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Microscopic Destination Choice: Incorporating Travel Time Budgets as Constraints

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Abstract

Despite empirical evidence, the common approaches for destination choice modeling do not usually account for an overall travel time budget. In fact, if congestion worsens workers will choose different workplaces instantaneously, a highly unrealistic representation of observed work trip destination choice. The objective of this paper is to incorporate travel time budgets as constraints for non-commute trips in the destination choice model, while the commute time will be given directly by home and workplace locations as defined in a synthetic population. Individual travel time budgets for every trip purpose were calculated using the household as analysis unit. The results indicate that travel time depends on the number of required trips by trip purpose and household sociodemographics. Increasing the number of trips for one purpose reduces the travel time allocated for the other trips, confirming the existence of an overall travel time budget. Household size is the most important sociodemographic variable, followed by the household income. Destination choice modeling with travel time budgets as constraint will add fidelity to trip-based travel demand models.

Keywords: microsimulation; destination choice; travel time budget; weibull survival model; trip-based model

1. Introduction

Modeling trip distribution is critical to traffic demand forecast and transportation planning. After trip generation, trip distribution is the second component in the traditional four-step transportation model. A number of methods have been put forward over the years to distribute trips among destinations: growth-factor methods, the gravity model and the destination choice model (Ortúzar and Willumsen, 2011). The growth factor model expands an existing origin-

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destination matrix and increases trip interchanges between origins and destinations in proportion to their relative growth. The gravity model has been borrowed from physics and postulates that the number of trips between an origin and a destination is proportional to the size (commonly expressed by population and employment) and inverse proportional to their distance. For the destination choice model, utilities are calculated from every origin to every possible destination, taking into account travel time, distances and costs as well as other factors such as psychological barriers of borders or rivers. Therefore, the latter is a more rigorous approach that allows adding many variables to destination choice, such as travel time, distance, costs, crossing of borders, crossing of rivers, ferry rides, and many more.

Both the gravity model and the destination choice model, the two most common approached for trip distribution, are calibrated to an observed trip length frequency distribution that is replicated more or less even if the level congestion, and therefore, travel times change. If congestion worsens, such models will attempt to select closer destinations and keep the average travel time constant. While this may be reasonable for trips where many alternative destinations exist, such as home-based shopping or home-based other trips, this behavior is unreasonable for work or school trips. If congestion worsens, workers will not be able to pick closer workplaces instantaneously, nor will students change their schools suddenly. The place of work and the school are long-term choice. Using a microscopic synthetic population allows keeping the workplace fixed until employee or employer decide to terminate the contract, regardless of whether congestion increases or not. Likewise, school places are kept constant until it is time to graduate.

Moreover, destination choice models commonly do not account for an overall travel budget. According to cross-sectional and longitudinal studies, travel time budgets tend to remain constant over time (Raux et al., 2011; Schafer, 2000; Zahavi, 1974). This property is dismissed by almost all contemporary travel demand models, including most activity-based models.

The objective of this paper is to incorporate travel time budgets as a constraint for non-commute trips in the destination choice model, while the commute time will be given directly by home and workplace locations as defined in a synthetic population. This approach is incorporated into the disaggregate model system SILO (www.silo.zone), where it replaces an aggregate trip destination step with a microscopic trip destination module. In a previous step, the aggregate trip generation step was replaced by a microscopic trip generation model (Moeckel et al. 2015). This destination choice modeling would add fidelity to trip-based travel demand models.

The organization of the paper is as follows. Section 2 reviews research related to travel time budget, after which Section 3 presents the data and method. Results and analyses are discussed in Section 4, while Section 5 presents the discussion of the results. Finally, conclusions and review the main findings are in Section 6.

2. Literature review

Travel time budget (TTB) is a rather old concept which postulates that, within the recurring and competing activities of people during a day, only a certain and quite stable period of time will be allocated to travel (Zahavi, 1974).

All over the world and in different years people in most countries travel between 60 and 75 min per day (Mokhtarian and Chen, 2004; van Wee, 2011). Cross-sectional studies obtained quite stable results: 21 cities in the U.S. (Zahavi, 1974), all over the UK (Downes and Morrell, 1981; Landrock, 1981; Prendergast and Williams, 1981), 4 cities of developing countries (Roth and Zahavi, 1981), 19 cities from 11 developed countries, 5 developing countries and 3 African villages (Schafer, 2000), two countries (Kitamura et al., 1997), the U.S., UK, Canada, Japan and the Netherlands (Timmermans et al., 2002) or 3 European countries (Joly, 2007; Raux et al., 2011). The results also were consistent over time in the San Francisco Bay Area between 1960 and 1990 (Purvis, 1994) and across the U.S. between 1954 and 1990 (Levinson and Kumar, 1995). The results may indicate that there is an unobserved desired travel time budget (Hupkes, 1982; Mokhtarian and Solomon, 2001) and that the variations that can be found in individual TTB are balanced out at the aggregated level (Mokhtarian and Chen, 2004).

On the other hand, some studies reported an increase on TTB over time. Levinson and Kumar found that daily travel time expenditure significantly increased from 1968 to 1988 in the metropolitan Washington area based on local data (Kumar and Levinson, 1995), although another study from the same authors found that TTB did not changed at the national level between 1954 and 1990 (Levinson and Kumar, 1995) using the Nationwide Personal Transportation Survey Series (NPTS). Contrary, Toole-Holt et al. (2005) used the same NPTS series to conclude an increase from 47.4 min/day in 1983 to 82.3 min/day in 2001 for the U.S., which is not consistent with the findings of Levinson and Kumar (1995). Given that such a substantial increase in TTB was not found anywhere else, it seems that this growth is inherent to their particular methodology but not supported otherwise. Based on the data sets from the National Travel Survey, the Dutch TTB between 1979 and 1998 increased a 7 % (van Wee et al., 2006). A higher rate (+26 % of increase) was obtained using the Dutch data from the Time Use Survey on the period [1975, 2000] (van Wee et al., 2006; Van Wee et al., 2002). Even though the reported increases on TTB, the same author concluded later that the theory on TTB seems quite robust and is useful in understanding the impact of land-use determinants on travel behavior (van Wee, 2011). The contradictory results on TTB increase could be produced by changes in the survey design, underreported travel time in the previous studies or an improvement on collection techniques from one survey to another.

Even though the majority of the studies conclude that the time allocated for travel varies within a narrow range, the transferability of the results should be taken with caution. On their overview of TTB theory, Mokhtarian and Chen (2004) identified the many differences on the approach (aggregated or disaggregated), modes included (private car, transit, walking, bicycle, etc.), level of analysis (traveler, person or household) or statistical approach (Poisson regression, system of equations or survival analysis) of the previous research. We will summarize the most common approaches and their advantages.

Usually, disaggregated studies consider as unit of analysis the person (Joly, 2007; Kitamura et al., 1997; Lu and Pas, 1999; Raux et al., 2011; Timmermans et al., 2002). However, other studies used households based on the principle that the individual time-use is a result of household level decisions and household functions as a unit (Golob et al., 1981; Kockelman, 2001; Principio and Pas, 1997). With declining household sizes observed in many parts of the world, it is important to distinguish between person and household travel budgets when comparing studies.

Not all studies are based on the same set of modes. Particularly the non-motorized modes were excluded in the firsts studies. The exclusion of any mode would bias the estimation of daily travel time expenditures and it can be severe for metropolitan areas where the automobile is not as dominant and the higher densities prevail (Mokhtarian and Chen, 2004). On the other hand, the classification of activities differed depending on the survey data. The most common analyses classify trip purpose in work, shop and leisure (Joly, 2007; Raux et al., 2011; Timmermans et al., 2002). Even though there have been studies that propagate constant TTB and other studies that concluded the opposite, the majority of studies appears to confirm constant TTB, at least at the aggregate level.

The statistical approaches to model travel time duration have been Poisson regression model; system of equations, survival analysis or utility functions (Mokhtarian and Chen, 2004). Among them, survival analysis is the only approach that can account for duration dependence and is the most used in the latest research (Joly, 2007; Raux et al., 2011; Srinivasan and Guo, 2003; Timmermans et al., 2002). Disregarding duration dependence can lead to a poor model fit, inaccurate forecasts and ineffective demand management strategies (Srinivasan and Guo, 2003). Survival analysis is a collection of statistical procedures for data analysis for which the outcome variable of interest is time until an event occurs (Kleinbaum and Klein, 2012), and is commonly used in clinical studies to model the time in remission of a disease or time until death. In transportation analysis, the survival time can be referred as the travel time and the event is travelling itself.

Finally, the most commonly studied variables in travel time expenditures are: age, gender, car ownership, employment status, household size, income, person group, time spent on other activities, area type or time of the day (Mokhtarian and Chen, 2004). In France, the trip duration did not show proportionality with activity duration at the disaggregated level (Joly, 2007), while the results in eight European cities indicated that sociodemographic and city-specific characteristics played a major role in travel time budgets, while residential density and accessibility had a very limited impact (Raux et al., 2011). Similar conclusions were obtained comparing eight cities across the world (Timmermans et al., 2002). The person group (or life style pattern) was characterized in order to provide a better description on time-use and time allocated to travel. Principio and Pas (1997) concluded that the lack of variation in sociodemographic characteristics to determine the person group indicated that, in some cases, sociodemographics alone might not be adequate descriptors of travel behavior and some information regarding the durations of in-home and out-of-home activities should be considered.

To sum up, in order to evaluate travel time budget, several decisions need to be made, including the level of analysis (person or household), travel modes to include, travel purposes to consider and more importantly, the most appropriated statistical approach to calculate trip duration and its explanatory variables. The most appropriated approach will depend on the available data and the objectives of the study.

3. Data and research methodology

3.1. Data Source

Travel time was calculated using the 2007-2008 TPB/BMC Household Travel Survey (HTS), a survey conducted jointly by the Baltimore (BMC) and Washington (MWCOG) metropolitan planning organizations. For this survey, 14,365 households reported their travel behavior. Each household completed a travel diary that documented the activities of all household members on an assigned day. Demographic information was also collected. The survey data includes 31,330 persons and 108,110 individual trips. This survey was used to calibrate the trip generation module of the SILO model (Moeckel et al., 2015).

3.2. Estimation of travel time budgets

As summarized in Section 2, the approach to estimate travel time budgets has not been homogenous on the literature and it has to be adapted to the research objectives and the available data. In our specific case, the decisions to be made included the level of analysis (person or household), travel modes, travel purposes, statistical approach and explanatory variables.

At this step of the traditional transportation model, the data for allocating the destination of each trip are considered for each household, rather than being individualized for household members. Moreover, even though individual time-use of each person in a household may vary, it is true that the time for each purpose will depend on the household structure and it be will balanced among the individuals. For example, a five-person household will spend less time per person on shopping trips than a 1-person household, assuming that a person shopping groceries would buy goods for the entire household. Therefore, assuming that the interactions among household levels would balance the total travel time budget, the travel time-use was investigated for the household as the unit of analysis.

To avoid biases in the travel mode and possibly underestimate the total travel time, all the travel modes considered in the 2007/2008 TPB/BMC THS were included:

- Transit
- Automobile (driver)
- Automobile (carpooled)
- Walk
- Bicycle
- Other modes

In line with the state-of-practice in trip-based modelling, the six trip purposes of the microscopic trip generation module SILO were distinguished using the 2007/2008 TPB HTS:

- Home-based work (HBW)
- Home-based shop (HBS)
- Home-based other (HBO)
- Home-based education (HBE)
- Non-home-based work (NHBW)
- Non-home-based other (NHBO)

At the household level, the explanatory variables would depend on the sociodemographic characteristics of the household, its location and its travel behavior (Principio and Pas, 1997). The usual sociodemographic and area characteristics were obtained from the 2007/2008 TPB HTS survey. However, the durations of in-home and out-of-home activities to classify travel behavior according to Principio and Pas (1997) are not yet defined on this second step of the traditional four-step transportation model. At this point, the trip-generation module will provide the number of trips dedicated for each trip purpose; which could be used as a proxy of the other activities that the household would perform. Therefore, the number of trips dedicated to the other trip purposes was added to the model as explanatory variables. The list of explanatory variables is summarized in Table 1.

Table 1. Explanatory variables

Type	Variable	Definition	Min	Average	Max
Sociodemographic	Household size	1, 2, 3, 4, 5+	1	2.18	8
	Females	Number	0	1.17	6
	Children (age < 18 years old)	Number	0	0.39	4
	Young persons(age between 18 and 25 years old)	Number	0	0.15	5
	Retired persons	Number	0	0.36	5
	Workers	Number	0	1.13	6
	Students	Number	0	0.43	6
	Cars	Number	0	1.72	10
	Licensed persons	Number	0	1.63	6
	Household income	Number	8,500	90,714	250,000
Location	Area type	Urban, suburban, rural	-	-	-
Travel behavior	Trips per household for HBW	Number	0	1.45	12
	Trips per household for HBS	Number	0	1.18	27
	Trips per household for HBO	Number	0	2.3	30
	Trips per household for HBE	Number	0	0.46	12
	Trips per household for NHBW	Number	0	0.82	11
	Trips per household for NHBO	Number	0	1.31	29

For the statistical approach, survival analysis was selected to account for duration dependence effects (for more specifics on survival analysis, refer to (Kleinbaum and Klein, 2012)). In survival analyses, the dependent variable is the time until an event occurs, which can be interpreted for transportation analyses as the travel time duration. In this context, the survivor function S(t) gives the probability that a trip (T) lasts longer than the specified time t, following Equation 1.

$$S(t) = P\ (T \leq T) = \exp\left[-\int_0^t \mathrm{h(u)du}\right] \qquad (1)$$

Where: S(t) is the survivor function; and h(u) is the hazard function.

The hazard function gives the instantaneous potential per unit time for the event to occur, given that the individual has survived up to time t. In our case, it indicates the instantaneous potential that the travel ends at that specific time t.

The techniques in survival analysis try to provide the relationship between the survivor function and the explanatory variables. The fitting techniques of the hazard function can be parametric or semi-parametric. While the first approach assumes that the hazard function follows a known distribution, the second approach does not rely on assumed distribution. Parametric survival models are more consistent with the theoretical survivor function, simpler and the calculation of the quantiles (i.e. median travel time) is completely defined. Therefore, if the underlying distribution assumption is met, parametric survival models are preferred over semi-parametric models (also called Cox proportional hazards model).

The Weibull model is the most widely used parametric survival model. Assuming a Weibull distribution, the survivor function can be expressed as Eq 2, while the median travel time can be easily calculated using Eq 3.

$$S(t) = \exp(-\lambda t^{p}) \quad (2)$$
$$t_{50} = [-\ln 0.5]^{\frac{1}{p}} \cdot \exp\left(\beta_0 + \sum \beta_i \cdot x_i\right) \quad (3)$$

Where $\lambda = \exp(\beta_0 + \sum \beta_i \cdot x_i)$, 1/p is the scale of the Weibull model, t_{50} is the median travel time, β_0 is the intercept of the Weibull model, β_i are the coefficients of the Weibull model and x_i are the explanatory variables.

The scale and coefficients of the model can be fitted using the typical statistical software. In our case, the free software environment R for statistical computing was used. The total travel time per household and trip purpose was selected as the dependent variable, and the independent (or explanatory variables) were the summarized in Table 1. The best model for each trip purpose was selected based on their AIC (Akaike Information Criterion) on a backwards stepwise approach.

After obtaining the model, the significance of each explanatory variable was checked based on their p-value. Moreover, the key property of the Weibull model was graphically checked for each fit. To do so, the log(-log) of S(t) was plotted against the log of time. The resulting lines should be straight and parallel to verify the main assumption of the model: log(-log) of S(t) is linear with the log of time.

4. Results

4.1. Total travel time

The results of the duration analysis with respect of the household total travel time budget are summarized in Table 2. As indicated on the footnote of the table, positive coefficients indicate that the variable increases the travel time budget and negative coefficients indicate that the variable decreases the travel time budget. The household income has the opposite interpretation, as the variable was transformed to its power -0.5. Only statistically significant parameters are reported.

The correlation between the fitted data and the observed data is quite good, around 63 %. As observed in Figure 1, the cumulative density function of the fitted values is very close to the cumulative density function of the observed values for the percentiles higher than 50. For lower percentiles, the model overestimates the observed total travel time. The Weibull survival model estimates a minimum total travel time of 45 minutes, which is higher than the total travel times of the less active households. In fact, some of the households reported no trips during the day and the model is not able to reproduce this behavior adequately.

Table 2. Weibull survival model for total travel time

Type	Variable	Total travel time budget
Sociodemographics	Intercept	*+4.562***
	Household size 2	*+0.404***
	Household size 3	*+0.591***
	Household size 4	*+0.623***
	Household size 5+	*+0.721***
	Females	
	Children (< 18 y.o.)	
	Young adults (18-25 y.o.)	*+0.071***
	Retired persons	*-0.032***
	Workers	*+0.057***
	Students	*+0.026**
	Cars	
	Licensed persons	*-0.035***
	Household income [hh_income^(-0.5)]	
Area	Suburban area	
	Rural area	*+0.038***
Travel behavior (household)	Trips for HBW	*+0.029***
	Trips for HBS	*+0.023***
	Trips for HBO	*+0.047***
	Trips for HBE	*+0.012**
	Trips for NHBW	*+0.052***
	Trips for NHBO	*+0.051***
Model fit statistics	Correlation (%)	*63.04*
	Weibull model scale	*0.566*
	Log likelihood (model)	*-79119*
	Chi-sq	*7242.91*
	Degrees of freedom	*16*

Note: 1) levels of significance: * 0.05, ** 0.01; 2) correlation between the fitted data and the observed data: 3) + stands for an increase on the travel time with the increase of the variable and – stands for a decrease on the travel time with the increase of the variable. The interpretation for household income is the opposite.

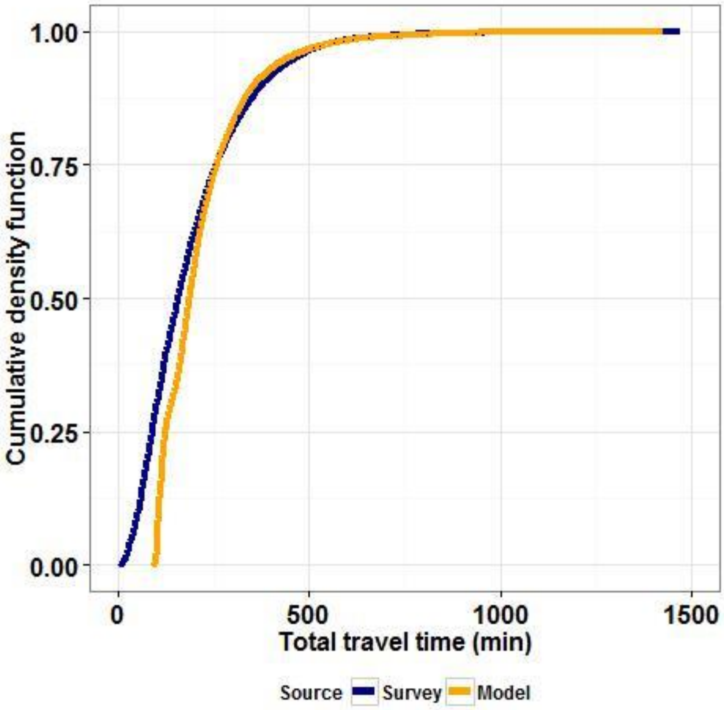

Figure 1. Cumulative density function for total travel time for the observed data (survey) and fitted data (model)

Among the sociodemographic variables, household size is one of the most significant variables. The coefficients of the variable are statistically significant for all the levels and positive: travel time increases as the household size increases, which was to be expected. Nevertheless, the increase is not linear with the household size, having the highest variation from 1 to 2 person household and from 2 to 3 person household. Then, the effect on the total travel time of adding a new individual to the household is lower and tends to stabilize. For example, the model will estimate a total travel time of 61 minutes for a household size of 1 worker in urban area that makes one trip for each travel purpose; while the model will estimate a total travel time of 91 minutes for a household of 2 persons, and 111 minutes for a household of 3 persons and 126 minutes for a 5 or more persons.

Figure 2 shows the effect of household size on the differences between the total travel time and the predicted total travel time. For households of one person, the model estimates less variability on total travel time than the observations. As the household size increases, the model captures better the observed total travel time and its variations. This result could indicate that the model requires better description of travel behavior of the small households, such as the inclusion of the life style pattern. It is also conceivable that smaller households are more heterogeneous, including very young and very old one person households. For bigger households, the sociodemographic and travel behavior based on the number of trips might be enough to capture the total travel time even though its variability is also significant. The majority of large households are families, making their travel time budgets somewhat more predictable than for single-person households.

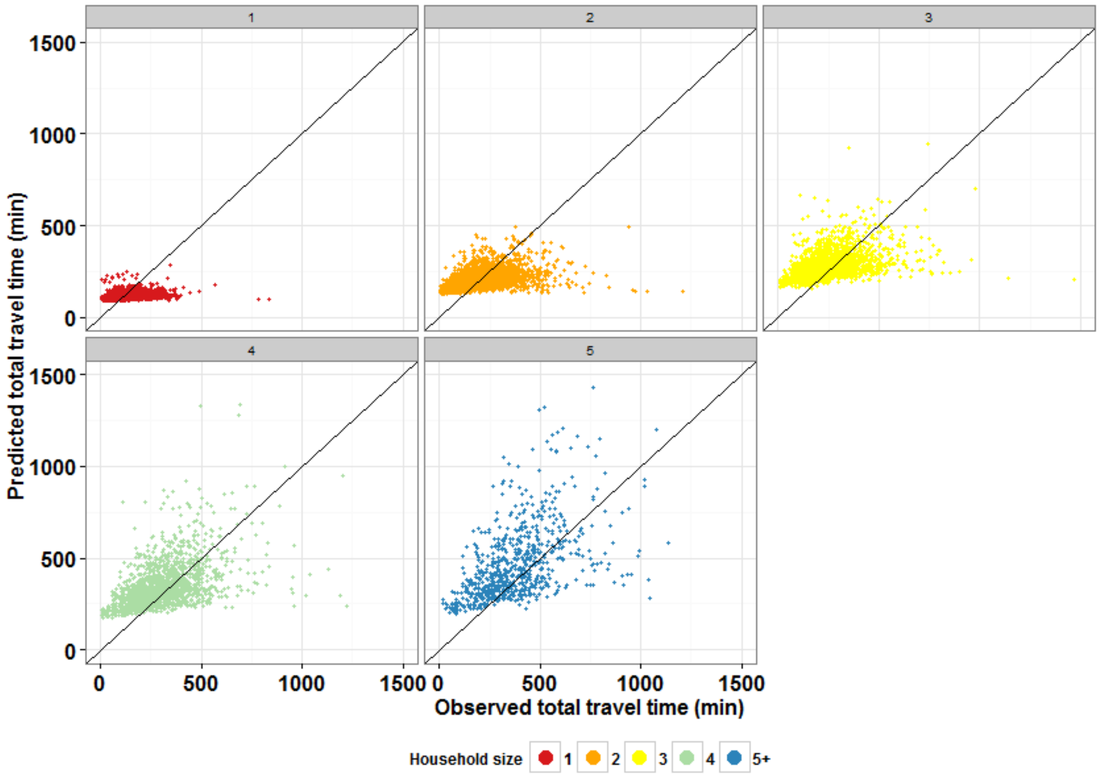

Figure 2. Influence of household size on the differences between the total travel time and the predicted total travel time

Age and employment status of the individuals is also significant. Households with young persons (between 18 and 25 years old) have higher travel time than households with adults or children; while being retired reduces the travel time. For example, the model estimates the total travel time for a retired couple is equal to 81 minutes, while for a young couple of students or a couple of workers, is 105 and 97 minutes, respectively.

The number of workers and students in the household also increased the total travel time, while a higher presence of licensed persons decreased the travel time, as they would probably be able to drive instead of taking transit, and thus reducing the travel time. Somewhat unexpectedly, the level of income was not significant in the model. Apparently, TTB are similar even across different income levels.

Regarding the location of the household, there are not statistical significant differences between urban and suburban areas. For rural areas, the total travel time is higher than for the other areas. For a couple of workers with the same travel behavior, moving from an urban area to a rural area will suppose an increase on the total travel time equal to 4 minutes.

As expected, increasing the number of trips per household per each purpose results in a higher TTB. The impact of each trip purpose is different, which indicates that the amount of travel time per trip purpose would differ (i.e. the coefficients are +0.029 for HBW and 0.012 for HBE, therefore the travel time for home-based work per trip is higher than the travel time for home-based education per trip). Moreover, their statistical significance indicates that total travel time was not completely characterized by the sociodemographic variables and some specifics of the travel behavior should be incorporated into the model.

4.2. Travel time by purpose

The same analysis is performed for the different trip purposes. The Weibull survival models for travel time by purpose are summarized in Table 3. Similar to Table 2, only statistically significant parameters are reported, and the positive coefficients indicate an increase on the travel time with the increase of the variable. The household income has the opposite interpretation, as the variable was transformed to its power -0.5.

Table 3. Weibull survival models for travel time by purpose

Type	Variable	HBS	HBO	HBE	NHBW	NHBO	HBW
Sociodemographics	Intercept	*+2.915***	*+3.645***	*+3.453***	*+3.248***	*+2.953***	*+3.814***
	Household size 2	*+0.191***	*+0.401***	*+0.184**		*+0.199***	*+0.203***
	Household size 3	*+0.325***	*+0.681***	*+0.217**	*+0.077***	*+0.177***	*+0.285***
	Household size 4	*+0.439***	*+0.782***	*+0.373***		*+0.105***	*+0.301***
	Household size 5+	*+0.542***	*+0.993***	*+0.439***			*+0.424***
	Females	*+0.049***	*-0.035**				
	Children (< 18 y.o.)	*-0.086***	*-0.049**	*-0.117***		*+0.177***	
	Young adults (18-25 y.o.)		*+0.054**	*+0.062**	*+0.115***	*+0.181***	
	Retired persons				*+0.096***		*-0.077***
	Workers				*+0.221***	*+0.068***	*+0.032**
	Students				*+0.082***		
	Cars				*+0.035***	*+0.049***	*-0.022***
	Licensed persons	*-0.065***		*-0.078***	*-0.068***		*-0.065***
	Household income [hh_income^(-0.5)]	*+37.84***	*+21.00***	*+29.72***		*+43.91***	*-28.56***
Area	Suburban area	*-0.062***			*+0.091***	*-0.078***	*+0.080***
	Rural area				*+0.147***	*-0.095***	*+0.188***
Travel behavior (household)	Trips for HBW	*-0.051***	*-0.123***	*-0.034***	*-0.126***	*-0.088***	*+0.318***
	Trips for HBS	*+0.285***	*-0.054***	*-0.022***	*-0.024***	*-0.037***	*-0.020***
	Trips for HBO	*-0.019***	*+0.151***	*-0.028***	*-0.017***	*-0.019***	*-0.016***
	Trips for HBE	*-0.037***	*-0.075***	*+0.287*	*-0.023**	*-0.062***	
	Trips for NHBW		*-0.045***		*+0.249***	*-0.038***	*-0.051***
	Trips for NHBO		*-0.025***		*-0.017***	*+0.229***	*-0.011***
Model fit statistics	Correlation (%)	*16.13*	*33.21*	*54.78*	*50.45*	*25.03*	*47.31*
	Weibull model scale	*0.756*	*0.808*	*0.620*	*0.721*	*0.829*	*0.574*
	Log likelihood (model)	*-31806*	*-47142*	*-11740*	*-26207*	*-30558*	*-46197*
	Chi-sq	*3337.96*	*3653*	*1021.52*	*1582.58*	*2861.91*	*4139.36*
	Degrees of freedom	*13*	*14*	*12*	*15*	*16*	*16*

Note: 1) levels of significance: * 0.05, ** 0.01; 2) correlation between the fitted values with the model and the travel times of the survey: 3) + stands for an increase on the travel time with the increase of the variable and – stands for a decrease on the travel time with the increase of the variable. The interpretation for household income is the opposite.

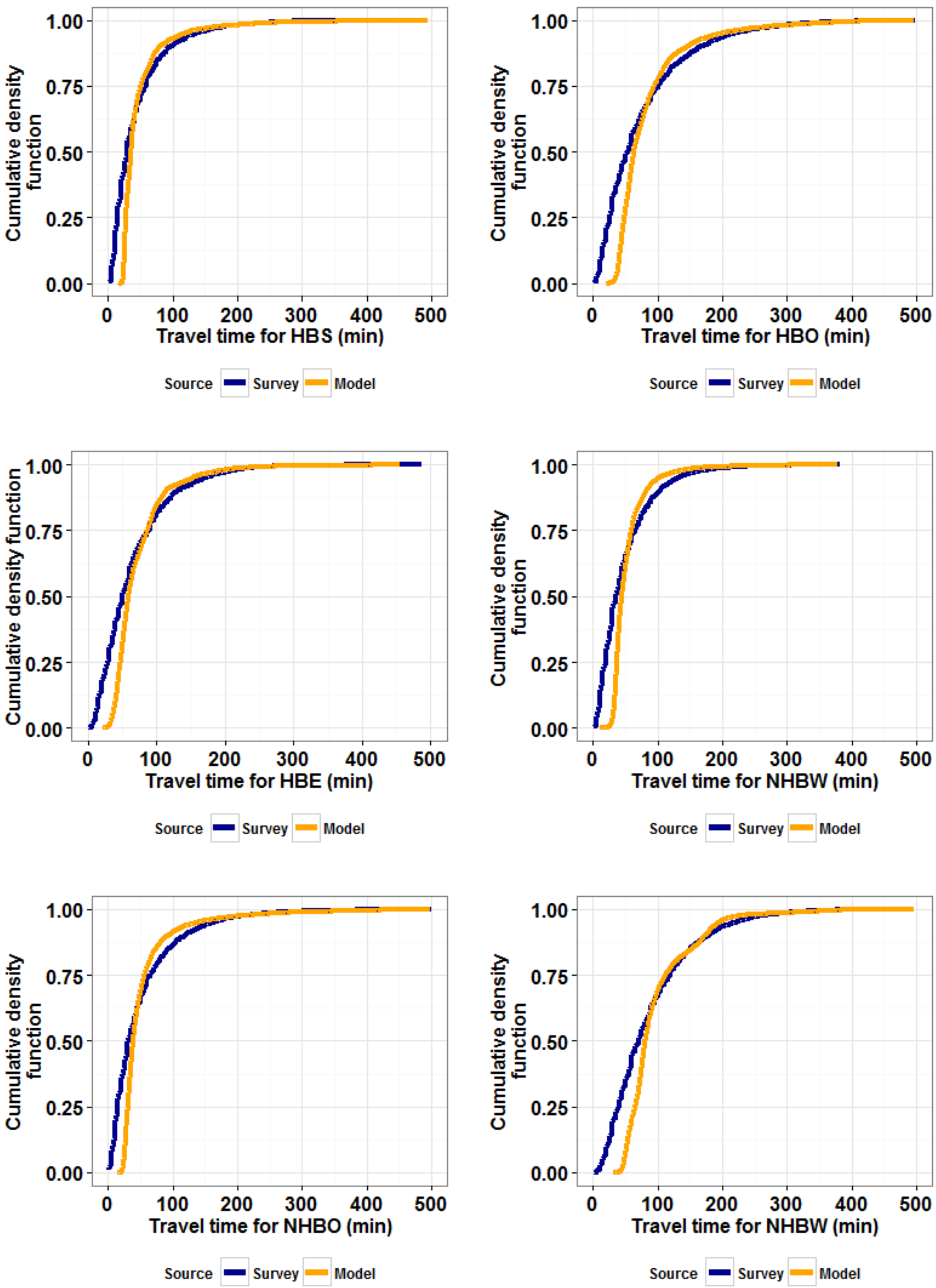

Figure 3. Cumulative density function for total travel time by purpose for the observed data (survey) and fitted data (model)

The correlation between the fitted values and the observed values varies between 16 % and 55 % being the worse correlation for home-based shop trips, and the best correlation for home-based education trips, closely followed by non-home-based work trips and home-based work trips. The better estimation of the educational and work trips could be caused by their mandatory nature, while shop and other trips are not strictly required and their destinations may vary more across households. Moreover, education and work trips are usually associated to bigger household sizes, where the survival model can capture better the variability on travel times.

Cumulative density functions were also plotted by purpose to compare the quantile distributions of observations and estimations (Figure 3). Similar to the total travel time, the model overestimates travel time for the less mobile households, and they behavior could not be adequately captured. The cumulative density functions show that HBW and HBE travel times have a wider variation range (the slope is less steep) than other trip purposes, such as shop or other. Specifically, these trip purposes have good correlations between the model and the observations, which could be in consonance with a better capacity of the survival model to capture longer travel times instead of very short travel times.

Household size was significant in all the trip purposes except for NHBW trips. Nevertheless, for this trip purpose the specific sociodemographic characteristics of the household were statistically significant and could be used as a proxy for the household size (i.e. having the number of retired persons, workers, students and young adults the household size could be estimated). For all the other trip purposes, increasing the household size produced a higher travel time than the reference (1 person). The increase was not linear, as it was not for the total travel time, which could indicate that larger household sizes tend to do fewer trips per person.

For the different trip purposes, the number of trips for other purposes decreases the travel time for the selected purpose. For example, for home-based other (HBO), the only positive coefficient is for the number of trips for HBO and the other five trip purposes have negative coefficients. Therefore, increasing the number of trips for another purpose will detract time from HBO. Similar conclusions can be obtained for the other trip purposes. These results agree with the hypothesis of a total travel time budget that would be allocated for each trip purpose based on the number of required trips.

Regarding the area type, the results are not homogeneous for all trip purposes. Living in suburban areas produced a higher travel time for non-home-based work trips and home-based work trips, but decreased the travel time for home-base shop trips and non-home-based other trips. These results indicate that households in the suburbs would dedicate more time for commute trips and have shorter and/or fewer non-commute trips. The coefficients for rural areas have the same sign and are greater than the coefficients for suburban areas, meaning that the findings for suburbs are even more pronounced in rural areas.

As expected, household size increases travel time for all trip purposes, as well as with the number of workers for the household. Contrary, the presence of children decreases travel time for all trip purposes except for non-home-based other trips. For the same household size, the presence of more children is expected to require more time for in-home activities, reducing the travel time for all other purposes. Though it seems counter-intuitive to find a negative coefficient on number of children for HBE TTB, households with more children will also make more HBE trips. As a consequence, the TTB on HBE for a household with two children is likely to be larger than for a household with one child. In other words, a household with two children is likely to spend more time on HBE trips in total but less time on HBE trips per child, possibly because some sibling may attend the same school.

On the other hand, the distinction between children and young adults was significant, as the coefficients for both groups of age are different, and in some cases have opposite sign. Young adults have similar behavior to adults, as their coefficients were closer to zero. For non-home-based work trips, they increase travel time instead of reducing travel time. The number of retired persons in the household is also significant, and has a quite surprising effect: it has positive effect on the travel time for non-home-based work trips. This could be linked to more trips for the workers to support the retired persons of the household. Not surprisingly, the presence of retired persons decreased the commute travel time.

Travel time decreased as the number of licensed persons in the household increases. This would indicate that for the same number of trips, the possibility of having a car increases the speed of the trip and therefore the travel duration decreases. As for the effect of gender, a higher presence of females in the household increased the travel time for home-based shop but reduces the travel time for home-based other trips. This would indicate that the females spend more time to go shopping than males, but spend less time on trips for other purposes (or generate fewer trips).

Finally, the household income had significant effect on all the travel times. Because of the transformation of the variable to the power of -0.5, the interpretation of the coefficient sign is the opposite to the other variables. In this case, the increase on the household income produced a decrease on the commute travel time, while it increased the travel time for other purposes. The households with lower income level are likely to travel with transit or less fast modes, and therefore, their travel times increased in comparison to households with higher incomes. Also, households with higher income would probably have more workers that would require more time to commute.

5. Discussion

The results of the research are compared to the findings of previous disaggregate studies. Despite the different variables included on the models and activities definition, some trends can be extrapolated.

For total travel time, Joly (2007) reported opposite effects of residential location in Switzerland and France: central locations reduce travel time budget in Swiss cities but increases travel time budget in French cities. Raux et al. (2011) found a positive effect of density in travel time: central locations had a higher travel time, which was surprising for the authors and justified as a higher degree of congestion in city centers. Our results are in consonance with the Swiss sample, having a higher travel time in rural areas than in urban and suburban areas, even though the impact is quite low. For travel time by purpose, Raux et al. (2011) and Timmermans et al. (2002) found no impact of the location of the household and its accessibility to transportation networks for working activities, while in our model had significant results. The bigger area covered in our study and spatial structure can cause the differences.

Regarding, previous studies found that males had a higher travel time budget than females, being significant for the total travel time budget and the travel time for work, shopping and leisure activities (Raux et al., 2011; Timmermans et al., 2002), while the gender was not significant in France and Switzerland (Joly, 2007). Our findings agree with the last study, as the presence of females on the household was only significant for HBS and HBO purposes. For the different age groups, our results agree with all three previous studies on lower travel time budget for retired persons and lower travel time budget for households with children. Moreover, Raux et al. (2011) also distinguished between children and young adults and found also a higher total travel time budget for young adults.

Income level and car ownership were not available to previous disaggregate studies, so our findings could not be compared.

Mokhtarian and Chen (2004) summarized the findings about total travel time from previous aggregate studies. Regarding age, people younger than 16 and older than 60 traveled significantly less than other ager groups, which is consistent with our findings. Moreover, at the aggregate level the young persons (between 17 and 24 years) had also a higher travel time budget than other age groups in the Netherlands and California, which was confirmed in our study. Our findings on employment status also agree with previous studies, as the employed people tend to spend more time traveling than unemployed people. For car ownership, income level and gender, the results of previous research were contradictory. In our case, the three variables were not statistically significant for the total travel time, which agrees with the conclusions from Zahavi and Talvitie (1980). The results on the area type were also contradictory, as the division of area types was different for each study (urban vs. suburban; large metropolitan area vs. smaller cities). For the same classification of area type, Mokhtarian and Chen (2004) identified that rural travel time was greater in Minnesota-St. Paul (Barnes and David, 2001) but smaller in Baltimore (Supernak, 1982). Changes in urban spatial structure, workplace locations and accessibility may have changed the impact of household location in the Baltimore area from 1982 to 2007.

6. Conclusions and further research

Despite empirical evidence, it has been uncommon to acknowledge travel time budget (TTB) in travel demand modeling. While activity-based models recognize that the day has no more than 24 hours and allows only for activities that fit into one day (Vovhsa et al., 2005), time budgets for travel time are commonly ignored. Moreover, if congestion worsens, common approaches in a traditional trip based model will attempt to select closer destinations; a highly unrealistic representation of observed work trips destination choice. If work and school trips are kept constant, the model needs shorten trips of non-work trip purposes if congestion worsens in order to respect the total TTB. This is accomplished in this paper by calculating individual TTB for every trip purpose.

Survival analysis is applied to estimate the median travel time per purpose. Travel behavior (as number of trips per trip purpose) was statistically significant for almost all travel times. This would indicate that travel time was not completely characterized by the most common sociodemographic variables and some details of travel behavior should be incorporated into the model. Moreover, the number of trips for other trip purposes reduced the travel time for a given purpose, meaning that trip purposes compete among each other. In other words, households distribute their total travel time among the different purposes and an increase on the number of trips for one purpose will reduce the travel time allocated for the other trips.

For all travel times, household size is one of the most significant variables, as it increases travel times. The increase is not linear with household size, having the highest variation on TTB from 1 to 2 person household and from 2 to 3 person household. Even though the model captures fairly good the variation on TTB for households bigger than 2 persons, it falls slightly short for households of one person. The life style pattern of one person households may be required to better describe their TTB.

The study also included the household income, which was found non statistically significant for the total travel time budget. Apparently, TTB are similar even across different income levels. Nevertheless, the time allocated for travel by purpose was significantly different depending on household income: higher incomes usually dedicate more time for home-based work trips and less time for other trip purposes. The other sociodemographic variables have the expected effect, as households with children or retired persons travel less time than other households. These results agree with previous studies.

In further research, the survival models will be incorporated into the microscopic destination choice module from SILO (www.silo.zone), substituting the current aggregate trip destination module. In application, the total TTB for a given household is calculated first. Then, the commute and school trips for all household members are selected based on the home, school and work locations. The time needed to complete those commute and school trips under current traffic conditions is subtracted from the total TTB for this household. Only the remaining TTB may be allocated to other trip purposes. The TTBs calculated for each non-work/non-school trip purpose are used to proportionally allocate the remaining TTB to non-work/non-school trip purposes. In the destination choice model, destinations are selected under the premise to respect the TTB for each purpose per household. Now, if congestion worsens, the remaining TTB will require shorter shopping and other trips. To the best of the authors' knowledge, this is the first time that a travel demand model explicitly respects TTB. Relatively constant work and school places and the adjustment of other trip destinations are considered to be a more realistic model sensitivity when travel times change.

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