Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 184 (2021) 753–760

Procedia
Computer Science

www.elsevier.com/locate/procedia

The 10th International Workshop on Agent-based Mobility, Traffic and Transportation Models, Methodologies and Applications (ABMTRANS 2021)
March 23 - 26, 2021, Warsaw, Poland

Expanding the analysis scope of a MATSim transport simulation by integrating the FEATHERS activity-based demand model

Dominik Ziemke[a,b,*], Luk Knapen[b], Kai Nagel[a]

[a] *Technische Universität Berlin, Transport Systems Planning and Transport Telematics, Salzufer 17-19, 10587 Berlin, Germany*
[b] *Hasselt University, IMOB (Transportation Research Institute), Agoralaan, 3590 Diepenbeek, Belgium*

Abstract

MATSim is an agent-based transport simulation model. In contrast to a pure dynamic traffic assignment (DTA) model, MATSim can react to more choice dimensions than route choice, which is the only choice treated by a typical DTA. Simulating the mobility and activity participation of individuals during the whole day, MATSim can additionally represent mode choice, departure time choice, and other decisions and is, therefore, policy-sensitive in terms of these choice dimensions. This allows for the analysis of a wide scope of policies. MATSim can, however, not model the choice of the sequence of activity participation nor the choice of activity participation as such. Also, choices of locations are not typically part of the modeling scope. Interventions into the transport and land-use systems may, however, be substantial such that they can effect changes in behavior in terms of these choices. To allow for the assessment of such reactions, the FEATHERS activity-based demand model is coupled with MATSim. This paper explores different options of integration and describes the development steps of the integration of FEATHERS and MATSim.

Keywords: agent-based simulation, transport modeling, transport demand modeling, policy analysis, model integration

---

1. Introduction

MATSim [7] is an agent-based transport simulation model. Every individual agent of the study area is simulated individually throughout a full day. In contrast to a pure dynamic traffic assignment (DTA) model, MATSim can react to more choice dimensions than route choice, which is the only choice treated by a typical DTA. Simulating the mobility and activity participation of individuals during the whole day, MATSim can represent additional choices like mode choice or departure time choice and is, therefore, policy-sensitive in terms of these choice dimensions. This allows for the analysis of a wide scope of policies.

---

[*] Corresponding author. Tel.: +49-30-314-21383 ; fax: +49-30-314-26269.
E-mail address: dziemke@vsp.tu-berlin.de

10.1016/j.procs.2021.04.022

MATSim can, however, not model the choice of the sequence of activity participation nor the choice whether or not to take part in activities altogether. Also, the choice of locations of mandatory activities is not part of the modeling scope. For the choice of locations of discretionary activities, a corresponding MATSim extension exists in experimental stage [6].

Interventions into the transport and land-use systems may be substantial such that it can be assumed that individuals do not only change modes or activity times, but potentially also the sequence of their activities, the locations of them or even the participation in activities altogether. To allow for the assessment of such reactions, the FEATHERS activity-based demand model is coupled with MATSim. This paper explores different options of integration and describes the development stages of the integration process. Bellemans et al. [2] describe the development steps of the FEATHERS modeling suite. While the first three of the four described steps are concerned with the development of an activity-based model, the fourth step aims at an agent-based micro-simulation framework involving traffic and route assignment on a microscopic level. The present paper constitutes an attempt to achieve this development step.

2. MATSim

MATSim [7] is an open-source simulation framework implemented in Java and models the transport system of a region by simulating individual agents with their daily activities and travel. Each agent has one or more daily activity-travel patterns (plans) that they try to follow and, in doing so, compete for space-time slots with all other agents on the transport infrastructure. All agents try to optimize their individual travel behavior by applying modifications along different possible choice dimensions (e.g. changing routes, changing modes of transport), trying out these modified plans in the simulation, and evaluating them based on the concept of utility maximization. Since all agents undergo this process simultaneously, this approach constitutes a co-evolutionary algorithm, from which eventually a stochastic user equilibrium emerges.

As agents with all relevant properties, full knowledge of their intentions, and a memory of their previous experience are maintained during the whole process, dependencies and constraints between different trips or trips and activities (e.g. timing constraints, availability of transport modes based on previous travel and status thereof, e.g. battery load) are inherently resolved. This makes the simulation framework particularly interesting for the analysis of novel, often more demand-oriented transport policies like specific restrictions (e.g. environmental zones with distinction by vehicle emission class), tolls or user pricing [e.g. 8] or the analysis of novel transport services (e.g. MaaS or autonomous taxis) and technologies (e.g. electric vehicles) [e.g. 4].

Different choices that agents can take to adjust their behavior are set by the modeler in the form of *innovative strategy modules*. As such, MATSim should be regarded a *demand-adaptation model* whose abilities reach into the domain of a typical activity-based demand model (ABDM or activity-scheduling model) like CEMDAP [3], TASHA [11], ALBATROSS [1], or FEATHERS [2]. MATSim is, however, not a ABDM in its own right as it cannot create activity-travel schedules based on demographic and socio-economic data. Those travel demand choices that are not covered within MATSim endogenously have to be provided exogenously [7, p.19]. Activities, their duration as well as their locations (in particular of mandatory activities) must be provided as input. To be able to create a policy-sensitive transport model also in terms of these choice dimensions, the ABDM FEATHERS is coupled with MATSim in this study.

3. FEATHERS

FEATHERS [Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS; sometimes referred to as “FEATHERS 0” for distinction from variants of the model, 2] models the activity participation and travel of individual members of the population of a study region for a whole day. FEATHERS predicts activity-travel patterns by Monte-Carlo simulation, where individuals take successive decisions based on 26 decision trees. The decision trees have been trained on the OVG (*Onderzoek Verplaatsingsgedrag Vlaanderen*) dataset, the official Flemish household travel survey, which encompasses some 16,000 people (data for the period 2007-2020 of the OVG 3-4-5 campaigns[1]). FEATHERS uses the activity-scheduling model of ALBATROSS [1] and is written in the C++ programming language.

For the synthetic population, socio-economic and demographic characteristics have to be known, including home locations, which are specified on the level of traffic analysis zones (TAZs). The model for Flanders consists of 2,386 TAZs, which are – apart from their location and spatial layout – specified by the number of job opportunities, number of shops, schools, etc. Furthermore, three travel impedance matrices specifying the time required to travel between all TAZs are required. These three matrices distinguish the off-peak, AM-peak, and PM-peak periods of the day. An initial estimate for the impedance matrices is skimmed from previously estimated travel demand that was assigned to the road network.

The schedule generation procedure is a Monte-Carlo simulation. The outcome for each of the successive decisions taken by the individual to determine a schedule is randomly drawn based on probabilities following from the trained decision trees [13]. In each step the characteristics of the partial schedule are used in the decision trees (conditional probabilities). The schedule is built by adding activities and trips. For each activity, the type, duration, start time, and location (TAZ) are determined. For each trip, the mode is determined, while timing and locations follow already from the activities.

Because of the Monte-Carlo kind of simulation, an individual (i.e. a member of the synthetic population with a specific identifier) does not necessarily have the same work location in two consecutive runs. Neither do they perform the same sequence of activities even if all input data like impedance matrices and TAZ characteristics etc. are identical. The variations in the results over repeated FEATHERS runs and the required number of repeated runs for reliable analyses for local effects have been studied in [12].

For Flanders, a calibrated and readily applicable FEATHERS model is in place. Next to the original FEATHERS model (“FEATHERS 0”) which uses decision trees for schedule prediction, there are other versions (used e.g. in the *Urban Tools Next* project for Rotterdam[2]), which can use both decision trees and discrete choice models [14, 10].

4. Steps towards integration in order to expand the analysis scope of the simulation

To model developments in the transport and land-use systems that go beyond MATSim’s own modelling scope (i.e. reactions in terms of those choice dimensions for which no *innovative strategies* do exist in MATSim), the following approaches may be considered:

1. Some effects can be treated by directly adjusting input data based on plausible assumptions, e.g. workplaces of agents can be changed by some systematic procedure [e.g., the de-urbanization scenario described in 9]. Such an approach may, however, impair the validity of daily plans as the effect of (changed) mandatory activities (e.g. work) on discretionary activities (e.g. leisure) is not addressed. Therefore, such an approach is rather only suitable in setups where only simplified home-work-home travel plans are simulated and, correspondingly, only commute travel is analyzed.
2. To obtain a more realistic representation of traffic patterns for all times-of-day, the transport simulation needs to be based on a representation of complete daily activity-travel patterns of the whole population. A simple approach is to sample activity-travel patterns based on real-world observations and assign them to agents based on some similarity measure [e.g. Hamming distances as in 17] between agent and the surveyed traveller. The disadvantage is that for many attribute combinations there will not be a reasonably fitting pattern to be sampled from.
3. A more elaborated approach is to apply an ABDM, which creates consistent activity-travel patterns based on the properties of the individual, which can, of course, encompass a changed environment (incl. a changed synthetic population itself) to which reactions are to be modeled in a policy study. A recent MATSim scenario generation procedure [16] based on the simple, aspatial activity-scheduling model actiTopp [5] fulfill this purpose principally, but is limited in terms of policy sensitivity due to actiTopp’s more limited modeling scope.

---

[1] https://www.vlaanderen.be/mobiliteit-en-openbare-werken/onderzoek-verplaatsingsgedrag-vlaanderen-ovg

[2] https://cvs-congres.nl/e2/site/cvs/custom/site/upload/file/cvs_2018/id_192_erik_de_romph_activity_based_model_rotterdam_abmr.pdf

The suitability of each of the three approaches depends on the magnitude and complexity of the interventions to be modeled. For more complex situations, the reasonable approach is to consistently model choices, i.e. apply variant 3. The present study makes a contribution in this regard by integrating FEATHERS with MATSim. Before explaining how this integration is put into practice, we discuss what types of integration are possible based on the methodological and technical structures of FEATHERS and MATSim.

4.1. Conceptually and technically possible types of interaction between FEATHERS and MATSim

In principle, it would be ideal to establish a person-centric interaction between MATSim and FEATHERS. This way, relevant properties and constraints could be shared between model components. One model component could directly react on relevant aspects modeled in the other component. This would mean that an individual agent with a given set of plans is allowed to modify their plan in terms of choice dimensions like activity sequencing in such a way that FEATHERS would directly modify the plan of the MATSim agent. Despite the fact that both MATSim and FEATHERS are microscopic, i.e. both models resolve travelers individually, there are conceptual differences between the two models, which are critical in terms of the type of interaction that is possible.

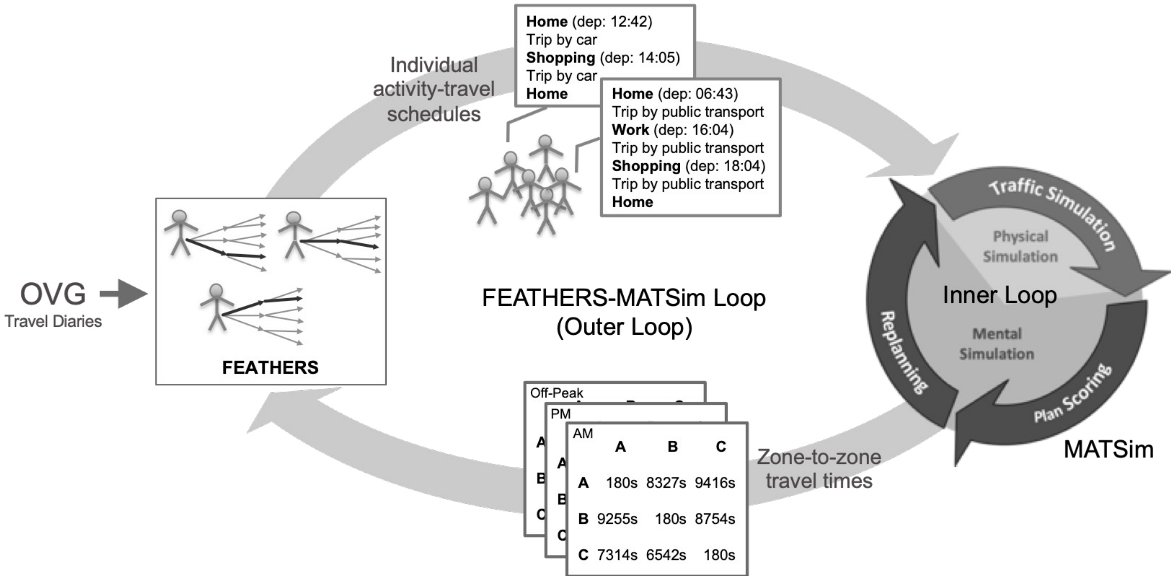
MATSim is an agent-based model. As described in sec. 2, the individual travelers have a memory of their experience and are aware of their intentions. Those plans (i.e. lists of the individual intentions to take part in activities during a day and to perform trips which connect these activities) can be modified. Since agents evaluate their plans based on a scoring function, there is a direct individual notion in terms of which plan is “better” for a particular agent and which plan is “worse”. Therefore, the changes in plans have a meaningful interpretation in terms of reactions to policies.

In FEATHERS, by contrast, individuals rather serve as containers of properties. Dependent on those properties, statistically correct activity-travel patterns are modeled. There is, however, no memory in any regard to past behavior, e.g. from an earlier model run. While it is possible to only “re-schedule” a single person, the new activity-travel schedules generated by this cannot be compared to a potentially existing previous activity-travel pattern of that individual in a meaningful way. Both patterns will be statistically correct in terms of behaving in accordance with the model estimation, but may – because of the Monte-Carlo style of simulation that FEATHERS is based on – be fundamentally different even if “re-scheduling” is done based on the exact same inputs. As a consequence, a person-centric interaction between the two models is not possible in the direction from MATSim to FEATHERS. Therefore, this component of the integration has to be accomplished on a system level as shown schematically in fig. 1.

As pointed out in sec. 2, MATSim is a demand-adaptation tool that can modify behavior of trip makers in terms of different choices. As such, there are decisions which can in principle be addressed by both FEATHERS and MATSim, e.g. mode choice and departure time choice. Therefore, attention must be paid not to let MATSim override decisions in a way that would act against the empirical knowledge contained in the FEATHERS estimation. This is particularly relevant as the modeling paradigms of both models are different. While FEATHERS applies a rule-based method trained on real-world travel diaries to create statistically correct activity-travel schedules, MATSim uses a utility-maximization procedure to improve activity-travel plans. Allowing agents in the MATSim simulation e.g. to change transport modes in order to improve their daily plan may not be compatible with FEATHERS’s schedule prediction as this can alter the distribution of choices among the population which FEATHERS tries to replicate. On the other hand, allowing such choices in the simulation is the very reason for applying the simulation in order to assess policies.

As a consequence, MATSim needs to be set-up in this combined application in such a way that the distributions for variables measured by the survey (and represented by FEATHERS) remain valid. Obviously, route choice can be treated by MATSim without conflict as FEATHERS has no notion about it. Departure times and the choice of transport modes are both modeled in FEATHERS. Strategies that modify them should, therefore, either be switched off in MATSim or their action scope be sufficiently confined. Examples for such constraints include defining opening times of activities and defining multiple typical durations of activities such that all activities modeled by FEATHERS can receive a good score if carried out as intended. Mode switching should only be allowed in MATSim to modes which can be considered to be available to a given agent based on the person’s properties as far as FEATHERS is aware of them. In doing so, the stability of relevant distributions in terms of these choices must be observed.

If relevant distributions of the corresponding variables (e.g. departure time distributions) prove to be sufficiently stable (in the MATSim outcome as compared to the upstream FEATHERS outcome) in a base-case simulation for a study area, the corresponding choice can be allowed on the MATSim side and, hence, also applied in the same way in subsequent policy analysis applications of the model. Notably, observing these rules is not fundamentally different



Home (dep: 12:42)
Trip by car
Shopping (dep: 14:05)
Trip by car
Home

Home (dep: 06:43)
Trip by public transport
Work (dep: 16:04)
Trip by public transport
Shopping (dep: 18:04)
Trip by public transport
Home

AM	A	B	C
A	180s	8327s	9416s
B	9255s	180s	8754s
C	7314s	6542s	180s

Fig. 1: Schematic visualization of integration between FEATHERS and MATSim.

to other MATSim applications where choice distributions also need to withstand such a validation. The critical part is that the FEATHERS outcome already includes some form of validation (based on the training of its decision trees) and the integration between FEATHERS and MATSim must be set-up in a way as not to spoil the intermediate result.

A constraint on a more technical level is the fact that MATSim is an open-source software written in Java, whereas FEATHERS is programmed in C++ and not available openly. This complicates model integration as standard dependency-management technologies cannot be applied. The integration has been established by wrapping the packaged executable version of FEATHERS into a WINE-based environment that can be called out of the MATSim Java code via a Java process builder. Information transfer is on a file-based level.

4.2. FEATHERS to MATSim: Converting FEATHERS schedules into MATSim plans to create a simulation scenario

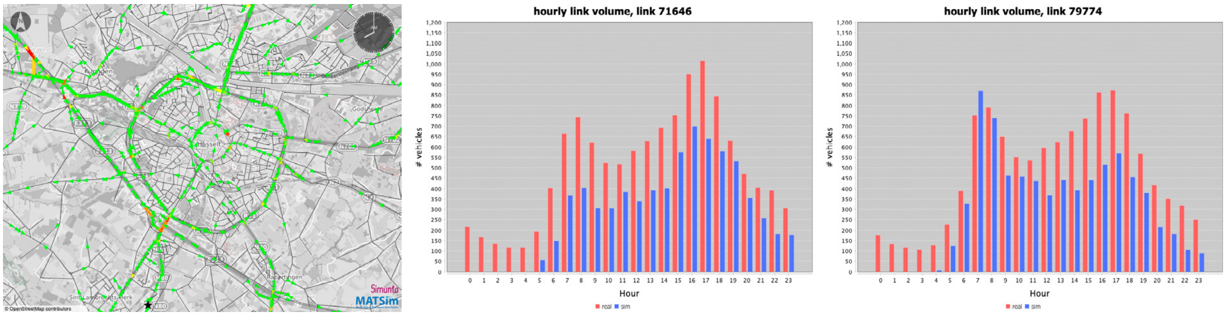
Activity-travel patterns created by FEATHERS are individually converted into MATSim daily plans (as indicated by the arrow with the label “individual activity-travel schedules” in fig. 1). In an exemplary study, this process has been applied for the residents of the city of Hasselt and vicinity. While FEATHERS resolves space into TAZs (cf. sec. 3), MATSim works coordinate-based. For this study, random coordinates in the corresponding TAZs have been chosen as trip origins and destinations. If a higher spatial accuracy is intended, a procedure to sample coordinates from the CRAB database (Centraal Referentie Adressen Bestand)[3] has been established as an alternative. CRAB is an open dataset provided by the Flemish government and contains every address in Belgium along with its coordinates and the type (residential or other).

For this Hasselt scenario, a 50% sample of the population has been assigned with activity-travel patterns by FEATHERS. These patterns have been individually converted into MATSim daily plans. In this direction, the information transfer is indeed person-centric as we regard it to be ideally. A MATSim agent can principally know all information that its counterpart person on the FEATHERS side of the coupled model possesses.

Fig. 2 shows results of the MATSim transport simulation scenario for Hasselt. Fig. 2a) shows the morning travel patterns, while figs. 2b) and c) show comparisons of simulated traffic volumes with corresponding real-world data for count stations on the southern arterial road (exact location marked by a star in fig. 2a). It can be seen that the numbers of simulated trips are below the real-world traffic counts for most times-of-day. Still, there is a clear correlation between the simulated and the counted numbers in terms of the distributions by time-of-day. The observation that for

---

[3] https://overheid.vlaanderen.be/informatie-vlaanderen/producten-diensten/centraal-referentieadressenbestand-crab



(a) Traffic at 8:00 a.m. (star = count station).

(b) Counts on southern arterial road, outbound.

(c) Counts on southern arterial road, inbound.

Fig. 2: Results of traffic as simulated in MATSim based on activity-travel patterns from FEATHERS (In histograms blue=simulated, red=observed).

most of the hours of the day simulated traffic is by a certain volume below real-world measurements is explained by the fact that transit traffic (through traffic) as well as commercial traffic is not included in this simulation while these demand segments contribute to the traffic volumes in the real-world counts.

The simulation scenario has been applied to analyze the effect of a new shopping site (large furniture store and additional smaller shops in its vicinity) in Hasselt. The expected number of visitors was taken from the mandatory environment impact statement delivered by the developer. The TAZ attraction in the FEATHERS input was adjusted accordingly. The FEATHERS-MATSim simulation was used to quantify the effects of implementing a barrier (Dutch: *slagboom*) that only allows local residents and public transport vehicles to pass a road in the vicinity of the new shopping site in order to prevent unintended cut-through traffic [15]. It was shown that the barrier has the effect that was intended by the policy without significantly increasing travel times in the surrounding network.

4.3. MATSim to FEATHERS: Using simulation-based travel times to update FEATHERS schedule prediction

As explained in sec. 3, FEATHERS requires impedance matrices as input to model individual activity-travel schedules of the residents of the study area. Initially, this has been done by applying a commercial standard route assignment package. As indicated by the arrow with label “zone-to-zone travel times” in fig. 1, travel impedance information is computed by MATSim on the zonal system that FEATHERS uses. MATSim can principally provide travel times based on simulation results on any microscopic relation by exact times-of-day via its router. FEATHERS, in its current version, requires travel times distinguished by three periods of the day (cf. sec. 3). Representative times-of-day have been chosen based on which zone-to-zone travel times are computed by MATSim.

As explained in sec. 4.2, also the resolution of space differs between FEATHERS (TAZs) and MATSim (coordinates). Therefore, a suitable definition for coordinate-based measure points to represent zones is required. Experiments have been carried out for different definitions (e.g. zonal centroid, different versions of averages over collections of random points per zone). The performance of the centroid-based version was found to be sufficient while it is computationally comparatively cheap and also easily interpretable. Therefore, this approach is used.

Fig. 3 shows a comparison between the so computed MATSim-based travel times and the travel times of the original setup of FEATHERS. While the overall match is good, there are some outliers in fig. 3b). These are likely zones that are connected to the rest of the network by locally overly congested network elements. These artifacts should vanish by adjusting capacities of affected links.

The travel times are written to a file in form of matrices according to FEATHERS’s input file specifications. By activating a dedicated submodule of FEATHERS, these travel time matrices are read, converted and stored in a binary format, which is required by FEATHERS to simulate activity-travel schedules using these updated travel times.

4.4. Automated iteration between FEATHERS and MATSim

As pointed out in sec. 4.1, an integration is established on a system level because a person-centric integration is conceptually not feasible in the direction from MATSim to FEATHERS. The outer loop in fig. 1 describes the iteration between the FEATHERS and MATSim components of the combined model. The iterations in MATSim itself

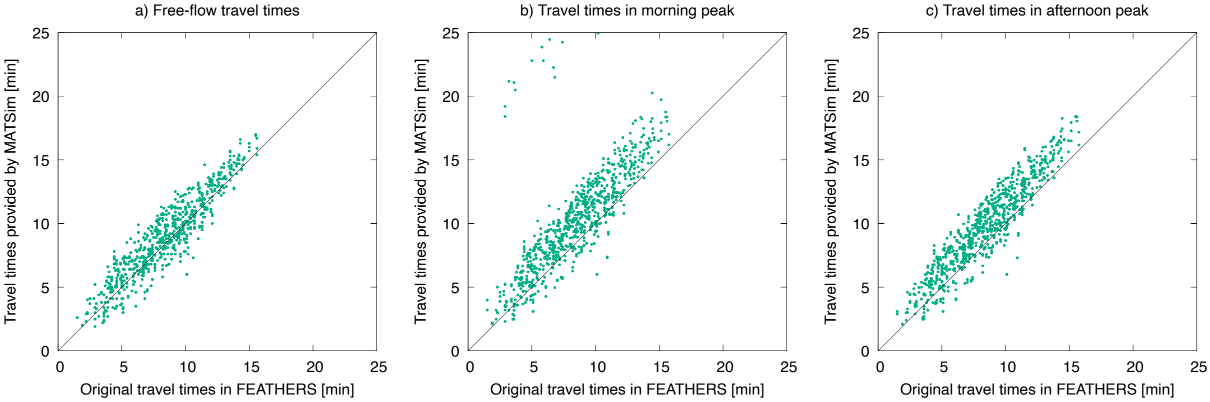


Fig. 3: Comparison of travel times between original computation in FEATHERS and travel times computed based on the MATSim simulation.

constitute the inner loop in this setup, which is shown in the right part of fig. 1. MATSim iterations can be ended when plan scores (i.e. the utility evaluation of the plan of an agent) do not change significantly anymore. The outer loop of the iteration between MATSim and FEATHERS can be ended when zonal travel times, which are obtained as output of the MATSim simulation, do not change anymore, i.e. lie on a diagonal in a comparison to the previous MATSim application in a visualization like fig. 3. By this, it is ensured that the travel time information that is used in FEATHERS for schedule prediction is consistent with travel times that emerge when the corresponding persons carry out these schedules in the simulated reality. As this consistency can normally not be expected to exist immediately, multiple iterations of the outer loop are necessary.

It must be noted that persons with the same identifier in two consecutive applications of FEATHERS do not have a relation (cf. sec. 4.1). Both serve to create activity-schedule plans that collectively replicate real-world travel, but are individually unrelated. This is why the feedback of information from MATSim to FEATHERS is not sensible on a higher specification level than zonal travel times. Given this, a consistency of zonal travel times in subsequent iterations of the outer loop is a suitable criterion to end iterations.

5. Conclusion and outlook

In this paper, we describe a coupling between FEATHERS and MATSim. While the information transfer from FEATHERS to MATSim is based on a (generally desirable) person-centric information transfer, the coupling in the reverse direction from MATSim to FEATHERS is achieved on a system level (zonal travel times). The methodological and technical structures of FEATHERS and MATSim are discussed to derive how the interplay between both coupled models needs to be designed to guarantee that MATSim's iterative utility maximization approach does not override empirical distributions of behavior embedded in intermediate results created by FEATHERS.

While MATSim is a demand-adaptation model, it is not a full ABDM that models activity-travel patterns based on a synthetic population with socio-economic properties directly. The coupling with FEATHERS adds this functionality. Therefore, the coupled model can e.g. be applied to model scenarios which include a grown population, new neighborhoods or otherwise changed spatial patterns for whose population new activity-travel schedules are required. Based on this model, such scenarios can be modeled for a given point *in* time, which can also be set in the future.

What this model does not provide is modeling a temporal progression of the urban system *over* time, which can be used to assess how an urban system changes in the future as an effect of aforementioned changes, e.g. price increases because of increased attractivity by the development of a shopping site as in sec. 4.4. In parallel work, the integration of MATSim with a full-scale land-use model (ILUT model) which is capable of modeling such developments *over* time is described [18]. The experience gained by the present study is also useful for an ILUT model as activity-travel patterns are required for future years in an ILUT setup. The application of an ABDM like FEATHERS for such a future year based on updated synthetic population works in principle similar to what is described in this study for a temporally unspecified policy situation with a changed population or spatial layout of the study area.

The described coupling of FEATHERS and MATSim can serve to broaden the analysis scope of simulations in terms of reactions to policies which MATSim itself cannot represent by it its demand adaptation (e.g. additional activities or changed activity sequences).

To obtain a meaningful representation of travel times, the whole region needs to be run as otherwise significant demand segments would be missing and the travel times be underestimated. Once this is done, the coupled model can in principle also be re-run partially, e.g. to analyze more local effects of local policies.

In future work, the combined model should be applied for policy studies to further assess its applicability and usefulness. In general, it would be desirable to have a model integration on a finer (ideally person-centric) level of resolution than it was achieved here. Updated versions of FEATHERS are under development. Since they all share the input and output file structures with the "FEATHERS 0" version described for the current coupling, a future substitution – and, by this, access to improved functionality – is achievable without prohibitive effort for adaptation.

Acknowledgements

The authors thank Tom Bellemans for discussions on the interaction of activity scheduling and transport simulation models and Bruno Kochan for discussions and help in terms of the FEATHERS model and software.

References

[1] Arentze, T., Timmermans, H., 2004. A learning-based transportation oriented simulation system. Transportation Research Part B 38, 613–633.

[2] Bellemans, T., Kochan, B., Janssens, D., Wets, G., Arentze, T., Timmermans, H., 2010. Implementation framework and development trajectory of FEATHERS activity-based simulation platform. Transportation Research Record 2175, 111–119.

[3] Bhat, C., Guo, J., Srinivasan, S., Sivakumar, A., 2004. A comprehensive econometric microsimulator for daily activity-travel patterns. Transportation Research Record 1894, 57–66. doi:10.3141/1894-07.

[4] Bischoff, J., Maciejewski, M., 2014. Agent-based simulation of electric taxicab fleets. Transportation Research Procedia 4, 191–198. doi:10.1016/j.trpro.2014.11.015.

[5] Hilgert, T., Heilig, M., Kagerbauer, M., Vortisch, P., 2017. Modeling week activity schedules for travel demand models. Transportation Research Record 2666, 69–77. doi:10.3141/2666-08.

[6] Horni, A., Nagel, K., Axhausen, K.W., 2012. High-Resolution Destination Choice in Agent-Based Models. Annual Meeting Preprint 12-1988. Transportation Research Board. Washington, D.C. Also VSP WP 11-17, see http://www.vsp.tu-berlin.de/publications.

[7] Horni, A., Nagel, K., Axhausen, K.W. (Eds.), 2016. The Multi-Agent Transport Simulation MATSim. Ubiquity, London. doi:10.5334/baw.

[8] Kaddoura, I., 2015. Marginal congestion cost pricing in a multi-agent simulation: Investigation of the greater Berlin area. Journal of Transport Economics and Policy 49, 560–578.

[9] Kaddoura, I., Laudan, J., Ziemke, D., Nagel, K., 2020. Verkehrsmodellierung für das ruhrgebiet: Simulationsbasierte szenariountersuchung und wirkungsanalyse einer verbesserten regionalen fahrradinfrastruktur, in: Proff, H. (Ed.), 11. Wissenschaftsforum Mobilität: Neue Dimensionen der Mobilität: Technische und betriebswirtschaftliche Aspekte, Springer Gabler, Wiesbaden. pp. 361–386. doi:10.1007/978-3-658-29746-6.

[10] Knapen, L., Adnan, M., Kochan, B., Bellemans, T., van der Tuin, M., Han, Z., Snelder, M., 2021. An Activity Based integrated approach to model impacts of parking, hubs and new mobility concepts, in: Procedia Computer Science, Elsevier, Warsaw, Poland.

[11] Miller, E., Roorda, M., 2003. A prototype model of household activity/travel scheduling. Transportation Research Record 1831, 114–121.

[12] Qiong, B., Kochan, B., Bellemans, T., Janssens, D., Wets, G., 2015. Investigating micro-simulation error in activity-based travel demand forecasting: a case study of the FEATHERS framework. Transportation planning and technology 38, 425–441. doi:10.1080/03081060.2015.1026102.

[13] Rasouli, S., Timmermans, H., 2013. Uncertainty in Predicted Measurement and Analysis, in: Transportation Research Board of the National Academies, TRB (Transportation Research Board), Washington, D.C.

[14] de Romph, E., Kochan, B., Clerx, W., 2018. Een Activity Based Model voor Rotterdam, het ABMR, in: Colloquium Vervoersplanologisch Speurwerk, Colloquium Vervoersplanologisch Speurwerk.

[15] Wallendorf, J., 2016. Agent-based simulation and traffic impact analysis of a new commercial park in Belgium. Master's thesis. Technische Universität Berlin.

[16] Ziemke, D., Charlton, B., Hörl, S., Nagel, K., 2021. An efficient approach to create agent-based transport simulation scenarios based on ubiquitous Big Data and a new, aspatial activity-scheduling model. Transportation Research Procedia 52, 613–620. URL: https://svn.vsp.tu-berlin.de/repos/public-svn/publications/vspwp/2020/20-11/.

[17] Ziemke, D., Joubert, J.W., Nagel, K., 2017. Accessibility in a post-apartheid city: Comparison of two approaches for accessibility computations. Networks and Spatial Economics 18, 241–271. doi:10.1007/s11067-017-9360-3.

[18] Ziemke, D., Kuehnel, N., Nagel, K., Moeckel, R., 2020. FABILUT: The Flexible, Agent-based Integrated Land-Use Transport Model. VSP Working Paper 20-01. TU Berlin, Transport Systems Planning and Transport Telematics. URL http://www.vsp.tu-berlin.de/publications.