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Procedia Computer Science 130 (2018) 865–871

Procedia Computer Science

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9th International Conference on Ambient Systems, Networks and Technologies, ANT-2018 and the 8th International Conference on Sustainable Energy Information Technology, SEIT 2018, 8-11 May, 2018, Porto, Portugal

Embedding intermodal mobility behavior in an agent-based demand model

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Abstract

Intermodality is the combination of different modes of transport along a single, seamless trip. It is assumed to reduce the amount of emissions generated by transport and being healthier for the users than conventional monomodal trips using passenger cars due to incorporating active modes of transport. In parallel, it promises to be competitive with passenger cars in terms of travel time. For determining the effects of measures that target at increasing the rate of intermodal trips, demand models that replicate the possibility to combine different modes of transport are needed. Herein, the extension of the agent-based demand model TAPAS for incorporating intermodal trips is presented. The given preliminary results show that the system is capable to compute the correct number of intermodal trips.

Peer-review under responsibility of the Conference Program Chairs.

Keywords: agent-based demand modelling; intermodality; nested logit model

1. Introduction

Intermodality, the usage of different carriers during a single seamless trip[1], is often appraised for being healthier and for polluting the environment less than the common use of conventional motorized vehicles. As well, it is assumed to solve problems of areas with a sparse population where public transport is economically unviable. Following this, the European Commission tries to foster intermodal behavior in regulations and by co-funding scientific projects. Yet, the concrete benefits of intermodality are barely measured. At present, accessibility-based approaches for computing the performance of intermodal trips compared to monomodal ones exist[2]. However, tools

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Peer-review under responsibility of the Conference Program Chairs.
10.1016/j.procs.2018.04.082

for computing the effects of measures aiming at changes in intermodal behavior and are capable to replicate the reactions of the affected population are needed. One class of tools that fulfills these requirements is the one of agent-based demand models. In the following, the extension of the agent-based demand model TAPAS[3,4] by intermodal options is described.

The work presented herein was performed within the context of the project "Urbane Mobilität"[5,6] that focusses at intermodality. Besides using simulation tools for computing the effects of measures on intermodal behavior and the traffic state, the project performs user surveys on this topic, develops new vehicle concepts for urban areas, incorporates an international perspective, and looks at the relationships between the urban space and intermodality.

Intermodality was first investigated for freight transport, and it is therefore not surprising that many approaches for modelling intermodal freight transport chains can be found. In contrary, only few models that describe the intermodal behavior of persons are known to the authors.

The remainder is structured as following: at first, the used simulation system is described in Section 2. Then, in Section 3, the extensions to this model for replicating intermodal behavior are presented. The used simulation scenario is given afterwards in Section 4, followed by a presentation of the results in Section 5. The report ends with a summary in Section 6.

2. Simulation System

For representing intermodal behavior and determining the effects that target at increasing the share of intermodal trips, a complex simulation system is used within the project. In the following subsections, the overall simulation system is presented first, followed by a description of the agent-based demand model TAPAS for which the extension by intermodal usage of transport modes is described herein.

2.1. The overall simulation system

The simulation system used within the project represents different levels of mobility choices. Long-term mobility choices, namely the selection of a place of inhabitance is modelled using the household location choice model SALSA[7,8]. Middle-term and short-term mobility choices are represented using the agent-based demand model TAPAS that computes the trips performed by a synthetic population including the visited places and the used modes of travel. Finally, the routes obtained from TAPAS are assigned to the road network using the open source microscopic traffic flow simulation SUMO[9,10]. The combination of TAPAS and SUMO has been applied for other research questions already[13]. For simulating intermodal behavior, SUMO has been extended by methods for computing intermodal routes. The changes performed on TAPAS will be described in Section 3.

2.2. The agent-based demand model TAPAS

The agent-based demand model TAPAS uses a disaggregated representation of the population. These single individuals are grouped into households which share mobility resources as well as the income and thereby the mobility budget. Each person holds among others the information about his/her age, the employment status, sex, and the availability of a driving license and of a public transport season ticket. Besides the population, the information about available activity places is given for the region, including, among others, work places, schools, universities, shop locations etc. In addition, the mobility offers available in the region are described using complex travel time and distance matrices for the different modes of transport. While the population is located within the area at the level of single buildings, the information about the travel time and distances are given as matrices at the level of travel analysis zones (TAZ) and additional functions are used for disaggregating them for obtaining the per-dwelling values.

When computing the demand within the region, the population is processed by iterating over the households first, and then over the individuals it consists of. For each person, a daily activity plan that matches the person's socio-demographic attributes is chosen from a set of 13,337 plans, which were obtained from the German mobility survey "Mobilität in Deutschland 2008"[14,15]. The activities included in the chosen activity plan are then processed in a hierarchic manner – most important activities, such as working are processed first followed by less important

activities, such as shopping. For each activity, the location at which it shall be performed as well as the mode of transport to access it are computed. The location is selected either using the Intervening Opportunities[16] approach or using the Gravity[17] model. The mode of transport to use is chosen either using a multinomial logit function or using a decision tree. The following investigations respectively use intervening opportunities and a multinomial logit function.

The result of this computation are trip chains for single persons that consist of the respective trip's starting and ending locations, the time the trip is started and the trip's duration, the chosen mode of transport and other attributes of the trip, of the person that performs it, and the used mode of transport. These measures can be post-processed for obtaining detailed information about the demand within the investigated region.

3. Model for intermodal behavior

Different possibilities exist for combining the modes of transport that are available within a city. A survey conducted within the project[18] in the year 2016 revealed a high amount of intermodal behavior, as shown in Figure 1. In contrary to other surveys, the survey asked whether specific modes or mode combinations have been used in the past and how often, not about the mobility behavior during a specific day. This explains the high amount of intermodal behavior. Please note that the survey did not consider walking as a mode of transport. Albeit the overall share of intermodality is high, some mode combinations can nonetheless be found only seldom. Regarding the implementation of intermodal behavior in TAPAS, it was decided to neglect these seldom combinations, mainly because their share is below the statistical deviations of the stochastics of the models employed in TAPAS. Resulting, only the combination of a bike with public transport (PT+BIKE) and the combination of a car with public transport (PT+CAR) were modelled.

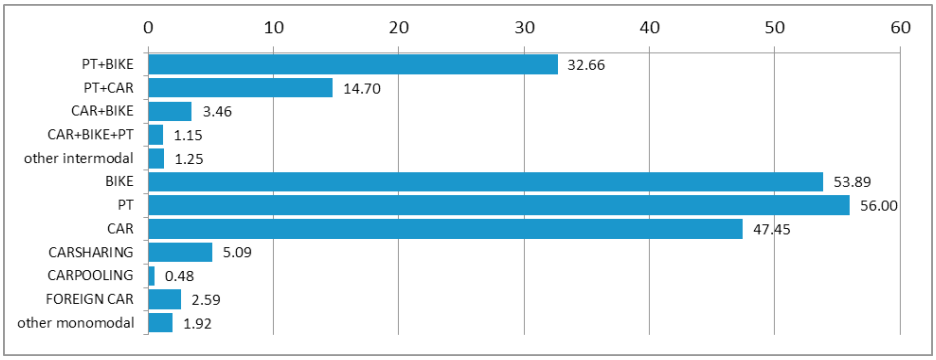

Fig. 1. Reported usage of monomodal modes and intermodal mode combinations.

Different options have been recognized for extending the mode choice within TAPAS by intermodal behavior. Finally, the decision for using a nested model was taken, depicted in Figure 2. This model treats public transport as the primary mode with one of the modes walking, bicycling, or driving an own car as a secondary access / egress mode. The reason for choosing this model hierarchy was the wish to keep it sensitive to both, changes in the public transport offer as well as to measures that affect bicycles and cars. The model uses variables that describe the person, the household she/he belongs to, and the trip. The person's variables include her/his age, and the availabilities of a season ticket, a driving license, and a car. The household variables include the numbers of the adults, of male persons, of half-day employed persons, and of persons with a driving license within the household, and additionally the household's net income and the number of cars. The trip's variables include the overall length, the number of sub-trips with activities and the information whether the trip is performed for working, education, shopping, for errant or for leisure activities.

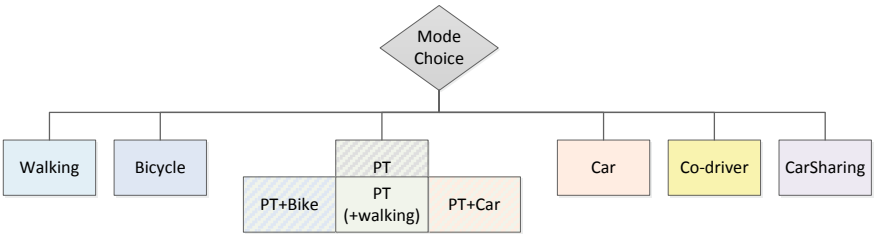

Fig. 2. Extension of TAPAS' mode choice model by intermodal trips.

The computation of the probability is the first step, yet it consumes much CPU time due to the large number of values needed by the nested model. To avoid unnecessary computations, the less time consuming determination of the points of mode change for the currently regarded relation are therefore determined first. They differ between the modelled secondary access / egress modes. In case of PT+BIKE, they include the public transport stations at which the public transport is entered and those at which public transport is left. For the PT+CAR combination, only the stop at which the public transport is entered is needed, as the remaining way is assumed to be passed as a usual public transport ride, i.e. the egress takes place by walking. These matrices have been computed by iterating over all possible bike and public transport, or, respectively car and public transport interchanges and selecting the ones with the least travel times. This has been done for every O/D pair. For some O/D combinations, no meaningful intermodal trips exist. In this case, interchange points marked as invalid are returned from the matrix and the secondary egress mode is rejected, skipping the computation of the probability for this mode combination.

After choosing the secondary mode, the values of the multinomial logit mode choice model for choosing public transport as the major mode are computed. They take into account the access / egress times, distances, and costs posed by the usage of the selected secondary mode. These values partially depend on the underlying infrastructure, including both, the road network as well as the transport offers and the possibilities to entrain a bike. To compute travel times and distances of intermodal mode combinations, the original computations of the monomodal modes bicycling, driving a passenger car, and public transport are used. This assures that implemented measures affecting cars, bicycles or public transport are regarded in intermodal combinations as well.

Further modifications were necessary, such as extending the representation of a "mode" for representing both, the primary and the secondary mode as well as according adaptations of the output functions. These extensions are yet implementation-specific and will be therefore not described herein.

4. Simulation scenario

The scenario used for evaluating the implementation of intermodal mobility was developed within the DLR project "Verkehrsentwicklung und Umwelt"[19] and covers the area of the city of Berlin. The socio-demographic and infrastructure settings replicate the year 2010. The population was set up to meet the official statistics and consists of 3.3 million persons living in 1.9 million households sampled from the German census data. The given sample was replicated using the SYNTHESIZER application to meet the distributions of age, gender, status, household size and income. Additional information about the availability of age, household sizes, income, and driver licenses was computed using the data from the SrV 2008 survey. The places of activities were generated by extending the commercially available NEXIGA data set. Figure 3 gives a quick overview about the simulated area by showing the distributions of persons and of available passenger cars.

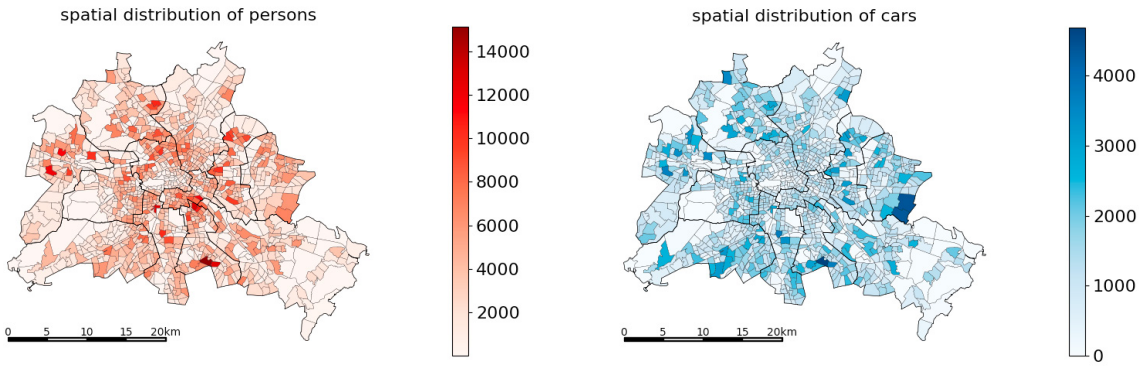

Fig. 3. The distribution of persons (left) and of passenger cars (right) within the modeled area.

Figure 4 shows some of the major socio-demographic attributes of the modeled population.

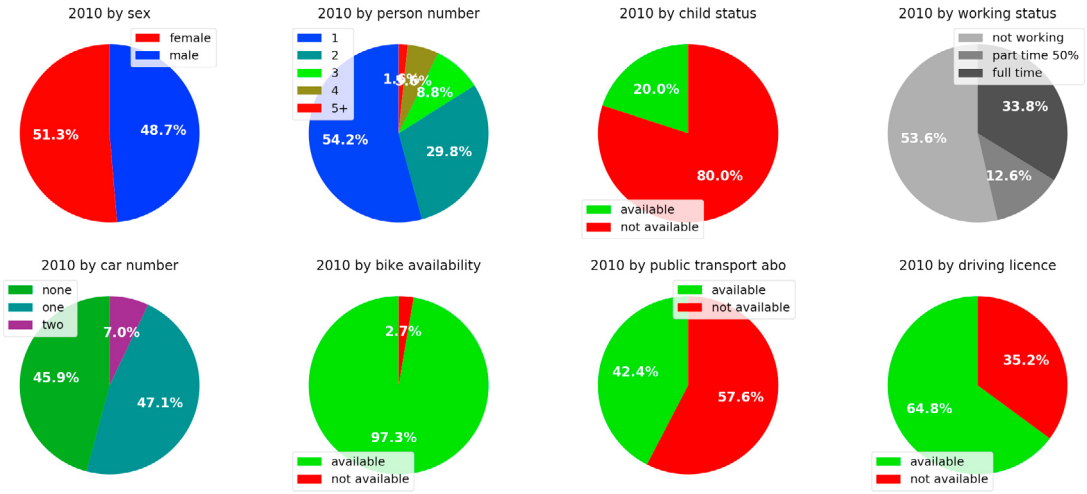

Fig. 4. Distribution of major attributes of the modeled population.

The evaluation of the base scenario is presented in the next section when being put against the obtained representation of intermodal mobility.

5. Results

The extended version of TAPAS was calibrated by adapting the search radii for different activity types, first, then by scaling factors for the usage of the modelled modes. Additionally, the mode constant used in the MNL model when selecting public transport was adapted to the intermodal mode combination PT+BIKE and PT+CAR individually. In the following, the obtained results are presented. Table 1 gives a comparison between modal split as given in the German survey SrV 2008 and SrV 2013 and the simulated one. The combination of using a bicycle and public transport is represented well, though only by setting the respective mode constant to a very high value of 100 – the mode constant for the monomodal public transport mode is at -4.8. Meanwhile, the combination of a private car and public transport remains at a too low level, even if setting the mode constant to a very high value of 1000. This will be discussed in the following.

Table 1. Mode share within Berlin as given in national survey and as simulated.

Mode	SrV 2008	SrV 2013	TAPAS
Walking	29.7%	30.8%	27.78%
Bicycling	12.5%	13.7%	14.16%
Car	33.6%	31.5%	34.28%
Public transport	21.3%	20.9%	22.59%
Other monomodal	1.0%	1.0%	0.06% (car sharing)
PT+BIKE	1.2%	1.2%	1.03%
PT+CAR	0.6%	0.7%	0.1%
Other intermodal	0.2%	0.2%	N/A

The spatial distribution of trips performed using PT+BIKE and PT+CAR is shown in Figure 5. Herein, only the trips starting at home are presented. For PT+BIKE, one can observe a high number of occurrences in Gropiusstadt located in the south of the city, which is the city's most densely inhabited area. The as well observable concentration of PT+BIKE trips in the inner city is well aligned to the results of a survey performed within the project. At most, the simulated PT+CAR trips concentrate in the inner city area as well. This is a relatively unexpected behavior, as most PT+CAR trips start in the city's outer areas as indicated by the survey.

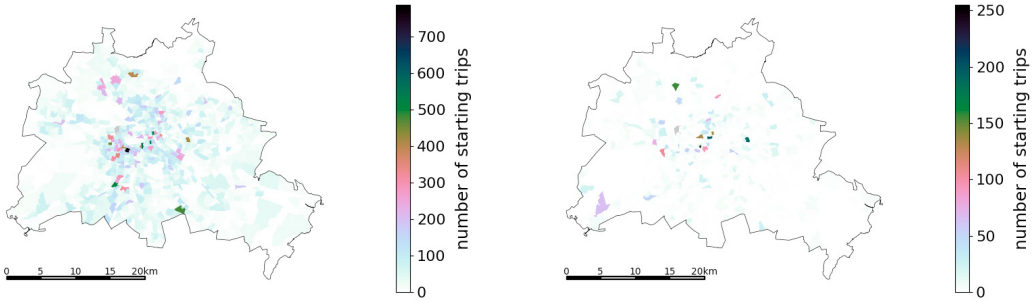

Fig. 5. Spatial distribution of the starting points of intermodal trips; left: PTBIKE, right: PTCAR.

Finally, the distribution of the trip lengths per mode is given in Figure 6, normed by the overall number of trips per mode. Again, the usage of PT+BIKE combination for longer trips is well represented while trips performed by PT+CAR are too short when compared to real-world behavior.

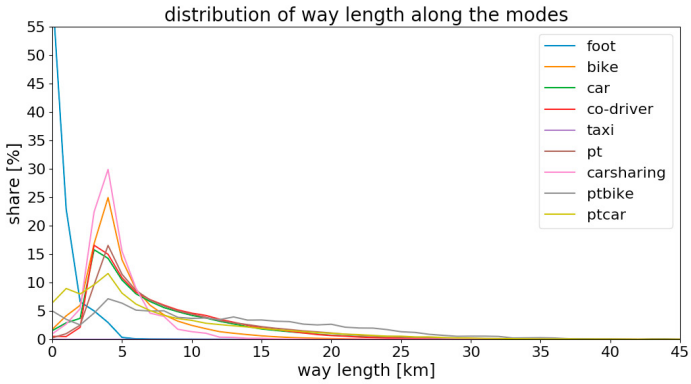

Fig. 6. Distribution of trip lengths along the modes and mode combinations.

6. Conclusion

The article presents an extension of the mature agent-based demand model TAPAS by intermodal trips. The extension was realized by sub-dividing the mode "public transport" into the original one that uses walking as access and egress mode and two new intermodal mode combinations. The first one uses a car for accessing public transport and continuing the trip by walking after leaving the public transport. Within the second one, both, the access as well as the egress are performed by bike, thereby assuming that the bike is taken on board of the public transport vehicle. The probability to choose either the monomodal public transport mode or one of the intermodal mode combinations is obtained using a nested multinomial logit model that considers the respectively regarded person's socio-demographic attributes.

The model was run for an existing simulation of an average day in the city of Berlin. It shows valid results for the combination of bicycling and using the public transport, yet only by scaling it up using a high value for the mode constant. Regarding the intermodal combination of a passenger car and public transport, the model fails in terms of the number of trips, their spatial distribution, and the distribution of their lengths. The reasons are yet unknown and will be investigated in the near future.

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