Analysis of Travel Behaviour Variability: a Study on Data Collection by GPS-enabled Smartphones during Eight Months

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GPS technology makes travel data collection less troublesome and analysis of travel behaviour variability possible from a temporal perspective. In this paper, we try to understand the variability of travel behaviour with the travel data obtained from GPS trajectories collected by 20 participants in Hakodate lasting for eight months (covering the seasons of summer and winter). Travel behaviour is represented by three dependent variables: the number of trips in a trip chain, the number of trip chains during a day, and the number of trips during a day. Independent variables from time dimension, trip dimension, weather dimension, and demographic dimension are investigated with generalized structural equation modelling (SEM) from ordinal family with probit link function. The estimation results show the interactions among these three dependent variables. Meanwhile, it shows that the significant variables from several dimensions. Data collection lasting for seasons shows that the snow, rain and temperature from the weather dimen-sion are significant explanatory variables influenc-ing people's organizing trip and trip chains on one day.

Key Words : *travel behavior variability, GPS data, trip chain, ordered probit models, structural equation modelling,*

1. INTRODUCTION

A sequence of trips is one of the results when people realize the needs of activities. People organize these trips influenced by various factors and try to obtain the maximum utility during the process of organizing trips. The number of trips in a trip chain, the number of trip chains in a day, and the total number of trips are three variables related to how people organize their trips (or travel demand) during the day. And it becomes a hot topic of identifying and analyzing key factors influencing variability of trip organizing. Existing research has already revealed the influencing factors from the dimensions of gender[1)], occupation[2; 3)], land use together with density [4-7)], and weather[8; 9)] etc.

Among these factors above, weather is a key factor influencing not only the traffic volume[10; 11)] in the macroscopic way, but also the travel behavior[12)] in the microscopic way. Generally speaking, weather variables change temporally through the year and spatially here and there. It is believed that people in a specific geographical location may adapt their travel behavior to the local climate[9)]. However, it is still not clear that weather's influence on people's travel behavior in the temporal prospective, to be specific, through a longer period of time, like several months covering different seasons. Existing research of analyzing trip organizing, especially under the influence from weather factors, is almost based on one-day trip data. It would be anticipatory to derive the results during several months. Consequently, in this paper, we try to do this job with person trip data during eight months, covering summer and winter, two distinct seasons. We use three dependent variables to demonstrate the process of how people organize trips: the number of trips in a trip chain, the number of trip chains in a day, and the total number of trips in a day, and jointly analyze the relationship between these dependent variables and independent variables from the several dimensions including weather dimension.

An important term in this paper is trip chain. Primerano et al.[13] summarized the definition of trip chaining, and two most commonly accepted definitions of trip chains are a sequence of trips with anchored points of 1) both homes, and 2) home and work/school. In this paper, we used the first definition to integrate the sequence of trips.

The reminder of this paper is organized as follows. The second section provides a brief review of the existing research on variability of trip/trip chains according to various factors. It is followed by the description of data set used in this paper. The fourth section discusses the ordered probit model and explanatory variables in this research. Then the results of estimation is discussed in the next section. Finally the conclusions and future research are drawn.

2. LITERATURE REVIEW

As mentioned in the previous section, existing research already explored the relationship of the trip organizing (including number of trips, the mode, number of trips chained together etc.) with the gender variables, age variables, occupation variables, land use variables and weather variables as shown in Table 1. In terms of the relationship with the weather variables, rainfall and snow are two of the most significant variables influencing the complexity of trip chaining. In addition, exisiting research results were almost based on data collected in a shorter period which could not cover the behavior variability among seasons.

Table 1 Summary of the existing research on trip (chain) variations

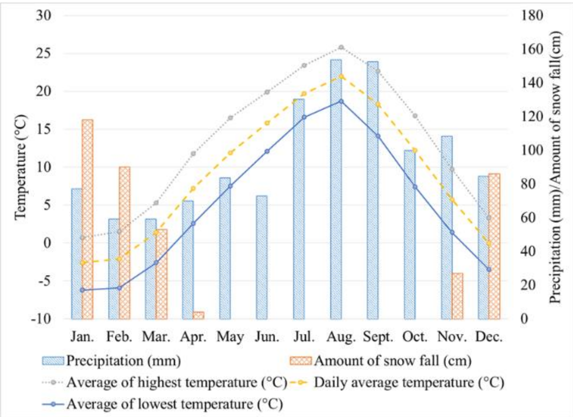
Year	Authors and reference number	Topic	Main findings	Data set	Period for data collection
1998	McGuckin & Murakami[1]	Examine trip-chaining behavior of adult men and women on weekday	Women tend to make more trips and chain more trips to the trip to and from work.	1995 Nationwide Personal Transportation Survey (conducted by telephone, using a computer-assisted telephone interviewing system)	24-hour period
2007	Ye et al.[14]	Relationship between mode choice and the complexity of trip chaining patterns	Causal structure in which trip chain complexity precedes mode choice performs best for both work and non-work tour samples.	2000 Swiss Microcensus travel survey (trip diary)	one-day
2007	Noland &Thomas[4]	Relationship between patterns of trip chaining and urban form (density)	Lower density lead both to a greater reliance upon trip chaining and to tours that involve more stops.	US Department of Transportation's 2001 National Household Travel Survey.	24-hour period
2007	Golob et al.[15]	Relationship between trip chaining travel activity and age	After age 64, travel demand shifts from car to car passenger and then to public transport in complex trip chains	a pooled (2002–2004) cross-section of the Sydney travel survey	24-hour period
2010	Schmöcker et al.[5]	The trip chaining complexity of individuals in London	Older people on average make more complex tours	London Area Travel Survey	one-day
2011	Currie & Delbosc[16]	Trip chaining behavior of Melbourne residents	Complexity of chains was Found to be larger for rail and tram than for car-based trips	Victorian Activity Travel Survey from 1994 to 1999	one-day
2011	Andrews et al.[17]	Examine perceptions, motivations and decisions relating to use of free bus passes	Elderly people tend not to do complex trip chaining and but to have more flexible time-space constraints.	On-board bus survey of 487 concessionary bus pass holders (by questionnaire)	period of one bus trip
2014	Liu et al[8]	Explores the interactions between time allocation, travel demand and mode choice under different weather conditions	Trade-offs between routine and leisure activities under abnormal weather conditions.	Four Swedish National Travel Survey (NTS) datasets, covering respectively from 1998 to 2001, 2003 to 2004, 2005 to 2006 and 2011.	one-day
2014	Chen and Mahmassani[18]	Impact of rainfall precipitation on activity decisions.	Travel behavior may differ under rainfall	2000 Bay Area Travel (BATS) survey, through land-line telephone	two-day period (one weekday and one weekend)

2015	Liu et al[19]	influence of weather on mode choice decision in different seasons and regions	The impacts of weather differ in different seasons and different regions	Swedish National Transport Survey(NTS) Data including four data bases, each covering certain period of time: 1994–2001, 2003–2004, 2005–2006 and 2011	one-day
2015	Liu et al[9]	Explore the influence of weather on individuals' trip chaining complexity.	The 'ground covered with snow' condition is the most influential factor on the complexity	Swedish National Transport Survey(NTS) Data including four data bases, each covering certain period of time: 1994–2001, 2003–2004, 2005–2006 and 2011	one-day

3. DATA SET DESCRIPTION

The data was collected in Hakodate City of Japan, a city with distinct seasons whose monthly average weather information can be found in Fig. 1. Longitudinal GPS data was collected from 20 surveyed participants in winter (December 2012 to April 2013) and in summer (June 2013 to October 2013). Each participant was assigned a smartphone fitted with a GPS module. An android application on the phone was used to collect coordinates along with travel plans such as destinations, purposes of trips, and modes of travel[20]. Travel plans were entered before the participants started their first trip of the day. The numbers of female and male participants were equal in the survey and only one had no driving license. Other basic demographic information of the participants are shown in Fig. 2.

Not all the participants collected records of data in each month. Since one of the objectives in this research is to investigate the influence of weather variance on daily travel behavior, participants whose behavior was observed in a limited period cannot provide meaningful information. As a result, participants whose data were collected in less than 7 months are not included in the further analysis. Finally, we got 16 participants with 3009 trip chains corresponding to 2283 person-days.



Data source: Japan meteorological Agency

Fig. 1 Average weather conditions in Hakodate (30 years from 1981 to 2010)

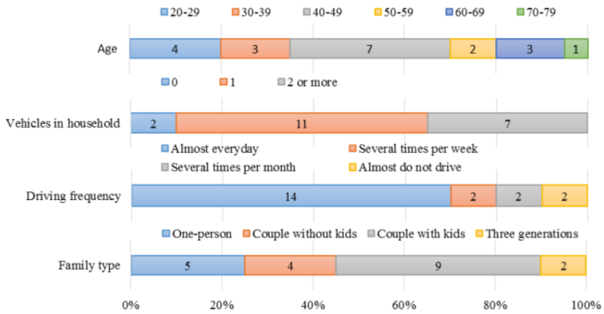


Fig. 2 Basic demographic information of the participants

4. MODEL SPECIFICATION

A generalized structure equation modeling (SEM) is used in this paper. Each of the three dependent variables are assumed to be able to be predicted by the explanatory variables from demographic, time, weather, and trip chain dimensions. The interactions among the three dependent variables are also checked and finally the structure of model in Fig. 3 is used for estimation.

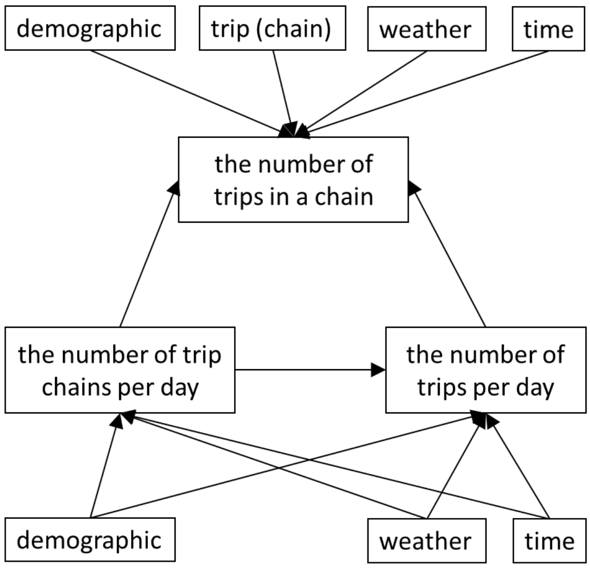


Fig. 3 Structure of SEM in this study

Since the number of trips per trip chain is the variable whose basic unit if trip chain and the other two dependent variables are those whose basic unit is person day, the value of the other two dependent variables on the same day as the trip chain happened are used in the calculation.

These dependent varialbes are count variables. However, we did not use negative binomial model but ordered probit model, because there are some outliers of these dependent variables and the latter can process them in an appropriate way.

Ordered probit models are used in this research to analyze how the variables from demographic dimension, time dimension, trip (chain) dimension, and weather dimension have impact on people's decision of organizing trips in trip chains. As mentioned in the introduction section, the number of trips in one day, the number of trip chains in one day, and the number of trips in a trip chain are chosen to be analyzed as the dependent variables respectively.

The ordered probit model is a regression model for ordinal dependent variables. Ordered probit model for a single latent variable y* can be expressed as:

$$y^* = \boldsymbol{X\beta} + \varepsilon \qquad (1)$$

where y* is the unobserved propensity to increase the number of trips in a trip chain, or the number of trip chains in a day, or the number of trips in a day in our paper. $\boldsymbol{X}$ is the vector of independent variables, and $\boldsymbol{\beta}$ is the vector of coefficients representing the effect of the covariates. ε is the random error term that is assumed to be uncorrelated with $\boldsymbol{X}$. $y*$ cannot be observed, instead the categories of response can only be observed as follows.

$$\mathrm{y} = \begin{cases} 1, if\ y^* \le \mu_1, \\ 2, if\ \mu_1 \le y^* \le \mu_2, \\ \vdots \\ j, if\ u_{j-1} \le y^* \le \mu_j, \\ \vdots \\ m, if\ y^* \ge \mu_{m-1}. \end{cases} \qquad (2)$$

where $\mu_1, \mu_2, \ldots \mu_{m-1}$ are unknown cut points need to be estimated.

$\boldsymbol{\beta}$ is the partial change in y^* with respect to $\boldsymbol{X}$. To be specific, when $\boldsymbol{X}$ changes in a unit and all other variables keep constant, y^* is expected to change by $\boldsymbol{\beta}$ unit.

The probability that observation i chooses alternative j is:

$$p_{ij} = p(y = j) = \mathrm{p}(u_{j-1} \le y^* \le \mu_j) = F(\hat{\mu}_j - \boldsymbol{X_i}\widehat{\boldsymbol{\beta}}) - F(\hat{\mu}_{j-1} - \boldsymbol{X_i}\widehat{\boldsymbol{\beta}}) \qquad (3)$$

where F is the standard normal cdf.

Maximum likelihood is used to estimate $\boldsymbol{\beta}$ and $\mu_1, \mu_2, \ldots \mu_{m-1}$.

Explanatory variables considered in this paper are from three dimensions: time dimension, trip or trip chain dimension, and weather dimension. Some variables from weather dimension are correlated from qualitative analysis. So excluding the variables with high correlation is necessary before estimating the ordered probit models. In order to test the correlation among variables, Pearson's correlation coefficient is used in this paper, and we use 0.75 as the threshold to decide the correlation is high or not. For the pairs of high correlated variables, only one variable in each pair is used in the model estimation. Explanatory variables after the exclusion of weather variables with high correlation are shown in Table 2.

Then the explanatory variables are tested for significance in a step-wise procedure for each of the three dependent variables in a separate way and the variables with a significance more than 95% will be used in the joint estimation.

Table 2 Specifications for explanatory variables

Explanatory variables	Description
Time Dimension	
Day of travel	What day is it when travel happens: Weekday (reference); weekend
Season	What season is it when travel happens: Summer (reference); winter
Demogrhapic Dimension	
Gender	Female and male
Age	20s, 30s, 40s, 50s, and 60s
Family members	The number of family members living together
Vehicles	The number of vehicles in the family
Family type	The structure of family type
Driving frequency	Almost do not drive, almost drive everyday, and several times a month
Trip (chain) dimension	
Period when trip chain starts/ends	Morning peak (reference); during morning peak and noon; noon; during noon and evening peak; evening peak; after evening peak

Whether commute trip is in the trip chain	Yes; no(reference)
Main mode in the trip chain	walk / bicycle; public transport; private car
Average speed (C)	Average speed of trip chain or all trips during one day; it is equal to total distance in a trip chain or one day divided by the corresponding trip time cost
Weather dimension	
Atmospheric pressure in city (C)	Daily average atmospheric pressure in Hakodate city
Precipitation (C)	Total daily precipitation during one day
Temperature (C)	Average temperature on the survey day
Humidity (C)	Average humidity on the survey day
Wind speed (C)	Average wind speed on the survey day
Sunshine duration (C)	The time of sunshine lasting on the survey day
Snow fall (C)	Total snow fall on the survey day
Snow accumulation (C)	Maximum snow accumulation on the survey day
Weather condition during day time	No rain/snow (reference), rain, snow
Weather condition during night	No rain/snow (reference), rain, snow

Note: variables with a C in parentheses are continuous variables; others are categorical variables.

5. ESTIMATION RESULT

The joint estimation results of number of trips in a trip chain, number of trip chains in a day, and number of trips in a day are shown in Table 3. These three dependent variables are interacted; more trip chains per day leads to less trips per trip chain; more trips per day leads to more trips per trip chain; and more trip chains per day leads to more trips per day.

Regarding trips per chain, trip chain with more trips is likely to start in the morning and at the noon except the morning peak. Higher speed of the trip chain leads to more trips in trip chain; main mode of the chain with a non-motorized vehicles leads to less trips in a chain. Demogrhic and weather features did not show significant impact on the number of trips per trip chain.

With regard to the number of trips a day, days with more trips are likely to start in the morning. Older participants are likely to have less trips on a day; while those living tother with more family members are likely to have more trips a day, maybe due to the household activities outdoors. Persons who have a higher driving frequency are likely to have more trips by vehchile due to its faster speed. Adults without kids are likely to have more trips, possibly due to more time for outdoor activies. Rain has negative effect on the number of trips a day due to its inconvenience on the travel.

About the number of trip chains a day, It is interesting to find that male with a higher age have more trip chains on a snowy day in winter. The possible explanation is that the male in the family had some pickup or drop-off trips in some cicumstances of severe weather. Person from larger size of family is likely to have less trip chains, possibly due to the balanced work burden among the family members. Higher temperature is likely to make people have more trip chains a day; snowy weather condition, on the contrary, decreases the possilibity of having more trip chains a day.

Table 3 Estimation results

explanatory varialbes	Coef.	Std. Err.	
trips in a chain			
chains per day			
1 chain	ref.	ref.	
2 chain	**-3.617**	**0.107**	**
3 or more chains	**-5.286**	**0.151**	**
trips per day			
2 trips	ref.	ref.	
3 trips	**3.731**	**0.326**	**
4 trips	**4.895**	**0.330**	**
5 trips	**6.328**	**0.334**	**
6 trips	**7.618**	**0.344**	**
7 trips	**8.181**	**0.351**	**
8 trips	**8.813**	**0.357**	**
9 or more ..	**9.573**	**0.359**	**
trip chain starts period			
MP	ref.	ref.	
NP-b-MP	0.370	0.359	
NP-b-MP-NOON	**0.516**	**0.094**	**
NOON	**0.431**	**0.098**	**
NP-b-NOON-EP	0.021	0.103	
EP	**-0.570**	**0.114**	**
NP-a-EP	**-1.092**	**0.137**	**
trip chain ends period			
MP	ref.	ref.	
NP-b-MP	**2.439**	**0.334**	**
NP-b-MP-NOON	**0.778**	**0.310**	*
NOON	**1.329**	**0.290**	**
NP-b-NOON-EP	**1.756**	**0.287**	**
EP	**2.106**	**0.292**	**

NP-a-EP	**2.239**	**0.296**	**
commute in trip chain			
no	ref.	ref.	
yes	-0.023	0.079	
main mode			
auto	ref.	ref.	
public transit	-0.189	0.127	
walk and bicycle	**-0.291**	**0.125**	*
speed	**0.010**	**0.003**	**
vehicles	-0.039	0.112	
fa_mem	0.064	0.068	
age			
20s	ref.	ref.	
30s	-0.123	0.186	
40s	0.112	0.156	
50s	-0.130	0.101	
60s	-0.279	0.306	
driving frequency			
almost donot drive	ref.	ref.	
almost everyday	-0.130	0.264	
several times per month	0.185	0.248	
family type			
couple with kids	ref.		
couple without kids	0.121	0.501	
one-person	0.102	0.236	
three generation	-0.189	0.520	
weather (day)			
other	ref.	ref.	
rain	-0.039	0.065	
snow	0.052	0.063	
atmospheric pressure	-0.002	0.004	
precipitation	0.001	0.003	
trips per day			
chains per day			
1 chain	ref.	ref.	
2 chain	**1.461**	**0.048**	**
3 or more chains	**2.485**	**0.083**	**
gender			
female	ref.	ref.	
male	0.073	0.053	
vehicles	**-0.332**	**0.088**	**
family members	**0.156**	**0.055**	**
age			
20s	ref.	ref.	
30s	**-0.941**	**0.135**	**
40s	-0.067	0.123	
50s	**-0.165**	**0.073**	*
60s	-0.029	0.240	
driving frequency			
almost donot drive	ref.	ref.	
almost everyday	**1.336**	**0.188**	**
several times a month	**0.800**	**0.174**	**
family type			
couple with kids	ref.	ref.	
couple without kids	**1.012**	**0.398**	*
one-person	0.235	0.194	
three generation	0.314	0.404	
season			
summer	ref.	ref.	
winter	-0.036	0.114	
weather(day)			
other	ref.	ref.	
rain	**-0.141**	**0.049**	**
snow	-0.058	0.080	
precipitation	0.003	0.002	
temperature	-0.002	0.006	
snow accumulation	0.001	0.002	
chains per day			
gender			
female	ref.	ref.	
male	**0.420**	**0.060**	**
vehicles	0.149	0.098	
family members	**0.418**	**0.062**	**
age			
20s	ref.	ref.	
30s	**-0.352**	**0.153**	*
40s	**0.775**	**0.142**	**
50s	**0.397**	**0.083**	**
60s	**0.737**	**0.274**	**
driving frequency			
almost donot drive	ref.	ref.	
almost everyday	**1.370**	**0.236**	**
several times a month	**1.044**	**0.232**	**
family type			
couple with kids	ref.	ref.	
couple without kids	-0.363	0.453	
one-person	0.395	0.220	
three generation	**-2.519**	**0.457**	**
season			
summer	ref.	ref.	
winter	**0.445**	**0.140**	**
weather(day)			
other	ref.	ref.	
rain	-0.031	0.055	
snow	**0.176**	**0.088**	*
atmospheric pressure	0.005	0.004	
temperature	**0.032**	**0.007**	**
Trips per chain			
μ1	2.783	4.061	
μ2	4.335	4.061	

μ3	5.574	4.062
μ4	6.643	4.062
Trips a day		
μ1	0.265	0.252
μ2	0.896	0.252
μ3	1.527	0.253
μ4	2.059	0.254
μ5	2.505	0.255
μ6	2.940	0.255
μ7	3.349	0.256
Chains a day		
μ1	8.520	4.091
μ2	9.838	4.091
Model fit		
Number of observations	3009	
log-likelihood at zero	-13506	
log-likelihood at final	-9799	

6. CONCLUSIONS

In order to explore how people organize trips in a day, SEM with ordered probit models are used in this paper to estimate the number of trips in a trip chain, the number of trip chains in a day and the total number of trips in a day. Explanatory variables from demographic dimension, time dimension, trip (chain) dimension, and weather dimension are used in the estimation. The result shows that the significant variables from several dimensions. Data collection lasting for seasons shows that the rain, snow and temperature from the weather dimension are significant explanatory variables influencing people's organizing trip and trip chains on one day.

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