POOLING LOGISTICS AS A MEAN FOR SUSTAINABLE URBAN FREIGHT DISTRIBUTION

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Abstract
By supporting trading activities urban freight distribution contributes to the dynamism of the cities. But policy makers have now to develop new logistics scheme that can minimize its negative impacts. This paper focuses on the consolidation of goods flows by using a Distribution Center. It appears to be a good solution to meet the new objectives of the policy makers: redesigning the flow of goods inside the city while not increasing the cost, reducing pollution and making the city more attractive. To dimension the DC, we have conducted a survey with the main customers of urban logistics services: retailers and store managers. The results of this survey are now used in order to optimize the delivery rounds in the city.

Keywords: Urban freight distribution, logistics pooling, vehicle routing problem

Introduction

The quality of the environment in urban areas is of vital importance. It is one of the main factors that determine whether a city is a healthy place to live, whether people enjoy living there, and whether they want their children to grow up there (EU, 2004). Urban freight distribution plays a major role in supporting trading activities and contributing to the dynamism of the cities but generate at the same time some negative impacts. Some of the main problems associated with increasing urban traffic are the following (Anderson et al., 2005):

- Economic impacts: congestion, inefficiency and resource waste, infrastructure damage.
- Environmental impacts: pollutant emissions, global warming, overconsumption of fuel, etc.
- Social impacts: the physical consequences of pollutant emissions on public health, traffic accidents, noise, etc.

To make cities more sustainable, numerous projects and innovations have been carried out in order to improve urban logistics. The main aims were to reduce motorized traffic and thereby reduce CO2 and greenhouse gas emissions in urban areas mainly by using three issues: consolidation of goods flows; low polluting vehicles; and regulation (Patier et Browne, 2010). Consolidation of goods, mainly based on the use of a distribution centre appears as a good solution to optimize the final delivery inside the city. The Vehicle Routing Problem-VRP can then be used to optimise the route for freight transportation. The traditional VRP is usually based on a homogeneous fleet size problem and many researchers have used these assumptions (Hasle and Kloster, 2007), but Vehicle Routing Problem becomes more complex when the vehicle fleet is heterogeneous, i.e., vehicles differ in their equipment, capacity, and cost (Taillard, 1999). The objective of this paper is to optimize urban freight distribution while taking into consideration the constraints and regulation of the city. Depending on the sum of products to be distributed, the fleet of vehicles has to be adapted in order to reduce the total costs and environmental impact. Thus, the problem that we consider in this paper is a Fleet Size and Mix Vehicle Routing Problem (FSMVRP) that is adapted to the environmental objectives, while focusing on the context of urban freight distribution. The next part of the paper gives an overview of the context of urban freight distribution and introduces the notion of Distribution Center (DC) as a logistics pooling system. Then a model of the Vehicle Routing Problem, using an heterogeneous fleet, and innovative objective functions to optimize cost and CO2 emission is developed. Finally, a case study in a medium city is proposed to validate the optimization model.

Context of Urban Freight Distribution

The main goal of urban freight policies is to improve the efficiency of freight movement in cities in order to increase their vitality while reducing the negative impacts.

Urban Freight Transport involves different actors, such as receivers (shops), shippers or producers (suppliers), transport operators, but also other stakeholders like city authorities, residents or visitors.

These later can be directly impacted by the negative externalities of freight transport activities: traffic congestion, noise, gas emissions, air pollution, etc. Despite the fact that goods transport in cities represents only 10% to 18% of road traffic, it accounts for 40% of air pollution and noise emissions (EU, 2006).

Classification of urban freight solutions
The urban freight distribution projects driven by local authorities mainly concern three areas (Lindholm, 2012):

- Restrictions such as: weight size and type of vehicle, loading and unloading area, time windows for distribution, etc.
- Consolidation of goods including: Hub, Central Distribution Center, Cross Docking Center, special container, etc.
- Infrastructure: concerns alternative ways of transporting goods using for example, rail, canals for waterway transport, trams or underground.

By introducing one more step in the supply chain, a distribution centre leads to additional handing, contractual problems, or loss of security, liability and customer service issues (Browne et al., 2005). Therefore, to encourage transport operators using a distribution centre, an appropriate mix of measures are used together: consolidation centers often work in combination with restriction measures. This paper focuses on optimal distribution of urban freight from a Distribution Centre under the constraints of time window for distribution.

Logistics pooling and consolidation centers
Consolidation appears as one of the key issues to improve urban goods transportation. The design and optimization of logistics scheme, long based on an economic approach; happen today through the integration of environmental and social concerns, in line with the objectives of sustainable development (Rosen and Kishawy, 2012).

Literature on logistics pooling and transport optimization (Cruijssen, 2006), (Ballot and Fontane, 2010), is mainly based on analytical methods and call upon strong hypothesis to simplify the models. They generally consider the case of pallets as shipment unit, full truckload delivery, and routing problem. The demand in most cases is considered as stationary and the delivery of batch of products is organized according to long delays through warehouses and logistics hub. Urban freight transport is different from mass distribution. Shipment units are parcels and cartons, the logistics flow is characterized by a non stationary demand of small quantities, to be distributed the same day or in D+1, to different destinations every day.

When using a distribution center (DC), the objective is to optimize the delivery round for each vehicle starting from the DC. The main constraints are the following:

- The total weight and number of parcels to be delivered, in order to choose the appropriate truck's capacity for each round,
- The number of stores to be delivered in the round, to estimate the duration of the stops,
- The location of the stores, to calculate the distances and estimate time transportation,
- Time slot for delivery at each store, which appears to be a big constraint in the case of urban freight distribution.

Vehicle Routing Problem and Sustainability
The environmental impacts of transport can be reduced by improving the concept of sustainable transportation (Moutaoukil and al., 2013). The term sustainable routing problem is used to describe modes of transport, and systems of transport planning that are consistent with wider concerns of sustainability (Faccio and al., 2013).

To develop the model, we must model the distance in the whole logistics network: between clients themselves, and between platform center (depot) and customers. Thus, the problem is defined as complete graph $G(N,A)$ where $N=\{0\}\cup\{1,\ldots,n\}\cup\{n+1\}$ defines the set of different nodes and $\{0\}$ and $\{n+1\}$ represent the depot and A is the set of arcs between each pair of nodes. The set of customers is represented by $Nc =\{1,\ldots,n\}$. For every arc (i,j) in A, the distance between nodes i and j is defined as dij. Arc eij belongs to the set of arcs A and has an associated non-negative costs cij . The demand at the depot is considered to be zero.

An unlimited heterogeneous fleet of vehicles is available. This fleet of vehicles is composed of V = {1, …,K} different vehicle types, each with a different cost and capacity. The following notations are used:

N = number of customers (nodes),
f_k = fixed cost of acquisition / rental of type k vehicle
α_k = cost /ton.km of type k vehicle,
β_k = cost /km of type k vehicle
δ_k = cost /ton of type k vehicle
q_i = demand for customer i,
d_{ij} = distance of the arc ij
C_k^p = capacity (weight) of a type k vehicle,
E_{empty}^k = emission of an empty vehicle of type k,
E_{full}^k = emission of full truckload of type k vehicle,
$E_{manufacturing}(k)$ = manufacturing emission of type k vehicle,
$D(k)$= Lifetime in km of type k vehicle,
T = Vehicle routes deadline
t^k = Unloading time of type k vehicle;

In addition, the following decision variables are used:

y_{ij}^k: flows on arcs (i, j) loaded on vehicle of type k,
x_{ij}^k : 1 if vehicle of type k is assigned to (i, j), and 0 otherwise.
Z_j^k: 1 if type k vehicle visit j, and 0 otherwise;
t_{ij} : Time runs on (i, j).

Basic principles for estimating CO2 emission

From the perspective of sustainable development, this section aims to evaluate CO2 emissions within routing problems. As demonstrated in literature (Ubeda et al., 2011), (Figliozzi, 2010), CO2 emissions depend on the weight carried by the truck, on the capacity of the truck that is used, on the distance traveled and the average speed of the truck. The average speed of course depends on the type of path in urban, regional or national routes. We have improved the formula given by [(Jancovici, 2007) and (Hickman et al., 1999)], to calculate the CO2 emissions based on truck type k, by setting the value of the average speed to 20 km/h for urban routes:

$$(g) = \sum_{k\in V} \sum_{(i,j)\in A} d_{ij} * \left[(E_{full}^k - E_{empty}^k) * \frac{y_{ij}^k}{C_k^p} + E_{empty}^k + \frac{E_{manufacturing}(k)}{D(k)} \right]$$

We point out that CO2 emissions are not directly related to the weight of the cargo but rather to the actual weight of the used vehicles including their load and their curb weight. This means that the usage of vehicles of adequate size reduce CO2 emissions. The incorporation of a lighter vehicle of course means that the vehicle's payload is reduced. To explore a fleet's ability to carry goods of different sizes, we investigate non homogeneous fleets where vehicles differ by their weight, payload and emissions.

Economic cost of the routing problem

As in some scientific work as in (Liu et al., 2009), the economic function of vehicle trips contains a fixed (depends on vehicle type) and variable cost (which depends on the type of vehicle, distance traveled and amount charged). To calculate the cost of a routing solution, we base on this equation witch is derived from the equation given by the National Road Committee of France (CNR) in their website (cnr.fr):

$$Cost(€) = \sum_{k\in V} \sum_{j\in N} f_k x_{ij}^k + \sum_{k\in V} \sum_{(i,j)\in A} \alpha_k \, d_{ij} y_{ij}^k + \sum_{k\in V} \sum_{(i,j)\in A} \beta_k \, d_{ij} x_{ij}^k + \sum_{k\in V} \sum_{(i,j)\in A} \delta_k \, y_{ij}^k$$

The first part of the economic objective function gives the total fixed cost of the vehicles used and the three others parts give the total variable routing cost. By adding the flow variable in the equation, our model introduces variable costs related to the load of the vehicle while in most publications, the variable cost is often only related to the distance traveled. Our assumption is closer to real life, where carriers invoice according to traveled distance and loaded weight.

Constraint of the routing problem

From literature, all constraints related to a FSMVRP were adapted, and a time constraint was added for routes. So, the constraints brought to our model are as follows:

$$\sum_{i=0}^{n} x_{ij}^{k} = \sum_{i=0}^{n} x_{ji}^{k}, \forall k \in V, \forall j \in N \quad (2) \qquad \sum_{i=0}^{n} x_{ij}^{k} = Z_j^k, \forall k \in V, \forall j \in N \quad (3)$$

$$\sum_{k=1}^{m} Z_j^k = 1, \forall j \in Nc \quad (4) \qquad \sum_{k \in V} \sum_{j \in N} y_{0j}^{k} = \sum_{i \in N} q_i \quad (5)$$

$$\sum_{k \in V} \sum_{j \in N} y_{j0}^{k} = 0 \quad (6) \qquad y_{ij}^{k} \leq \sum_{k \in V} Q_k x_{ij}^{k}, \forall (i,j) \in A \quad (7)$$

$$\sum_{i=0}^{n} y_{ij}^{k} - q_j * Z_j^k = \sum_{i=0}^{n} y_{ji}^{k}, \forall k \in V, \forall j \in Nc \quad (8)$$

$$t^k \sum_{(i,j) \in A}^{n} x_{ij}^{k} + \sum_{(i,j) \in A}^{n} t_{ij} x_{ij}^{k} \leq T, \forall k \in V \quad (9)$$

$$y_{ij}^{k} \geq 0; \quad t_{ij} \geq 0 \ \forall (i,j) \in A \ \forall k \in V \quad (10) \qquad y_{ii}^{k} = 0, \forall i \in N, \forall k \in V \quad (11)$$

$$x_{ij}^{k} \in \{0,1\}, \forall (i,j) \in A, \forall k \in K \quad (12) \qquad Z_i^k \in \{0,1\}, \forall i \in A, \forall k \in K \quad (13)$$

Constraint(2) ensure that a vehicle that arrives at a customer will also be the same type that leaves, while constraints (3) and (4) state that each customer is visited exactly once, so the type of vehicle arriving and leaving one particular customer has to be the same. Constraints (5) and (6) indicate that vehicles are loaded when they leave the depot and must return loaded. In (7), the total load on a trip is constrained not to exceed the capacity of the vehicle assigned to that trip and equation (8) represents the movement of goods assuming that all customer demands must be satisfied. The constraint of max time of a route is represented in (9). Constraints (10) ensures that the flow and time are non-negative and (11) means that there is no flow from a customer to itself; while constraints (12) and (13) define that each arc has the value 1 if it is used and 0 if it is not used by a vehicle of type k.

Case Sudy in a Medium Sized City

Such a project was started in Saint Etienne, a medium size city in France. The objective was to reduce the negative impact of urban freight transport by using a distribution centre located nearby the highway. After a cross docking operation, a limited number of vehicles are delivering the parcels to the customers inside the city. In 2012, a survey was conducted with 100 store managers in the hyper-center of the city in order to identify their logistics activities. The results gave information on the constraints and on the daily and weekly demand at each store such as (Neubert and Moutaoukil, 2013):

- The stores can receive a range from less than 1 receipt per week to more than 4 a day.
- City regulation policies impose that the delivery of the stores must be done before 11 AM.
- 40 % of the stores open between 9 and 10, and 40% after 10. This results in a very short delay, 1 or 2 hours to organize the delivery trips from the DC.

As an example, in a given day, 10 addresses are visited, located around the depot. The demand vector is given by the following table:

Manufacturer	1	2	3	4	5	6	7	8	9	10
Demand (Ton)	0.09	0.11	0.07	0.5	0.7	0.03	0.11	0.06	0.05	0.6

Table 1: Manufacturer's demand

To operate our case study, we used a set of parameters that define the main characteristics of a given vehicle, summarized in the following table:

Category	Type of vehicles	Total authorized weight (ton)	Useful load (ton)	Cost/km	Cost/ton	Fixed Cost	E^{k}_{Empty} (g/CO_2)	$E^{k}_{full}(g/CO_2)$	$E_{manufacturing}/k$	Unloading time (min)
LDV *	1	<1.5	0.4	0.13	0.037	104.84	58.6	59	6.8	5
	2	1.5-2.5	0.7	0.15	0.04	104.84	68.4	68.4	8.3	7
	3	2.6-3.4	1.2	0.17	0.045	104.84	88	88	10.2	9
HDV **	4	3.5	1.4	0.23	0.05	111.58	100.9	101	10.5	10
	5	3.6-5	2.37	0.29	0.065	111.58	136	196	11.9	13

*LDV: light duty vehicles ** HDV: heavy duty vehicles

Table 2: Parameters of simulation [adapted from CNR and (Jancovici, 2007)]

Case Study Results

For the case study discussed, the model gives different results depending on the optimization criterion. First, the basic scenario with direct deliveries from the depot to the clients has to be assessed. Its evaluation is summarized in table below.

		Direct scenario
Assess-ment	Economic	417,93
	Environmental	4670,6
	Distance travelled	68,22
	Number of routes	10
	Number of vehicles	3 of type 2 and 7 of type 1

Table 3: Direct scenario results

Choosing the economic function to optimize the delivery run, it gives the following results:

Optimization		**Economic**	
Delay of delivery		2h	1h
Assessment	Economic	*79,431*	*121,89*
	Environmental	2859,9	2687,3
	Distance travelled	27,59	34,62
	Number of routes	2	4
	Visiting Order	Type 3: (0,5,7,1,3,8,6,0) Type 4: (0,10,4,2,9,0)	Type 1: (0,2,7,6,0) Type 2: (0,4,3,9,0) Type 2: (0,10,8,0) Type 3: (0,5,1,0)

Table 4: Economic optimization results

Depending on the deadline for delivery, the economic optimization use different types and number of vehicles. Thus, when the maximum duration for a route is 2h, the delivery process uses two types of vehicles: type 3 and type 4 with one run for each. The total traveled distance of the two routes in this scenario is equal to 27,59 km. However, when we have only 1h for maximum duration, the model uses more vehicles with different types to satisfy clients demand in this tight deadline. Thus, in this case, the model uses 4 vehicles: two of type 2, one of type 1 and one of type 3. This needs more distance to be travelled which is equal to 34,62 km. We see clearly that when the maximum duration for delivery is decreased by one hour, total cost increases from 79,431 to 121,89 and at the same time, CO2 emissions increase from 2859,9 g to 2687,3 g. The economic optimization gives better results than the direct delivery, whatever the criterion of evaluation. The following figures show geographically different routes:

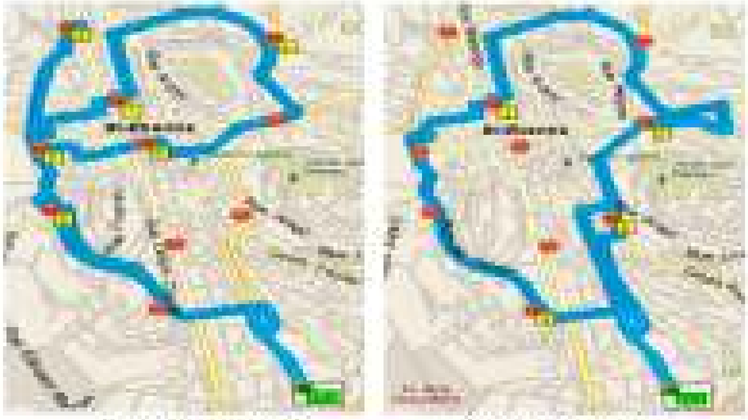

Route 1: Vehicle type 3 Route 2: Vehicle type 4

Figure 3: Economic Routes with delivery delay T= 2h

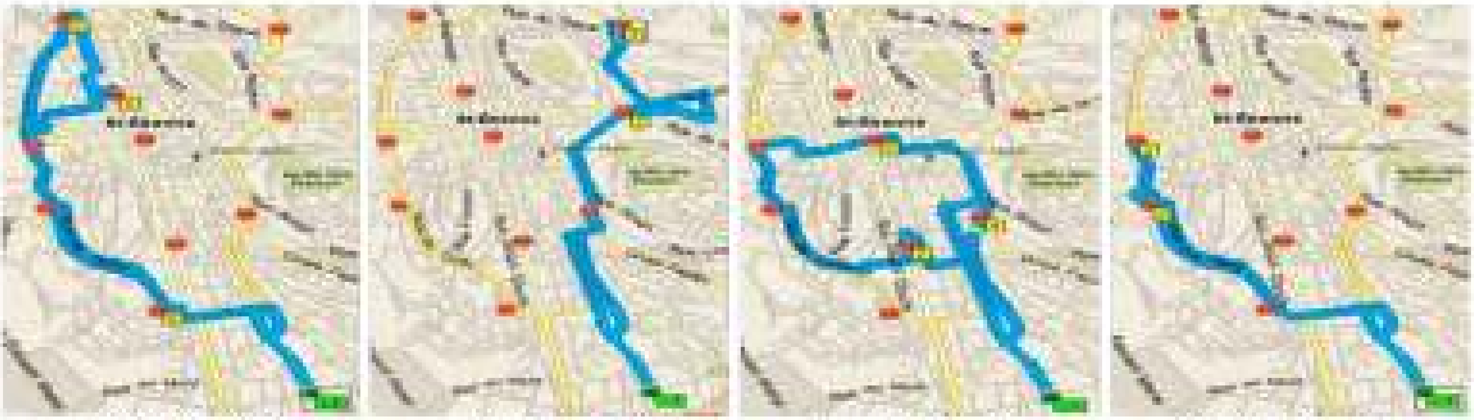

Route 1: Vehicle type 1 Route 2: Vehicle type 2 Route 3: Vehicle type 2 Route 4: Vehicle type 3

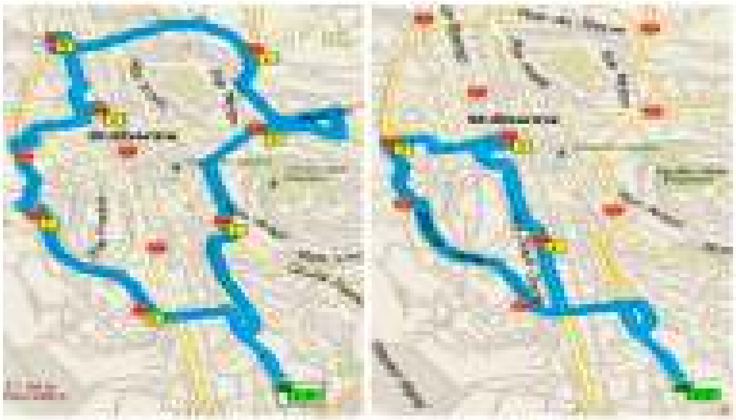
Figure 4: Economic Routes with delivery delay T= 1h

In the case of environmental optimization, the model gives the following results:

Optimization		**Environmental**	
Delay of delivery		2h	1h
Assessment	Economic	86,677	125,15
	Environmental	*2009,8*	*2398,4*
	Distance travelled	19,48	29,4
	Number of routes	2	4
	Visiting Order for each vehicle type	Type 3: (0,9,10,8,7,6,1,2,0) Type 4: (0,5,3,4,0)	Type 1: (0,8,7,6,3,0) Type 2: (0,4,0) Type 2: (0,9,10,0) Type 3: (0,5,1,2,0)

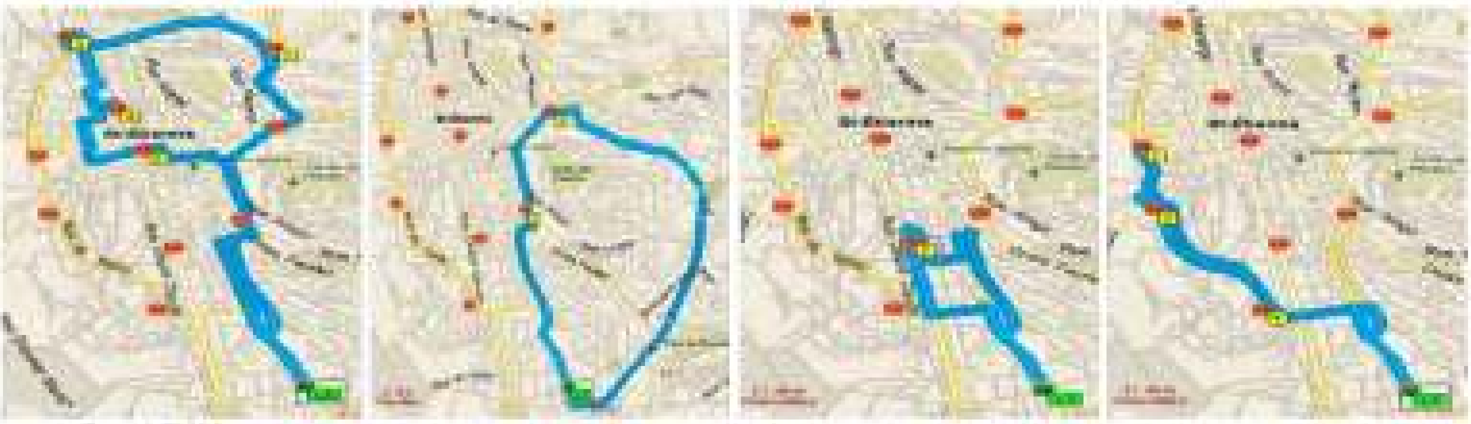
Table 5: Environmental optimization results

The following figures show geographically the different routes:



Route 1: Vehicle type 3 Route 2: Vehicle type 4

Figure 3: Environmental Routes with delivery delay T= 2h



Route 1: Vehicle type 1 Route 2: Vehicle type 2 Route 3: Vehicle type 2 Route 4: Vehicle type 3

Figure 4: Environmental Routes with delivery delay T= 1h

The environmental optimization uses different types of vehicles depending on the delivery deadline. Thus, when the maximum duration is 2h, the model uses two types of vehicles: type 3 and type 4 with one run for each. The total traveled distance of the two routes in this scenario is equal to 19,48 km. However, when we have only 1h of maximum duration, the model uses more vehicles with different types to satisfy clients demand in this tight deadline. Thus in this case, the model uses 4 vehicles: two of type 2, one of type 1 and one of type 3. This needs more distance to be travelled which is equal to 29,4 km. We see clearly that when the maximum duration for delivery is decreased by one hour, CO2 emissions increase from 2009,8 g to 2286,4 g and at the same total cost increases from 86,677 to 125,15 euros. We highlight also that the environmental optimization gives better results than the direct delivery, whatever the criterion of evaluation. Generally, we can conclude that the roads and the number and types of used trucks, depend on the optimization criterion and on the maximum time allotted to the distribution problem.

Conclusion

This paper deals with the problem of urban freight distribution in large cities in European countries. By supporting trading activities it contributes to the dynamism of the cities, but policy makers have now to develop new logistics scheme that can minimize the negative impacts. Many actors have to be considered in such projects, beginning with city traders and retailers who do not want to reduce the quality of service of their actual replenishment. Implementing a Distribution Center often appears as a good solution to meet the new objective of the policy makers: redesigning the flow of goods while not increasing the cost, reducing pollution and making the city more attractive. The experience actually conducted in St Etienne just started. It is based on a detailed analyze of the situation, including different stakeholders: haulers, citizen, retailers and store managers. This paper shows the impact of the delay for delivery on the economical and environmental performances of a distribution center. The main result is that policy makers should consider at the same time the change in the logistics process, i.e. using a distribution center, and the change in the restriction, i.e. changing deadline for delivery from 11 AM to 12 AM.

Acknowledgment

Authors would like to thank Region Rhône-Alpes for its financial support (Research Cluster GOSPI).

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