Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 12 (2016) 413 – 424

Transportation Research Procedia

www.elsevier.com/locate/procedia

The 9th International Conference on City Logistics, Tenerife, Canary Islands (Spain), 17-19 June 2015

# Urban Freight Transport: From Optimized Routes to Robust Routes

Mohamed Guedria a,b, Nicolas Malhene b, Jean-Christophe Deschamps b *

*a EIGSI La Rochelle, France*
*b IMS Université Bordeaux, France*

**Abstract**

This paper considers two well-known strategies for the organization of tours for urban deliveries: the vehicle routing problem (VRP) and the optimization of vehicle loading plan problem. Experience shows that optimal solutions are rarely implemented given the many intervening disturbances on an urban tour. As illustrated using a simple theoretical scenario, we propose a hybrid approach between the two strategies and introduce the concept of robustness in the tour, in order to guarantee a predefined level of performance.


Peer-review under responsibility of the organising committee of the 9th International Conference on City Logistics

*Keywords:* Packing Problem, VRP, City Logistics, 2L-CVRP, Robust vehicle routing

## 1. Introduction

City logistics or transport Goods in Town should be considered as a complex system involving many actors (public and private), objectives, constraints and different cultures. Urban logistics is essential to the vitality of a city but it is associated with many obstacles and problems, which do not match up with the needs of the stakeholders. For several years various experiments have been carried out in order to reduce these nuisances. Research efforts are focused on achieving sustainable development and more responsible supply chain management. Our paper focuses on the problem of inner city deliveries to try to define various criteria of optimization and identify interesting approaches in terms of

* Corresponding author. Tel.: +33 5 17 83 20 06;
*E-mail address:* Mohamed.guedria@eigsi.fr


Peer-review under responsibility of the organising committee of the 9th International Conference on City Logistics
doi:10.1016/j.trpro.2016.02.076

sustainable performance.

This article is divided into four parts: First, the characterization of the urban context through the explanation of the issues and the complexity of urban logistics. The second part presents the problem of urban delivery. Next, we illustrate this problem through a scenario that involves three approaches:

- The first one is a simple case of vehicle routing problem: in this case we give priority to the vehicle tour.
- The second, which gives priority to the loading plan and relaxes priority to the vehicle tour.
- The third, explains the compromise between the first two approaches with a hybrid optimization (tour, loading).

Finally, the fourth and last part, we will introduce the tour robustness concept and how can we reduce the planning horizon.

## 2. Characterization of the urban context

### *2.1.Complexity of urban logistics*

The current urban context is extremely complex because it encompasses multiple, diverse and interdependent components with several different actors. However, the stakes are high because the urban saturates at the last mile following the high demand for home delivery and e-commerce for consumer goods (Evad, 2013). The "Business to Consumer" (B2C) now is booming and is an important part of urban logistics (Durand, Jesus, & Frederick, 2010). Increased urban development increases intramural congestion and reduces the space dedicated to vehicles. Paradoxically, the reintroduction of shops in town centres' generates a flow of goods in increasingly confined places. Our research is in this context and aims to develop new logistics systems to meet city sustainability objectives (Trentini, 2012).

### *2.2.Issues of urban logistics*

The configuration of logistics in the urban context must meet three major issues (Brunet, 1997) (Barnier & Toucelet, 1999) (Torres, 2002):

- Economic: sustainably reduce operating costs related to logistics.
- Environmental: sustainably reduce emissions of greenhouse gases, energy consumption and pollution caused by transport.
- Societal: increase quality of life in the sustainable city by reducing congestion and noise pollution and improving accessibility and mobility within the city.

As part of our research, the answer to these challenges falls through the definition of new tools for route optimization of delivery vehicles.

### *2.3.New tools for TMV Urban Goods Transport*

Our research is based largely on the development of new technologies and new tools available to transport professionals: fleet management, shipment tracking, geolocation, etc. These new tools allow reporting information in real time and in particular to account for unexpected disruptions such as congestion, breakdowns, absent recipients, urgent delivery, etc. Each of these disturbances deteriorates the performance of a tour that was optimized from a static point of view. The combination of these tools should enable the deployment of dynamic optimal solutions.

## 3. Problems of delivery round

The problem of urban vehicle routing optimization depends primarily on two criteria: the distance travelled by vehicles and the loading of these vehicles (Crainic, 2009) . In parallel to our literature review, we conducted a survey of various transportation companies, focussing on a carrier specialized in the transport of refrigerated goods. This initial study suggests that structured approaches that emerge from research have not yet been adopted by all transport professionals working on the road. These professionals still use informal rules; we will say common sense to build their delivery rounds for example:

- First: come the so-called priority customers in relation to time constraints delivery set in advance between the transport company and the customer,
- Finally: come the repository geographically closest customers to minimize the distance travelled by the truck-load,
- In Between: the tour more or less follows the logic of minimizing the distance travelled by the vehicle.

This intuitive approach works effectively from a static point of view. Delivery drivers often have a very good knowledge of their territory. But in an urban context increasingly subject to disturbances, the performance of these tours that could be described as customary rounds tends to move away from the defined optimum. It then becomes necessary to think dynamically by improving both vehicle loading and tour planning.

### *3.1. Scenario overview*

The case of basic study we present includes 5 positions (one customer per position). Each position requires one delivery (D) and each one consists of rectangular boxes (m) of different sizes. So considering all D of m boxes to be delivered to customers. The result of this description the following mathematical description: consider an undirected graph G = (V, E), where V is the set of vertices (positions) including n customer and a central depot (node 0) and E = $\{(i, j): i, j \in V, i \neq j\}$ is the set of edges.

### *3.2. Variable declarations*

In the model, we start with predefined data. For example: the number of vehicles in the fleet, where the customers are, how they expect pallets, etc.

- N = All positions
- $K$ = Set of vehicles
- D = Set of deliveries
- M = Infinite number
- $t_{ij}$ = Travel time between two positions $i, j$
- $dist_{ij}$ = Distance between two positions $i, j$
- $n$= Number of pallets or box that node i is waiting
- $n_{pickup}$ = The order pickup position
- $n_{delivery}$ = The order delivery position
- $k_{capacity}$ = The capacity of a truck k
- $k_{pos}$ = Truck position
- $[tmin_i, tmax_i]$ = Time window in node $i$
- $Ind$ = Congestion index (it depends on the time of delivery)

### *3.3. Decision variables*

A decision variable is a variable in the problem, the value is not yet known. In mathematics, often used as an unknown variable x. The variable has a field that specifies all possible values that the variable can take.

- $x_{ij}^{k}$ = *Decision Variable,1* if the truck k takes the arc between the position *i* and *j*, 0 otherwise
- $v_{i}^{k}$ = If truck *k* visit node *i*
- $d_{i}^{k}$ = Amount of palettes or boxes that takes truck *k* from order *i*
- $c_{ij}^{k}$ = Load of the truck *k* on the arc between node *i* and *j*
- $ov_{i}^{k}$ = The order of nodes visited by a truck
- $a_{i}^{k}$ = Arrival time of a truck in node *i*
- $nbbt_{i}^{k}$ = Amount of boxes that a truck *k* will handle in a node *i*
- $s_{i}^{k}$ = Truck *k* service time in position *i*

### *3.4. Constraints*

$$\sum_{i=0}^{N} x_{ij}^{k} = v_{j}^{k} \quad \forall k \in K, \quad j, i \in N, \quad i \neq j, \; j \neq 0 \tag{1}$$

$$\sum_{i=0}^{N} x_{ji}^{k} = v_{j}^{k} \quad \forall k \in K, \forall j, i \in N, i \neq j, j \neq 0 \tag{2}$$

$$d_{i}^{k} \geq 1 - M(1 - v_{i}^{k}) \quad \forall k \in K, \forall i \in N, i \neq 0, \quad i \neq 0 \tag{3}$$

$$\sum_{i=0}^{N} x_{ip}^{k} = \sum_{j=0}^{N} x_{pj}^{k} \quad \forall k \in K, \forall p \in N, i \neq p, j \neq p, p \neq 0 \tag{4}$$

$$\sum_{j=1}^{N} x_{0j}^{k} \leq 1 \quad \forall k \in K \tag{5}$$

$$\sum_{j=1}^{N} x_{j0}^{k} \leq 1 \quad \forall k \in K \tag{6}$$

$$\sum_{i=0}^{D} d_{i}^{k} = nb_{boite_{i}} \quad \forall i \in D, \forall k \in K \tag{7}$$

$$\sum_{i=0}^{D} \sum_{k=0}^{K} d_{i}^{k} = n_{demande} \quad \forall i \in N, n_{delivery} = i, \forall k \in K \tag{8}$$

$$k_{capacity} \geq \sum_{i=0}^{N} c_{i}^{k} - M(1 - v_{i}^{k}) \quad \forall k \in K, \forall i \in N \tag{9}$$

$$bmin_{i} \leq a_{i}^{k} \leq bmax_{i} \quad \forall\, v_{i}^{k} = 1 \quad \forall k \in K, \forall i \in N \tag{10}$$

$$k_{maxtime} \geq \left[ \sum_{i=0}^{N} \sum_{j=0}^{N} x_{ij}^{k} * (t_{ij} + s_{i}^{k}) \right] \quad \forall k \in K, i \neq j \tag{11}$$

$$c_{i}^{k} = \sum_{i=0}^{n} \sum_{in=0}^{D} d_{in}^{k} * v_{i}^{k} \quad \forall k \in K \tag{12}$$

$$nbbt_{i}^{k} = \sum_{i=0}^{D} d_{i}^{k} \quad \forall i \in D, \forall k \in K, \forall i \in N \tag{13}$$

$$s_{i}^{k} = Ind * (1.2 * nbbt_{i}^{k}) \quad \forall k \in K, \forall i \in N, i \neq 0 \tag{14}$$

Constraints (1)-(2) ensures that each vehicle will visit once a customer, constraint (3) guarantee if the truck k has a delivery for a position i he must visit this position. Then constraints (4) guarantee the continuity of a tour. Constraints (5)-(6) guaranteed that each vehicle enters and exits once the depot, also the capacity of the vehicle is respected by constraints (7)-(8)-(9). To respect time window for each customers we use constraints (10)-(11) and then to indicate the load of a truck k on the arc with destination j we use the constraint (12). Constraint (13) give as the amount of boxes that truck k will handle in a node I and to calculate service time at each position i for a truck k we use constraint (14).

### *3.5. First approach: focus on tour*

In this first approach, we aim to minimize the total distance travelled and at the same time we suppose that the load of the vehicle was maximized previously (Fuellerer, Doerner, Hatl, & Lori, 2009). The time during which the vehicle is stopped in order to carry out a delivery (downtime) is not taken into account. The vehicle loading plan is independent of the order of the tour.

From these assumptions the following mathematical formulation:

- Minimise time traveled

$$min \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=0}^{K} x_{ij}^{k} * tt_{ij} i \neq j \tag{15}$$

- Along with
    - $tt_{ij}$ = time traveled between two positions $i, j$

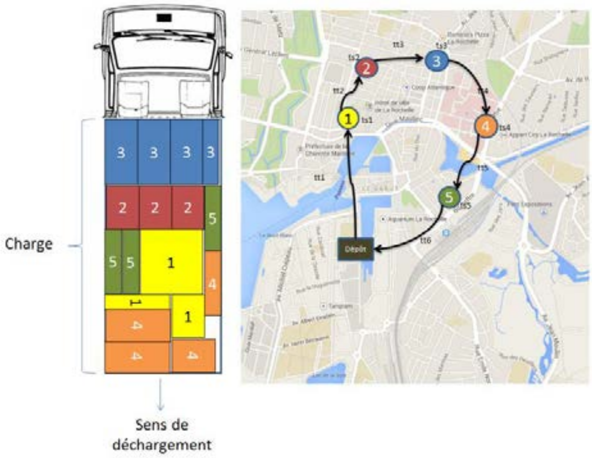


Fig. 1. Optimization of the tour and maximizing the load of container

In this approach, the downtime per delivery point is not yet known, since the loading plan does not take into account the order of the tour. Due to the separate optimization of vehicle routing and loading plans, the overall tour time rises considerably.

### 3.6. Second approach: priority loading

For this second case, the goal is to maximize the loading of the vehicle and minimize the time of service for each customer visit. By conducting the tour using an optimal loading plan, there is a risk of conducting a sub-optimal tour and increasing overall travel time.

Constraints to meet:

- Maximize load **c** trucks

$$max \sum_{i=1}^{N} \sum_{j=0}^{N} \sum_{k=0}^{K} x_{ij}^{k} * c_{j}^{k} i \neq j \tag{16}$$

- Minimize **ts** truck service time

$$min \sum_{i=1}^{N} \sum_{j=0}^{N} \sum_{k=0}^{K} x_{ij}^{k} * ts_{j}^{k} i \neq j \tag{17}$$

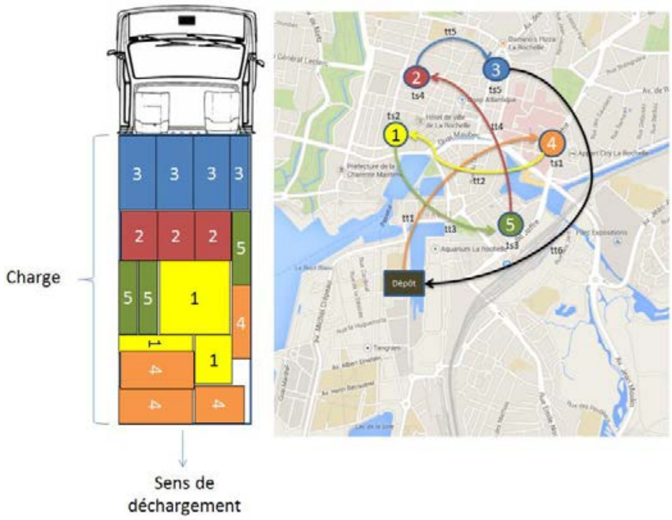


Fig. 2. Maximizing the load of the container and by minimization of the customer service time

In this approach the construction of the tour depends on the loading plan, and deliveries are unloaded starting from the back of the vehicle, and finishing with goods from the front of the vehicle (Figure 2). Therefore, the overall distance travelled may increase. This solution minimizes the downtime of the vehicle position (client) but reduces overall optimization in terms of distance traveled.

### *3.7. Third approach: time compromise tour / downtime*

The overall tour duration is the sum of the travel time and the downtime at each of the positions. Is there a more optimal solution than earlier approaches in terms of the carbon footprint and the total duration of the tour?

The purpose of our third case then is to find a balance between the first two cases and to jointly minimize the time of service delivery (downtime) and the travel time (distance). The right compromise between maximizing vehicle routing and loading plans is necessary. However, the stakes are high, since the number of constraints is very important and the optimization also depends on the shape and the number of items to be delivered.

Constraints resulting from this hypothesis:

- Minimize **ts** truck service time

$$max \sum_{i=1}^{N} \sum_{j=0}^{N} \sum_{k=0}^{K} x_{ij}^{k} * \ ts_{j}^{k} i \neq j \tag{17}$$

- Minimize the total journey time **tt**

$$min \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=0}^{K} x_{ij}^{k} * \ (tt_{ij} + ts_{i}^{k})\ i \neq j \tag{18}$$

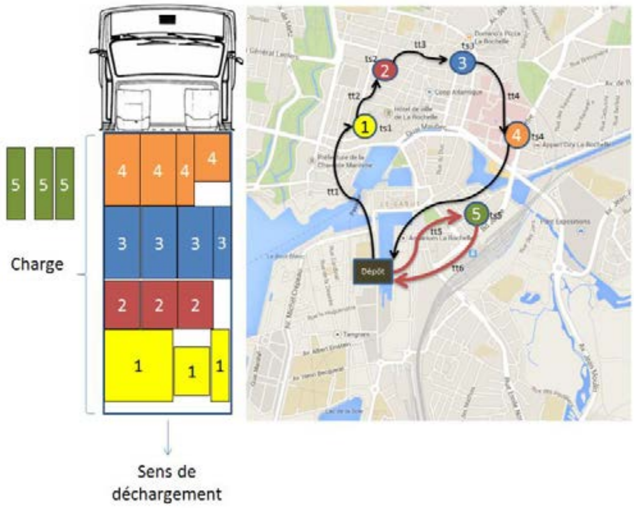


Fig. 3. Minimize service time and travel time

This solution provides a loading plan that meets the optimal tour but which exceeds the vehicle load capacity. Thereafter a new tour is implemented. However, can one verify that this joint optimization can provide optimization of fuel consumption and carbon footprint, even if one may use more than one vehicle and whether this solution will always be reliable and robust in performance?

## 4. Two different points of view

Whatever the implementation optimization approaches for our tour scenario, there will be a difference between the actual and planned.

Delivery drivers face many unexpected disruptions such as congestion, breakdowns, absent recipients... Therefore, optimization, even if it is optimal in the beginning, can degrade significantly during the execution of the actual plan as a result of unexpected disruptions.

In our very simplistic scenario the impact is not important. On the scale of a fleet of vehicles loaded with goods to supply an entire city, the impact will grow and generate far more important issues such as offset delivery schedules, non-deliveries, degradation of the level of service and therefore a loss of competitiveness for the operator. Mathematical models are performing for vehicles routing problems solving. Nevertheless, we should keep in mind that there is always a gap between the planned optimized routing and its execution. As a result, the performance of the service is deteriorated. In order to reduce this gap two proposals can be introduced:

- One concerns a robust solution and that supports a limited level of service degradation to ensure continuity of performance
- The second deals with an innovative delivery concept based on a small urban vehicle associated with shortened delivery tour.

### *4.1. First point of view: introduction of robustness concept*

The two objectives are sought optimization and robustness, which are inherently contradictory (Chaari, 2010), in fact the robustness seeks to remain as faithful as possible to the problem while optimizing seeks to simplify it to make it effective. The robust optimization is an approximation of a stochastic problem (HAJJI, 2003) (Adulyasak, 2014) (SUN, 2015), it is easier to define and solve. It also remains a better approximation than a deterministic formulation but still allows one to find the maximum or minimum of a global problem.

The robust optimization concerns situations or scenarios on the data are considered and where the objective is to determine a solution that provides acceptable performance overall despite sustained disturbances. This performance may deteriorate due to unexpected disturbances such as absent addressees or vehicle breakdowns. In this case, the aim is to ensure a continuity of the system despite disturbances by finding the right compromise between the loading and the tour. However, the performance degradation of the system must have a minimum threshold (lower limit). This can be fixed according to several evaluation criteria:

- Profitability: Profitability can be translated through a threshold cost / tour should not exceed a limit set by the carrier. In this case there is a lower limit which is known from the start.
- The most expensive tour: In this case the choice of the lower limit is through the classification of solutions possible depending on the cost. This can give us an idea about the most expensive tour among all possible tours.

The evaluation of the system performance drop can result through the figure below. This figure shows how our system performance may degrade due to unexpected incidents:

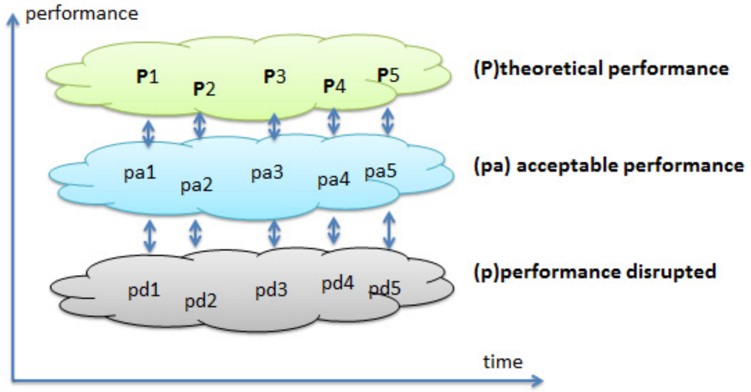


Fig. 4. System performance during the period of disturbances

This approach consists to define the performance levels planned expected, so we seek an acceptable performance cloud. The goal is not to only optimize our tour but to keep our level of performance in this performance cloud. In this case we guarantee that the expected results will be as planned despite the disturbance. For this we take the theory of constraints where privilege the flow capacity. The evaluation of cloud performance can result through Figure 5 below.

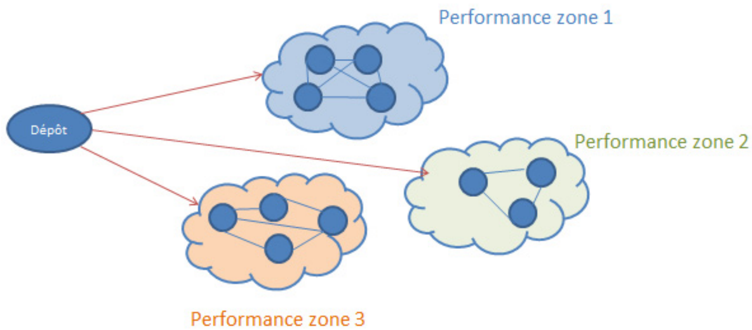


Fig. 5. Cloud performance area independently of the order of tour

When using the cloud performance we guaranteed that all customers served in the performance area will be delivered in time without paying attention to the order of delivery.

*4.2. Second point of view: Shortening delivery tour*

This second point of view considers a succession of very short tours so that an event cannot affect significantly the performance of the planed delivery tour. The implementation of such tours is based on light vehicles. In the classic case of vehicle routing problems, delivery of goods is done with vehicles that have a relatively high load capacity even in an urban context. This assumes that the time for delivery 'T' is as long in time. We hear it by the total time of our "T" tour is relative to the size of our vehicle. A vehicle with a large capacity will create the following constraints:

- Optimization of tour and loading plan more difficult (more complex)
- A longer tour is much more exposed to internal and external disturbances that may at any time degrade the optimal starting solution.

Indeed, it is proposed in this case the division of our time for delivery in a small segments, $T = t_1, t_2, ... t_n$, using light vehicles with low capacity (max $1m^3$) and a 100 km autonomy to minimize stresses which undergoes our system.

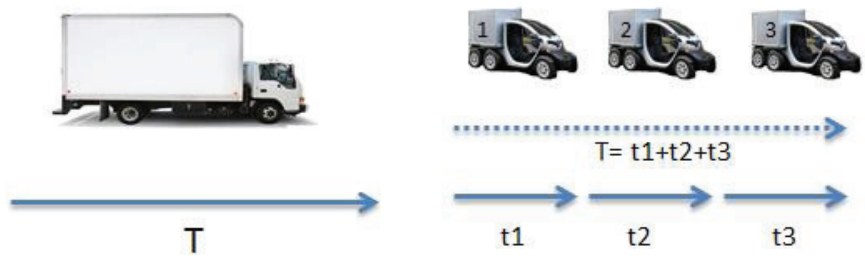


Fig. 6. The planning horizon Division

Then light vehicles operate in a small area inside which different delivery points exist but also collect points exist. The French project VELUD supported by ADEME experiments such light electric vehicles. Derived from Renault Twizzy©, the vehicle is composed of two parts: the tractor and the trailer which can be disconnected quickly and easily.

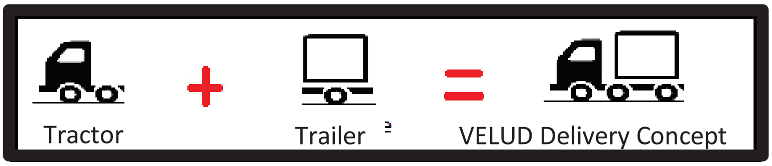


Fig. 7. VELUD Delivery Concept

In this second point of view, it is possible to consider different trailers for one tractor in order to implement an innovative logistic scheme:

1. The operator takes a full loaded trailer
2. The operator delivers different points
3. The operator let the empty trailer in a logistics point
4. The operator pick up a new full loaded trailer on the logistic point
5. The operator delivers different points…

In our mind, this organization can be a first step to support the concept of circular economy. It aims to solve two major problematics: the last delivery kilometer and the first meters collect. This is done through the implementation of an Urban Consolidation Center which combines two activities:

- To receive the freight from producers in order to organize its delivery in the center f the city,
- To collect waste from the center of the city and to transport those waste toward recycling centers.

In this point of view, the standardization of the trailer allows extending concepts developed in Physical Internet (Montreuil 2012). Then the small area can be defined as a CLOUD (Collaborative Logistics area to Optimize Urban Deliveries). In our future works, we will develop innovative schemes based on these concepts.

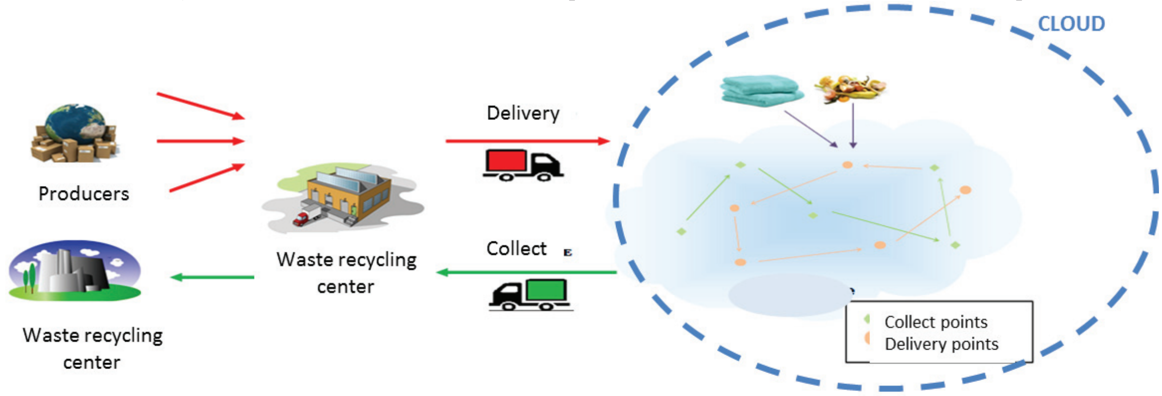


Fig. 8. CLOUD and first step toward circular economy

## 5. Conclusion

In this document we operate through different approaches the two major problems of urban distribution logistics. They are in fact the logic of vehicle routing and logic of loading plans, which are more complex in the context of the last mile. This requires a method of robust hybrid optimization that depends largely on the problem considered and different goals we want to achieve.

In VELUD project, we assume that electric vehicles are not a basic copy of classical vehicles. The prototype developed in the project follows this logic. Its structure allows introducing a real breakthrough in terms of use. The possible configurations of the cell placed on the trailer are numerous: cold, tray, with or without additional battery, etc.

A new logistics system that integrates electric vehicles using shorter tours can simplify this type of optimization. Finally, the optimization method should lead to a consensus between the two levels of optimizations (tour and loading) without forcing our end result and ensuring continuity of performance.

## References


Adulyasak, Y. &. 2014. Models and Algorithms for Stochastic and Robust. *Transportation Science, forthcoming*.

Barnier, V., & Toucelet, C. 1999. Ville et environnement – de l'écologie urbaine à la ville durable Problèmes politiques et sociaux. *La documentation française*, 829.

Baudouin, D. 2006. *Les espaces logistiques urbains*. Paris: La documentation française.

Brunet, R. 1997. Le dévéloppement durable en haut de l'échelle. 34.

Chaari, T. 2010. *Un algorithme génétique pour l'ordonnancement robuste : application au problème du flow shop hybride.*

Côté, J. F. 2013. An Exact Algorithm for the two Dimentional Orthogonal Packing Problem with Unloading Constraints. *CIRLET*, 30.

Crainic, T. G. 2009. Intelligent freight-transportation systems: Assessment and the contribution of operations research. *Transportation Research Part C: Emerging Technologies*.

Delaître, L. 2008. Méthodologie pour optimiser le transport de marchandise en ville. Application aux villes moyennes et dans le cadre de l'agglomération de La Rochelle.

Dessouky, M. M. 2007. A Robust Optimization Approach for the Capacitated Vehicle Routing Problem with Demand Uncertainty.

Durand, B., Jesus, G.-F., & Frédéric, H. 2010. La logistique urbaine, facteur clé de dévéloppement du B to C. 3-14.

Evad, R. 2013. Fédération de e-commerce et de la vente à distance.

Fuellerer, G., Doerner, K., Hatl, R., & Lori, M. 2009. Ant colony optimization for the two-dimensional loading vehicle routing problem. 12.

Iori, M. S.-G. 2007. An exact approach for the vehicul routing problem with two-dimentional loading constraints. *Transportation science*, 253-264.

Khebbache-Hadji, S. 2010. Problème de tournée de véhicules avec chargement et fenêtre horaire (2L-CVRPTW). *MOSIM 10*, 9.

Selma, K.-H. 2010. Problème de tournée de véhicules avec chargement et fenêtre horaire (2L-CVRPTW). 9.

SUN, L. e. 2015. Robust Optimisation Approach for Vehicle Routing Problems with Uncertainty. *Mathematical Problems in Engineering*.

Torres, E. 2002. Adapter localement la problématique du développement durable : rationalité procédurale et démarche qualité.

Trentini, A. 2012. Proposition d'un système urbain mixte, conception et pilotage du système. 76.