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# The multi-echelon location-routing problem : concepts and methods for tactical and operational planning

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## Abstract

Freight transportation constitutes one of the main activities that influences economy and society, as it assures a vital link between suppliers and customers and is represents a major source of employment. Multi-echelon distribution is one of the most common strategies, and has not been deeply reviewed in cost optimization literature. This paper presents the main concepts of multi-echelon distribution with cross-docks and the notation standards for cost optimization in this field. A literature review is also presented, in order to list the main problems and methods that can be helpful for scientists and practitioners of outbound logistics field.

**Keywords:** location-routing problems, multi-echelon distribution, cross-docking, combinatorial optimization, survey.

## 1. Introduction

The freight transportation sector is continuously changing as a consequence of the growth and transformation of the economic activity. In recent years companies have changed their inventory and distribution strategies for better adapting them to the changing demand. Moreover, the new advances in technology have been a positive factor for the development of new markets and new consumer needs, one of the most relevant is the “just in time” policy in freight distribution, and in urban context in particular.

In freight distribution three main shipping strategies are predominant(Watters, 2001). Direct shipping consists on delivering freight directly from the manufacturing plants to the retailers. Multi-echelon distribution with warehousing is the technical name given to systems made by one or more factories, a number of storage areas, known as warehouses, and the final destination of freight. Freight requests are made to warehouses, which have a stock of freight. These warehouses command freight in big quantities to factories. Multi-echelon transportation with cross-docking differs from the warehousing strategy in the fact that cross-docking platforms don't have the possibility to stock, but consent the consolidation and transshipment operations.

In real-life distribution, we observe several multi-echelon systems. Nowadays, the trend is to decrease the warehouse areas to increase the cross-docking strategies, due to the high cost of storage and inventory. Consolidation is then preferred to storage, and some products or services are known to have a preferential distribution system based on cross-docks. We present the main sectors where multi-echelon distribution with cross-docking is observed (Gonzalez-Feliu, 2008):

- *Postal and parcel delivery distribution systems* are in fact based on multi-echelon distribution, with several intermediary cross-docking platforms where freight is transshipped or consolidated. Such systems have been improved due to globalization and the raise of international communications and trade.
- *Press distribution* is presented as a mixed system where national and regional platforms are used to distribute the printed products to the stores through a system of consolidation platforms, where these products are re-packaged to be sent to the corresponding retailer.
- *Spare parts in the automotive industry* is another example of a mixed system. In fact, some companies have changed their regional warehouses into regional cross-docks (which serve one or few countries), and only one area warehouse, to which several regional cross-docks are assigned.
- *Logistic systems for urban freight distribution* have also evolved into multi-echelon systems with consolidation platforms, called Urban Consolidation Centers (UCC). They are located in the periphery of the urban area and receive the freight entering the city to transship it into low-pollution vehicles that have access to the city centers.
- *Multimodal transportation*, specifically the containerized distribution, is a classical example of a multi-echelon system with cross-docking where freight is conserved unaltered from its departure to the arrival at its final destination.
- *Grocery distribution, home delivery services and e-commerce* trends seem be close to such systems to improve the service quality and decrease operational costs, more precisely with the development of intermediary reception points.

The main difficulty of individuating an classing operational cost optimization methods for multi-echelon distribution systems with cross-docking is that each field uses a different notation and no standard vocabulary has already be proposed. To deal with it, we propose a general definition of a multi-echelon distribution system, presenting the vocabulary and notation which will be followed in this study. In this section we will define the basic concepts of multi-echelon distribution, giving the principles of the multi-echelon distribution planning organization.

The aim of this paper is to present a guide to scientists and practitioners about cost optimization for multi-echelon distribution systems with cross-docking facilities. In section 2 we will present the generalities of multi-echelon distribution, giving a general description of the system and a standardized notation. Then, a generalized optimization model for system cost of multi-echelon distribution systems with cross-docks is presented, as well as several examples of such systems in real-life outbound logistics. Section 3 will contain a detailed literature review on vehicle routing optimization for tactical and operational decision support of these distribution systems. Main guidelines on further researches based on the literature review will also be enounced.

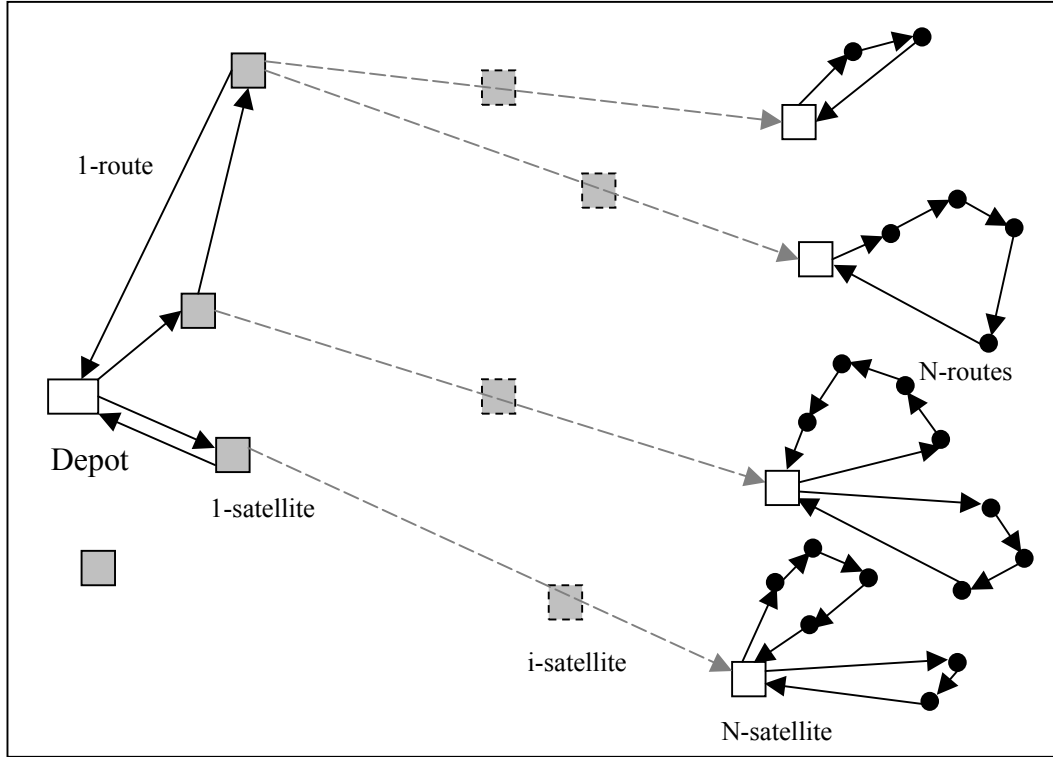
## **2. The NE-LRP: concepts and general formulation**

Consider a  $N$ -echelon distribution system composed by  $N$  stages. The depots are the starting points of the distribution chain (mainly, a plant or general warehouse). If we consider the transportation network as a graph, a depot is considered a  $0$ -node. In real distribution systems we can observe multiple depot cases, but the general formulation will be related to single depot problems since a multi-depot  $N$ -echelon distribution system can be modelled as a single depot  $N+1$  echelon distribution systems that presents negligible costs and unlimited capacities for the first echelon. We define as  $e$ -satellite an intermediary facility associated to the stage  $e$ . They will also be defined as  $e$ -nodes on the graph. At a  $e$ -satellite, the freight is transhipped. Also other operations, such as labelling, packaging or customs and quality controls can take place. In any case, satellites are intermediary platforms for distribution support where inventory or warehousing activities are not allowed.

The customers are defined as the final destinations of the freight (in many real applications they are the stores or retailers, but also households in some home-delivery services). We use this definition analogously to vehicle routing optimization. The customers constitute the set of  $N$ -nodes on the graph. The overall transportation network can then be decomposed into  $N$  echelons:

- the 1st echelon, which connects the depots to the 1<sup>st</sup>-echelon intermediary facilities;
- $N - 2$  intermediate echelons interconnecting the different intermediary facilities;
- the  $N^{\text{th}}$  echelon, where the freight is delivered from the  $(N-1)^{\text{th}}$  echelon intermediary facilities to the final destinations.

To deliver the freight, a number of vehicle fleets are defined. Each echelon  $e$  usually has its own fleet of vehicles, defined by different characteristics (capacity, dimensions, speed), and can be heterogeneous or homogeneous. An  $e$ -echelon vehicle is a vehicle belonging to echelon  $e$ , i.e. travelling from an  $e-1$ -satellite to an  $e$ -satellite.



**Fig. 1** Example of a N-echelon distribution network

Let us denote the system as a graph  $G$  with three types of nodes. The depots will be represented by the set  $V_0 = \{s_1^0, \dots, s_{n_0}^0\}$  (the depots will be also known as 0-satellites) and the customers by the set  $V_c = \{c_1, \dots, c_n\}$ . For each echelon  $e$  the set of  $e$ -satellites will be denoted by  $V_s^e = \{s_1^e, \dots, s_{n_e}^e\}$ . The  $e$ -satellites can be capacitated and this capacity can be noted as the maximum number  $ms_k^e$  of  $e+1^{\text{th}}$ -echelon vehicles allowed to receive freight at the  $e$ -satellite  $s_k^e$ . Moreover, each customer  $i$  has associated a demand  $d_i$  to be delivered. The demand of each customer can not be split among different vehicles only for the  $N^{\text{th}}$  echelon. For the other stages, we consider that each  $e$ -satellite can be served by more than one  $e^{\text{th}}$ -echelon vehicle, so the aggregated freight assigned to each  $e$ -satellite can be split into two or more vehicles. Each  $e^{\text{th}}$ -echelon vehicle can serve more than one  $e$ -satellite in the same route, and it is considered that each  $e$ -satellite can be served by any number of  $e^{\text{th}}$ -echelon vehicles, or by none. The model presented below is mono-commodity, i.e. the volumes of freight belonging to different customers can be stored together and loaded in the same vehicle at all echelons. Moreover, each  $e^{\text{th}}$ -echelon vehicle has the same capacity  $K^e$ .

We define as  $e^{\text{th}}$ -echelon route  $y_k^{ie}$  a Hamiltonian circuit made by a  $e^{\text{th}}$ -echelon vehicle which starts from  $e-1^{\text{th}}$ -echelon satellite  $k$ , serves one or more  $e^{\text{th}}$ -echelon satellites and ends at the departure node.

The problem is easily seen to be NP-Hard via a reduction to VRP, which is a special case of NE-LRP arising when just one echelon and one satellite (with no travel cost from the depot to the satellite) is considered.

According to the definition of NE-LRP, if the assignments between customers and satellites are determined, the problem reduces to  $1 + \sum_{e=1}^{e=M} n_{se}$  VRP (1 for the first echelon and  $n_{se}$  for each  $e^{\text{th}}$  echelon).

The main question when modelling NE-LRP is how to connect the different echelons and to manage the dependence of each  $e^{\text{th}}$  echelon from its predecessor. The presented formulation is based in set-partitioning problems, and two types of variables are used.

We have formulated a Mixed Integer Programming Model for a generic NE-LRP. This model considers the overall transportation cost (including cross-docking operations) as the objective function to optimize. The first type of variables are the route variables  $y_k^{ie}$ , a  $\{0, 1\}$  variable that shows if the route  $y_k^{ie}$  starting at  $e$ -satellite  $i$  is used or not. Each route  $y_k^{ie}$  is defined by its cost, the nodes that serve and the order they are visited. Moreover, the variable  $D_k^e$  is a real variable which shows the freight quantity that is delivered to  $e$ -satellite  $k$ .

The model is defined as follows:

$$\min \sum_{e=1}^N \sum_{k \in V_{se}} \sum_{i \in R_e} c_i^e y_k^{ie} + \sum_{e=1}^N \sum_{k \in V_{se}} (S_k^e D_k^e + SL_k^e s_k^e) \quad (1)$$

s.t.

$$\sum_{s \in V_{se}} \sum_{k \in V_{se-1}} \delta_{sk}^{ie} y_k^{ie} = 1 \quad \forall e \in \{1, \dots, N\}, \forall i \in R_e \quad (2)$$

$$m_s^e \geq \sum_{k \in V_{se-1}} \sum_{i \in R_e} \delta_{sk}^{ie} y_k^{ie} \quad \forall e \in \{1, \dots, N\}, \forall s \in V_{se} \quad (3)$$

$$D_0^1 = \sum_{c \in V_c} d_c \quad (4)$$

$$\begin{aligned} y_k^{ie} &\in \{0, 1\} \quad \forall i \in R_{e-1}, \forall k \in V_{se-1}, \forall e = \{1, \dots, M\} \\ D_k^e &\in \mathfrak{R}^+ \quad \forall k \in V_{se-1}, \forall e = \{1, \dots, M\} \end{aligned} \quad (5)$$

The objective function to minimize (1) is the total cost resulting on the addition of transportation costs to those derived from the different operations at the satellite. Constraints (2) show that each customer is served by only one route. In case of customers having a demand that exceeds the capacities of the  $M$ -vehicles, they will be represented as a number of customers receiving full vehicles, plus one, receiving the remaining load. Constraints (3) show the limitation capacity of each satellite, and constraint (4) shows that all the demand has to be served.

### 3. NE-LRP variants and solving methods : a review of the scientific literature

Although multi-echelon transportation systems are very common in real cases, they are usually decomposed into an addition of single-echelon distribution cases. Moreover, most of the optimization tools used for tactical and operational planning derive from methods for the vehicle routing problem (VRP). This family of problems has been deeply studied. For a detailed survey on this family of problems and the main variants, see Toth and Vigo (2002), Cordeau et al. (2007) or Golden et al. (2008).

A VRP variant which refers to a two-echelon distribution system, the vehicle routing problem with satellite facilities (VRP-SF). In this variant, the network includes facilities that are used to replenish vehicles during a route (Bard et al., 1998a, 1998b; Agnelelli and Speranza, 2002). When possible, satellite replenishment allows the drivers to continue the deliveries without necessarily returning to the central depot. However, the transportation cost of 1<sup>st</sup>-echelon vehicles is not considered in the system, i.e. only the second-echelon cost is taken into account in the objective function. Crevier et al., 2007 studied a variant of this problem where inter-satellite trips are allowed for satellite replenishment, presenting a model which considers the inter-satellite transportation costs and a heuristic method to solve the problem. This method combines the adaptive memory principle and a tabu search procedure.

We can find in literature different families of problems, which are very similar and can be considered as different variants of the NE-LRP. This problem is defined as the generalization to N-echelon distribution systems of classical LRP, and was first introduced by Jacobsen and Madsen (1980) for a real decision problem for a two-echelon distribution system. Laporte (1988) hypothesized the NE-LRP in a general study of possible LRP variants.

The 2E-LRP (Jacobsen and Madsen, 1980) consists of determining the location of the satellites, allocating the customers to the best satellites and determining both first-echelon and second-echelon routes. The authors propose three fast heuristics for solving a real case application where two newspaper editors combine their resources in terms of printing and distribution in order to decrease the overall costs. The authors propose three fast heuristics. The first is the Three Tour Heuristic, which is based on the observation that if the last arc of each route, the problem becomes similar to a Steiner Tree Problem. This tree is constructed by a greedy one-arc-at-a-time procedure. The other two heuristics, which are sequential, combine heuristics for both VRP and Location-Allocation problem. The ALA-SAV heuristic is a three stage procedure composed from the Alternate Location Allocation (ALA) of Rapp and Cooper (1962) and the Savings algorithm (SAV) of Clarke and Wright (1964). The third heuristic (SAV-DROP) is also a three stage procedure composed from the Clarke and Wright Savings algorithm and the DROP method of Feldman et al. (1966).

A NE-LRP variant that presents several simplifications respect to classical NE-LRP is the N-echelon Capacitated VRP (NE-CVRP). In this family of problems only one depot is considered and the intermediary facilities allow a limited number of vehicles for transshipments (Gonzalez-Feliu, 2008). The satellites do not present location costs and constraints but only allocation costs and capacity limitations related to the number of

vehicles that can host. Gonzalez-Feliu et al. (2006) presented a first MIP formulation for the 2E-CVRP derived from multi-commodity network design to study the limits and the general behavior of the mathematical model. The model is tested on four sets of instances using Xpress linear programming solver. The instances, available at OR Library website (Beasley, 1990), cover several two-echelon distribution cases of different sizes (from 12 to 50 customers and 2 to 5 satellites). Optimal solutions are found for instances up to 21 customers and lower bounds are presented for all the instances. The authors also introduce some cuts which make the calculation time decrease. More lower bounds for this problem are proposed by Mancini et al. (2009). First, the authors split the problem into two simpler sub-problems, one for each level; then, in a second phase, a global lower bound is computed by addition of the sub-problems costs without considering the interactions between both levels. Crainic et al. (2008) proposed a two-phase heuristic algorithm based on a clustering first routing second procedure plus a classical local search procedure. This heuristic has been used to make a satellite location analysis in order to built instances up to 250 customers (Crainic et al., 2009), providing also a first sub-optimal solution as a reference for further methods for the 2E-CVRP.

Crainic et al. (2007) developed a theoretical route optimization methodology for the two-echelon freight distribution system in congested urban areas defined in Crainic et al. (2004). The methodology is a support for day-before planning operations in a system where satellites are used as intermediate transshipment points for the freight distribution, and the synchronization between the vehicles of both echelons is one of the most constraining aspects of this problem. Two classes of models are proposed: a service network design model for the 1<sup>st</sup>-echelon vehicles, which approximates the second echelon routing costs gives a first estimation of the overall costs; then a second model optimizes the 2<sup>nd</sup>-echelon trip costs considering the first-echelon vehicle movements.

The road-train routing problem, first studied by few authors for real applications and mathematically formulated by Semet and Taillard (1993), also known as truck-and-trailer routing problem (TTRP), concerns defining a route for a road-train, which is a vehicle composed by a truck and a trailer (both with space for freight loading). Some of the roads are not accessible by the entire convoy, but only by the truck. In these cases, the trailer is detached and left at a customer's location (called a "root") while the truck visits a subset of customers, returning to pickup the trailer. In a way, this problem can be represented as a two-echelon distribution system, using the LRP notation. The intermediary facilities become the customers where the trailer is parked while the truck visits a group of customers. The difference from a classical 2E-LRP is that is that in this case some customers can be served directly a 1-route. A two-stage algorithm is proposed by the authors. An initial solution is obtained by a sequential algorithm and improved by tabu search, where customers are reallocated. This method do not distinguish between locational and routing moves.

As said above, few TTRP application were proposed before the theoretical problem formulation. Two studies deal with milk collection at the farmyards, and were presented as applied solving methods for a real situation. The milk is collected at storage tanks on the farmyards every or every other day and must be transported to dairy plants. Some of the farmyards cannot be visited by a lorry-trailer combination because of space restrictions. Wren (1971) and Brunswicker (1986) allow only one transshipment location per trailer and a



fixed lorry-trailer assignment. In both cases, a 3-stage heuristic procedure is presented. In the first phase (*clustering*), customers are grouped considering the number of vehicles and their characteristics (mostly the capacity of each lorry-trailer convoy). The second phase (*allocation*) consist in determining, for each convoy, one transshipment location. The third and last stage is the *routing* phase.

More heuristic methods for the TTRP can be find in literature. Semet (1995) proposed a clustering first routing second solution method. First customers are allocated to roots then the resulting routing problems are solved via Lagrangian relaxation. Gerdessen (1996) assumes that all customers have unit demand and each trailer is parked exactly once. Initial solutions are found using a number of sequential heuristics. These are then improved by a selection of VRP improvement heuristics. Chao (2002) developed a two-stage algorithm where in the first phase an initial solution is obtained with a cluster first route second heuristic and the second phase improves the initial solution using a tabu search algorithm with customer reallocation moves. Scheuerer (2006) presents two new construction heuristics: a clustering-based sequential insertion procedure and an adaptation of the well-known sweep algorithm by Gillett and Miller (1974) and a tabu search improvement procedure. Moreover, the author adapts these procedures to the multi-depot and the multi-period version of the problem. Hoff and Løkketangen (2007) have presented a case study for milk collection in Norway. The problem they consider is essentially a multi-depot, multi-period TTRP with heterogeneous vehicles and without trailer customers. They propose a sophisticated tabu search algorithm for solving their problem and report successful solution of real-world instances, improving on the existing tour plans used by their industry partner. Lin et al. (2009) propose a simulated annealing (SA), then computational tests on the instances proposed by Chao (2003) are presented to compare the proposed SA algorithm to Chao's and Scheuerer's procedures.

Drexl (2006) defined the VRP with Trailers and Transshipments (VRPTT) as the generalization of the TTRP when trailers can be pulled by different lorries on its itinerary and several transshipments are allowed. The author introduces also the notion of support vehicles, which are connecting the depots with the transshipment points without the possibility to visit any customers (1st-echelon vehicles). The problem is solved using branch-and-cut and branch-and-prize. Tan et al. (2006) applied a hybrid evolutionary algorithm (HMOEA) to the multi-objective variant of the VRPTT. The algorithm uses specialized genetic operators, a variable-length representation and a local search method. The authors compare it with a non-hybrid genetic algorithm (using only the proposed genetic operators) and a hybrid genetic algorithm where standard operators are used instead of those proposed by HMOEA.

Yang and Xiao (2008) define the Vehicle Routing Problem with Transshipment Centers. In this problem, the planner has the option of use both direct shipping and two-echelon strategies, and have to choose for each customer the best strategy to produce a route configuration in order to reduce total transportation costs. Although some service characteristics, as periodicity and types of products are considered, the overall system consists on one supplier, one retailer and one transshipment center. This study is closer to supply chain management than to travel cost optimization.

Only one problem involving more than two echelons is found in literature. Ambrosino and Scutellà (2005) propose a mathematical programming formulation for a number of static and

dynamic scenarios based on the general multi-echelon LRP. To explore the computational complexity of the models, linear programming approaches are used to find the optimal solution or at least provide lower bounds for problem instances based on a real-life case. Computational testing is limited to locating distribution and transshipment points and assigning large customers and customer zones to these distribution facilities. As such, the multiple echelon approach and routing considerations discussed in the earlier sections are not explored in the computational experiments. The optimal solution could only be found for the smallest problem instance, involving possible locations for 2 distribution centers, 5 transshipment points, 5 large customers and 25 customer zones. As the problem instances become larger, the gap between the best integer solution found, within a time limit of several days for the large instances, and the MIP lower bound provided by CPLEX increases rapidly up to more than 45%. As a result, heuristic approaches seem to be more appropriate, even for the scaled down problems used for the computational experiments.

#### 4. Conclusions and research guidelines

In this paper we have overviewed the main optimization problems for multi-echelon distribution with cross-docks in tactical and operational planning horizons. We have proposed a standard conceptualization and notation for the route optimization problem, the ME-LRP. We have also made a classification of the literature in this field, showing that the main ME-LRP deal with realistic cases of two-echelon systems. Moreover, the system structure in multi-echelon distribution planning is becoming important in cost optimization approaches.

Since nowadays no reference instances are used, the comparison among the various methods will be difficult. A standard notation and one or more sets of instances (for example, Chao 2002, Drexl 2006a, Gonzalez-Feliu et al. 2006, Crainic et al., 2009) will facilitate the development of methods for these problems. Two-echelon location routing and its variants seem to be the most prominent problems to be studied. Two types of methods can be developed. Exact methods will show the difficulties of the connections between echelons and will help to provide new instances and references for the development of heuristics. This second type of methods will be able to solve real-life problems and continue in a similar direction respect to the procedures presented in this paper.

#### References

- [1] Ambrosino D., Scutellà M. (2005), Distribution network design: new problems and related models, *European Journal of Operational Research* vol. 165 pp. 610–624.
- [2] Angelelli, E., Speranza, M. (2002), The periodic vehicle routing problem with intermediate facilities. *European Journal of Operational Research* vol. 137, pp. 233–247.
- [3] Bard, J. F., Huang, L., Jaillet, P., and Dror, M. (1998), A Decomposition Approach to the Inventory Routing Problem with Satellite Facilities. *Transportation Science* vol. 32, n. 2, pp. 189-203.
- [4] Bard, J., Huang, L., Dror, M., Jaillet, P. (1998), A branch and cut algorithm for the VRP with satellite facilities. *IIE Transactions* vol. 30 pp. 821–834.
- [5] Beasley, J. E. (1990), Or-library: distributing test problems by electronic mail, *Journal of the Operational Research Society* 41, 1069 - 1072. URL : <http://people.brunel.ac.uk/mastjib/jeb/info.html>.

- [6] Brunswicker J. (1986), *Optimale Standort- und Tourenplanung für die Rohmilcherfassung eines Molkereibetriebes Lit*, Munster.
- [7] Clarke G., Wright J. (1964), Scheduling of vehicles from a central depot to a number of delivery points, *Operations Research* vol. 12 n. 4 pp. 568–581.
- [8] Chao I. (2002), A tabu-search method for the truck and trailer routing problem, *Computers and Operations Research* vol. 29 pp. 33–51.
- [9] Cordeau J. F., Laporte G., Savelsberg M., Vigo D. (2007) Vehicle Routing. In Barnhart C. and Laporte G. (eds.), *Transportation*, Elsevier, North Holland, pp. 367-428.
- [10] Crainic T. G., Laporte G. (1997), Planning models for freight transportation, *European Journal of Operational Research* vol. 97 pp. 409–438.
- [11] Crainic T. G., Mancini S., Perboli G., and Tadei R. (2008), Heuristics for the two-echelon capacitated vehicle routing problem. Publication CIRRELT 2008-46, Université de Montréal, Canada.
- [12] Crainic T. G., Mancini S., Perboli G., and Tadei R. (2009a), Two-echelon vehicle routing problem: a satellite location analysis. In *Proceedings of the VI International Conference on City Logistics, Puerto Vallarta, Mexico*, Institute of City Logistics, Tokyo, Japan.
- [13] Crainic T. G., Ricciardi N., and Storchi G. (2004), Advanced freight transportation systems for congested urban areas. *Transportation Research Part C* vol.12 pp. 119-137.
- [14] Crainic T. G., Ricciardi N., and Storchi G. (2007), Models for evaluating and planning city logistic transportation systems. Publication CIRRELT-2007-65, Université de Montréal, Canada.
- [15] Crevier B., Cordeau J. F., Laporte G. (2007), The multi-depot vehicle routing problem with interdepot routes, *European Journal of Operational Research* vol. 176 pp. 756–773.
- [16] Drexler M. (2007), *On some generalized routing problems*. PhD. Thesis, University of Nuremberg, Germany.
- [17] Gendron B., Semet F., Stroyk C. (2002). Adaptive Distribution Systems. *TRANSTECH: Transport Technology Product & Process Innovation Management*, Presses Universitaires de Valenciennes, pp. 36-42.
- [18] Gerdessen J. (1996), Vehicle routing problem with trailers, *European Journal of Operational Research* vol. 93 pp. 135–147.
- [19] Gillett B., Miller L. (1974), A heuristic algorithm for the vehicle dispatch problem, *Operations Research* vol. 22 pp. 340–349.
- [20] Golden, B. L., Raghavan, S. et Wasil, E. A. (2008), *Vehicle routing: Latest advances and challenges*, Kluwer, Boston, USA.
- [21] Gonzalez-Feliu J., Perboli G., Tadei R., and Vigo (2006), The two-echelon capacitated vehicle routing problem. Technical Report OR/04/06, Politecnico di Torino.
- [22] Gonzalez-Feliu J. (2008), *Models and methods for the City Logistics : The Two-Echelon Vehicle Routing Problem*. PhD. Thesis, Politecnico di Torino, Turin, Italy.
- [23] Hertz A., Mittaz M. (2001), A Variable Neighborhood Descent Algorithm for the Undirected Capacitated Arc Routing Problem *Transportation Science*, vol. 35, pp. 425–434.
- [24] Hinojosa Y., Puerto J., Fernández F. R. (2003), A multiperiod two-echelon multicommodity capacitated plant location problem, *European Journal of Operational Research* vol. 23 pp. 271–291.
- [25] Hoff, A., and Løkketangen, A. (2008), A Tabu Search Approach for Milk Collection in Western Norway. In *Proceedings of the Sixth Triennial Symposium on Transportation Analysis*, TRISTAN, Pukkett, Thailand.
- [26] Jacobsen S., Madsen O. (1980), A comparative study of heuristics for a two-level routing-location problem, *European Journal of Operational Research* vol. 5 pp. 378–387.

- [27] Laporte G. (1988), Location-routing problems, in: A. A. B.L. Golden (Ed.), *Vehicle routing: methods and studies*, North-Holland: Amsterdam, pp.163–197.
- [28] Lin S. W., Yu V. F., Chou S. Y. (2009), Solving the truck and trailer routing problem based on a simulated annealing heuristic, *Computers & Operations Research* vol. 36, pp. 1683-1692.
- [29] Mancini S., Perboli G., Tadei R., Crainic T.G. (2009). A branch-and-bound for the Two-Echelon Vehicle Routing Problem. In *Proceedings of the Fourth ODYSSEUS International Workshop on Freight Transportation and Logistics*, Çeşme, Izmir, Turkey.
- [30] Min H., Jayaraman V., Srivastava R. (1997), Combined location-routing problems: A synthesis and future research directions, *European Journal of Operational Research* vol. 108 pp. 1–15.
- [31] Nagy G., Salhi S. (2007), Location routing: Issues, models and methods, *European Journal of Operational Research* n. 177 pp. 649–672.
- [32] Rapp Y. (1962), Planning of exchange locations and boundaries, *Ericsson Technics* vol. 2 pp. 1–22.
- [33] Scheuerer S. (2006), A Tabu Search Heuristic for the Truck and Trailer Routing Problem, *Computers & Operations Research*, vol. 33, pp. 894–909.
- [34] Semet F., Taillard E. (1993), Solving real-life vehicle routing problems efficiently using tabu search, *Annals of Operations Research* vol. 41 pp. 469–488.
- [35] Semet F. (1995), A two-phase algorithm for partial accessibility constrained vehicle routing problem, *Annals of Operations Research* vol. 61 pp. 45–65.
- [36] Tan K. C., Chew Y. H., Lee L. H. (2006), A hybrid multi-objective evolutionary algorithm for solving truck and trailer vehicle routing problems, *European Journal of Operational Research* vol. 172, pp. 855-885.
- [37] Toth P., Vigo D. (2002), *The vehicle routing problem*, SIAM Society for Industrial and Applied Mathematics, Philadelphia, USA.
- [38] Vahrenkamp R. (1989), Transportation logistic in rural setting: the case of milk collection, Tech. Rep. Technical Report 5/1989, Fachbereich Wirtschaftswissenschaften, Gesamthochschule Kassel.
- [39] Wren A. (1971), *Computers in Transport Planning and Operations*, Ian Allan, London, UK.
- [40] Yang F. M., Xiao H. J. (2007), Models and algorithms for Vehicle Routing Problem with Transshipment Centers, *Systems Engineering - Theory & Practice* vol. 27, n. 3, pp. 28-35.