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Urban Freight by Rail: A MILP Modeling for Optimizing the Transport of Goods

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Abstract. The present paper discusses an alternative way of transporting freight by using urban rail infrastructure. Instead of deploying trucks for the transport of goods, we study the possibility of using existing suburban rail. As a first contribution, several decision-making problems are identified dealing with urban freight. In this paper, the addressed problem deals with a commuter line on which each station can be used as a loading/unloading platform for goods such as demand (goods boxes) is known in advance. As a second contribution, a Mixed Integer Linear Program (MILP) model is proposed to minimize the total waiting time of daily deliveries such that each box is transported from its departure station to its arrival station. Numerical results show that the model is able to solve moderate size instances in very short amount of time.

Keywords: urban freight transport, rail freight, Mixed Integer Linear Programming.

1 Introduction

Freight transport can be defined as the physical process of transporting commodities and merchandise goods and cargo. Within the borders of cities, the most common way for the transport of goods is the land (ground) shipping by trucks. Although ground transport of freight by trucks represents only 10% of total traffic, it causes 40% of pollutant emission in big cities [1]. In addition, use of trucks for the freight transport increases the risk of accidents. Faced with this situation, the authorities react through more restrictive policies for urban transport such as the progressive ban on the most polluting vehicles (in several European cities), or even the introduction of a toll proportional to the degree of pollution of the vehicle (eg: the city of Milan in Italy). Also, European Union coordinates its actions through the Transport Committee of the EU by setting ambitious targets for member countries such as zeroing pollutant emissions linked to transport of goods in town until 2030 [2]. In December 2015, the United Nations conference on climate change “COP21” fixed a more restrictive environmental objective which will surely have an impact on the urban transport.

On the other hand, some cities such as Paris, London, New York, etc. have an important network of subway and/or commuter (suburban) trains which may be used for the transport of goods. Those vehicles (and the rail devoted to them) are most of the time dedicated only to passengers.

In this paper, we study the possibility of using urban rail infrastructure for the delivery of goods from one point to another within the borders of a city. Our second contribution is the development of a mathematical framework to solve the assignment of demand to trains in order to reduce the waiting time.

The remainder of this paper is organized as follows. In section 2, we provide a literature review on the problem under study. In section 3, we analyze a freight transport process by rail and identify some decisional problems among which the problem of loading/unloading goods, for which a Mixed Integer Linear Programming model is presented in section 4. In section 5, we present the solution limits of the MILP model by testing numerous problem instances. Section 6 concludes the study and provides further research perspectives.

2 Literature Review

Freight transport in metropolitan areas is almost exclusively done by trucks [3] (between 85% and 90% in France [4]). However, the capacity of city ground transport is limited and nuisance caused by trucks is very high (e.g.: noise, gas emissions, increased traffic ...). The author Dablanc [5] noted that transport operations in cities cause between 20% and 30% of all road traffic but, depending of the pollutant considered, they produce between 16% and 50% of air pollutants. For example, Paris statistics show that 90% of freight is carried by trucks, representing 20% of urban traffic and 1/3 of pollutant emission in the city [6].
The use of rail network, equipment and infrastructure is one of the solutions proposed by some research papers. In [7] and [8], authors propose a freight transport by rail as a sustainable urban logistics due to decreased greenhouse effect. In [9] and [10], authors study an intermodal road-rail transport and identify possible actions on a local level to improve both the competitiveness and environmental benefits of urban freight transport. In [11], author performs an analysis of urban freight by using passenger subway in Newcastle. For more information on urban freight by rail, we refer the reader to Robinson and Mortimer [12].

Beside previous scientific papers, there are few case studies for the use of rail in city logistics. As our knowledge, three cases have been published which are described as follows:

- Case 1: MONOPRIX in Paris [13] & [14]. MONOPRIX is a supermarket chain in France and the SNCF Group (Société Nationale des Chemins de Fer français) has been delivering a small part of goods to some supermarkets of the chain. This is done with using the commuter line D (abr. RER D) in Paris, for the transport of a number of goods such as soft drinks, textiles, beauty and home products and leisure, from MONOPRIX depots in outside Paris (Combs-la-Ville and Lieusaint) to a dedicated station located inside Paris which is Bercy. Thereafter, the flow of product to stores is carried by trucks running on NGV fuel, to respect the principle of emission reduction on the logistics line. The line has a length of 30 km, it can carry 210 000 pallets per year (equivalent to 120 000 tons), with 5 trains of 20 cars per week.
- Case 2: New York subway [15]. The study is subject to waste collection in the New York City through metro stations. The collect is done at night, and as the New York metro runs 24/24, it is mixed between freight transport (waste in this case) and passenger transport. This solution enables the collect of 14 000 tons of waste per year, with 11 dedicated metro, covering 359 stations with 567 stops.
- Case 3: Cargo Tram of Dresden [16]. A portion of 4 km tram line in Dresden is used to route automotive parts and modules, from VW depot which is close to the rail terminal in the city, destined to their factory that is located in the city center. This solution allow to make face to insufficient storage area in order to ensure daily production. This line ensures the delivery of 300 000 tons of products per year with 10 daily trips. This allows significant saving in terms of CO_2 emissions.

3 Identification and Classification of Decision-Making Problems for Mixing Freight with Passengers by Rail

In this paper, urban rail network which is mainly dedicated to passenger transportation is considered also for freight transport. This kind of logistics solution is called mixed freight/passengers transport in which urban infrastructure (railways and stations) and trains (commuter rail, subway and/or tram) are shared between freight and passenger transports. We have identified 9 levels of mixed possibilities (shown in Figure 1):

- The first possibility considers the sharing of trains, that resulting in a total mixed freight/passengers. Indeed, with passengers in the train, traffic must meet the operating constraints for passenger transport. In this case, it will use the system during off-peak times (during peak hours, the passenger flow is quite important).
- The second possibility considers the separation of trains. The freight transport can be performed during passenger's operating hours or, during off-operating hours (if the service for passengers

stops, eg at night). For each of them, we have many possibilities of infrastructure sharing as shown in Figure 1.

In the rest of study, we consider the most complicated case, where all components are shared (however, we consider the transport of goods during off-peak times of passengers transport). The other mixed possibilities are special cases of the considered one.

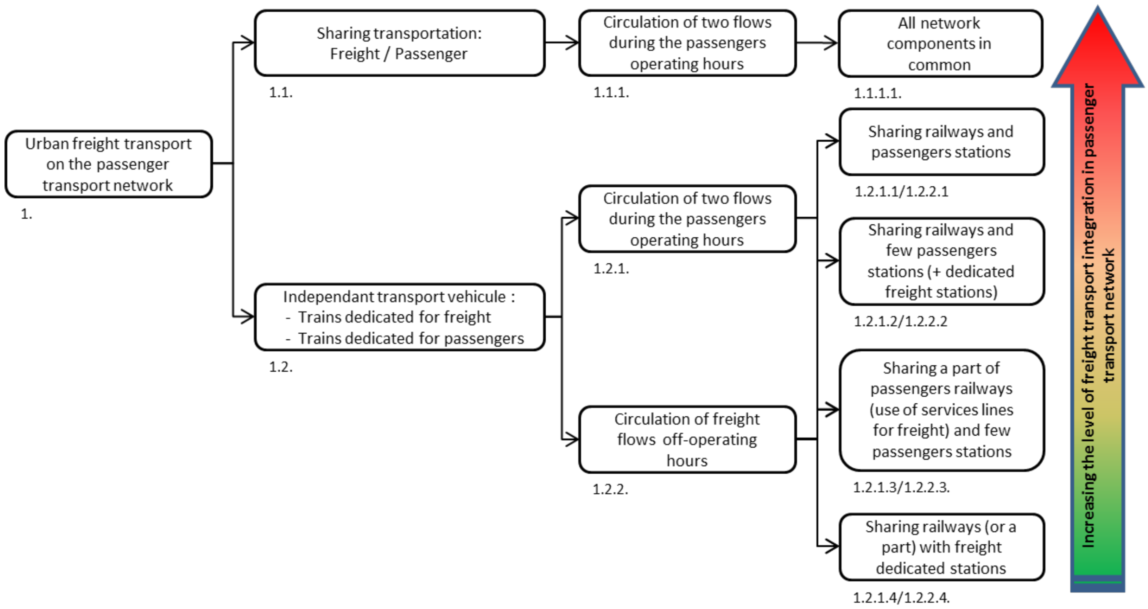

Figure 1: All possible mixed freight / passengers transport strategies (9 possible strategies).

For example, passenger transport by rail in Paris is shared by three complementary means of transport:

- The subway in the city center, with a network of 220 km and serving 302 stations.
- The tram around the city center and in some localities of Ile de France (Paris area), with a network of 104 km and serving 181 stations.
- The commuter rail (RER) linking the localities of "Ile de France" to the center of Paris City, with a network of 587 km and serving 257 stations.

The analysis of the existing network in Paris shows that it would be beneficial for the RATP Group (Régie Autonome des Transports Parisiens) to extend its activity for freight transport. The proposed freight transport solution in the city would be very profitable to deploy in cities with a large rail network, however, even with one line (ex. Tram) we can also deploy it and make it profitable for city and transport company.

We have identified two important characteristics about Paris rail network:

- Each line of the network is independent of other lines (in terms of infrastructure and operating).
- There are indirect interconnections between certain lines, through connection point with transshipment.

With these two characteristics and some other assumptions, we have developed a first study case that consists of a unique line with several stations where we can proceed to the loading and unloading of goods.

Through the analysis of the freight transport process, we have identified six issues in several decisional levels (numbered 1 to 6 in Figure 2):

- 1st decisional problem is posed at the operational level for the loading and unloading trains (this issue is developed in the next section).
- 2nd decisional problem is posed at the operational level to identify in each time which is the transport capacity of the whole system (in term of goods quantity). This will permit to the transport company to determine the optimal goods quantity to be transported in each time slot during an operating period.

- 3rd and 6th decisional problems are posed at two levels. At the strategic level, we must adjust a dimension of space that will be dedicated to store goods before and after their transports. At the operational level, we must decide how to place the goods in this area.
- 4th decisional problem concern trains and is posed at two levels. At the tactical level, we must decide how much space would be dedicated to goods transport in passenger trains (ex: 1 car from all 5 cars). At the operational level, the problem is to determine the optimal trains frequency.
- 5th decisional problem concerns the arrangement of goods inside trains for minimizing the necessary time for their unloading in their arrival station.

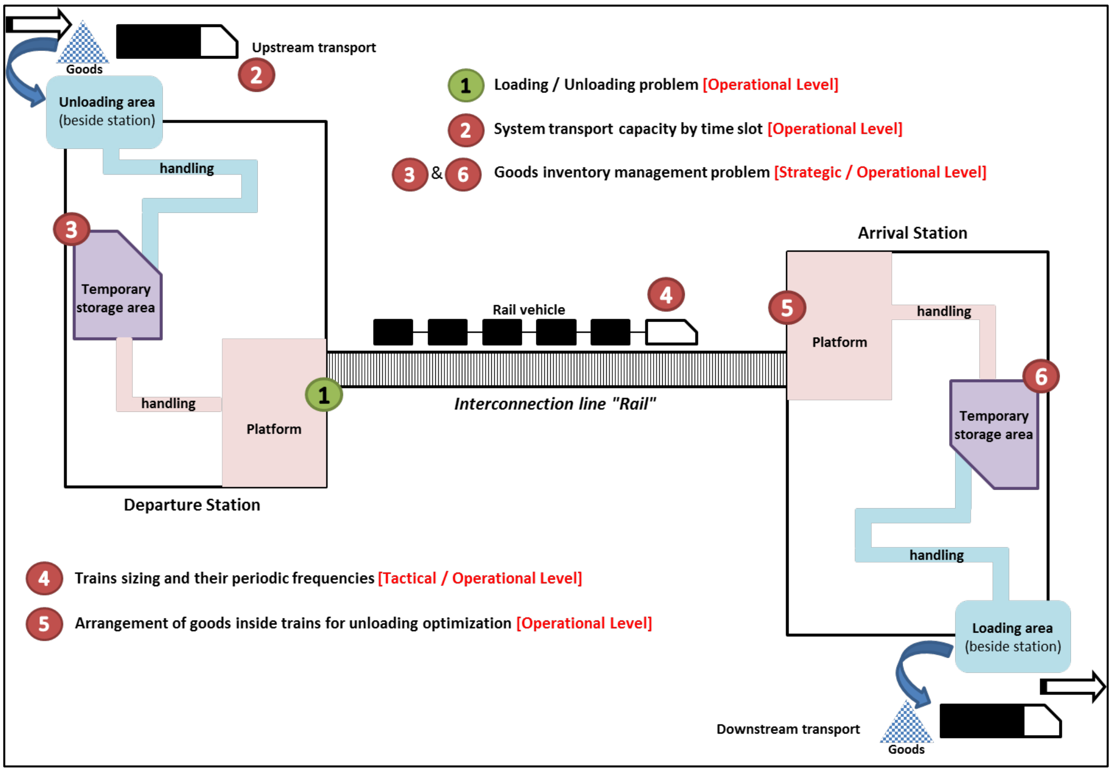

Figure 2: Decisional problems throughout the freight transportation process.

In the next section, we consider the first issue that concerns how to load/unload goods in trains on the network, respecting the different technical and operational constraints.

4 Problem Formulation

We study the case where all network components are in common (case 1.1.1.1. in figure 1). To investigate the train loading and unloading problem (first issue in figure 2), we consider a single line from the network. On this line, there are several stations in which one can proceed to the loading and unloading of goods (Figure 3 provides an illustration). The goods are packed in boxes with standardized dimensions. All passenger trains can transport goods with a maximum capacity to be defined by the unit of standardized boxes. Goods are transported to different clients, requiring different quantities of goods (measured in term of standard size boxes), with independent departure ready times.

The assumptions of the problem are the following:

- Client demands are known in advance and there are J demands per day.
- Goods are put in standard size boxes which are transported to the delivery point(s). Although each client may require different products in different quantities, standardization of boxes allows us measure the need of each client in number of boxes. We note Q_j the number of boxes required to pack the demand of client j.

- Customer demands are brought to the departure stations by trucks in different times within a day. We note r_j the departure ready time of goods demanded by client j.
- Goods transport takes place during off-peak times of day.
- The train departure time from the station 1 is known in advance, l_t. T trains are deployed to serve S stations.
- Each train is divided in two parts: first one dedicated for passenger transport and second, for goods transport. The capacity of goods transport is the same for all train, *cap*.
- Any station can be used to load or unload goods, i.e., any station can be a departure and/or an arrival point for goods.
- The travel time between two successive stations is the same, *tt*.
- The maximum waiting time of a train at each station is $Wait_{max}$.
- To board passengers, the minimum waiting time of a train at each station is $Wait_{min}$.

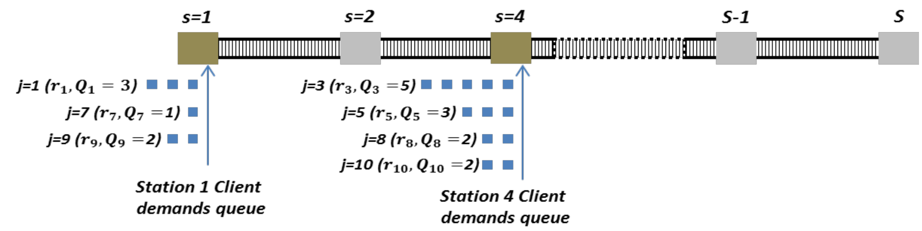

Figure 3: Illustration of transport line.

As the stations space is very limited in cities, we have considered it as critical resource. Thus, the objective function is the minimization of total waiting time of daily deliveries. In fact, in order to increase boxes turnover, it will be necessary to transport goods of client demand, from all stations of the transport line as soon as possible after their reception in their departure station.

Table 1: Notation used in the MILP model.

Indexes	$j: 1, \ldots, J$	for clients
	$t: 1, \ldots, T$	for trains
	$s: 1, \ldots, S$	for stations
Parameters	r_j	departure ready time for the demand of client j
	dep_j	departure station for the demand of client j
	arr_j	arrival station for the demand of client j
	l_t	train t departure time from the station 1
	J	number of clients
	T	number of trains
	S	number of stations
	tt	travel time between two successive stations
	Q_j	number of boxes required to pack the demand of client j
	Cap	goods transport capacity of a train
	$Wait_{max}$	maximum waiting time of trains at any station
	$Wait_{min}$	minimum waiting time of trains at any station
	Time	loading/unloading time for a single box
Decision variables	x_{jts}	1 if demand j is present in train t at station s, 0 otherwise
	C_{ts}	waiting time of train t at station s
	R_{jts}	time at which train t loads goods of client j at station s

The mixed integer linear programming (MILP) model is presented below.

$$Minimize \sum_{j=1}^{J} \sum_{t=1}^{T} (R_{jts} - x_{jts} * r_j) \qquad s = dep_j$$

subject to

$$\sum_{t=1}^{T} x_{jts} = 1 \quad \forall j \text{ and } s = dep_j \qquad (1)$$

$$x_{jts} - x_{jts+1} = 0 \quad \forall j, t \text{ and } s \in [dep_j,\ arr_j - 1] \qquad (2)$$

$$\sum_{\forall j \in J_s} x_{jts} * Q_j \leq Cap \quad \forall t, s \qquad (3)$$

$$\sum_{\forall j \in J'_s} x_{jts} * Q_j * time \leq Wait_{max} \quad \forall t, s \qquad (4)$$

$$x_{jts} * r_j \leq l_t + (tt * (s-1)) + \sum_{s'=1}^{s-1} C_{ts'} \quad \forall j, t \text{ and } s = dep_j \qquad (5)$$

$$C_{ts} \geq Wait_{min} \quad \forall t, s \qquad (6)$$

$$C_{ts} \geq \sum_{\forall j \in J'_s} x_{jts} * Q_j * time \quad \forall t \text{ and } s \in \{dep_j, arr_j\} \qquad (7)$$

$$C_{ts} \leq Wait_{max} \quad \forall t, s \qquad (8)$$

$$R_{jts} \geq l_t + (tt * (s-1)) + \sum_{s'=1}^{s-1} C_{ts'} - M(1 - x_{jts}) \quad \forall j, t \text{ and } s = dep_j \qquad (9)$$

$$x_{jts} \in \{0,1\}, C_{ts} \geq 0,\ R_{jts} \geq 0 \quad \forall j, t, s$$

Constraint set (1) assigns each demand to one train at departure station, with constraint set (2) ensures that every demand is assigned to a single train in the portion of the line between departure and arrival stations. Constraint set (3) is the capacity constraint. Here *j* is taken in J_s representing the set of jobs whose arrival station is not *s*. Since at arrivals stations goods are unloaded from the train, constraint set (3) considers only goods kept in the train. Similarly, constraint set (4) sets the total loading and unloading times smaller or equal to the train waiting time at a station. Here *j* is taken in J'_s representing demands for which *s* can be a departure or an arrival station. Constraint set (5) respects the ready time of goods meaning that a demand cannot be assigned to a train arriving earlier than the ready time of the demand. Constraints set (6), (7) and (8) determine waiting time of train *t* at station *s*. Finally, constraint set (9) determines the time at which train *t* loads goods of client *j* at station *s*.

5 Experimental Study

5.1 Instance generation

We consider a single line on which 10 stations are ordered. Without loss of generality, stations are indexed from 1 to 10. The direction of flow for goods is from lower indexed stations to greater indexed ones. We consider train frequencies during off-peak times (from 10 am to 3 pm). 30 trains pass through the line in this period (1 train every 10 minutes). The capacity of a train is 15 boxes (30% of train capacity will be dedicated to goods transport). The travel time between two successive stations is 5 minutes. The maximum waiting time of a train at a given station is 1 minute and the minimum waiting time for passenger boarding is 30 seconds. The required time for the loading and unloading for a single box is 10 seconds. Other parameters are generated as follows:

- Clients: We suppose that the number of daily demand vary between 10 and 100.
- Time of demand: departure ready times are generated using a uniform distribution $r_j \in U[0,300]$ (in minutes) where 0 corresponds to 10 am and 300 corresponds to 3 pm.
- Demand sizes: the size of a demand can be any number between 1 and 5 ($U[1,5]$) measured in standard boxes.
- Departure and arrival stations: randomly generated between 1 and 10 for each demand (excluded station 1 for arrival stations and station 10 for departure stations).

5.2 Numerical results

For each different number of demands, 10 problem instances are generated. Thus a row of table 2 corresponds to a group of 10 instances for which, we report the running time, optimality gap (if a problem instance is not optimally solved), and the number of infeasible instances in the corresponding group. This last one can occur if the total daily demand is greater than the total capacity of trains. Another reason is due to the total loading/unloading time of boxes (all items cannot be charged in a train if the total waiting time of trains is smaller than the required time for the loading/unloaded of the boxes). We tested instances using an i5-2300 CPU 2.80 GHz computer with 8 GB RAM. CPLEX version 12.5 is used to implement the MILP model.

Table 2 presents a synthesis of results for all tested instances. Column 1 shows the number of daily demand. Column 2 shows the number of optimally solved instances. Column 3 shows the average optimality gap for those which are not solved within 5 minutes (if an instance is not optimally solved within 5 minutes, we stop CPLEX). Column 4 shows the number of infeasible instances. Finally, column 5 shows the average solution times (in seconds).

Table 2: Preliminary results for instances with 30 trains.

Nbr. of demand	Nbr. optimal	Avg. opt. gap	Nbr. infeasible	Avg. sol. time
10	10	0	0	≈0
20	9	0	1	0.2
30	10	0	0	0.3
40	9	0	1	0.4
50	10	0	0	0.5
60	9	0	1	1.2
70	9	0	1	1.2
80	10	0	0	1.4
90	9	0	1	2.6
100	9	0	1	3.6

Results presented in table 2 are encouraging for the performance of the MILP. All instances are quickly solved and in the worst case, the running time is around 11 seconds (observed for an instance containing 100 demands). All instances are optimally solved and there are only 6 instances which are infeasible. One analysed those six instances, one can observe that the infeasibility is due to demand ready times at the departure station. Some demands have late ready times which occur after the passing time of the last train dedicated to freight transport. Thus, the absence of a train for transporting such demands causes the infeasibility of problem instances.

An important functionality of the MILP is being able to quickly find the feasibility of a problem instance. This way, managerial decisions can be made very fast and problem parameters can be modified to prevent any infeasibility issue. We observed that increasing number of demand slows down the solution of the MILP. To determine if a similar observation occurs in the presence of varying number of trains, we generated new instances containing 10 to 100 demands and 10 to 100 trains. For each combination of different numbers of trains and demands, 10 problem instances are generated (thus a total of 1000 instances). All other parameters are the same. Train arrival times at the departure station are generated randomly respecting the time horizon in which customer demand occurs.

Numerical results show that all instances are, if feasible, quickly solved. The maximum running time is around 7 seconds which is observed for some cases containing 100 demands and 100 trains. Nevertheless, not all the instances are feasible. In fact among 1000, there is a total of 191 instances which are infeasible. The table 3 shows the partition of infeasible instances according to numbers of demands and trains.

Table 3: Number of infeasible instances.

Nbr. of demand	Nbr. of trains									
	10	20	30	40	50	60	70	80	90	100
10	5	1	0	0	0	0	0	0	0	0
20	7	2	0	0	0	0	0	0	0	0
30	9	6	0	1	1	1	0	0	0	0
40	9	4	0	0	2	0	0	0	0	0
50	10	5	0	2	1	1	0	0	0	0
60	10	6	1	1	0	0	0	0	0	0
70	10	8	1	1	1	1	0	0	0	0
80	10	8	2	5	2	2	0	0	0	0
90	10	10	3	1	1	2	0	2	0	0
100	10	10	1	3	1	1	0	0	0	0

The infeasible instances occur because of previous reasons: insufficient capacity and/or insufficient time for the loading/unloading operations, demand ready time larger than train passing times. Note that the infeasibility of instances is also quickly (within some milliseconds) verified by the MILP thanks to which, in practice, managers can quickly adjust parameters by increasing the number of trains to satisfy 100% the daily demand.

6 Conclusion and Perspectives

We studied in this paper a new configuration of freight transport within a city using the rail infrastructure. We propose to study a simplified problem which deals with a single line where each station contains an area for the loading/unloading of goods. Trains pass regularly and the customer demand is known in advance. We proposed a MILP model to minimize the total waiting time of daily deliveries. Computational results show that the optimization model is able to quickly solve moderate size instances containing up to 100 demands per day.

For future work, this study would be extended by considering heterogeneous network with multiple lines and various modes of transport (commuter rail, subway and tram). Other objective functions such as maximizing the total profit or the quantity of daily transport could be studied. Another perspective would be the development of a decision-making tool based on a discrete event simulation model. This way, we could validate the efficiency of online decision making algorithms to consider real time customer demand. Moreover, the simulation model could take into account randomness in operations (for ex. late trains, incident on the network ...).

References

1. European Cooperation in the Field of Scientific and Technical Research: COST 321 Urban Goods Transport, Final Report of the Action. Official Publication of the European Communities (1998)
2. European Commission: White Paper - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, COM/2011/0144 final. European Commission (2011)
3. Lindholm, M., Behrends, S.: Challenges in urban freight transport planning – a review in the Baltic Sea Region. Journal of Transport Geography. 22, 129--136 (2012)
4. National Institute of Statistics and Economic Studies, http://www.insee.fr
5. Dablanc, L.: Goods transport in large European cities: difficult to organize, difficult to modernize. Transportation Research Part A: Policy and Practice. 41(3), 280--285 (2007)
6. Mairie de Paris: Le transport de marchandises dans la ville de Paris. Direction de la Voirie & des Déplacements, Agence de la Mobilité - Usagers & Marchandises (2009)
7. Dinwoodie, J.: Rail freight and sustainable urban distribution: potential and practice. Journal of Transport Geography. 14, 309--320 (2006)
8. Browne, M., Allen, J., Woodburn, A., Piotrowska, M.: The potential for non-road modes to support environmentally friendly urban logistics. In: 1st International Conference Green Cities 2014 – Green Logistics for Greener Cities, pp. 29--36. London, UK (2014)
9. Behrends, S.: The urban context of intermodal road-rail transport – Threat or opportunity for modal shift? In: 7th International Conference on City Logistics, pp. 463--475. Procedia – Social and Behavioral Sciences, 39, Mallorca, Spain (2012)
10. Behrends, S.: The significance of the urban context for the sustainability performance of intermodal road-rail transport. In: 15th meeting of the EURO Working Group on Transportation, pp. 375--386. Procedia – Social and Behavioral Sciences, 39, Paris, France (2012)
11. Motraghi, A., Marinov, M.V.: Analysis of urban freight by rail using event based simulation. Simulation Modelling Practice and Theory. 25, 73--89 (2012)
12. Robinson, M., Mortimer, P.: Urban freight and rail – the state of the art. Logistics & Transport Focus. January/February 2003, 46--51 (2003)
13. Dablanc, L.: Freight transport for development toolkit: Urban freight, Department for International Development, The World Bank (2009)
14. MONOPRIX: L'acheminement des marchandises par voie ferrée et véhicules roulant au GNV vers les magasins monoprix et MONOP' de Paris. Dossier de Presse Ferroviaire, July 04, MONOPRIX (2007)
15. Metropolitan Transportation Authority: NYCT Trash Can Free Stations Pilot Update. Report Presentation, January, Metropolitan Transportation Authority (2014)
16. Quak, H.: Sustainability of Urban Freight Transport. Retail Distribution and Local Regulations in Cities. PhD Thesis, Erasmus Universiteit Rotterdam (2008)