Dynamic considerations in transport modeling: A proposal for an agent-based freight transport demand generation model

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Summary

Competition between freight and passenger transport for the use of the road infrastructure is an increasingly important problem. This paper aims at proposing some advances in fundamental research in transportation modelling and analysis, and to present some results obtained on the Belgian network. In this paper, a disaggregated dynamic demand model for freight transport is proposed. In this model, the freight transport actors are represented by agents. These agents are extracted from existing databases. Their behaviour is then generated by means of a simulation that tries to represent the interactions between shippers and carriers who both try to minimize their costs. The carriers try to fill their trucks and to combine several trips to maximize their benefits (by minimizing the empty-trips for example) facing the well-known Vehicle Routing Problem (VRP) associating a time-dependent cost function with each arc of the network. These functions are built using standard OD matrices for passenger transport combined with global traffic density data. By doing this, one takes into account the passenger flows everywhere and at every moment of the day. These dynamic cost functions are then used by the transporter-agents of the simulation that tries to minimize their costs. In the meanwhile the shippers try to find the best transport opportunity by putting the carriers into competition. A time-dependent OD matrix for freight transport is built as result from this process.

Keywords: Multi-agents, simulation, freight transport modeling, origin-destination matrix, generation.

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Competition between freight and passenger transport for the use of the road infrastructure is an increasingly important problem. This paper aims at proposing some advances in fundamental research in transportation modelling and analysis, and to present some results obtained on the Belgian network.

In this paper, a disaggregated dynamic demand model for freight transport is proposed. In this model, the freight transport actors are represented by agents. These agents are extracted from existing databases. Their behaviour is then generated by means of a simulation that tries to represent the interactions between shippers and carriers who both try to minimize their costs.

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1. Introduction

Demand modelling in transportation research has, for many years, been focused on passengers’ needs. Even though it has some weakness, the well-known four-step model is
the most widely-used to model transport flows. This trip-based model is essentially a tool for analysing the performance of transportation networks at aggregated levels. It is less efficient at understanding the behaviour of the transportation actors and the impact of subtle policies that could modify their behaviour (Hensher and Button, 2000; McNally M.G., 2000). Moreover the increase in demand for transport has given rise to phenomena such as congestion, whose impact on demand cannot be analysed with a standard four-step model as the individual behaviour of the various actors is not explicitly taken into account.

These weaknesses led to the development of activity-based approaches where travel behaviour is derived from the set of activities in which passengers wish to participate. The transport demand is thus the result of an activity schedule. Although some models are already available for passenger demand and traffic, disaggregated tools are still largely missing both at the operational level and, more crucially, at the conceptual level. Our approach is a progressive one, gradually introducing disaggregation into existing methods and models.

This paper suggests an exploratory freight-transport demand-generation model. This actor-based, disaggregated model is designed to cope with the important question of competition for infrastructure and can be seen as a combination of the first three steps of the four-step model (i.e. generation, distribution and modal choice).

This paper is organised as follows, Section 2 describes the model focusing first on transport demand in sub-section i, and then on transport supply in sub-section ii. Finally Section 3 shows the results and introduces further research.

2. The model

The main idea behind our model is to derive freight transport demand from the interactions, needs, and behaviours of the freight transport actors. For this purpose, multi-agent systems, designed to solve such complex problems, are used. By looking into the meaning of individuals’ actions and by simulating the interactions between the actors of a complex system, multi-agent system designers chose to analyse the emerging pattern from individual behaviours (Ferber, 1995; Oliveira, 1999). Various definitions of an agent exist in the literature. In this paper, we used the following definition, inspired by Ferber (1995):

**Definition:** An agent is an autonomous entity which:
- has a (partial) perception of its environment,
- is able to communicate with other agents,
- is able to act in its environment,
- has and tends to accomplish some objectives, and
- owns its own resources.

Multi-agent systems have proven their efficiency in various fields such as expert-system implementation (Kwon & Lee, 2001; Park & Sugumaran, 2005), urban planning (Valbuena et al., 2010; Augustuijn-Beckers et al., 2011), ecology (Saqalli et al., 2010), social sciences (Pavon et al., 2008), and the spread of infectious diseases (Carley et al.,
2006; Lee et al., 2008). Multi-agent systems were also used in some studies of freight transport models. For example, Sirikijpanichkul et al. (2007) used multi-agent models to optimise the location of intermodal freight hubs. Van Katwijk et al. (2004) built a test bed for agent-based road-traffic management. El Hmam et al. (2006) proposed a hybrid model of traffic flow, using multi-agent systems. Such hybrid models (Magne et al., 2000; Bourrel & Lessort, 2003; Leclerq & Moutari, 2007) are part of traffic-flow theory and were not designed to understand the impact of political decisions or phenomena such as congestion on the decision-making processes of transport actors. Hackney & Marchal (2011) analysed the links between several scenarios of social interaction and the emerging pattern of passengers’ transportation flows. Our model extends the work of Wisinee et al. (2007) who suggested a micro-simulation model for urban-freight movement incorporating the relationship between freight agents in the supply chains, focused on the metropolitan Tokyo area. Indeed, the main contribution of this paper is to develop micro-simulation tools for a larger study area (i.e., the Walloon region) and in an inter-urban context.

More precisely, the freight flows for a standard working day are generated from the interactions between freight actors, represented by agents. On the one hand, firms need to be supplied with raw materials and to deliver their products, while, on the other hand, carriers have trucks at their disposal which can carry out the transport service along the road network. In a nutshell, the model first simulates the fact that each firm asks some carriers to transport their goods. The carriers then suggest a price for the service, and the requesting firm chooses the best offer amongst these quotations (see Figure 1).

So there are two types of agents interacting in the simulation: agents representing firms and agents representing carriers. The agents representing firms have a limited perception of the transporters. Each firm only knows its nearest transporters and has no perception of the others or of the entire network. Each firm is able to request a quote from the nearest transporters and to analyse their suggestions. In general, the firms tend to want their resources (i.e. their goods and raw materials) transported from an origin to a destination. On the other hand, transporters perceive the network. Each transporter is able to communicate with interacting firms to put forward quotes as needed. They are able to pick up and deliver goods, and on the other hand the transporters tend to maximise their profits by fulfilling as many contracts as they can by using their resource (i.e., their trucks).

In this paper, the agents representing the different actors involved in the transportation are generated on the basis of the “Entreprises” (Service public de Wallonie, 2008) database. This database, maintained by “La Direction des Réseaux d’Entreprises” of the Walloon Region of Belgium, contains about 4 800 companies located in Wallonia. It includes 433 transport companies. The information is continuously updated, with a new version of the database being published every 6 months.
Piotte Jeremy and Jourquin Bart

Fig. 1. Basic freight-transport-demand model concepts

Each agent representing a Walloon firm is characterised by:
- its location at the NUTS-5 level (i.e., the municipality level),
- its number of employees,
- its main activity sector.

Each agent representing a transporter is characterised by:
- its location at the NUTS-5 level (i.e., the municipality level),
- its number of employees.

The model suggested in this paper is thus based on the idea of comparing demand and supply (see Figure 1). The model simulates iterative negotiations between one of the firms and its nearest transporters. After each negotiation, the firm chooses the best offer and the chosen transporter updates its stock of trucks by planning its routes and the contracts it has accepted. The way a firm-demand is generated is described below, while the way quotations are built is described in the next sub-section.

2.1. Demand characterization

This section focuses on the way demands are generated and their characteristics derived from real-world information. In other words, the purpose of this section is to refine the
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“Demand” box from Figure 1, generating realistic transport needs and taking private trucking (see Figure 2) into account.

Fig. 2. Demand characterisation

2.1.1. Shipment sizes, demand frequencies and destination of the goods

A particular demand is defined by an origin, a destination, a quantity and must be made at a given frequency. The origin is given by the location of the firm from which the transport will start. The destination is set using a stochastic gravity model. This spreads the total demand over the different destination zones (NUTS-5 regions) according to the number of workers in each zone. The probability of a firm located in zone A choosing a destination zone i is given by $x_{Ai} = G_A E_i / r_{Ai}^z$, where $r_{Ai}$ is the distance between location A and i, $E_i$ is the number of workers in zone i, $G_A$ is a normalisation factor (so that $\sum_i x_{Ai} = 1$), and $z$ is a simulation parameter which is generally set to 2 in the literature.
Finally the quantities and frequencies of the demands were estimated using the ECHO (Guilbault et al., 2008) survey conducted by the Institut National de Recherche sur les Transports et leur Sécurité (INRETS, France). ECHO intends to have a good understanding of transport practices. Its originality lies in the study of the shipment size, and coverage of 3,000 firms in the industry, wholesale trade and warehousing sectors. A shipment is generally associated with a transport service and a vehicle movement. As a result it is directly linked to the number of vehicle-kilometres on the network. It is worth noting that the ECHO survey shows a very substantial number of small-size shipments (50% of the shipments weighed less than 30kg).

We undertook an analysis of the ECHO data. The objective of this analysis was to characterise every firm by probability functions of shipment size and shipment frequency according to their size and main activity. First, the firms were regrouped by size (see Table 1). The number of shipments was much more closely correlated with the size of the firm than was the average size of the shipments (see Figures 3 and 4).

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>2</td>
<td>20 ≤ E_i &lt; 50</td>
</tr>
<tr>
<td>3</td>
<td>50 ≤ E_i &lt; 100</td>
</tr>
<tr>
<td>4</td>
<td>100 ≤ E_i &lt; 200</td>
</tr>
<tr>
<td>5</td>
<td>200 ≤ E_i &lt; 500</td>
</tr>
<tr>
<td>6</td>
<td>500 ≤ E_i &lt; 1000</td>
</tr>
<tr>
<td>7</td>
<td>1000 ≤ E_i</td>
</tr>
</tbody>
</table>

Fig. 3. Mean of the annual number of shipments for the different firm-size groups

Secondly, the firms were regrouped by main activity sector. Unfortunately, several main-activity sectors were underrepresented in the ECHO survey, making it difficult to take the
potential impact of the activity sector on the frequency of shipments into account. However, we did derive the distributions of the average shipment sizes for the various activity sectors. The distributions of five randomly chosen NACE groups are plotted, for illustrative purpose, in Figure 5.

In conclusion, we assumed that the shipment-frequency distribution of a given firm is a function of its size, while the shipment-size distribution is a function of its main activity sector. Thus for each size-group, a frequency distribution was derived from the ECHO data by applying a regression (see Figure 6). As for each main-activity-sector-group, a shipment size distribution has been built the same way.

Fig. 4. Mean of the shipment sizes for the different firm-size groups

Fig. 5. The distribution of shipment sizes in five activity sectors
According to Eurostat (http://epp.eurostat.ec.europa.eu), 36% of the goods transported in Belgium, in 2007 were handled by private truckers who drive only for the firm they are linked to as a transport department in the firm. The fact that firms use their own transport service to carry all or part of their goods cannot be ignored. However, to the best of our knowledge, little disaggregated data is available about this practice. However, the Centre de recherches economiques (1999) surveyed 750 European firms practicing private trucking and managed to build statistics on the number of trucks used by private truckers (see Table 1).

Table 2. The number of trucks used by firms for private trucking (Source: Centre de recherches economiques, 1999)

<table>
<thead>
<tr>
<th>Stock of trucks</th>
<th>1-5</th>
<th>6-10</th>
<th>11-15</th>
<th>16-20</th>
<th>21-30</th>
<th>31-50</th>
<th>51-100</th>
<th>101-200</th>
<th>200+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of firms</td>
<td>219</td>
<td>125</td>
<td>75</td>
<td>45</td>
<td>54</td>
<td>57</td>
<td>54</td>
<td>47</td>
<td>45</td>
<td>721</td>
</tr>
</tbody>
</table>

To take private trucking into account, a private trucker is allocated to a proportion $k$ of the firms operated by a private trucker. The simulation parameter $k$ is calibrated so that the total proportion of the quantities transported by private trucking corresponds to 36%. These firms have a number of trucks stochastically given by the statistics shown in Table 2. The private carrier associated with a given firm acts like a regular carrier, except that it is contacted by its firm for every demand. Regular carriers are called only if no more trucks are available inside the firm.
2.2. Transport supply characterisation

Like the enterprises, the carriers’ agents and their characteristics (location, number of employees) were generated using the enterprises (2008) database. A truck stock was assigned to each carrier as a function of its number of employees. As they receive transport demands, carriers must supply quotations giving the price of their transport services. This section thus focuses on the supply side of the transport market and presents the way these prices are calculated by the carriers.

Ortúzar & Willumsen (1990) described the supply side of the transportation system as composed of the infrastructure (network) (made up of a set of links and their associated costs) and a set of vehicles. Although the set of vehicles is sometimes considered as part of the (derived) demand, especially in assignment models in which it is actually hidden under the demand flows (Bellei et al., 2005), the set of carriers and their trucks is considered here as part of the supply side of transportation (see Figure 7).

Fig. 7. Supply characterisation
To calculate their price, carriers first have to calculate their own costs, by associating a time-dependent cost function to each network link. The cost function used in this model is presented in the next subsection, and discussed in the second subsection. The transport-supply characterisation deals with the Vehicle Routing Problem (Magnanti, 1981; Golden and Assad, 1986; Labé and Toint, 1997; Laporte, 1997). It is a well-known NP-hard optimisation problem.

2.2.1. Transportation costs

When a carrier receives a demand, it must calculate the cost of fulfilling the contract, using the cost-functions associated with the network’s links. This model focuses on the Belgian road network. A free flow cost ($C^0$) and a capacity ($K$) are associated with each link. In a first version of the model, the carriers based their cost analysis on the free flow cost of the shortest path (Dijkstra, 1959) between two nodes. Over time this has been refined by building and using time-dependent cost functions. Indeed, by using a static origin-destination matrix and a 24 hour flow distribution on the Belgian network (Service public fédéral Mobilité et Transports, 2005), the flows on every link at several points during the day ($x(t)$) can be estimated. Several cost functions exist in the literature. Amongst them, the most widely-used are: Smock’s (1962) function, $C_a(t) = C^0 a^{x_a(t)/K}$, generalised by Overgaard (1967), $C_a(t) = C^0 a^{x_a(t)/K}$, where $\alpha$ and $\beta$ are calibration parameters; and the classical Bureau of Public Roads (1964) function which is the one actually used in this model: $C_a(t) = C^0 (1 + \alpha (x_a(t)/K)^\beta)$. where $\alpha$ and $\beta$ are calibration parameters. The common used values for $\alpha$ and $\beta$ are respectively 0.15 and 4. Using these costs functions, the carriers also try to minimise their costs by combining different demands together. They are facing the well-known Vehicle Routing Problem (VRP).

2.2.2. The vehicle routing problem

The VRP has been extensively studied. It is defined on a graph $G=(V,A)$ where $V=\{1,\ldots,n\}$ is a vertex set representing $n$ different customers to whom quantities $q_i$ ($i=1,\ldots,n$) of goods must be delivered. $A=\{(i,j): i,j \in V \text{ and } i \neq j\}$ is a set of arcs that links the vertices. A fleet of $k$ trucks is available in a depot $O$. Looking at the travelling costs $c_{ij}$ associated with the arc $(i,j)$, the nub of this problem is to find the best way to deliver to the $n$ locations, under various constraints such as the limited capacity of the trucks, the limited routes, time-windows, etc. In this section, the terms costs, travel times, and distance will be used interchangeably.

The VRP is known to be NP-hard. Exact methods can be used to solve relatively small problems. The commonly used algorithms employed to find exact solutions are branch and cut-based algorithms (Baldacci et al., 2004; Land & Doig, 1960; Lysgaard et al., 2004). To deal with larger problems, one often uses heuristics and approximation algorithms. Laport et al. (2000) undertook an important literature review on heuristic algorithms, which focused on the classical heuristics and tabu-search metaheuristics.
Several variants of the VRP exist in the literature. In this paper we will consider the following variations and constraints:

1. **The Capacitated Vehicle Routing Problem (CVRP)** is a variant of the classical VRP in which the set of vehicles are limited in capacity Q.
2. **The Duration Constrained Vehicle Routing Problem (DCVRP)** is a variant of the classical VRP in which the total travel time of a truck may not exceed a given time T.
3. **The Vehicle Routing Problem with Pick-Up and Delivery (VRPPD)** is a variant of the classical VRP in which the goods must be picked-up at a given vertex before being delivered at another vertex.
4. **The Vehicle Routing Problem with Time-Dependent Costs (VRPTDC)** is a variant of the classical VRP in which the costs (travel times) depend on the time of the day (Ichoua et al., 2003).
5. **The Stochastic Vehicle Routing Problem (SVRP)** is a variant of the classical VRP in which some elements of the problem are random (Gendreau et al., 1996).
6. **The Dynamic Vehicle Routing Problem (DVRP)** is a variant of the classical VRP in which relevant information on the route planning is unknown by the planner when the planning process starts (Larsen, 2000).

In this paper, the carrier agents (the planners) have a truck fleet of capacity Q (Q=25T). For legal reasons, the total travel time of these trucks may not exceed a given time T (T=8h). The carrier agents receive demands sequentially until the most urgent demand requires a truck to leave the depot. At this moment, the carrier agent must plan a route for this first truck, even though new demands are still arising. Consequently the carrier agent must decide which demands this truck will fulfil, and which will be fulfilled by other trucks at a later time. This problem lies at the frontier between SVRP and DVRP. Notice that as we were working on a small region (Belgium), we assumed that the planned route of a truck would not change after it left the depot. Moreover the demand is defined by an origin and a destination, and the carrier agent must take into account the fact that his trucks must first pick up and then deliver the goods. Finally, the travel times associated with the set of arcs are time-dependent (but not stochastic) as discussed in the previous subsection.

This section does not aim to suggest fundamental improvements to the existing algorithms, but rather to deal with a realistic variation of the VRP. The VRP addressed here is actually a combination of common variants which are often considered one at a time. Moreover, unlike the studies mentioned earlier, the variant of the VRP considered in this research is just a part of a more sophisticated model. Every carrier must deal with at least one VRP. Therefore the computing time for solving a particular VRP must be kept very small. For these reasons, we decided to use a “simple heuristic”.

The heuristic used in the simulation is an insert and shake heuristic inspired by Gendreau et al.’s (1992) GENIUS algorithm. This algorithm was first designed to address Travelling Salesman Problems (TSP), so the algorithm had to be adapted to the VRP problem by modifying the shake heuristic. In this shake algorithm, the vertices can be either switched in a route or removed from a given route and inserted into another one. Notice that when routes are built by the carrier, it is required that the carrier remembers
which vertices are complementary. Indeed, to keep the pick-up and delivery constraint satisfied, the carrier must avoid switching vertices in a way that would make a delivery destination occur before the delivery pick-up in a route. Moreover as the shake algorithm can permute vertices from one route to another, carriers must avoid putting the origin of a delivery in one route and its destination in another route. Every time a demand is received by a carrier agent, it uses the following rules to choose whether to insert the origin and destination vertices in an existing route or to assign the contract to a new route:

If some trucks in the depot already have a planned route then:

(Step 1: insert)
For all N concerned routes (i=0 to N):
Copy the route i;
If possible, insert the vertices one after another into the copy at the positions that minimise the additional route cost, taking care not to violate the capacity and travel time constraints;
If the insertion occurred then:
Save the additional route cost;
Else:

(Step 2: shake)
If δ_i=0 then:
For j=0 to N (where N is a simulation parameter):
\( a = \text{Random} \in \{0,1\} \)
If \( a=0 \) then:
Copy one vertex and remove it from the route;
Re-insert the vertex at the position that minimises the route cost, taking care not to violate the pick-up and delivery constraint;
Else:
Remove two complementary vertices from the considered route;
Apply Step 1 to these two vertices;
If a route j has been shaken then:
\( \delta_j=1; \)
Re-apply Step 1 for Route i;
Else:
Do not insert the demand vertices into this route;
If \( \delta_j=1 \)
Do not insert the demand vertices into this route;
Select the copied route k at which the additional cost is minimised;
Replace the original by the copied route with the new vertices;
Else:
If a truck will be available in time to fulfil the contract:
Create a new route based on these two vertices and assign one truck to it;
Else:
Refuse the contract.
3. Results, discussion and further research

In this paper, an exploratory model providing new tools for analysing road-freight flows is introduced. The behaviour and interactions between firms and carriers is simulated. Attention has been paid to the negotiation process occurring when the firms put the carriers in competition with each other. These carriers try to combine different demands together so that they maximise the value of the contracts they can take on and the related profit. This problem, known as the Vehicle Routing Problem, has been dealt with by using a “classical insert & shake heuristic”. Better solutions for this kind of problem do exist, using more recent approaches such as the Tabu-Search (TS) heuristics (Laporte et al., 2000). However we decided to stick to classical heuristics, for reasons of computing time. One demand takes less than a second to be simulated (VRP included), but as we need to simulate several thousand demands this is actually quite limiting in terms of computing time per demand. A TS heuristic would imply a large increase in computing time because it should be applied several times to the solution of all transporters as the demand changes. Moreover, we wanted to deal with a realistic VRP. While most previous research has dealt with quite simple VRPs with only one or two constraints, in their daily work, carriers are faced with an intricate VRP with numerous constraints. The time horizon of the model is one day. This model thus doesn’t take into account the possibility for the firms to benefit from reduced prices by fixing several contracts with the same carrier.

This research is still continuing. However the structure of the model is built and ready to receive new modules to take into account more subtle details in its origin-destination matrix-generation process. Moreover, the model is designed to generate time-dependant origin-destination matrices that contain the empty trips which are often not taken into account by freight generation models. This model is coded in JAVA and has been tested on an Intel® Pentium® Dual CPU 3.6GHz with 4 Gb RAM. Some 100,000 demands were simulated in less than 40 hours. The whole simulation process is represented in figure 8.

This simulation uses various parameters that can be calibrated by the user like $z$ in the gravity model and, $\alpha$ and $\beta$ in the time-dependent cost functions. As mentioned earlier, we chose to use $z=2$, $\alpha=0.15$ and $\beta=4$ as it is often the case in the literature. However, one more parameter is left to be calibrated. $k$ has been introduced in the private trucking section. It represents the portion of firms that use private trucking. The simulation has been running several times to calibrate this parameter and to understand how sensitive the simulation is to it. The results are shown in table 3. These results show that a bit more than 50% of the firms use private trucking if one wishes to calibrate it so that 36% of the transported quantities are transported by private truckers. That is consistent with the results of the Centre de recherches économiques (1999) which shows that for small distances (<200km) - like the distances considered in the Belgian transport market -, private trucking seems to be used as much as transport societies. One can also remark that whatever the value of $k$, the loading rate varies between 35% and 40% which is also
consistent with what is observed in the real world. Also, the total distance travelled by all trucks grows as private trucking transporters grow. Indeed, the private carriers only transport the goods from one firm so a lot of contract combinations that could improve the global quality of the VRP solution are impossible. Moreover the firms that use private truckers try to use them as long as they can even though a transport society might be able to transport the goods in a cheaper way, resulting in a global suboptimal solution as well.

In the current version of the model, it is assumed that firms which use private trucking use it as long as they can no matter the distance their trucks must travel. However, this assumption is not consistent with the data gathered by various independent identities such as Eurostat. We know that private trucking is often used for smaller distances than professional carriers. This is not currently taken into account, and should be refined in the upcoming improvements to the model.

By now the time distribution of the demands of the firms is made by maximising the work undertaken during the working day (6h-19h). However, in the real world, the demand seems to be distributed differently. This can be illustrated by the distribution of

Figure 8. Whole simulation process
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deliveries in Bologna given by the Centre de recherches économiques (1999) (see Figure 9). More attention should also be paid to this time distribution in the next set of model improvements.

Table 3. Simulation results for the Belgian scenario

<table>
<thead>
<tr>
<th>k</th>
<th>N demands</th>
<th>Dropped demands [%]</th>
<th>OD lines</th>
<th>Total quantity [T]</th>
<th>Quantity PT [T]</th>
<th>Quantity PT [%]</th>
<th>Total distance [km]</th>
<th>Total TKm</th>
<th>N trucks</th>
<th>Quantity [T]/(truck*day)</th>
<th>Loading rate [%]</th>
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<tr>
<td>0</td>
<td>95867</td>
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Figure 9. Time distribution of deliveries in Bologna (source: Centre de recherches économiques, 1999)

One of the main assumptions we made through this model is that transport assignments are traded on a spot market. However, this is not always true. In the real world, a significant part of those transport assignments are carried out by service provider with whom there are long term service agreements. We plan to refine this by adding the possibility for carriers to propose such long term contracts to the firms or to propose better prices for those firms who have already been one of their customers.
Another crucial step for further researches will be the validation of the simulation. This validation process is still on-going but we plan to validate the simulation by comparing the results to real world observed data. First, the OD(t) matrix generated in the simulation will be assigned on the network. Then several key-points of the network will be chosen and the number of trucks transiting by those points will be compared to real world data. Moreover, since this model aimed to take very different factors and phenomena into account, sensitivity analysis should be performed to understand which of these phenomena lead to the greatest variability. Such a sensitivity analysis would show which part of the model is most important and might require more in depth study. Finally, as stated in the introduction, to our knowledge there is not much literature on such dynamic freight transport generation models. Alas the lack of literature on this subject makes it difficult to compare our results to the results of other studies or models.

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References


