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# AN ALTERNATIVE UGM PARADIGM TO O-D MATRICES: THE FRETURB MODEL

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## ABSTRACT

This paper presents an alternative methodological approach to O-D matrix and analyses its validity on the viewpoint of Bonnafous' operability triangle. The proposed model is able to estimate the impacts of urban goods movements in terms of number of vehicles, total travelled distances and road occupancy rates without generating O-D pairs. The originality of the model arises on two main elements. The first is that the modelling unit is neither the trip nor the quantity of goods, as in many literature works, but the number of movements, i.e. the number of pickup and delivery operations, which is found as the main invariant in urban goods movement generation. The second is that it follows a bottom-up approach, i.e., starting from a rich database of urban goods operations and routes, a set of behavioural functions are defined. The paper is organised with the notion of operability triangle: the model must be at the same time coherent, relevant and measurable. This analysis allows to show how the model FRETURB resolves this problem of magic triangle and also how it was resolved up to here by the various forms of modelling of the urban freight in literature.

*Keywords: urban goods modelling, statistical analysis, operability triangle, road occupancy*

## INTRODUCTION

Our knowledge of urban passenger transport, in particular regarding our capacity to model it, is clearly more advanced than our knowledge of urban goods transport. Thus a range of operational models is now available for passenger transport that relies on knowledge and formalisms that have become standardised over several decades. This standard is expressed, for example, by the fact that four models now take up most of the European market for traffic models (Visem/Visum1, Cube2, TransCAD3 and Emme34). However, we are far from having as many instruments available for modelling urban freight.

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[1] From PTV (RFA).
[2] From Citilabs (USA).

The purpose of this article is to present how this gap in knowledge of urban goods transport has been partially filled over the past few years. Indeed, a direction has been taken recently with the FRETURB model, leading to a new family of models, delivery models (Russo & Comi, 2010).

Initially presented in 1998 at the 8th WCTR at Antwerp (Routhier and Aubert, 1999) and subject to regular development since, this model permits reproducing and simulating urban traffic linked to goods transport with exogenous variables whose values are generally available in the current statistical databases of urban areas. This means that the model can be integrated without performing an *ad hoc* statistical survey on goods transport, explaining why it has been possible to apply it to forty French cities, two Swiss ones, and that it is currently being implemented in Belgium and Italy.

Observing that too little was known about urban goods transport, in the 1990s the French government decided to implement a vast national research programme called “Goods in the City”. This programme planned for the funding of a major survey whose design was entrusted to the LET (Laboratory of Transport Economics).

To perform this preliminary methodological reflection, we started from a simple observation: the relative efficiency of surveys on personal mobility that fuel urban mobility models relied on the fact that these surveys were designed progressively as according to the specifications of the models. Thus there was a strong correlation between the increasingly less questionable pertinence of successive models and that of statistical information. A historic pact was therefore achieved between surveys and models, since the success of one mutually strengthens the other.

The reflection requested in the framework of designing a novel survey consisted in achieving a comparable pact. This demanded sketching out a model of urban goods transport. We only knew that it could not be a simple transposition of interregional freight models since every attempt in this direction had failed: they had all come up against the obvious fact that a model that simulated tons or tons-kilometers made no sense in a space where a ton of freight can sometimes be transported as a single batch, for example, a pallet of mineral water, and sometimes in thousands of lots, for example, as drugs delivered daily to chemists’.

Since the objective of a possible model was not, obviously, to formalise and then simulate a flow of goods measured in tons or in tons-kilometres, what could it be? This objective was simply to treat the economic problem which is, by definition, one of scarcity, in this case scarcity of road space, aggravated by delivery activities. Hence a simple objective for a survey and the model it must fuel: it has to analyse and formalise road occupancy by urban goods transport activity with the intuition that this occupancy results from both the mobility of the vehicle and from its being parked on the road during delivery (or when picking up goods). This intuitive hypothesis, which should to a great extent be validated (Bonnafous, 2001), naturally leads to *choosing the “movement”, i.e. the delivery or pickup, as the unit of observation,* in the model and the survey it requires.

We start in section 2 by presenting the formalisation of the FRETURB model in the form of a theoretical sketch of the model that determined the content of the surveys performed in three French cities of different sizes. We then present in section 3 the nature of the surveys

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[3] From Caliper Corporation (USA).
[4] From INRO (Canada).

required to validate such a model and estimate the parameters. Section 4 is devoted to presenting some of the results of these surveys, in particular those that confer a degree of operationality to the FRETURB model. In section 5, we attempt to better understand why this operationality, long provided by passenger transport models, has been prevented by specific obstacles related to urban goods transport. Lastly, in section 6, we analyse which methodological procedures have (or do not have) conferred operationality to the many UGM produced by the scientific community up to now.

# THE SPECIFICATIONS OF FRETURB

The sketch of the model used as the basis for the surveys was less precise than that which followed, in particular regarding the hypotheses that underlie its specifications (Routhier and Toilier, 2007). It should be recalled that this sketch was derived from two essential elements of the model which are:

- its objective which is to depict and then simulate road occupation by a vehicle whether at standstill for a delivery or in circulation;
- a unit of observation from which this road occupation can be reconstituted and which is *the event corresponding to a delivery or pickup of goods*. Regarding what follows, paradoxically, this event will be called “movement”. The paradoxical nature stems from the fact that during this movement (delivery or pickup of goods), the vehicle is at standstill!

Our first hypothesis is that the average weekly number of trips $m_e$ of firm *e* is assumed to take the form:

$$m_e=\varphi(a,w,p)+\varepsilon_e \qquad [1]$$

where :*a* is the category of activity of the firm (45 activities distinguished);

*w* designates a class of workforce;

*p* is an index that distinguishes different functions of the premises served (shops, warehouses, offices, head office).

$\varepsilon_e$ is a residual term that expresses that relation [1] is not an exact equation.

In all the relations that follow, we shall omit the residual terms to reduce the size of the equations, although it is obvious that, as with any transport model, we are working within the logic of behavioural equations and not accounting ones. The model’s pertinence is highlighted by the fact that the variances of these residual terms are negligible in comparison to the variances of the variables to be explained. The surveys presented in the next section have confirmed this pertinence as we shall see in section 4 for crucial elements of the model. The three variables that determine the number of movements for the firm concerned are of course not independent: if the firm is a chemist’s, there is little chance that it will have several dozen employees; on the other hand if it is a hypermarket, there is little chance that it will have fewer than 10 employees. Thus if we combine the three criteria by assuming that 45 activities of firms are distinguished, 10 classes of workforce and 4 premises functions, then there are theoretically 1800 possible combinations. In reality, the surveys showed that only 116 of these 1800 combinations correspond to non-empty subassemblies.

This therefore leads us to partition all the firms:

$E = \{E_1, E_2, \ldots E_c, \ldots E_C\}$ such that:

$e \in E_c \Rightarrow m_e = m_c = \varphi(a_c, w_c, p_c)$ [2]

Where $a_c$, $w_c$ and $p_c$ are particular values of three variables for a firm of category *c*.

We note $s_{z,c}$ the number of category *c* firms belonging to zone *z* of the city, so that the breakdown of firms by zone and by category is expressed by a matrix of localisation in the urban space **S**:

$\mathbf{S} = s_{z,,c[[1,Z]],[[1,C]]}$

Equation [2] permits expressing the number of movements generated by zone $m_{zc}$:

$m_{z,,c} = s_{z,,c} \times m_c$

This permits defining a matrix of movements by zone *z* and by category *c*:

$\mathbf{M} = m_{z,,c}$

Once an exhaustive file of firms by zone is available, including for each the values of variables *a, w* and *p*, and the parameters of equation [2] have been estimated, matrix **M** of movements is known. The aim is then to deduce what these movements involve in terms of occupancy of road space, which remains the objective of the model. To pass from the unit of observation corresponding to the movement to an occupation of road linked to parked vehicles or vehicles in ccirculation, we hypothesise that it is necessary to take into account the characteristics of the operator responsible for the trip. It is relatively easy to understand that ten deliveries performed by a transporter (for a third party account) in the same round will involve far fewer vehicle-kilometres than if each delivery were performed directly, which is frequently the case when operating on one's own account. It is also clear that the occupation of the road linked to a delivery stop differs according to whether it is ensured by a heavy goods truck or by a small vehicle.

The surveys showed that for this double aspect of road occupancy, movement and driving, the most decisive characteristics are:

- the type of vehicle used (utility vehicles less than 3.5 tons, straight trucks, semi-trailers);
- the management mode (own or third party account);
- organisation "single leg delivery", with one trip, or by round with several trips.

The combination of these factors thus leads to 12 logistical categories of operator that will be identified by the index *l*. There is a relation between the category of firm *c* and the nature of the operator ensuring the movement: a chemist's is rarely supplied by a heavy goods truck whereas the latter ensures almost all the deliveries to certain types of firm. We also assume that each category *c* of firm is served by a logistic category *l* of an operator according to a frequency $f_{c,l}$ independent of the zone to which the firm belongs. Hence we use a matrix of logistic frequency:

$\mathbf{L} = f_{c,l}$

The phenomenon of generating movements by zone and by logistic category is therefore written as:

$\mathbf{G} = \mathbf{M.L} = g_{z,l}$ [3]

The generation matrix **G** is used to establish the usage of the road involved by these movements. More specifically, the aim is to determine:

- road occupancy linked to movements, *i.e.* delivery or pick-up stops, which is measured in hours-vehicles (passenger car equivalent);
- road occupancy linked to trips, which are measured in vehicles-km (passenger car equivalent), which is easily expressed in hours-vehicles when the speeds are known.

Regarding the first aspect of this road space "consumption", each logistic category of movement *l* implies an average road usage time denoted $t_{z,l}$, which is assumed variable according to the zones of the conurbation but assumed constant for the same zone and the same category of movement. In reality, this hypothesis of constant duration results in an average value between stops in spaces on and off the road. The former are usual in sparse zones whereas the latter are more frequent in dense zones. Thus the total stopping time on roads in zone *z* is written as:

$$T_z = \sum_l g_{z,l} . t_{z,l} \qquad [4]$$

When implementing the model in practice, the values of $t_{zd}$ will be distinguished according to major categories of zones (for example, from very dense to sparse) and according to the category of vehicle used so as to measure this road occupation in hours-vehicles (passenger car equivalent[5]).

Regarding the second aspect of spatial consumption linked to the trip of delivery vehicles, the aim is to reconstitute the consequences of logistic categories *l* on the trips that each category can cause. For example, it is clear that a logistic operation that includes ten deliveries in the same round will generate far fewer vehicle-kilometres than ten single leg deliveries with as many return trips. Likewise, in the case of making a final estimation of road usage rounded to the same unit (passenger car equivalent), the measurement will differ as a function of the size of the vehicles distinguished by logistic categories *l*.

- We denote:
  - $\partial_{z,l}$ the distance of the average trip induced by a movement generated in zone *z* involving logistic *l*,
  - $\partial^*_{z,l}$ the average distance of the first and last trips involved by a movement generated in zone *z* with logistic *l,*
  - $\partial^{**}_{z,l}$ the average distance between two points of successive deliveries (called connectors) of the same round, the first connector being in zone *z* and the delivery involving logistic category *l*,
  - $n_l$ the average number of connectors in logistic category *l.*

Thus we can write:

$$\partial_{z,l} = \frac{1}{n_l}(2\partial^*_{z,l} + (n_l - 1)\partial^{**}_{z,l}) \qquad [5]$$

With a single leg delivery, when $n_l = 1$, we obtain the trivial result: $\partial_{z,l} = 2\partial^*_{z,l}$. When $n_l > 1$, the distance of transport involved on average by a movement generated in zone *z* and with

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[5] A light goods vehicle (LGV) = 1.5 PVE (passenger vehicle equivalent); rigid truck = 2 PVE; semi-trailer = 2.5 PVE.

logistic *l* does not raise a problem of addition with the distances involved by all the other trips once the averages of the terms on the right of equation [5] can be estimated satisfactorily, as will be mentioned in section 4.

Using matrix **G** of the generation of movements defined by equations [3] and [5], we therefore obtain, for the total movements generated by zone and logistic category:

$$d_{z,l} = g_{z,l}.\delta_{z,l} \qquad [6]$$

Obviously, when the traffic flow speeds are known, the conversion of vehicle-kilometres into vehicle-hours does not constitute a problem and this result has the merit of being added with that of equation [4]. To be pertinent, however, this global result assumes that the vehicle-kilometres generated are spatialised and, more generally, assigned to the network. This corresponds to the developments of FRETURB which was implemented in different urban configurations[6] (Routhier, Toilier, 2007). This assignment step is not described here.

Nonetheless, prior to this assignment, using equation [6] or the equation derived in terms of time, different summations can be performed that can consist in grouping generations of trips for groups of zones, such as a shopping district or city centre, or the macroscopic result can be considered for the entire urban area. What remains important for the model is that it conforms to its objectives and that it permits simulating the consequences of a contextual change on road congestion, for example:

- a policy of greater warehouse centralisation (reduction of $\partial^{*}_{z,l}$) ;
- changes in the regulations on delivery times (which act on the breakdowns of $g_{z,l}$ as a function of time slots);
- an incentive to develop transport for the account of third parties (higher values of $n_l$);
- changes in the regulations on authorised vehicles (different logistic frequencies for the size of vehicles);
- a policy favouring cooperation between transporters operating within the same territory (higher values of $n_l$) ;
- the development of night deliveries (higher values of $n_l$ and increased speeds);
- etc.

The contribution of FRETURB with this type of simulation depends in particular on this model being implemented in a city that has not conducted a specific survey on urban goods transport but which does have a file of business localisations. In order to ensure that the model can be extrapolated to other environments, it is advisable to check that it includes invariants that are transposable from one city to another or else easily calculated. This returns us to the surveys that fuelled the model.

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[6] The reports on developments of FRETURB implemented with an assignement on the network in Genève, Zurich and Paris (Région Ile-de-France), are not published yet.

# THE SURVEYS USED TO FUEL AND VALIDATE THE MODEL

The national research programme "Goods in the city" planned for a major survey, as mentioned previously. A large number of attempts had been made previously (Ambrosini and Routhier, 2004; Allen *et al.*, 2012). The fact that they had failed to elucidate the mechanism involved satisfactorily, was because these surveys most frequently focused on a single unit of observation (the transport of a certain weight between an origin and a destination) which was undoubtedly pertinent for interregional transport but not very useful, to our knowledge, on goods in an urban environment, especially regarding road congestion. Hence the methodological choice of consisting in modelling parking and trips represented in the following figure, in order to present the effects on road use of trips between two places of movement (shipment or delivery) and the information required.

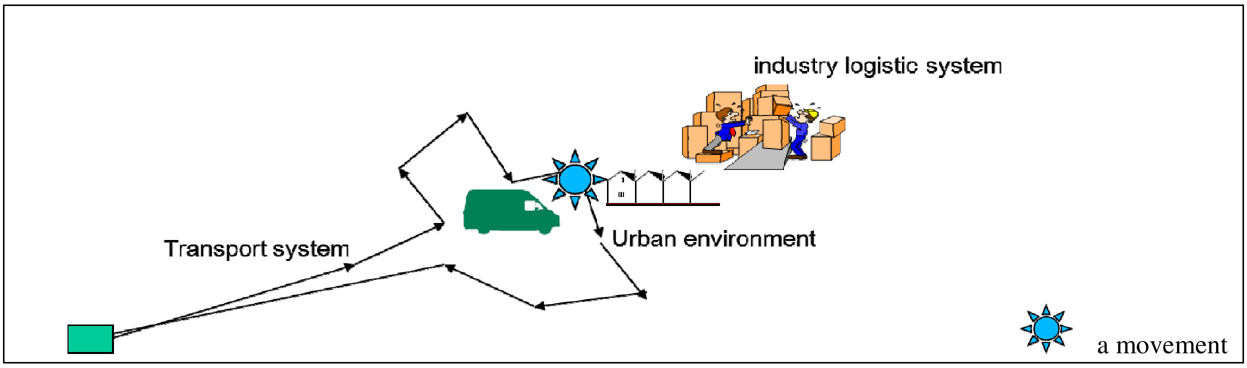

Figure 1 – The movement, a pertinent statistical unit of observation

Two types of information are involved. The first is related to the stopping of the vehicle during the delivery: time, place, duration, in a reserved space or on the road, the size of the vehicle, etc. The second is related to the trips linked to the sequence of movements: distances, round organisation, times, etc. It then appeared that to fuel useful quantitative analyses and a delivery model in particular, it was necessary to organise *a delivery survey for which the unit of observation could only be the movement.*

These surveys were conducted in France in 1995-1997[7] in three cities: Marseille, Bordeaux and Dijon[8]. These cities were chosen due to the variety of their sizes[9], and also because their local administrations volunteered to participate in this research. These surveys addressed firms that shipped and received goods and drivers that ensured the transport. They therefore included two sections. The first provided a precise description of the firm's activity as well as all the movements (goods deliveries and pickups) made by this firm over a full week. For the second section, each of the drivers who visited a firm received a questionnaire that permitted describing their vehicle, the round, its stops and the goods delivered at each delivery and pickup points on the round.

For both the firm and driver, the information was collected at the place where contact existed between these two actors: the place of movement. It was therefore possible to capture simultaneously information on three fundamental elements of understanding urban goods

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[7] A new wave of surveys is currently in progress assisted by the same researchers from LET in the Paris region (spatial scale NUTS 3) and again in Bordeaux and Marseille.

[8] Spatial scale: LAU 1 (Patier and Routhier, 2009).

[9] Marseille (1,050,000 inhabitants), Bordeaux (750,000) and Dijon (240,000).

transport: the logistic organisation of companies at firm level, the environment of the loading and unloading points and the organisation of transport. All the elements, in fact, which allowed fuelling and validating the equations presented in the previous section.
To ensure good statistical representativeness, the firms surveyed were drawn from an official register and stratified as a function of the characteristics used to build equation [2]:

- their activity (45 types of activity codified on the basis of the European nomenclature NACE700),
- the number of employees reflecting the size of the firm,
- the type of premises in which the firm is located.

This led to the construction of a database for the three cities that described all the delivery and pickup operations of 4400 firms, associated with the description of 2200 driver circuits.

# A FEW RESULTS RELATING TO THE HYPOTHESES UNDERLYING THE MODEL

We present here the results that permitted validating the hypotheses underlying the model presented above and estimating the determinants of the three essential variables of the model, *i.e.* the number of movements, the durations of parking and the average distances generated by these movements.
*Concerning the estimation of the number of movements*, the aim is to verify the pertinence and calibrate the parameters of equation [2]. The surveys made it possible to confirm that, in category *c,* the weekly number of movements $m_c$ was correctly explained by its class of activity $a_c$, its class of workforce $w_c$ and the function of the premises $p_c$. If we consider, for example, the category of activity "retail trade", the weekly number of movements per firm is a regular function of the class of workforce, as shown in figure 2. We also observed that this function is independent of the city surveyed.

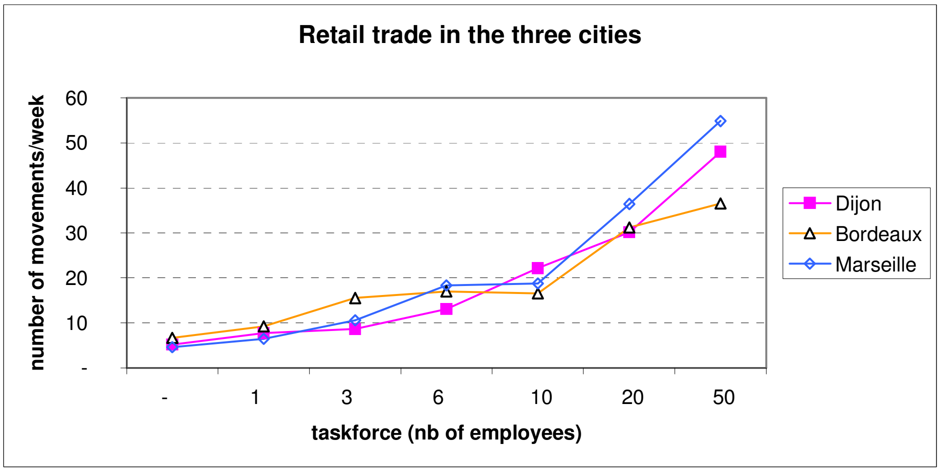

Figure 2 – Number of weekly movements as a function of the class of workforce (retail trade in the three cities)

If we consider the role that the sector of activity plays in the generation of movements, we obtain a confirmation of the pertinence of this explanatory variable, as shown in figure 3 which presents the phenomenon of trip generation by employee.

Here we have grouped the 45 categories of activity into 8 classes. Some of them bring into relief major differences between the cities, for example, for the activity "wholesale trade - warehouses": we counted 4.3 trips per week per employee in Marseille, 4 in Bordeaux and only 3 in Dijon. This was due to a structural effect due to the grouping of firms independently of their size. However, the three cities have different distributions for this factor: the seaport tradition of Marseille and Bordeaux has led to them to conserve a very large number of warehouses. Consequently, using the number of firms by class *c* known for each city with precision, equation [2] reflects such effects of structure.

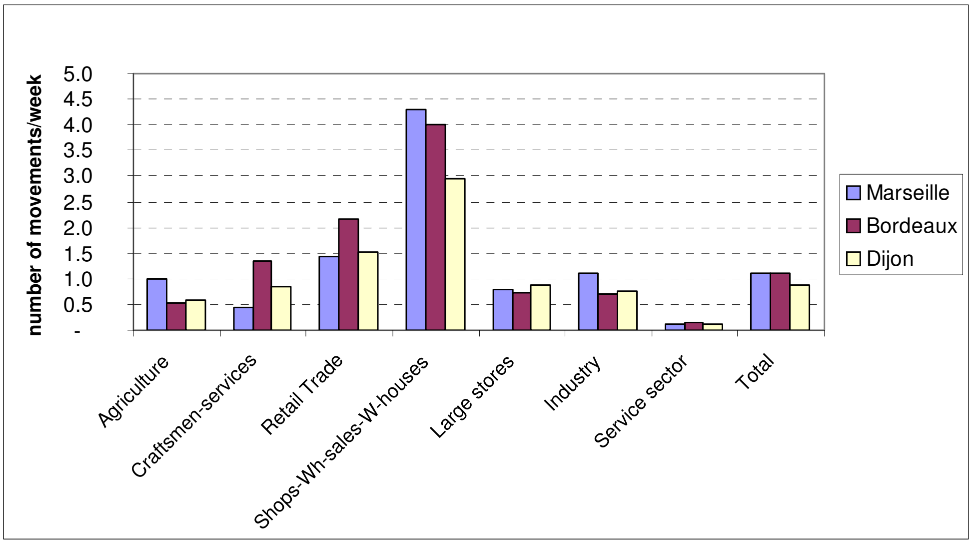

Figure 3 – Number of movements per week per employee as a function of the activity of firms

*Regarding the estimation of parking durations,* this is a crucial component of the model since the surveys showed clearly that these durations, with a stop on the road in a city centre, could lead to greater congestion than that caused by the circulation of delivery vehicles. It was therefore important to validate the hypotheses underlying equation [4], especially that concerning the logistic categories *l* which involve three types of vehicle.

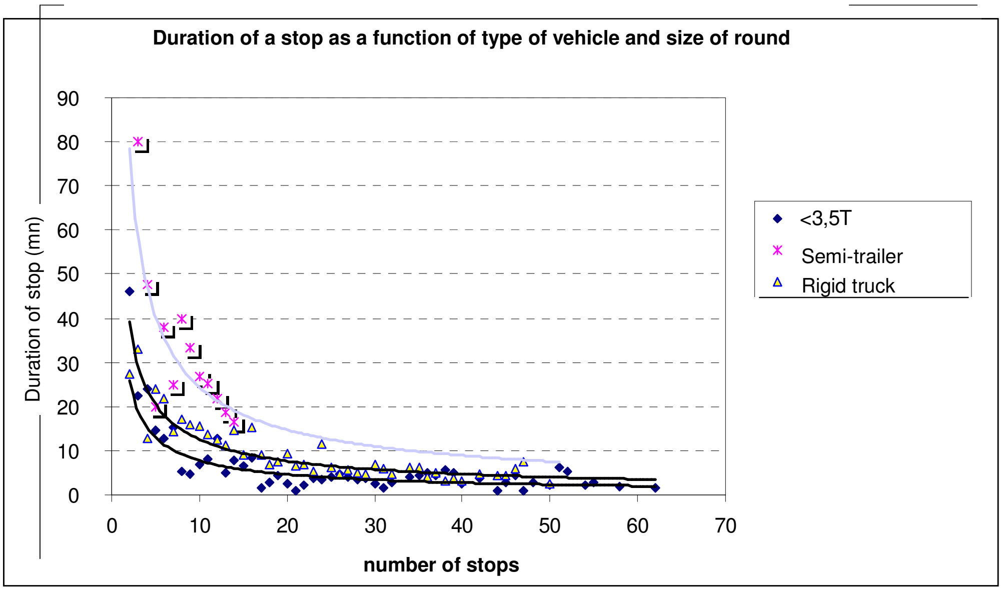

Figure 4 – Duration of parking and number of stops as a function of type of vehicle

Figure 4 represents the average durations of stops in the three cities according to the type of vehicle and the size of the round. It confirms the need to take into account the type of vehicle and the resulting regularities.

Thus knowledge of the logistic categories *l*, especially the type of vehicle and the type of circuit (single leg or round trip deliveries) permits estimating parking durations $t_{z,l}$ for each movement in a given zone (central or sparse). All the elements of equation [4] are therefore measurable.

*Regarding the estimation of distances*, the aim is in particular to calculate variables $\partial^{*}_{z,l}$ and $\partial^{**}_{z,l}$ of equation [5]. The first represents the average distance of the first and last legs $\partial^{*}_{z,l}$ of a round. It is correlated with the distance of the zone concerned from the centre of gravity of the city as shown in the figure 5.

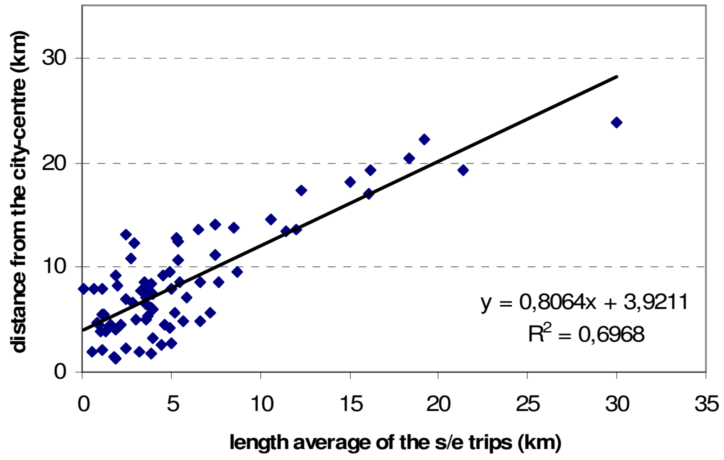

Figure 5 – Average length of the first/last legs as a function of the distance to the centre.

The distance of single leg deliveries ($\partial^{*}_{z,l}$ for $n_l$=1) is correlated with the radius of the city (weighted by the number of movements):

Table 1 –: average distance of a single leg and radius of the city

| | Weighted radius of the Town (km) | Average distance of a single leg (km) |
|---|---|---|
| Marseille (568 km²) | 8.8 | 18.2 |
| Bordeaux (928 km²) | 6.3 | 11.7 |
| Dijon (161 km²) | 3.6 | 5.1 |

Urban morphology therefore influences these distances in the following way: the larger the city, the more the average distances per trip increase, whether for single leg deliveries or for rounds, though not in the same way. For a single leg, the decisive explanatory variable is the radius of the city, whereas the decisive explanatory variable for the first or last leg of a round is the distance of the place of loading or unloading from the centre of gravity of the city. In the first case, the installation of FRETURB assumes that the size of the city is taken into account. In the second, the geo-localisation of the zones is sufficient to use the model in its general form.

The average distance between two connectors or successive delivery points ($\partial_{z,l}^{**}$, for $n$>1) varies according to the size of the delivery vehicle, as presented in figure 6 relating to the case of Bordeaux. In France, light goods vehicles (LGV) are used in the densest zones of cities. They make rounds including a large number of stops with trips that rarely exceed 5 km.

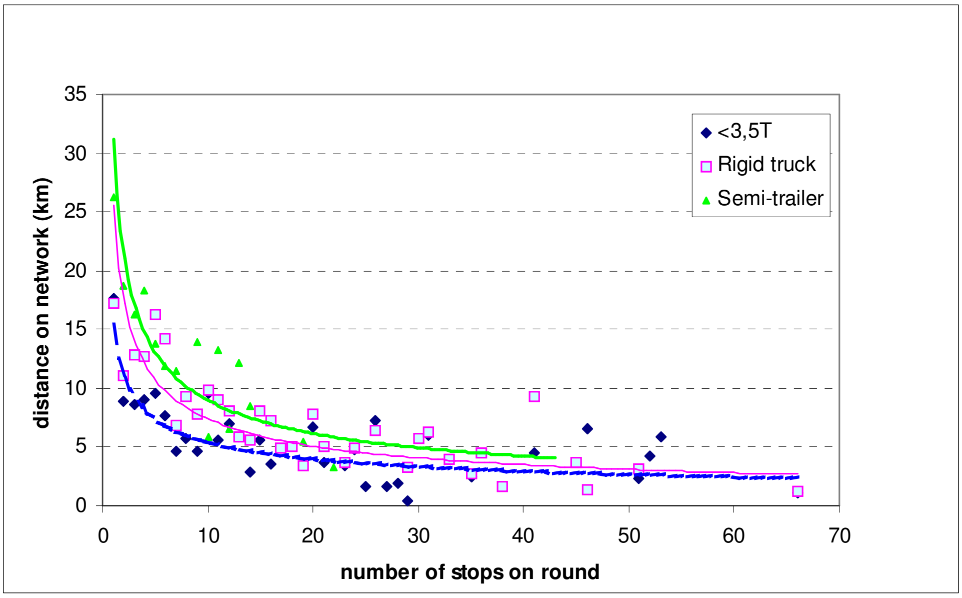

Figure 6 – Length of a trip according to the number of movements on the round and the category of vehicle

This logistic consistency can be found in the relation between distance and number of trips, as shown in figure 7.

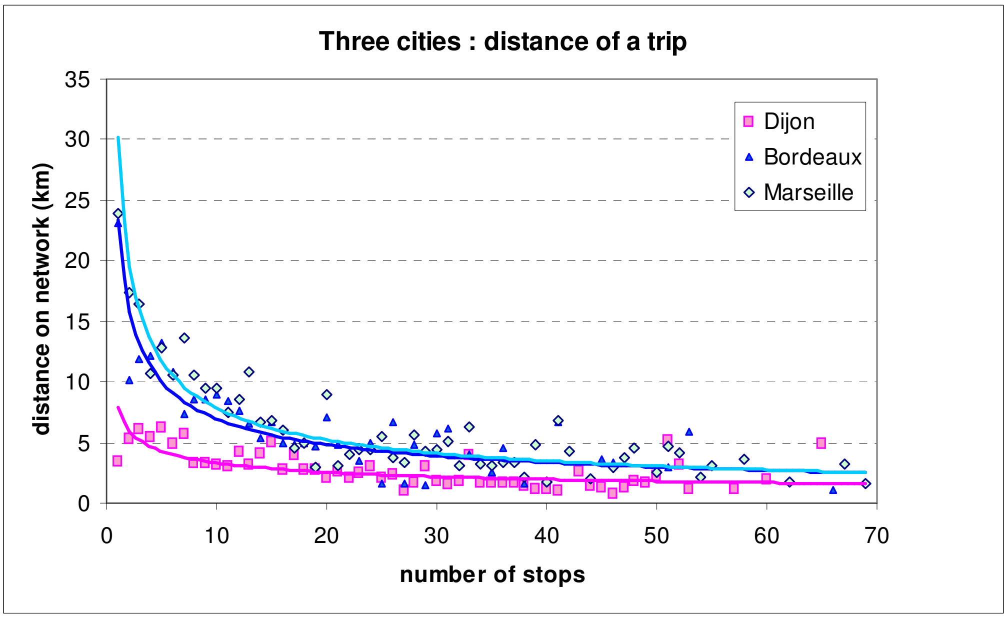

Figure 7 – Length of a trip according to the number of stops of a circuit in the three cities

These examples of results back up the logistic consistency of the hypotheses of the model given in the previous paragraph. The quantities $\partial^{*}_{z,l}$ and $\partial^{**}_{z,l}$ can be measured by the statistical adjustment functions resulting from the surveys performed jointly with the construction of the model (Routhier et al. 2001, Routhier and Toilier, 2007).

It also appears that the estimations of the number of movements and parking durations can be calculated independently of the city of application of the model and that the distances travelled can be calculated using information easily obtainable on the morphology of the city. Equation [5] which determines the distances travelled can therefore be calculated for any city possessing a sufficiently well-informed register of businesses. This explains that the FRETURB model could be applied to several dozen cities in Europe without it being necessary to perform a specific survey. It is easy to imagine the complications and cost of performing such surveys.

These are the results that lead us to declare the operationality of the FRETURB model. In order to compare it to the operationality of other models in the literature, it appeared useful to make a detour by providing a brief reflection on the concept of operationality.

## THE QUEST OF OPERATIONALITY

In industrialised countries and frequently in developing ones, surveys exist on the mobility of the inhabitants of large cities and there are models that reproduce this mobility and allow simulating the most probable effects of modifying supply. Thus it is possible to provide information for evaluating investments, for example, on new subway and tram lines, and evaluations of new transport policies, for example relating to regulations, road use and urban tolls. Indeed, we have been using operational models for passengers for several decades so it is useful to know why and how the methodological obstacles that have been overcome have remained until only recently for UGM models.

Just what is meant by the operationality of a model? Naturally, it is its capacity to achieve the objective for which it was built. Generally, the objective of transport models is to simulate traffic in a network according to different exogenous hypotheses. For example, the objective could be to simulate interurban traffic according to different economic and demographic hypotheses, to identify the risks of saturation of a national road network over a time frame of 15 to 20 years. It could also be to simulate terrestrial goods traffic and its modal distribution according to different transport policy hypotheses. And it could be to simulate the evolution of urban mobility in the case of setting up a toll system.

In these examples, it can be said that we have operational models, provided that the databases necessary for estimating parameters exist. In this case, the condition is that the model must provide *measurability,* a characteristic without which it cannot be operational.

If we accept that these models are operational, it is also because they are consistent, not only in the ordinary meaning of internal consistency, i.e. without contradiction, but they must above all be consistent with their objectives. By taking the last example above, that of the simulation of the effects of an urban toll on traffic, it is clear that the model must be designed so that the generalised cost of mobility can be calculated as a function of the toll simulated. It is therefore desirable that the specifications of the model are consistent with this objective. Failing this *condition of consistency with the objective*, operationality is impossible.

Lastly, it goes without saying, but it is nonetheless better to say it, that the model cannot be operational if it is unable to represent reality satisfactorily. Thus *an ordinary condition of pertinence* must be verified systematically.

We emphasise that these three conditions form a kind of magic triangle of operationality for two main reasons. The first is that when these three conditions are satisfied, the approach has a good chance of reaching its theoretical objectives (since it possesses the necessary consistency), of reflecting the state of things satisfactorily (since it is pertinent) and of being sufficiently controllable (since the measurability of the concepts involved is ensured). However, although the triangle of these three conditions is sufficient to ensure operationality and bestow a "magic" characteristic, a second reason must be taken into account. Every time an attempt is made to conform with one of the three conditions of operationality, there is every chance of compromising at least one of the other two conditions.

Therefore if, to improve the pertinence of the analysis, we consider going into the detail of the choice of trips: their reasons, the constraint surrounding them, their duration, their cost, their integration in a sequence of activities or movements, etc. there is a strong chance of coming up against formidable problems of measurement, regarding the statistical estimation of these elements and their variability, and also problems of consistency, regarding the increasing level of disaggregation, suggesting that greater pertinence aggravates difficulties of theoretical formalisation.

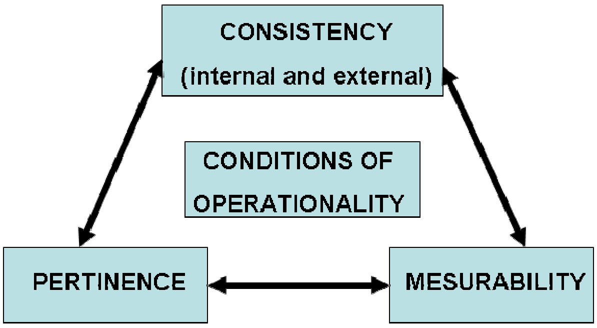

Figure 8 – The problem of models (or the magic triangle of operationality)

Obviously, we could call on more examples of this challenge known by all who have had to tackle a quantitative approach that consists in satisfying these contradictory requirements. In this game, the "modeller" has two solutions for reducing these contradictions:
- either they *reduce the ambitions of the investigation, whether it be the magnitude of the object or their objectives*;
- or *proposing a methodological innovation*.

Thus in the case of personal urban mobility, as with any model, ensuring operationality has traditionally relied on reducing the object or on a methodological innovation and, in most cases, on both as in standard urban traffic models. Indeed, the object which, in the broad meaning, can be considered as being daily mobility, *has therefore been reduced to one of its elementary components, i.e. a trip* defined by a place of origin, a place of destination, a time and a mode of transport, all items that can be identified by survey and thus measurable. This mobility can be specified by the choice of circuit which, usually, is not asked during the survey, but which is reconstituted in another step of the model, that of assignment; *the initial methodological innovation thus relies on the breakdown of mobility decisions into a four step* *sequence*, as well as on the bold hypothesis of the independence of these four steps comprising the generation, distribution, modal distribution and assignment in the network.

Passenger transport at all geographic scales, from local to world-wide, is reproduced by models that can be considered as operational and subject to constant progress that combines methodological innovations and more ambitious objectives, for example, the change from trip to a programme of activity. For goods transport it can also be considered that a certain level of operationality is ensured at interregional and international scales (M. Ben-Akiva, H. Meersman & E. Van Voorde, 2008) though it is more complicated in urban environments.

Thus, if we consider examining the goods transported in detail (their nature, weight, volume, packaging, etc.) to ensure the pertinence of modelling urban freight, there is a strong chance of coming up against considerable measurement problems, regarding the statistical estimation of these items and their variability, and also problems of consistency, in that the increased level of disaggregation implied by greater pertinence aggravates the difficulties of theoretical formalisation.

We think that the FRETURB model is operational as its object has been reduced, that is to say the representation of road occupation, and there has been a (modest) methodological innovation, that is to say the choice of movement (goods deliveries and pickups) as unit of observation. These conditions of operationality remain to be situated in relation to those of the many urban goods models (UGM) proposed by the scientific community.

# THE QUEST OF OPERATIONALITY OF UGM

As we have just seen, the operationality of the passenger transport model with four steps relies on the pair of object reduction-methodological innovation. This family of models is also operational for interurban goods transport since most long distance freight transport is characterised by full truckload (FTL) strategies and by the use of standard handling units (especially containers). The change from transported units to vehicles and then to the load of a network is thus relatively easy (mention the problem of transport or of Hitchkock).

Regarding urban goods transport, there is no such standard model despite the fact that they both generally result in goods O-D matrixes. We consider that these models are very diverse given their very different reductions of object and methodological innovations. Hence the efforts seen regularly in the literature that consist in giving some kind of order to these attempts using model typologies (Russo and Comi, 2010; Anand and al., 2012; Comi et al., 2012; Gonzalez-Feliu and Routhier, 2012). Most typologies are based on the variable of observation or modelling, but when examining these models more closely, it can be postulated that the similarities and differences result from the procedure used to build the model, in particular the reduction of its object and the choice of measurable observations. On this basis, four main categories of model can be distinguished: classical models with four steps, models with four steps adapted to urban goods transport, combined models and models with direct estimation of origin-destination pairs from count data.

The first category, that of ***classical four step models***, emerged in the 1970s, with the first models being limited to generation. The aim of this first group of models was to characterise the transport demand of urban business and industrial zones to dimension infrastructures and promote the economic development of these areas (Demetsky, 1974; Meyburg and Stopher, 1974; Loebl and Crowley, 1976; Watson, 1975). Other more exhaustive models included services, waste and construction (Schwerdtfeger, 1976; Slavin, 1976; Maejima, 1979; Ogden, 1992; Ministerie VROM, 1996; Eriksson, 1997), but in every case the aim was to include UGM in the rationale of transport and town planning. Although the question of delivery generation was sometimes dealt with, when looking at these models more closely it can be seen that the unit considered was always a movement of goods, *using a logic very close to that of urban passenger transport*. These models are consistent with the objective of planning which they attempt to pursue by estimating the number of truck trips (Routhier, 2001). All these approaches therefore shared the characteristic of data collection using cordon line surveys to fuel an econometric model. These surveys were therefore specific to each city with the passage of vehicles as the unit of observation though without information as to the nature or packaging of the goods or the mode of logistic organisation.

Also, these approaches stemmed from the desire by the public authorities to manage traffic flows, hence the direct link with the four steps: initially, the number of vehicle trips for urban goods transport was generated by emission and attraction, then origin-destination pairs were obtained with a distribution model, generally using gravity or entropy minimisation methods (Slavin, 1976; Maejima, 1979; Ogden, 1992; CROW, 1996; Eriksson, 1997; Jannsen et Vollmer, 2005); the third step (modal choice) is replaced by the choice of vehicle given the mono-modal nature of UGM (Patier and Routhier, 1997). When necessary, traffic assignment was implemented (Jannsen and Vollmer, 2005).

To ensure operationality with a method derived from the standard method for passenger transport, the object of these models must be considerably reduced since the rationales of passenger transport and goods transport are not analogous in the urban context. Firstly, most of these models are restricted to flows between distribution platforms and business activities, with the exception of Jannsen and Vollmer (2005) who modelled commercial transport (thus linked to a professional activity and not goods transport) and thus according to a rationale closer to that of individual passenger transport. Secondly, the modes of organisation are not taken into account. These models do not have many methodological innovations in comparison to the four step models used for urban passenger transport, though reducing the object does not appear pertinent for UGM. Indeed, several authors conclude that classical four step models are not adapted to the problem of UGM (Gentile et Vigo, 2006), hence the interest of seeking new paths of reflection.

This is the context in which the second category of models came into being: ***four steps adapted to UGM***. These models are also closely linked to the distribution of business activities and thus transport for third parties. However, innovation is leading to an increasing number of approaches and far more diverse tools and mathematical models are available, thus there are forevermore evolutions. Nonetheless, we observe that these models all obey the same logical structure, whatever the methodological choice in terms of mathematical expression and approach to calculation. These steps are:

- Generation of needs for goods.
- Estimation of a goods O-D matrix.
- Construction of trip sequences.

- Estimation of a trip O-D matrix.
- Traffic assignment when necessary.

Although this sequence can be found in all the models of this category, several different methodological approaches can be identified, though most of the models use the quantity of goods as the unit of generation. This is linked to the viewpoint of the transport operators and in direct relation with operational research, as will be seen further on.

For the first step, we therefore find econometric models that estimate the quantity of goods generated by an urban activity attracting goods then the quantity of goods emitted by each zone of influence in the city, whether urban or peri-urban (Boerkamps and van Bisbergen, 1999). This quantity of goods is then distributed to obtain the first O-D matrix (Boerkamps and Van Bisbergen, 1999; Gentile and Vigo, 2006): that which links the place of shipment and the place of delivery, by omitting the mode of organisation. Thirdly, the rounds can be organised. These rounds can be derived from data obtained from specific surveys (Russo and Carteni, 2006), result from discrete choices (Nuzzolo et al., 2012) or from round optimisation algorithms (Boerkamps and van Bisbergen, 1999; Gentile and Vigo, 2006) or from multi-agent simulation methods (Wisetjindawaat and Sano, 2003). Then, on the basis of these rounds whose origin and different destinations have already been identified, a second O-D matrix is obtained, this time relating to vehicle trips.

Finally, traffic assignment can be done by using classical algorithms. A “sub-variant” of these models proposes adding an additional step to convert the quantity of goods into number of deliveries (Comi et al., 2012). However, this change amounts more to a sleight of calculation rather than a fundamental step, since it permits introducing indicators linked to the number of deliveries but does not change the model’s operational structure.

It is noteworthy that with this type of model, rounds can be built by using operational research methods, or more specifically by optimising vehicle rounds (Vehicle Routing Problems, or VRP). In these combinatorial optimisation problems, the objective is to build a certain number of rounds by conforming to a set of constraints, while minimising the cost or by maximising the profit (Toth and Vigo, 2002). Several authors have studied variants of the problem to simulate UGM, notably in terms of conformity with temporal constraints (Taniguchi et al., 2001) or to take account of urban “consolidation” strategies. In all these approaches, the object treated is the round, which must be optimised as much as possible using a goods O-D matrix (commodity), which does not always correspond to reality. Consequently, several authors warn against a rationale of rigorous optimisation since it is not always understood and applied to the letter by practitioners, especially drivers (Gonzalez-Feliu, 2012). Therefore, an alternative model consists in building rounds on the basis of empirical data and then optimising transport with full trucks and the logistics of consolidation centres (Gendron and Semet, 2009).

The third category of model, that of ***combined models***, is more difficult to define, as they combine two or more approaches. Ogden (1978) was the first to make a distinction between goods O-D (commodity flow) and vehicle O-D (vehicle trip). The author proposed two coupled models, by linking places of delivery with their origins by a quantity of goods then a third generating a vehicle O-D matrix. Another approach (Holguin-Veras et al., 2010), started by generating goods O-D (generation and distribution) and then converting them into the stops of a round, to which were added returns and empty first legs, generated specifically.

The rounds were then built using discrete choice methods. These models appear to result from a combination of two other groups, since they extend classical modelling of goods to the logic of commercial transport. The main limits of these methods, which remain highly theoretical, are related to the complexity of the mathematical formulations developed and the efforts of calculation required to implement these procedures with sets of realistic data. They also come up against the requirement of measurability, as meant in the framework of our “magic triangle”. This family of models is very similar to the previous one in terms of object reduction, but it introduces a methodological innovation by separating the goods O-D from the vehicle O-D, as the models assume that one is the direct consequence of the other.

A subgroup of combined models uses the round as unit of generation. So far, we have identified three models of this group, which require identifying the stops of each round in order to then build it. Generation is ensured in a way similar to that of the previous group, by using vehicle stops as the working unit. In other words, during the generation phase, each stop of the round (whether the vehicle transports goods or not) is generated. Each stop is then assigned to a round. Sonntag (1985) proposed using the Savings method frequently used for optimising rounds. In this way each round is built without knowing the quantity of goods (indeed, this model is linked to business trips and not exclusively to goods transport). Hunt and Stefan (2007) proposed a method closely linked to a group of specific surveys to characterise mods of organisation, and used a discrete choice model to build the rounds.

These methods do not comprise the generation of a goods O-D matrix, rather they pass from generation to building rounds directly. It is noteworthy that to achieve operationality, these models combine the reduction of a larger object (the round, and thus an object composed of elementary units: vehicle stops) and a methodological innovation: that of taking account of modes of organisation and considering a “typology” of rounds on the basis of in-depth knowledge of these modes of organisation. It is also important to note that these models refer to commercial transport, i.e. goods transport for third parties and part (but not always all) for own account transport, as well as trips by craftsmen, business representatives and other professionals, including certain categories more akin to the area of passenger transport than goods transport. Another limit is the hypothesis that all sequences of trips are rounds, i.e. that the point of departure and destination is the same, as several surveys have shown that this mode of operation only covers part of the trips made to transport urban goods.

To become operational, these models reduce the object to a round whose composition is not defined in detail (no idea is given of the weight delivered or picked up at each stop) and whose point of origin and destination is the same. This also comprises a methodological innovation, that of generating rounds and thus of having to reproduce them without having the quantity of goods, which supposes the impossibility of using the operational search method described previously, without the incorporation of an adaptation. The two main approaches comprise using discrete choice models (Hunt and Stefan, 2007) or using optimisation and approximation methods (experimental modelling). In the latter case, the objective function to be minimised is not the cost of the round but the difference with real rounds in terms of number of stops and overall length.

The fourth category is that of ***models derived from counts***, or the simultaneous generation of O/D matrixes (Holguin-Veras and Patil, 2007; Munuzuri et al., 2012). They use data stemming from cordon line surveys or counts to reduce data collection costs, and generate trip O-D matrixes by adapting the method proposed by Cascetta (1984) for UGM. These models have to be reduced to origin-destination given the quantity and quality of the input data and they present limits, but the cost of data acquisition for better fitting is lower than for the other categories. However, these models remain less widespread than the others due to the considerable reduction of their object, which rules out returning to modes of organisation or determinants of transport flow generation. They nonetheless remain useful tools for studies applied to well-defined zones for concrete diagnostics.

Table 2 – Synthesis of main UGM models (generation-distribution models)

| **Category of model** | **Coherence of objective** | **Modelling object** | **Pertinence** | **References** |
|---|---|---|---|---|
| Classical Four steps | Incorporating UGM in urban transport plans | Trip | Easy to compare with people transport, strong object reduction | Demetsky (1974); Meyburg and Stopher (1974); Watson (1975); Loebl and Crowley (1976); Slavin (1976); Schwerdtfeger (1976); Maejima (1979); Ogden (1992); Ministerie VROM (1996); Eriksson (1997); Jannsen and Vollmer (2005) |
| Adapted Four steps | Forecasting, public policy decision support | Trip (retail) converted into routes | City (context) dependent. Few models used out of a research context | Boerkamps and Van Bisbergen (1999); Wisetjindawaat and Sano (2003); Gentile and Vigo (2006); Russo and Cartenì (2006); Russo and Comi (2010); Nuzzolo et al. (2012) |
| Combined models | Incorporating UGM in urban transport plans | Vehicle trip and commodity flow | Object reduction that takes into account the LTL nature of routes | Ogden (1978); Slavin (1998); Sonntag (1985); Hunt and Stefan (2007); Holguín-Veras et al. (2010) |
| O-D synthesis | Public policy strategic decision support | Trip | Big object reduction (lack of data). Context dependent | Holguín-Veras and Patil (2007); Muñuzuri et al. (2012) |
| FRETURB | Road occupancy. Public policy for urban goods | Movement (delivery and pick-up) | Easy to assess | This paper and its references |

# CONCLUSION

If the history of modelling urban passenger and goods traffic had stopped ten years ago, we could have summed up the situation by observing that, by comparison, UGM modelling suffered from a considerable lag in development. The panorama proposed in the previous section suggests that this lag is shrinking. It also suggests an explanation for this lag: the methodological choice that consists in transposing the advances of passenger models perhaps hindered the operationality sought. O-D matrixes and the four step model may have been obstacles for the pertinence and measurability of UGM; they may also have been obstacles for methodological innovations. Thus, globally, reducing the object of many of these models, summarised in a synthetic table in the appendix, may have been detrimental to their generalised use. It was observed that the most promising innovations relied on non-standard choices of variables to be elucidated, variables that have only a distant relation with the component of an O-D matrix: for example, a round or a movement. Whether continuing along the path taken by the FRETURB model or another one, the odds that the UGM of tomorrow will not have evolved from passenger models are pretty safe.

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