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Modeling urban goods movement: How to be oriented with so many approaches?

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Abstract

This paper proposes an analysis of the different model construction and development approaches in the context of urban goods movement (UGM). We focus on the model development issues more than on the mathematical tools applied in these models. First, we explore the main UGM models in the field, identifying their main construction schemas and their features limits. From this analysis, we propose a classification of UGM modeling frameworks, synthesizing them on a table that illustrates their construction schemas. Second, we analyze their limits and find a first set of synergies between the different thinking schools. This analysis allows us to highlight the strong points and override their weaknesses, and to propose a set of recommendations for planners and modeling schools in order to find co-operative schemas that improve the models' efficiency.

Keywords: Urban goods movement; modeling approaches; systematic review; multidisciplinarity

1. Introduction

It is usually considered that urban goods transport implies a complex system, including a transport system, infrastructures and urban planning, and the logistic strategies of shippers (including forwarding and supply chain activities, land use and the community environment). The main stakes of urban goods movement (UGM) can be considered from the angle of different standpoints and scales: the reliability of different logistic chains, local traffic growth, local traffic congestion, the economic fabric of urban centers, environmental nuisances (noise, pollutant emissions), the optimal location of urban logistic

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centers, greenhouse gas savings, and also the effects of urban sprawl and changes in consumer behavior. In order to solve the different problems relating to these stakes, many different modeling approaches are implemented and, as can be seen from studying several works, there is no standard method used for modeling UGM 00000. Some recent reviews explore the modeling issues related to UGM, but they focus on the mathematical tools used by the authors and not on the construction schemas and the relation between the modeling approaches and the object the authors want to model.

The aim of this paper is to analyze the different model construction and development approaches in the context of UGM. To this goal, we will explore the main models in the field in order to identify their main construction schemas and their limits then we will discuss their synergies and their articulation to reach common targets. The paper is organized as follows. First, we make an analytical review of the literature, in order to identify the main structural elements that define their construction and development. Then, we will synthesize the UGM models into a table that illustrates their construction schemas. Finally, we propose to analyze their limits and find a first set of synergies between the different thinking schools, in order to highlight the strong points and override their weaknesses.

2. The main approaches for UGM modeling

All modeling approaches consist in reducing the object studied in order to understand the mechanisms involved. The first thing to be done is therefore to identify this object clearly. This identification entails defining the model's scope of application, by stating the objectives, which then makes it possible to determine one or more fundamental variables of observation according to which the model will be built. On the basis of this identification, it is then possible to implement mathematical and computer processing methods to build a model adapted to the object concerned. Here we propose to describe the different models applied to Urban Goods Movements known to us though this scheme of interpretation.

2.1. Function of the model

Several authors have cited and studied urban goods models [2][5][6][10][19][21][31][32][33]. However, the lecture and interpretation of what is a urban goods models is still difficult to unify. For example, several authors mix demand estimation models and vehicle routing optimization approaches [11][28]. Other authors cite optimization and simulation techniques but do not give a special attention to demand estimation [5]. Other authors focus on policy oriented [2]. As we observe, these models have different functions and are not easily comparable without taking into account these fundamental differences. The main categories of models, related to their function, are the following:

- Demand estimation models. Their main aim and function is to estimate the demand of freight in a urban area and to relate this demand to the socio-economic and spatial characteristics of the chosen area.
- Fixed-demand optimization models. These models are related to linear programming and optimization research. Their function is not to estimate the demand to distribute but to optimize the transportation processes and other associated operations. Note that in many works related to city logistics, models of the second category are cited [5][13][31][32]. These models derive from the well-known families of location-routing and vehicle routing problems [13]. The demand is known or estimated with other categories of models.
- Multi-actor simulation models. Like the optimization models, their main function is not to estimate the demand but to simulate the behavior of the involved stakeholders.

- Macro-economic and public decision support models. They deal with the evaluation of actions and solutions for urban goods distribution improvements and are in general dependent on the other proposed models.

In this paper we aim to focus on the first category of models, because they constitute the base of urban goods movement diagnosis and can provide the input data for the other models.

2.2. Model scope and initial objectives

The model's scope of application has to be adapted to the nature of the entities to be modeled in two dimensions, in space and time. For example, the goal of a town planner is to study road and rail transport infrastructures, the construction of logistic platforms, traffic management in existing structures or, lastly, congestion and the measurement of greenhouse gas emissions. On another hand, the goals of private carriers and other stakeholders like real estate companies are more related to profit and cost optimization, although the environmental component starts to be main stake also in the private sector [15].

It is then important to view the objectives of the model in its initial phase. We observe that not all models have the same basic objective, and that three categories of model can be distinguished on the basis of their objectives. The first category is that of diagnostics models, whose prime objective is to provide current and detailed information on the formation of urban goods movements (UGM) in contexts where it is not possible to perform often long and costly surveys. Then there are simulation models that are not always diagnostics models, as several of them rely on hypotheses that are not always linked to current practices. Lastly, the third group gathers models whose objective is to provide decision-aids for studying and analyzing public policies in the areas of transport and territorial development. The allocation of a model to such or such category is not obvious because it can belong to several category in its final use.

2.3. Modeling unit

Whatever the modeling approach chosen, once the objective has been set, it is first necessary to define the variable to be observed and modeled; in other words, in our field this means identifying the factors generating mobility. For example, regarding the transport of persons, the object of observation used for decades has been the transport of an individual. It could also be the departure of each individual from their home or each motive for movement. Each of these choices has a certain number of advantages although results in a series of approximations that have be taken into account.

In goods transport, and more specifically in modeling urban goods transport, two main units of observation are used to perform measurements relating to the object to be modeled. The first category is that of trip models, which unity is the moving (trip) of the vehicle between an origin and a destination point. These models were first used in the 70s for interurban goods transport. According to Gentile and Vigo [11], by analogy with the modeling of the transport of persons, these models estimate the number of trips generated by each zone or each point considered, then an origin-destination matrix (O-D) of the goods is deduced. It is possible to formulate a conversion rule of vehicles in tons transported by a loading.

In order to take into account the specificity of urban goods transport, the object chosen is the round (or the route). Based on vehicle typology, each type being defined by different characteristics and type of activity served, standard rounds are generated for which precise stopping points are deduced with the estimation of the distance traveled for each round. This type of model is used in urban contexts [18][19][30][31].

Another much more widespread approach in urban goods transport consists in taking as object the quantity of goods to be transported, then the rounds are modeled by using methods for the most part stemming from operational research. These models are also known as commodity-based [11], and are commonly used for UGM diagnostics and simulation. In these models, generation takes place at the level of the quantity of goods to be transported. For each area or point considered, their requirements for goods are estimated as a function of demographic, socioeconomic and geographic characteristics, in order to reconstitute the rounds and estimate the number of vehicles required to deliver the goods at these points. The rounds are estimated by using algorithms drawn from operational research, for example by solving a vehicle routing problem for each category of route.

The third approach considers movement as a basic unit. A movement is either a delivery or a pick-up of goods performed with a given vehicle for an establishment [24]. The movement is the event which make possible the link between the logistics behavior of the establishment and the transport system. It is also possible to compare the movement to a shipment that can be tracked throughout the transport chain, although there is a major difference: during its circuit, a shipment can be shipped in several vehicles, just as well as it can in the same vehicle.

2.4. The different model building approaches

Regarding model building, there are two main types of approach, namely “top-down” models and “bottom-up” models. Top-down models are generally built by starting with a formulation or a type of model defined beforehand (for example, the well-known four-step model) which is applied and adapted to available data, and by deriving or modifying it if necessary. Bottom up type models result from detailed analysis of the data collected, often obtained by using methods developed for modeling [3][23]. Returning to top-down models, we can see that a great variety of approaches can be grouped into several meta-models.

Firstly, there are models based on the four-step sequential procedure. These models, often adapted as a function of the unit taken into account, are often organized as follows. The first step is the generation of trips which can be done directly by generating origin trips and then destination trips [17], by analogy with emission and attraction in modeling the transport or persons. This is followed by a distribution step. In these models, two main approaches are used: the first is distribution derived from entropy minimization models. The second, more complex and desegregated, is that used for discrete choice models. The third step (rarely used) is that of round reconstitution. Generally, these models reconstitute rounds by using empirical and statistical procedures, without calling for round simulation algorithms, as they only rely on available databases. The final step comprises the assignment of vehicles to rounds and inserting them, if necessary, in the global urban traffic.

The second group concerns the models that use the round as unit and are also based on a sequential format [30]. These models are often organized in three steps. The first step is that that of round identification, done by defining the point of departure and the different destinations. The second step permits defining the order of delivery in each round, generally by using empirical approaches. In this step, each movement belongs to a round and is characterized by its origin and destination. Finally, assignment is performed in the same way as for the models of the first group.

The third group is derived from round optimization algorithms. They are organized in two phases since they are not designed to estimate global real flows but optimize transport plans. The first consists in estimating the demand to be delivered, on the basis of a generation model used to generate the quantity of goods to be delivered and picked up as a function of the socioeconomic and geographic characteristics of an establishment. Then vehicle round optimization models are applied to this demand. Heuristic algorithms are usually used to solve these optimization problems.

Another variant is that of goods models intended to build rounds for a range of activities without having optimization as an aim. These models are often built in three phases. Firstly, the demand is generated at each point or area of delivery. The demands are then grouped by operator, which can be assimilated with a distribution phase (determination of origins and destinations). Lastly, a round construction algorithm is applied for each vehicle (belonging to an operator). Two types of procedure are often used: algorithms stemming from operational research, as with group 3, or discrete choice models [29]. Generally, these models do not have an assignment phase but it can be assumed that the main methods used for assignment can be applied.

Bottom-up models do not obey predefined structures but are derived from observation. The procedure used by these models is based on the collection of specific and precise data performed according to a method of survey consistent with the structure of the underlying model [8][25]. The construction of such models derives from the analysis of these data. In the first case, the data collected are linked to the object studied, in this case movement. Observing the movement amounts to describing at the same time and place the characteristics of the delivery (type of goods delivered or picked up, its weight, volume and packaging), the type of vehicle used for this operation, the status of the transport operator (work done by the consignee or by the shipper directly, or by a third party), the form and size of the round, and the behavior and logistic environment of the establishment involved. From these data we obtain a univocal relation between the characteristics of each establishment surveyed (type of activity, size) with the transport operator responding to the demand made by the establishment. By performing a typological and statistical analysis of movements, it is possible to link the flows of goods generated by the different activities with the vehicles concerned and the organizations that set them in motion (direct tracking, rounds of different sizes) and thus calculate the kilometers generated by the different types of vehicle in a city. In that case, regression mathematical approach is generally used to define those relations.

The advantage of these models is that they allow the use of invariance and characteristic variables that describe reality clearly on the one hand and building hypotheses of the evolution of the transport system and urban logistics statistically validated against the reference scenario on the other. This is not the case of the models used according to the top-down approach that mostly use data poorly adapted in terms of precision, space and time, and simply because the unit of observation introduced in the model is poorly adapted to the way in which the model functions.

2.5. The choice of granularity

In relation with the elements presented above, another important aspect to be taken into account is the granularity of the model we are developing. The granularity of a model is essential to make the complexity of the phenomena to be modeled understandable without degrading the explanatory capacity of these data. More specifically, it appears important to avoid reducing the explanatory capacity of the data by over-aggregating or desegregating them, as long as the modeling method and the samples allow this. Regarding this, and according to the model, we observe three levels of data aggregation as a function of the model's objectives. Three approaches are predominant in literature: aggregated models, desegregated models and segmented models. Aggregated models are those that use data in an aggregated form, mainly to define O/D couples. Desegregated models are those that use very desegregated data, individuating elemental generation units like the establishment. Segmented models are those that are between the two other categories, using a zonal approach and activity clusters. Finally, micro-simulation models are those that produce desegregated data that allows traffic assignment [8] [16][18] [34].

The choice of a model and its granularity also depends on the computational capacity of the hardware available. For example, a multi-agent model is desegregated, so it needs more memory allocation and sometimes more parallel computing structures than an Econometric aggregated model does. Moreover, a

Land-Use and Transportation Interaction (LUTI) model can require specific GIS software and graphic tools that require high computational power. These aspects have to be taken into account when developing a model. Lastly, choosing a model is greatly influenced by the availability of the data used to fuel it. Disaggregated models are known to require considerable quantities of data. These can be produced by random data generators such as models used for the dynamic traffic simulation, since aggregated models are less data hungry.

2.6. Commercial applications and tools

Contrary to the models and applications devoted to personal transport, only a few commercial tools have been developed from existing models and devoted to urban policy oriented applications. However, mention can be made of three that have been marketed: Wiver [30], then integrated on the Viseva framework [18], Venus [17], Nätra [8] and Freturb [24]. Two of them (Viseva and Venus) are integrated in global traffic models. Another (Freturb) provides results in terms of numbers of movements, vehicles*km, parking time, energy consumption and greenhouse gas emissions over an ordinary week or day. Freturb is used in France and Switzerland, whereas Wiver and Venus are used in Germany. Sales of the other models have been somewhat lower.

3. A classification of UGM models

These observations therefore allow us to define a classification of UGM modeling approaches. In this classification, we have taken into account only the models developed in the context of urban goods movement characterization. On the basis of this classification, we propose a table summarizing the main models described in the literature. Each column corresponds respectively to the following fields:

- *Model:* reference where the model is described. In case of several works describing the same model, the reference one (mainly the first peer reviewed publication) is retained.
- *Scope of application:* the main scope of application, related to both spatial and economics variables and measurements (global or partial).
- *Initial goal:* the main objective of the initial model (diagnostics, simulation, optimization or other decision-aid function).
- *Unit of modeling:* the basic elemental unit of the model (trip, round, commodity, movement or shipment)
- *Model development:* the approach that directs the model development (top-down or bottom-up).
- *Methodological frameworks:* mathematical and methodological approaches used in the model to represent the chosen object.
- *Applications on real cases :* when applicable, real urban areas where the model has been applied.
- *Commercial tools:* when applicable, commercial tools developed from the model.

Table 1. Main scope and goals of the selected models, as well as their corresponding real application and commercial tools

Model	Scope	Initial goals	Real applications	Commercial tools
Sonntag (1985) [32]	Global	Diagnosis / policy oriented	Several German cities	WIVER, VISEVA
Eriksson (1996) [8]	Partial	Forecasting	Oslo, Akerkus	NÄTRA
Routhier and Aubert (1998) [26]	Global	Diagnosis / policy oriented	Several French cities, Geneva	FRETURB
Boerkamps and van Binsbergen (1999) [4]	Partial	Forecasting	Groningen (Nl)	-
Wisetjindawat and Sano (2003) [36]	Partial	Simulation	Tokyo	-
Janssen and Vollmer (2005) [19]	Partial	Diagnosis	Several German cities	VENUS
Russo and Carteni (2006) [28]	Partial	Simulation	Campania Region	-
Gentile and Vigo (2007) [11]	Partial	Diagnosis	Several Italian cities	-
Holguín-Veras and Patil (2007) [17]	Partial	Local diagnosis	Guatemala city	-
Filippi et al. (2010) [10]	Global	Forecasting / policy oriented	Rome	-
Muñuzuri et al. (2010) [23]	Partial	Simulation	Sevilla	-

Table 2. Main modeling development characteristics of the selected models

Model	Modeling unit	Model development	Methodological frameworks
Sonntag (1985) [32]	Round	Bottom-up	Round generation and trip estimation (savings function)
Eriksson (1996) [8]	Trip	Bottom-up	Demand generation and trip distribution
Routhier and Aubert (1998) [26]	Movement	Bottom-up	Demand generation, round estimation and distribution
Boerkamps and van Binsbergen (1999) [4]	Commodity	Mixed	Probabilistic generation, round estimation and trip distribution
Wisetjindawat and Sano (2003) [36]	Commodity	Top-down	Four-step model adapted to commodity; microsimulation approach
Janssen and Vollmer (2005) [19]	Trip	Top-down	O/D estimation
Russo and Carteni (2006) [28]	Route	Top-down	Demand generation (commodity) and trip distribution
Gentile and Vigo (2007) [11]	Commodity	Mixed	Demand generation
Holguín-Veras and Patil (2007) [17]	Commodity	Top-down	Demand generation and O/D estimation
Filippi et al. (2010) [10]	Commodity	Top-down	Demand generation and discrete choice O/D estimation
Muñuzuri et al. (2010) [23]	Shipment	Mixed	Demand generation and O/D macroscopic estimation

4. Synergies and barriers between the different disciplines

After having presented the main models and their structural issues, we want to focus on their synergies and barriers. Most of the models result from the application to UGM of modeling frameworks developed on the context of person or interurban freight transport. Only few models [24][30] follow the idea that urban goods present several specificities that make them different to classical freight transport, in terms of modeling approaches.

The main specificity of Urban goods movement derives from the fact that urban goods flows are subjected to different organization patterns with respect to classical interurban transport : about 75% of the deliveries and pick-ups are carried out in rounds of very different size and the 25% remaining are direct trips. A wide range of vehicle sizes are involved. Own account (by consignee and consignors) represents more than 50% of the total number of pickup and delivery operations. There is a wide variety of loading and packaging units. Moreover, the sources of productivity carried out by the goods movement are often few dependant on transport optimization: for example, a craftsman could make himself a long and costly transport by himself in order to find the materials which fit at the time and place he needs. That is the first reason for what there is today a lot of UGM modeling approaches according to the different objectives.

Another fact is that it is not easy to define a simple relationship between goods flows and vehicle flows: according to the different situations, the relationship between Ton.km and Vehicle.km are very different. The first consequence is that the commodity flows as model unit, commonly used in the top-down models, are not easily converted in vehicle flows. The case is more easy in the interurban goods transport where most vehicles are big heavy vehicles, with a load average settled.

Thus we now analyze the limits of these models related to the unit of measurement used. The round can be considered as a composite object as it contains several trips and thus several destinations for goods. Each of these trips is a link of the entire round with the same transport company, the same vehicle, same driver, etc.), and generating them separately implies a large number of approximations. Trip models are based on O/D matrix definition. By generating O/D matrixes by analogy with the transport of persons, the first approximation amounts to not taking into account the relation between the trips of the same round. This makes the construction of rounds more random, making it necessary to build them a posteriori. The second approximation amounts to assimilating the movement of goods with that of persons. However, there are several differences between these two types of transport. Trip models suppose that rounds of urban goods vehicles can be obtained by applying a conversion rule. This rule supposes that goods vehicles have more or less the same capacity. This is the case with interurban transport for which most of the vehicles are semi-trailers with a useful load of about 25 tons. However, urban goods vehicles are not standard [3] and are in general smaller, more heterogeneous and less optimized. For this reason many authors stated that trip models are not adapted to UGM diagnosis and simulation [11][17].

Commodity models are often related to operations research. More specifically, a vehicle routing problem (VRP) is solved for each category of vehicles. This leads to considerable approximations, since although this type of algorithm is often included in the software used for optimizing transport with respect to the best known problems, their use is only possible in the framework of two main hypotheses: the first assumes that transport is organized in rounds, with types of organization specific to serving a third party. However, according to the results of UGM surveys, 25% of trips are direct, mostly made by the shippers (consignors or consignees) themselves. The second condition is that the transport considered obeys the rationale of optimization, which in many cases does not reflect real situations. This raises the question of the capacity of these models to satisfy social demand. On the one hand, most of the algorithms proposed in these models are sophisticated formulae rarely used in commercial packages which use simple and fast algorithms. On the other hand, very few urban transport operators use this type of software application, or else they use them for medium term transport plans to identify potential rounds that will be modified during current operations as a function of daily demand. Shipment models seem not to be adapted to urban areas. Indeed, no shipment models have been proposed in literature for UGM characterization. Moreover, in data collection, we can state the limits of using shipment as a measurement unit in the urban environment.

Movement and round models seem the most adapted to UGM problematics. However, each approach has its limits, more precisely related to the quantity of data that is enough to ensure a good accuracy in the estimation. This fact is also related to mathematical and methodological approaches. Concerning it, we can state the following issues:

- *Trip modeling procedures*: This category of models are developed analogously to classical four steps models for person transport. However, this approach can be useful in simulation for some categories of establishments and services, for example for e-commerce or express courier demand generation.
- *Discrete choice approaches*: it is good to use it in simulation (for hypothetical future trends and changes) but other methods seem to better approximate the current situation.
- *Operations research algorithms*: computational times (very good methods, including metaheuristics, need big computational times and it is not always possible to wait more than few minutes for the simulation). Moreover, real transportation management systems use fast heuristics and do not implement very complex algorithms. Another limit is that of using these methods for diagnosis. Indeed, these methods are carrier oriented and, according to many surveys, in current practices we can find several organization schemes, not all of them that follow an optimization approach. This heterogeneity is due to the fact that the number of choice criteria of the overall operators is so high that it is impossible to apply a system optimization approach to model the current situation at the urban scale. To this, we must also consider the external factors that play an important role in the global equilibrium of urban goods transport.
- *Bottom-up models*: This approach is good for diagnosis in the current context, since they are based on detailed real information. Such approach seems to be the only one able to take into account the diversity of urban reality. However, their main limit is that they consider current practices so simulation seems limited to scenarios similar to the existing situations or that can be adapted to this model's input data.

Moreover, the applied methodologies are strongly dependant on the academic schools, related to scientific disciplines, as for example: statistics and empirical researches (inferential statistics models), mathematical formalisms (analysis), computer sciences and algorithmic research (computation theory). Each model takes its basis from these categories. However, these disciplines are seldom communicating and they can seem to follow opposite directions in modeling the urban goods movement.

Lastly, the methodologies applied are strongly dependent on academic schools of thought and scientific disciplines, for example: statistics and empirical research (inferential statistics models), mathematical formalism (analysis), computer science and algorithmic research (computation theory). Each model takes its basis from these categories. However, these disciplines seldom communicate with each other and can appear to follow opposite directions when modeling urban goods movements.

5. Conclusion

This paper explored the main model construction and development schemes used in UGM characterization. From this analysis, two major schools of thought can be identified. Mathematical formalism dictates how reality is represented: the model is defined according to a theoretical plan, according to hypotheses which are not overall verified in the current situations. For example, route optimization is not everywhere the effective rule for a lot of actors which main work is not the transport. This requires making strong hypotheses on the nature of the reality to be modeled. That concerns essentially top down approaches. On another hand, observation of an existing situation orients mathematical formalism: the model is developed by using data measured and then interpreted in terms of mathematical expressions. The adjustment bottom-up approaches belong to this school.

Moreover, we have highlighted several disciplines and angles of attack that are not necessarily contradictory and which may be associated in a meta-model. Two models (Freturb and Wiver) can be used to identify an initial situation with usual methods. A round optimization model permits simulating the behavior of certain companies (though not all). The obtained results do not describe current situation, but the best one. By using discrete choices it is possible to simulate scenarios on the basis of declared preferences (through surveys or other means). Data are available for use in global models adapted to the issue of UGM. It is preferable to implement them.

In cases where no field data exist, or if costs are prohibitive, it is better to use models that have already been calibrated as a function of behaviors described elsewhere. For example, Freturb, but also all the other models [22].

Finally, we want to propose several research guidelines and recommendations. Modeling is not possible without knowledge of the existing situation, with in particular knowledge of that which is subject to change and that which is invariable. The best unit of observation must be as rich as possible in terms of quality and quality of information (a good unit of measurement and a good "lens" for observing reality).

It is advisable to generate synergy between the different disciplines and approaches in view to seeking the invariants to be used in the models before attempting to optimize partial situations whose global impacts are difficult to measure afterwards. We can propose today two examples of recent approaches. A first approach is that of mixing two models in order to optimize the number and the location of the delivery areas in France [6]. Another example that leads to an interesting meta-model is that of the European project CITYMOVE [1]. In order to optimize the performance of a new vehicle concept, it seems necessary to immerse it in the current flows of other vehicles in a real situation thanks to a dynamic traffic modeling system (for example a multi-agent flows model). In order to fit the reality, the current behavior of the vehicle-agents has to be simulated thanks to a bottom-up model calibrated on reference data. This project aims to develop an innovative integrated vehicle solution fitting with the integrated city transport solution approach for a secure, flexible, reliable, clean, energy efficient and safe road transportation of goods across European cities, having also a significant impact on reduction of CO_2 emissions and improvement in terms of safety and security.

We believe that the mixing of several existing models is a promising approach. However that needs to consider new challenges: to develop interaction procedures between each model in space, period and time, to develop data collection fitting with the global problem and to make possible the exchange between the various schools and languages of the stakeholders involved in the project.

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