Modélisation de la Mobilité Urbain à échelle Métropolitaine : une Comparaison des Modèles de Transport Franciliens ; Modélisation de la Mobilité Urbain à échelle Métropolitaine : une Comparaison des Modèles de Transport Franciliens

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Modeling Urban Mobility at a Metropolitan Scale: a Comparison of Paris Transportation Models

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Abstract

Modeling transportation systems is strategic to evaluate urban development projects by providing traffic estimates and social, economic or environmental impacts. This paper puts forward an analysis grid highlighting Travel Demand Models (TDMs) characteristics and specificities to spell out the modeled mobility aspects and their operational capacities. This grid is then applied on 5 operational models used in the Paris region.
In order to build this analytical framework, the standard model structure based on the supply, the demand, the mobility uses and their impacts is assessed. The proposed grid is articulated around the spatio-temporal frame, the demand, the transportation modes and services supply, and the mobility uses representations. Travel demand representation is treated in-depth by focusing on mobility decisions modeling. A final analytic table comparing Paris region models highlights the different mobility aspects revealed by each and discusses their specificities and their link to the TDMs' operational uses.

Keywords: Transport Modeling & Simulation; Socio-Economics and Foresights; Transport Project & Policy Evaluation Tools; Urban Mobility; Metropolitan Transportation Models, Travel Demand Forecast; Comparison Framework; Paris Region

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1. Introduction

Modeling urban transportation systems at a spatial scale encompassing an urbanized area and its attraction basin of related settlements is strategic to evaluate urban development projects as well as transportation master plans. The so-called travel demand models (TDMs) model demand in interaction with modal networks. As Batty (2009) details, they aim to replicate preconceptions and observations of mobility in order to quantify its evolutions, which enables testing projects or policy scenarios by providing traffic estimates and a large range of social, economic or environmental impacts.

Voorhees (1959) was one of the first to pave the way to TDMs by providing the basis of four-step modeling. The rise of the discrete choice theory and its application to transportation with McFadden (1974) in the 1970s has then allowed dealing with travel demand modeling issues from the mode choice modeling step. That research field was then adapted to operational models in the following decade. Until the 2000s the field theory has been set up with Ben-Akiva and Lerman (1985) and Ortuzar and Willumsen (2011)'s handbooks. Since then most of the literature mainly focuses on technical and theoretical improvements such as advanced discrete choice models.

Almost no recent paper tries to build a general framework establishing a complete description of contemporary TDMs' characteristics and spelling out the different mobility aspects they reveal. Such tool would ease understanding and comparing models in order to better assess their range of application and efficiency, and to identify developments for better representing mobility phenomena. In order to fill this gap, this paper aims to build an analysis grid general enough to compare every TDM and detailed enough to observe the specificities of each. This grid is then tested with an application on five TDMs used by different mobility actors.

After conducting a review of TDMs comparisons and presenting the analysis grid, the latter is applied to each model in turn ranging from classic four-step models to tour-based models. A final summary table is drawn as synthesis and benchmark providing stem directions of improvement for each model. This synthesis highlights TDMs differences and the consistency between their structure and the operational needs.

2. Review of TDMs comparisons

Most of the recent literature on transportation models comparison is divided between operational model comparisons and theoretical model comparisons while TDM results comparisons is almost absent in public academic research. But operational models comparisons often focus on transport models dedicated to one aspect of mobility and not to overall urban transportation models, such as automobile ownership or freight transportation models. Second, theoretical models comparisons are often limited to specific transportation models such as Land-Use and Transport Integrated (LUTI) models.

The review of automobile ownership models by de Jong et al. (2004a) is exhaustive and gathers more than thirty-three different models into nine model classes. The comparison is based on sixteen criteria clearly reflecting the different aspects included in each model class. A more recent research by Anowar et al. (2014) provides another interesting framework proposition for automobile ownership model comparisons based on the dynamic/static and the endogenous/exogenous aspects of the models. Moreover Shaygan et al. (2017) also proposes a car ownership model comparison, but based on the different urban environments they are applied to, enhancing the metropolitan characteristics of the field where the models are applied and nurturing international model comparison.

For freight transportation modelling, de Jong et al. (2004b) build their analysis by detailing the methods used on the different steps of four-step models providing practice use cases and development propositions. This classification is interesting but does not facilitate comparing urban transportation models that are not following the four-step model scheme. On a less detailed approach, Tavasszy (2008) links the decision problems encountered by freight modelling to modelling challenges and the general modelling techniques used to answer those challenges. Chow et al. (2010) improved this approach by providing a table showing the policy decisions model types are best for answering at. Freight modelling approaches are theorized in Tavasszy and de Jong (2013)'s handbook.

In order to establish a LUTI model comparison, Wegener (2004) first distinguishes eight urban systems that are mobility choices ranging from long term choices to immediate choices. Models are then ranked according to their way of integrating the different choices faced by individuals. Yet it does not build many criteria for comparisons and it does not draw a summary table synthesizing the analysis and confronting the models. Hunt et al. (2005) push the exercise further with a detailed way of addressing the phenomena represented in the LUTI models and their treatment in the model. Batty (2009) takes a different approach opposing LUTI models class to urban dynamics models class and to cellular automata, agent-based and microsimulation model class. This last approach focuses on technical modelling solutions that are not the core of this research as it does not reflect the mobility aspects integrated in the models.

To conclude this review, there clearly is a lack of recent literature about urban transportation models classification and comparison aiming at showing the essence of the models and their global consistency, even though some interesting comparison frameworks can be found for more focused operational or theoretical models, especially for LUTI models such as in Hunt et al. (2005).

3. An Analysis Grid for Transportation Models

3.1. General organization

A first step before building the grid is to understand why there are several model types that have appeared while the TDM building is rather standardized by Ben-Akiva and Lerman and Ortuzar and Willumsen's handbooks on the academic side, and by institutional guidelines such as the United Kingdom's WebTAGs on transport modelling. Those standard frames rely on a dispatching among three blocks: Supply, Demand and Uses. That structure is therefore found within every model the authors have encountered so far. The model customization by different entities comes from a different way of building each of the blocks. In order to represent every model and how it is customized by each entity, the aimed grid should be organized around the main blocks and detailed within so as to explicitly show models divergences.

To reach this objective, the analytical framework proposed in this paper is built around 4 main criteria blocks from the transportation economics structure: the definition of a spatio-temporal frame, the demand block, the supply block, and the meeting of both demand and supply with the uses. The framework details those blocks with 22 precise criteria in order to show its structure, the mobility behaviors considered and the articulation with the other blocks such as the modalities of the feedback from the uses to the demand and supply blocks.

3.2. Spatio-temporal representation

The spatio-temporal frame representation block defines the perimeter and the level of accuracy of the model. It is divided among 5 criteria:

- The *analysis unit* details whether the model decisions are made at individual, trip or tour scales,
- The *zone modeling* details the number of Traffic Analysis Zones (TAZ) in the model and the average surface and population encompassed in one TAZ. This criterion illustrates the spatial granularity of the model,
- The *external demand modeling* details the treatment of the demand issued out of the spatial framework such as touristic or professional travels and travel from neighboring territories,
- The *time period modeling* details the periods of the day represented,
- The *departure time modeling* details the ways the demand is affected between the time periods and whether modifications of departure times are considered.

3.3. Demand representation

The demand representation block identifies how the demand is generated with the general choice structures, the demand segmentation, the implementation of constraints, and the different specific demand characteristics considered. It is divided among 9 criteria:

- The *mobility choices modeling* details which choices are modeled ranging from long-term choices to immediate choices: residential location, travel, mobility tools ownership, destination, time, mode and route. Mobility tools are defined by Scott and Axhausen (2006) as any equipment that enables traveling, from Public Transit (PT) pass to driver's license and automobile,

- The *decision architecture* details the ordering and the articulation among the mobility choices and the overall model type, whether it is a four-step, an activity-based, a tour-based or another model. It also includes information about demand pivot procedure implementation studied by Daly et al. (2012),
- The *traveler segmentation* details the number of population segments and the socio-economic criteria differentiating those groups,
- The *activity segmentation* details the number of activity segments and the motives differentiating those groups,
- The *budget constraints* detail the consideration of financial constraints when mobility choices are made,
- The *interpersonal relations* constraints detail the consideration of relationship and interaction effects among household members when mobility choices are made such as the constrained mode choice when a household member is already driving the only car owned by the household,
- The *freight demand* details the treatment of freight, whether it is omitted, exogenous or endogenous,
- The *mobility tool ownership* details the treatment of mobility tool choices, whether it is omitted, exogenous or endogenous and which mobility tools are considered,
- The *intermodality* details the treatment of intermodal trips involving a combination of different modes in the same trip, and which combinations are considered.

3.4. Supply representation

The supply representation block illustrates the representation of modes and mobility services and the way the supply of infrastructure and services is represented. It is divided among 5 criteria:

- The *modal coverage* details which mode choices options are considered,
- The *road network representation* details the road network specificities, whether it includes nodes and links, for which mode it is used, if parking difficulties and fares or if congestion are considered,
- The *Public Transit network representation* details the PT network specificities, whether it includes network, line or mission, and if PT vehicles frequencies, price, comfort or congestion are considered,
- The *active modes representation* details whether active modes are omitted or considered without or with specific supply network,
- The *other mobility services representation* details whether mobility services other than PT are omitted or considered without or with specific supply network.

3.5. Uses representation

The uses representation block shows how the interaction between the demand and the supply is translated into traffic generation for the different modes. It is divided among 3 criteria:

- The *car traffic* details the process to dispatch travelers on the car network with exogenous, endogenous, static or dynamic time values for the links,
- The *PT traffic* details the process to dispatch travelers on the PT network with exogenous, endogenous, static or dynamic time values for the links,
- The *other modes traffic* details whether other traffics are considered and how they are processed.

4. Candidate models

It is necessary to first describe the models studied and their socio-technical background before comparing them. Previous research has already assessed the different Paris region TDMs, but the reports of IARUIF by Nguyen-Luong 1998 and of the EXPEDITE 2002 European project only focused on giving development advices without illustrating model comparisons. More recently Garcia Castello (2010) has characterized Paris region TDMs along 4 general classes, but without aiming to compare them. The existing documentation assesses the models independently, but it does not try to confront them against the mobility aspects they are able to reveal. Common denominators for each studied TDM are the use of a shared Paris region passenger mobility survey – called EGT – last conducted in 2010 and the goal to evaluate multimodal scenarios affecting the demand and the transportation supply. The following model descriptions are based on unpublished technical documentation provided by DRIEA, RATP, SNCF Transilien and Ile-de-France Mobilités.

4.1. MODUS

MODUS is an aggregated four-step model developed by the DRIEA IF, a French State agency of the Paris region in charge of implementing French State transportation policies. It was first developed in the 1990s and the last version was launched in 2009. MODUS has been designed to help decision-making and to feed other local administrations, transportation operators and air pollution controller's models. It especially focuses on car flows forecast for a better motorway network representation as DRIEA is a highway operating and managing entity. It is also used for State expertise on road infrastructure projects and large PT projects.

The model structure follows the four-step model scheme. The generation step relies on a linear model, the distribution on a gravity model, the mode choice on a MNL and the assignment step is divided between a PT assignment step and a road network assignment step feeding back on the distribution and mode choice step creating a loop. Freight and external trips are exogenously implemented as additional fixed demand matrices.

MODUS divides the Paris region in 1289 TAZ and 50 additional specific zones dedicated to external flows for airports, interurban train stations and zones at the border of the road network. This zoning describes more accurately the denser urban areas. Two temporal scales are considered: the AM peak-hour and the PM peak-hour. The Car peak-hours are extended to account for a 2.3h AM peak-period and for a 2h PM peak-period. These peak flows are calculated from the daily demand matrix generated by the demand model and then proportionally dispatched over the periods to the ratio observed in the EGT before adding exogenous flows.

Three modes are described at the trip level: car, PT and active modes. The road network was drawn by the DRIEA in 2010. It distinguishes 10 road types on 27,000 links and it is used for the other models. It uses flow-speed relationship diagrams for the different road types that are then adjusted with the last observed data. The PT network is drawn from the Paris region operators' network data. MODUS represents mobility by dividing it into 12 different segments for each mode: 2 user segments differentiating PT dependency; and 6 activity segments differentiating home to work/study trips, work/study to home trips, shop trips, leisure trips, non-work based to home trips and non-home based to work trips. At the end of the demand module Car trips are adjusted reproducing the average occupancy ratio observed with the EGT for the AM or PM peak-period.

The assignment is performed on VISUM's Tribut module, with a feedback on the demand allowing to take into account congestion effects. The PT assignment is similar but without loop taking into account PT congestion.

4.2. GLOBAL

GLOBAL is an aggregated four-step model internally developed by RATP, a French PT operator and infrastructure owner that is the historical operator of the Paris metro system. It was first developed in the 1970s and the last version has been released in 2014. It focuses on PT planning and aims to ensure the qualitative and quantitative supply contracted and to size PT infrastructure investments.

The model structure follows the four-step scheme. The generation step relies on linear models for segment: work related trips, education related trips and other activity related trips. The distribution is made out of the processing of external data while the other activity related trips' distribution involves a gravity model. External trips are added after the distribution step with a log-log model for the emissions and attractions linked to train stations distribution and a zonal pro-rata distribution of emissions and attractions linked to airports.

In GLOBAL, the Paris region is divided among 2294 TAZ that can be adapted to each case study. This zoning respects the administrative borders and is established so that one zone encompasses only one heavy rail stop at most. The centroids have been manually positioned to account for each zone's specific environment. The temporal framework is based on a 2h AM peak-period reduced afterward to 1h to encompass the AM peak-hours, which vary with the location in the region. The AM peak-hour is used for sizing the mobility supply.

The PT network is made of 36,000 links on 1,600 lines operated by 2,000 missions with details about the Level Of Service (LOS), the frequency, and the platform to platform transfer times. The road network is the one set up by the DRIEA. The mode choice at the trip level is modeled using a 2 stages NL model structured with a principal mode choice segmented between long and short trips, and then a second choice level for the minor access and egress mode to PT between active mode and car. The multiple possible paths are considered with a logsum term as described in de Jong et al. 2007.

The road network assignment is performed with a shortest path algorithm taking congestion into account as an exogenous phenomenon and without capacity constraints. The PT assignment is based on a more complex multipath algorithm to account for different perceptions of the generalized cost of a route, unreliable travel times and varying access and egress real length. The PT assignment algorithm assigns stochastic perturbation factors on the network and calculates the shortest path out of 16 different configurations.

4.3. IMPACT

IMPACT is a disaggregated activity-based model developed by Significance and Aecom for RATP. It was first implemented in the 1980s as a model complementary with GLOBAL and the current operating version of IMPACT has been released in 2015. Its main objective is to model transportation policies' socio-economic impacts on the Paris region with a more detailed user-oriented demand representation fostering fare impacts quantifications.

It is organized around two main modules: a demand module and a supply module feeding back the demand module until convergence. A PT pass ownership modelling step is embedded in the demand module while external trips are not endogenously modeled, but their observed share out of every trip from the EGT 2010 is reproduced.

IMPACT is based on the same zonal representation and supply networks as GLOBAL. The day is divided into 5 periods covering the whole day and distinguishing the AM and PM peak periods. A specific Level of Service (LOS) peak matrix is used for the AM peak period and its reverse is used for the PM peak period while a LOS off-peak matrix is assigned to the other time of day periods.

The mobility demand module is divided into 4 sub-modules dealing with 16 activities modeled at the trip level. A first sub-module for mandatory trips based on 5 trips purposes related to work, education – segmented among 3 education levels – or business affairs has input data about home and work/education locations and runs a 2 stages NL mode choice model. A second sub-module for non-mandatory trips based on 8 trips purposes related to shopping – daily, weekly or exceptional –, leisure – conviviality, walk, other – and personal business – nearby or specialist – uses input data to run a 2 stages NL mode-destination choice, including a strata sampling procedure to reduce the destination choice set to 5 zones. After this mode-destination choice, a generation model sub-module forecasts changes in trip frequencies from changes in travel costs or in trip destinations for non-mandatory trips. Finally, a fourth sub-module models the 3 other supplementary trip purposes. Overall 9 modes are modeled: walk, bike, car driver, car passenger, two-wheeled vehicle, bus, rail, bus and rail, PT and car.

Then the supply module is divided among five sub-modules on a simplified highway network – 51 zones and 153 links – as IMPACT focuses on system impacts and not local impacts. A highway congestion sub-module models highway travel costs adjustments, aggregate speeds and congestion measure for the road network; a bus speed sub-module models bus travel costs adjustments; a parking sub-module adjusts highway travel and parking costs; a PT overcrowding sub-module models PT cost adjustments; and a final adjustment sub-module gathers and applies the costs adjustments from the previous supply sub-modules. The total demand is finally compared with the total available supply as a convergence criterion.

4.4. ARES

ARES is a disaggregated tour-based model with a structure very similar to four-step models developed by PTV for SNCF Transilien, the French public commuter train operator in the Paris region. It is developed since 2012 and has been operating since 2014. Its main objective is to analyze urban mobility with a focus on PT – and especially commuter trains – planning and uses.

The model is divided into a supply module, a principal demand module, a freight demand module, an external trips demand module, a road network assignment module and a PT assignment module. The freight demand module is very detailed as it deals with an endogenous freight demand matrix generated by a specific tour-based model, while the external trips demand module adds a fixed demand matrix. Automobile ownership is exogenously considered in the principal demand segmentation following the organization of four-step models with a linear model for the generation and a gravity model for the distribution.

ARES relies on 1478 TAZ with 76 additional zones for external for transits and exchanges, for train stations and airports, and for zones at the border of the road network. The modeled time periods are the AM peak period, the PM peak period and the day.

The mobility supply is made of the base road and PT networks. The latter is detailed with existing vehicle routes and time-schedules. Parking penalties are incorporated in travel costs to account for difficulties and added costs to park a vehicle. 5 modes are considered: walk, bike, PT, car driver and car passenger. Intermodal trips are represented as trips with a principal mode and an access/egress minor mode. The consistency of tours is considered by removing some modes from the choice set depending on the first trip made. The population is segmented among 11 groups based on residence location, automobile ownership and main activity before a mode choice step made with MNL models.

The road network assignment is performed with a car matrix and a truck matrix simultaneously assigned. A pre-assignment is made with 2010 DRIEA flow data, and then the model processes with its own assignment procedure involving a Wardrop equilibrium. The comparison between the observed and calculated flows allowss to get a control procedure to adjust the road network characteristics so that the calculated flows match the observed flows with a fixed error tolerance. The PT assignment is based on a Kirchhoff model to account for non-optimal preferences of generalized time with a maximum number of transfers set to 3. The assignment has a feedback on the demand modules to equilibrate supply and demand and to model congestion.

4.5. ANTONIN

ANTONIN is a disaggregated tour-based model described in Debrincat and Merret-Conti (2016) and developed on Cube by Significance for Ile-de-France Mobilités – the new name of STIF –, the mobility planning authority of the Paris region. The first version of ANTONIN was developed in 2000 and the last version has been released in 2015. Its main objective is to give reliable evaluation of policy, major event and infrastructure projects impacts on the Paris region mobility. It especially focuses on a complete urban mode representation to get a full description of urban mobility.

ANTONIN is built around 5 main modules: a LOS module generating the travel times and costs, a demand module generating activity tours to define the OD matrix at the day level, a time of day module to set the analysis period, a pivot module and an assignment module. The fixed external trip matrix is added after the pivot procedure. Mobility tool set ownership successively featuring driving license, automobile, two-wheeled vehicle and PT pass ownership is endogenously generated in the demand module.

1805 TAZ represent the Paris region respecting administrative borders, natural frontiers, infrastructures and the zone convexity. Each zone has a function unicity linked to the land-use. The zones can be modified to match the study of local projects. Three main periods can be modeled: the AM peak period, the off-peak period and the day. ANTONIN calculates daily OD matrix that are then transformed through factors reproducing the observed shares in the EGT 2010 for the corresponding period of analysis.

The road network has parking constraints details and the PT network has timetables converted into frequencies at the different period of analyzes. PT level of service is calculated with a composite cost to represent the different itinerary opportunities associated with the PT mode. Cost calculation is different for users under and over 55 to account for the influence of age over route choice. 7 modes are represented: walk, bike, PT with walk access, PT with car access, two-wheeled vehicle, car driver and car passenger. Intermodality appears for accessing PT. In the demand module, mobility tools ownership is first modeled with MNL models. Second, home-based trips are generated for 8 activities with a stop-repeat model to determine their number. Then a mode and destination is allocated to each primary tour with a 2 stages NL or 3 stages NL depending on the activities. Finally, secondary tours are generated for 6 activities with the same process. A pivot procedure concludes the demand module to reduce forecast errors from calibration data.

In ANTONIN, the assignment step is still under development. The road network currently uses a Cube module with a shortest path algorithm under capacity constraints. The multipath PT assignment incorporates comfort effects based on a specific Revealed and Stated Preferences survey conducted in the Paris region.

5. Results

The application of the analytical grid yields the comparison table detailed in Table 1. This table efficiently illustrates how mobility is represented in each model. It also puts forward main model's features fit to their operational entities history and operational needs: MODUS has a finer description of the car mode as its assignment feedbacks, which is logical as DRIEA provides expertise on large infrastructure projects; GLOBAL focuses on the peak hour representation used for sizing PT infrastructures and a developed PT assignment procedure illustrating its main use for studying PT infrastructure projects at RATP; IMPACT is activity based and has an extended procedure to accurately evaluate the demand by motives and with some mobility tools modeling showing its objective to forecast regional impacts affecting user demand; ARES especially focuses on the freight demand and its general tour-based and disaggregated approach matches the commuter train operator aim of SNCF Transilien; ANTONIN also has a tour-based and disaggregated approach with a finer demand representation describing diverse modes and mobility tool ownership as Ile-de-France Mobilités is a planning entity for urban mobility.

Three principal model groups can be drawn from this comparison: the four step models group – MODUS and GLOBAL –, the activity model group – IMPACT – and the tour based group – ARES and ANTONIN –. All those models are articulated around the historical car and PT modes they represent with a lot of detail, and account for many phenomena such as congestion, comfort, parking fares and difficulties and transfer costs between stations or modes. The transportation motives are addressed by each model through detailed activity segmentation with at least 6 travel motives dealt with. The temporal representation also yields a lot of results on the peak periods, which are the more stressful for the transportation system. The Paris region zoning is also very detailed and reaches the limits of the available socio-economic data collected at administrative unit zone.

The model confrontation also allows drawing developments potentials for improving the models' ability to provide a full mobility description such as:
Residential location choice as is done with LUTI models and budget constraints. Even though LUTIs are difficult to implement, an efficient calibration of such model could be valuable as Saujot et al. 2016 states; Mobility tool ownership choice that has begun with ANTONIN and IMPACT. It would give information on car fleets evolutions and on PT fare revenues evolutions and could also include interpersonal constraints affecting the availability of each mobility tool in a household; Departure time choice as emerging behaviors seems to indicate a shift of the peak hours with a possible future decrease due to home office practices growth; New mobility services and intermodality representation that are fostering and quickly growing in the Paris region. Bike, ride and car sharing seem to be high potential mobility services to incorporate soon; Dynamic modeling to account for temporal evolutions and to represent the non-optimal situations faced in real-life with intermediary phases where equilibriums are not met. It could also benefit from the availability of real-time traffic data, which is now available from many PT operators.

Table 1. Model Comparison Analytic Table.

BLOCKS AND CRITERIA			**MODUS**	**GLOBAL**	**IMPACT**	**ARES**	**ANTONIN**
Spatio-temporal representation	Analysis unit		Trip	Trip	Trip	Tour	Tour
	Zone	Zone #	1289	2294	2294	1478	1805
		Avg surface	*9.8 km²*	*5.2 km²*	*5.2 km²*	*8.1 km²*	*6.6 km²*
		Avg pop.	*9.3k*	*5.2k*	*5.2k*	*8.1k*	*6.6k*
	External Demand modeling		Exogenous fixed matrix	Exogenous fixed matrix	Reproduction of the observed inner trips share	Exogenous fixed matrix	Exogenous fixed matrix
	Time Period modeling		AM peak period PM peak period Off-peak hour Day	AM peak period reduced to 1h	AM peak period PM peak period 3 Off-peak periods	AM peak period PM peak period Day	AM peak period Day
	Departure Time (DT) modeling		Reproduction of the daily share	One time period modeled	Reproduction of the daily share	Reproduction of the daily share	Reproduction of the daily share
	Modification of DT		*Omitted*	*Omitted*	*Omitted*	*Omitted*	*Elastic for Car*

Demand representation	Mobility Choices	Location	Omitted	Omitted	Omitted	Omitted	Omitted
		Travel	Considered	Considered	Considered	Considered	Considered
		Ownership	Omitted	Omitted	Considered	Omitted	Considered
		Destination	Considered	Considered	Considered	Considered	Considered
		Mode	Considered	Considered	Considered	Considered	Considered
		Time	Omitted	Omitted	Omitted	Considered	Omitted
		Route	Considered	Considered	Considered	Considered	Considered
	Decision Architecture Aggregation level *Feedback and pivot procedure* *Mode choice structure*		**4 step** **aggregated** *Car assignment feedback on Distribution* *Mode choice*	**4 step** **aggregated** *No feedback* *Mode choice*	**Activity based** **disaggregated** *Assignment feedback on Demand* *Mode and Mode x Destination choice*	**Tour based** **disaggregated** *Assignment feedback on Demand* *Mode choice*	**Tour based** **disaggregated** *Assignment feedback on Demand* *Pivot procedure* *Mode x Destination choice*
	Traveler Segmentation *Segmentation criteria*		2 groups *PT dependency*	Omitted	Omitted	16 groups *working, studies, vehicle, location*	2 groups *income*
	Activity Segmentation *Segmentation criteria*		6 motives *work, education, shopping, leisure, home-based*	6 motives *work, education, childcare, other*	16 motives *Mandatory: work, education* *Other: shopping, leisure, other*	8 motives *work, education, shopping, leisure, accompaniment*	13 motives *work, education, shopping, leisure, other*
	Budget Constraints		Omitted	Omitted	Omitted	Omitted	Omitted
	Interpersonal Constraints		Omitted	Omitted	Access to the household car(s)	Omitted	Omitted
	Freight Demand		Exogenous	Omitted	Omitted	Endogenous	Omitted
	Mobility Tool Ownership		Omitted	Flat-rate *Car variable*	Explicit *driving license, car, motorcycle, bike, PT pass modeling*	Omitted	Explicit *driving license, car, motorcycle, PT pass modeling*
	Intermodality		walk x PT within PT	walk/car x PT within PT	walk x PT bus x rail car x PT	walk x PT within PT	walk/car x PT within PT
Supply representation	Modal Coverage		active mode, PT, car	walk, PT, car	walk, bike, bus, rail, PT, motorcycle, car driver, car passenger	walk, bike, PT, car driver, car passenger	walk, bike, PT, motorcycle, car driver, car passenger
	Road Network representation		car links, no nodes congestion	car links, no nodes parking fare and difficulty	car and motorcycle links, no nodes congestion, parking fare	car link, no nodes congestion, bike, parking difficulty	car and motorcycle link, no nodes congestion, parking fare and difficulty
	Public Transit Network representation		line frequency, fare, transfer cost	line frequency, fare, transfer cost	line congestion, frequency, fare, comfort	line congestion, frequency, fare, transfer cost	line congestion, frequency, fare, comfort, transfer cost, age (± 55)
	Active Modes representation		Omitted	Omitted	Omitted	Omitted	Omitted
	Other Mobility Services representation		None	None	None	None	None
Uses representation	Car Traffic		Endogenous static times Wardrop equilibrium Assignment procedure outside the model	Exogenous static times Shortest Path	Endogenous static times Simplified assignment on 51 zones Car-Bus interaction procedure outside the model	Endogenous static times Wardrop equilibrium	Endogenous static times Shortest Path
	PT Traffic		Endogenous static times Kichhoff law Assignment procedure outside the model	Exogenous static time Multipath assignment	Endogenous static times Shortest Path procedure outside the model	Endogenous static times Kirchhoff law	Endogenous static times Multipath assignment
	Other modes Traffic		None	None	None	None	None

6. Conclusion

In order to analyze the expressive power of metropolitan transportation models, this research has developed an analytical framework reflecting the structure of mobility systems and enabling to compare different types of models. The final grid relies on the representation of logical blocks from the economics theory: spatio-temporal framework, demand, supply and uses. Those blocks have been further characterized with 22 criteria not only focusing on technical features but also on the mobility aspects described by each model. The final analytic table resulting from this analysis enables to quickly assess the way TDMs address mobility.

Beside this first main contribution, this paper has applied the analytical framework to five TDMs used in the Paris region, namely MODUS, GLOBAL, IMPACT, ARES and ANTONIN. This application has illustrated the TDMs' capacity to reveal the different mobility choices and mechanics included in the models, and put forward main model features are linked to their operational use. The model confrontation in this table also highlights the mobility aspects that are still lacking from all the models and sheds light on development potentials.

In order to go beyond this paper's conclusion and to give a complete overview of metropolitan models, a first step would be to integrate other LUTI and multiagent models in the analysis. Integrating some metropolitan characteristics such as proposed by Shaygan et al. 2017 would enable to build a framework favoring national and international model comparisons to foster innovative model developments. The analytical grid should finally evolve to account for the new mobility aspects revealed by the models and to illustrate how they are addressed.

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