners took about one-third of all joint trips. Trips by employed persons were only around 20%. Another third of the trips was taken by other combinations of household members. TABLE 2 further shows information based on persons. The third analysis – the share of joint trips taken by a given person – reveals information similar to the combination of household members. Pensioners had the highest share of joint trips with others in their household: on average, around 40%. One-quarter of them even had joint-trip shares over 58%. In contrast, the mean value of joint trips for workers and students was only around 16% to 20%. Examining the number of days in a week with joint trips (fourth analysis in TABLE 2), we see that pensioners once again had the highest values. FIGURE 1 shows more detailed statistics on this aspect.

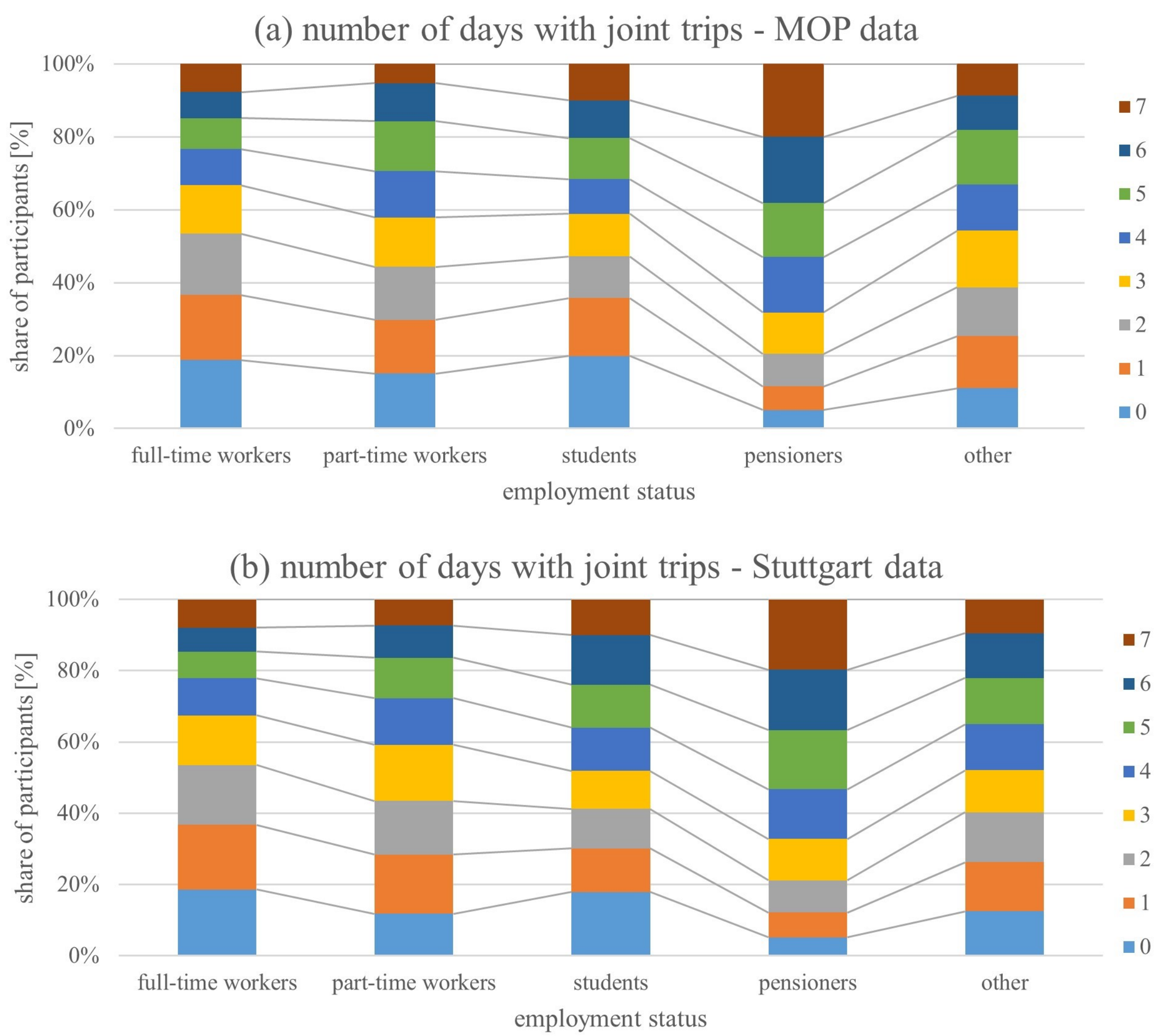

FIGURE 1 Number of days with joint trips, by employment status.

There were hardly any pensioners who did not take a joint trip in a week, whereas 20% of workers and students did. Part-time workers had higher mean values than full-time workers, which may indicate they were taking more transport trips – for example, picking up or dropping off their children. FIGURE 1 supports this theory. About 40% of all part-time workers took joint trips on at least four days, while only about 30% of full-time workers did so.

We also investigated the distribution of joint trips in family households in particular. FIGURE 2 shows the distribution of joint trips in different household sizes among adults and children. The values shown are mean values for the given household size and the sample. For example, in 3-person households (MOP data), 62% of the trips were made by adult 1 and adult 2 (adult numbers are randomly assigned by the household while filling in the questionnaire). The share of trips taken exclusively by adults decreased with growing household sizes. This is reasonable, since there were more other people in the household available for a joint trip. The share of trips taken by adult 1 with children and adult 2 with children revealed another interesting aspect. Trips done by adult 1 and children were about double the share of trips done by adult 2 and children in 3-person households. In contrast, in bigger households, this distribution was less dominated by adult 1. With increasing household size – which generally equates to more children in the household – joint trips made with children were more evenly distributed between adult household members.

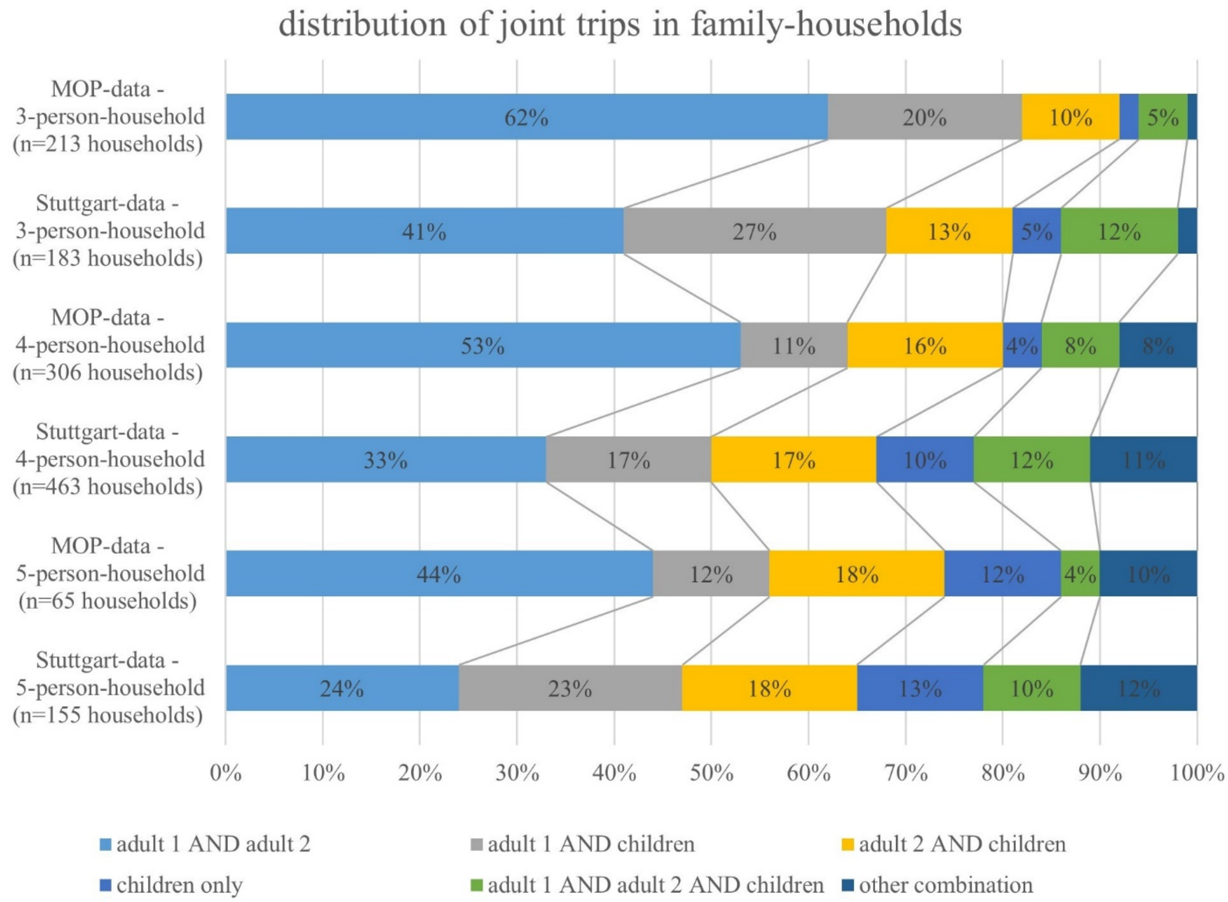

FIGURE 2 Distribution of joint trips in family households.

Characteristics of Joint Activities

We also analyzed the characteristics of joint activities for all people living in at least two-person households. Altogether, they were similar to the characteristics of joint trips. People also undertook joint activities more often on weekends. On weekdays, about 12% to 13% of the activities were undertaken jointly. This share rose to about 35% on Saturdays and 40% on Sundays. Joint activities were also dominated by the purposes home, leisure, and shopping (>90% of the total). This weekend effect is comprehensible, since people generally have more time not occupied by mandatory activities. TABLE 3 contains more details on the characteristics of joint activities. Here again, as with joint trips, pensioners (= elderly people) undertook the largest share of joint activities. On average, about 32% (MOP data) and 36% (Stuttgart data) of all their activities were undertaken jointly with other household members. For workers and students, the share was less than half of that. These results were also in line with the purposes of joint activities, since pensioners usually have no mandatory activities, such as work or education. On average, they undertook joint activities on 3.2 days of a week and 25% of the sample even had joint activities on five days a week or more. Workers and students had mean values of less than two days per week.

TABLE 3 Joint Activities – Characteristics

Combination of household members by employment status	**share of joint activities [%]**	
	MOP data	**Stuttgart data**
all full-time workers	11.34%	10.34%
all pensioners	41.69%	42.96%
full-time worker & part-time worker	8.78%	10.94%
other	38.19%	35.75%

Combination of household members by age	**share of joint activities [%]**	
	MOP data	**Stuttgart data**
all persons aged 36 to 50	7.34%	8.34%
all persons aged 51 to 60	9.40%	8.72%
all persons aged 61 to 70	21.32%	20.55%
all persons aged over 70	20.12%	15.87%
persons aged 61 to 70 and 51 to 60	7.23%	4.55%
persons aged 61 to 70 and over 70	9.09%	8.24%
other	24.89%	33.26%

Share of joint activities related to all activities of a person [%] (only for persons living in at least two-person households)	**MOP data**			**Stuttgart data**		
	MEAN	**Q1**	**Q3**	**MEAN**	**Q1**	**Q3**
full-time workers	12.82	0	19	14.62	4	21
part-time workers	13.31	2	19	13.52	4	18
students	8.26	0	13	10.20	0	15
pensioners	31.98	12	48	36.00	15	54
others	19.07	4	30	19.92	5	30

Number of days undertaking joint activities in a week (only for persons living in at least two-person households)	**MOP data**			**Stuttgart data**		
	MEAN	**Q1**	**Q3**	**MEAN**	**Q1**	**Q3**
full-time workers	1.71	0	3	1.78	1	3
part-time workers	1.92	1	3	1.95	1	3
students	1.31	0	2	1.42	0	2
pensioners	3.22	2	5	3.24	2	5
others	2.18	1	3	2.21	1	3

Combination of Joint Trips and Activities

The descriptive results shown above help to identify situations and factors that influence joint trips and activities. However, our ultimate goal was to integrate the decisions for joint actions into the modeling of activity schedules in our travel demand model *mobiTopp*. Therefore, we combined the two dimensions of trip and activity. Since we model primarily activities in our travel demand model, we treat trips as the consequence of undertaking an activity. This yields four alternatives:

1. The activity AND the trip to reach the start of the activity were undertaken jointly.
2. Only the activity was undertaken jointly.
3. Only the trip to reach the start of activity was undertaken jointly.
4. No joint actions occurred.

Descriptive Results

For each activity, we assigned one of the four alternatives shown above. To do so, we combined our results of joint trips and activities. FIGURE 3 shows the distribution of the alternatives for each activity purpose for all persons living in at least 2-person households.

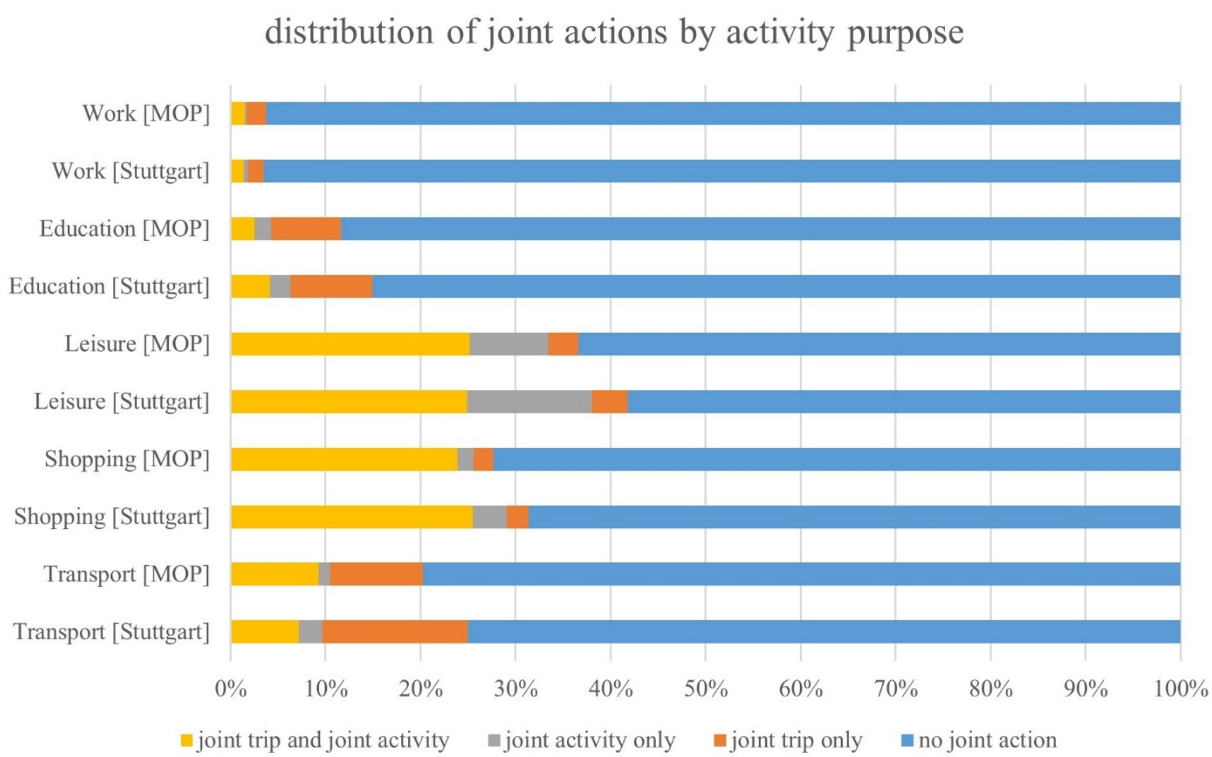

FIGURE 3 Distribution of joint actions by activity purpose.

Joint activities and trips were again dominated by the purposes leisure and shopping. In most of these cases, joint activities went together with a joint trip. Taking a joint trip only was rare for these activity purposes. For other purposes, such as education or transport, joint actions were clearly dominated by joint trips. This makes sense, since education and transport purposes are often associated with taking a child to school. For the child, the way to school was a joint trip but not a joint activity. The same holds true for the parent: Joint trip (purpose transport), but no joint activity. For the purpose work, the shares of any joint action are the smallest.

Multinomial Logistic Regression Model

The multinomial logistic regression model bases on all activities undertaken by people living in at least 2-person households. We investigated relevant parameters pointing towards a joint trip, a joint activity, or both. We only used the MOP data, since this is also our data source for estimation in *actiTopp*. We used half the sample (= 88,265 observations) for estimating the model and half for a test application. The alternative "no joint action" was the reference category. All information pertaining to the activity schedule, such as the timing of the activity, the household context, socio-demographic information, other activities within the week activity schedule, other activities done by other household members, etc., was available for the regression model. Note that we had not yet made a link between the decisions of different household members. Here, we used the regression model simply to get first impressions of relevant parameters for the decision. This information comes into use later, when modeling joint trips and activities in our model (see next section).

We tested the model with various variables indicating information about the activity, tour, day and person context. Finally, we only included parameters significant at the 1%-level according to the Wald-Test on overall effects (see TABLE 4). These parameters can be divided into 3 groups: The first group contains person-specific variables. Employment status of the person was relevant for the decision of any joint action. This result is in line with our descriptive findings and also with other studies in the U.S. that pointed out the life cycle stage as relevant influencing factor (*6; 10*). The negative coefficients of the presence of children under 10 in the household are an unexpected result in contrast to other variables. This may be caused by the fact that taking care of children impedes joint trips of parents. Nonetheless, this was not studied more closely here. The second group contains day-specific parameters, such as day of the week. The variables Friday, Sunday, and Saturday resulted in higher likelihoods to perform a joint action (i.e., all estimates were positive). Similar results have also been shown by Srinivasan and Bhat (*7*) investigating data from the American Time Use Survey. The third group contains activity-specific parameters. Here, activity purpose and starting hour of the activity were most important. The importance of these variables already came to light in our descriptive results and are in line with findings from the Puget Sound Transportation Panel (*6*) or the American Time Use Survey (*7*).

TABLE 4 Logistic Regression Results

No.	Variable	Wald Chi-Square	Parameter Estimates		
			joint trip + activity	**joint activity**	**joint trip**
0	Intercept		-2.647 ***	-4.278 ***	-2.818 ***
	person/household-specific variables				
1	person is pensioner	595.693 ***	0.572 ***	0.612 ***	0.358 ***
2	person is student	83.455 ***	-0.429 ***	-0.488 ***	0.034
3	person is worker in vocational training	202.131 ***	-1.589 ***	-1.714 ***	-1.099 ***
4	number of children under 18 in household	339.393 ***	-0.235 ***	0.004	0.309 ***
5	household has children under 10	291.258 ***	-0.110 **	-0.368 ***	-0.881 ***
	day-specific variables				
6	day is Friday	101.867 ***	0.317 ***	0.090	0.088 **
7	day is Saturday	824.859 ***	0.817 ***	0.679 ***	0.411 ***
8	day is Sunday	1,576.372 ***	1.147 ***	1.105 ***	0.946 ***
9	main tour purpose of day is work	868.517 ***	-0.910 ***	-0.634 ***	-0.735 ***
10	main tour purpose of day is education	66.186 ***	-0.438 ***	-0.250 **	-0.434 ***
	activity-specific variables				
11	activity is on last tour of the day	134.841 ***	0.350 ***	0.197 ***	0.065
12	activity purpose is leisure	759.125 ***	0.212 ***	0.138 **	0.444 ***
13	activity purpose is shopping	760.298 ***	0.560 ***	0.840 ***	-1.276 ***
14	activity purpose is transport	43.319 ***	0.685 ***	-0.579 ***	-1.414 ***
15	activity purpose is work	326.478 ***	-0.064	-0.828 ***	0.183 ***
16	activity is first activity on day	104.198 ***	-1.007 ***	-2.034 ***	-1.140 ***
17	duration of activity [hours]	516.271 ***	-0.004 **	-0.026 ***	0.025 ***
18	activity starting hour is between 0 AM and 5 AM	808.250 ***	-1.287 ***	2.773 ***	-1.515 ***
19	activity starting hour is between 6 AM and 8 AM	89.367 ***	-0.619 ***	-0.049	-0.027
20	activity starting hour is between 10 AM and 12 AM	89.381 ***	0.385 ***	0.544 ***	0.324 ***
21	activity starting hour is between 1 PM and 3 PM	206.940 ***	0.518 ***	1.089 ***	0.541 ***
22	activity starting hour is between 4 PM and 6 PM	310.640 ***	0.680 ***	1.189 ***	0.735 ***
23	activity starting hour is between 7 PM and 9 PM	236.001 ***	0.686 ***	0.681 ***	0.899 ***
24	activity starting hour is between 10 PM and 11 PM	190.960 ***	0.819 ***	1.122 ***	0.959 ***

***,**,* = significance at 1%,5%,10%-level; n = 88,264

LL (0) = -122,360; LL (constant) = -70,280; LL (full model) = -58,974

McFadden pseudo R^2 (based on constant LL) = 0.16

Test application

	Data [observed]		**Data [modeled]**	
joint trip and joint activity	11,969	13.56%	11,896	13.48%
joint activity only	3,300	3.74%	3,385	3.84%
joint trip only	6,466	7.33%	6,257	7.09%
no joint action	66,529	75.38%	66,726	75.60%

MODELING WEEK ACTIVITY SCHEDULES

We now provide a short description of the *mobiTopp* travel demand model and its activity generation module, *actiTopp*. Thereafter, we share our first thoughts on how to implement the integration of joint trips and activities into this model.

mobiTopp Model and its Activity Generation Module *actiTopp*

mobiTopp (*4*) is an agent-based model simulating travel demand over a period of one week. Each agent, representing a person in the planning area, has an activity schedule consisting of activities of different types (e.g., home, work, education, leisure, and shopping) to be executed during the simulation period. The simulation takes place in two stages: long-term and short-term. The long-term stage models features that are stable over a longer period. These include the population synthesis, the assignment of activity schedules, the locations of work and school, and such agent characteristics as carsharing membership or transit pass ownership. The short-term stage models the actual activity-travel behavior of agents simultaneously and chronologically. It consists mainly of models to determine the destination and mode for each trip according to the predefined activity schedule. Since its original design, *mobiTopp* has been extended to allow for simultaneous choice of destination and mode (*20*), carsharing (*21*), and electric vehicles (*22*). Furthermore, the activity generation module has also been extended. The econometric approach *actiTopp* uses a stepwise modeling of activity schedules based mainly on logistic regression models. It generates week-long activity schedules as input for the short-term stage of *mobiTopp*. For more details about *actiTopp*, see Hilgert et al. (*17*).

Model Improvements - First Suggestions

We propose a hierarchical approach to integrate joint trips and activities into *actiTopp*, and illustrate this approach using the example of a 3-person household. First, we determine the probable share of joint activities based on the personal characteristics of each household member. Second, the first person in this hierarchy (i.e., the one who will probably have the most joint actions) is modeled by *actiTopp* and assigned a week activity schedule. Third, the resulting set of activities and trips is then examined to see whether they are done jointly or not. Therefore, a regression model such as the one presented in this paper. We also estimate the other party "with whom" joint activities are undertaken, based on persons in the household and their characteristics. This all results in an adapted set of activities for person 1. For each activity, information of with whom the activity is undertaken (or solo) is added as a characteristic. Fourth, *actiTopp* models the week activity schedule for the second person in the hierarchy. Elements of this person's schedule may be pre-defined, since person 1 may have joint activities or trips together with the second person. Therefore, we need to adapt the modeling process of *actiTopp* to consider these aspects. After the modeling, we decide again whether some of the activities of person 2 may be done jointly. Since person 1 is already modeled, only the combination of persons 2 and 3 is possible for further joint activities. Finally, person 3 is modeled by *actiTopp*, based on the pre-determined joint activities involving persons 1 and 2. The activity schedules, including information about joint actions, is then handed over to the short-term stage of *mobiTopp* Consequently, we further need to consider the joint characteristics in destination and mode choice models as well.

Knowing that some implementations, such as that of Bradley & Vovsha (*15*), model joint aspects as joint choices for all household members, we have decided to omit that from our model at this point. The modeling of activity schedules for an entire week increases the degrees of freedom for many modeling steps. Thus, joint choices are more difficult to implement based on the current structure of *actiTopp*. We will investigate the potential of this aspect for future versions.

CONCLUSIONS / FURTHER RESEARCH

Taking a trip or undertaking an activity together with other people results in different decision behavior than doing the same alone. Spatial and temporal flexibility both decrease as decision making require at least the consensus of two people, thus imposing other characteristics on these trips and activities.

In this paper, we have illustrated the relevance of joint trips and activities to the accuracy of travel demand models. Such joint actions account for some 20% of all trips and 15% of all activities during the week, and even more on weekends. Using two German travel surveys, we have defined a method to identify joint actions and shown descriptive results and characteristics of these actions. We have also combined the two dimensions, trip and activity, to show their connections and dependencies. For leisure and shopping, joint activities are often combined with joint trips. For education and transport, joint trips are often undertaken without joint activities. We further estimated a logistic regression model to identify the relevant parameters of joint actions. The results here are in line with our descriptive ones and those of other researchers. Employment status, activity purpose, activity starting hour, and day of the week proved to be among the most relevant parameters for the decision. We have finally offered a preview of how joint trips and activities can be integrated into our travel demand model *mobiTopp* and, more specifically, into our activity generation module *actiTopp*. On this basis, it is now possible to consider joint activities and trips in modeling travel behavior in the course of one week. The stability and variability of travel behavior must be taken into account. Routines in individual travel behavior may also influence joint trips and affect the individual as well as the travel behavior of other household members. Thus, the complexity of the modeling steps increases when the simulation period is lengthened to one week. This is one main focus of our future research. At this point, we have only a framework for modeling joint actions. We must still test and implement this framework, and evaluate the modeling techniques.

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