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Freight distribution systems with cross-docking: a multidisciplinary analysis

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Abstract

Freight transport constitutes one of the main activities that influences economy and society, as it assures a vital link between suppliers and customers and it represents a major source of employment. Multi-echelon distribution is one of the most common strategies adopted by the transport companies in an aim of cost reduction. This paper presents the main concepts of multi-echelon distribution with cross-docks through a multidisciplinary analysis that includes an optimisation study (using both exact and heuristic methods), a geographic approach (based on the concept of accessibility) and a socio-economic analysis. a conceptual framework for logistics and transport pooling systems, as well as a simulation method for strategic planning optimisation.

Keywords: Freight transport systems, cross-docking, simulation, collaboration, socio-economic issues.

Freight distribution systems with cross-docking: a multidisciplinary analysis

1. Introduction

The freight transport industry is a major source of employment and supports the economic development of the country. However, freight transport has many negative aspects including congestion and environmental disturbance, which negatively affect quality of life. In recent years companies have changed their logistics 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, leading to the development of multi-echelon transport schemas. A wide variety of fields have developed these approaches:

- The *press distribution* sector usually has a transportation network where the products are distributed to the stores through a system of consolidation platforms, in which they are re-packaged to be sent to the corresponding retailer (Jacobsen and Madsen, 1980; Gonzalez-Feliu and Morana, 2010).
- *Logistic systems for urban freight distribution* have also evolved into multi-echelon systems with consolidation platforms, called Urban Consolidation Centres (UCC). They are located in the periphery of the urban area and receive the freight entering the city to tranship it into low-pollution vehicles that have access to the city centres (Crainic, 2008).
- *Intermodal transportation*, specifically the containerised distribution, is a classical example of a multi-echelon system where freight is conserved unaltered from its departure to the arrival at its final destination (Ferreira and Sigut, 1995).
- *Grocery distribution* is a field which presents an heterogeneous group of supply chains. Some of them are based on distribution systems with cross-docking (Tremeac and Raux, 2009) presenting several echelons.
- *Spare parts and automotive distribution* trends seem to be close to such systems to improve the service quality and decrease operational costs, more precisely with the relocation process started by several key companies (Tremeac and Raux, 2009).

Two strategies are used in multi-echelon systems: warehousing and cross-docking. Multi-echelon transport with The cross-docking strategy differs from that of warehousing in the fact that intermediary platforms do not have the possibility to stock, but allow the consolidation and transhipment operations.

This work deals with multi-echelon distribution with cross-docking, and aims to provide a conceptual framework for multi-echelon transport systems with cross-docking. First, the background issues on multi-echelon systems with cross-docking are presented. Second, an optimisation analysis is carried out to see the advantages and the potential of these systems, as well as the importance of transport pooling. Then, the computational results are presented and commented. Finally, in order to complete the optimisation analysis by a socio-economic approach, the limitations and obstacles of these approaches are studied using a qualitative analysis on both documentary and interview-based data.

2. Background issues

In freight transport, decisions on the transport network settings have a direct impact on the service quality but also on their costs. It is then important to adapt the transport network to the economical, geographical, organisational and quality constraints (Deflorio et al. 2009). In the last years, several strategies and logistics models have been developed in order to increase effectiveness of freight transport systems. Multi-echelon systems with cross-docking is one of the most popular, since it allows to reduce the logistics costs by implementing no-inventory transport systems. Moreover, it is the base of most collaborative transportation systems (Gonzalez-Feliu and Morana 2010).

The main questions in freight transport planning are related location and network design, vehicle routing and scheduling, vehicle assignment to a route and crew assignment to each operation. These research subjects can be found in literature, and recent surveys are proposed for optimisation issues (Toth and Vigo 2002; Leung 2004; Golden et al. 2008; Partyka and Hall 2010). In order to deal with multi-echelon transport with crossdocking planning and optimisation, several problems have been proposed in literature. This is the case of multi-echelon facility location problems (Asken 1985) and network design issues (Wieberneit, 2008). Although these problems have been well studied in supply chain design and long-term planning, multi-echelon transport with cross-docking has been the subject of several works (Asken 1998; Crainic 2008).

The Location Routing Problem (LRP) seeks to minimise total cost by simultaneously selecting a subset of candidate facilities and constructing a set of delivery routes that satisfy a number of constraints. In multi-echelon variants, the intermediary facilities have to be chosen between a number of candidates, and the origin of the freight (the depot) can be one or more. In general, these problems follow the concepts defined by Jacobsen and Madsen (1980). The problem consists of determining the location of intermediary facilities (considering that the starting depot is already determined), allocating the customers to transfer points and designing both 1st-echelon and 2nd-echelon routes. The authors propose three fast heuristics and compare them. In a theoretic approach. Therefore the multi-echelon LRP has been hypothesised (Laporte 1998), and several formulations for the two-echelon case have been proposed and analysed (Gonzalez-Feliu 2008).

The Pickup and Delivery Problem (PDP) is a family of combinatorial optimisation problems which deal with vehicle routing in which the same vehicles make both the pickup and the delivery requests. An explicit multi-echelon variant of the PDP is the VRP with cross-docking operations, described in Wen et al. (2007). Two types of vehicles are defined: one type make the delivery operations at a cross-docking platform and the other type is charged of picking up the freight and shipping it to customers. At each cross-docking platforms, delivery vehicles must arrive before pickup vehicles. The authors propose a mathematical formulation for instances with only one cross-docking platform and a Tabu Search heuristic procedure which uses two neighbourhoods and is finally embedded within an Adaptative Memory Procedure (AMP), in order to reach better and most robust solutions.

3. Optimisation analysis

In this section we present the conceptual issues of transport cost optimisation in multi-echelon systems as well as two simulation approaches (respectively exact and heuristic) in order to show the potential of these approaches.

3.1. Issues for a single-transporter multi-echelon transport

Consider a *N*-echelon distribution system composed by *N* stages. To represent it into a graph *G* we define three types of nodes: depots, *e*-satellites and customers. The depots are defined as the starting points of the transport operations. We define as *e*-satellite an intermediary facility associated to the stage *e*. At an *e*-satellite, the freight is transhipped and no inventory and warehousing activities are 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 optimisation. The overall transport network can then be decomposed into *N* echelons:

- the 1^{st} echelon, which connects the depots to the 1^{st}-echelon intermediary facilities;

- $N-2$ intermediate echelons interconnecting the different intermediary facilities;
- the N^{th} echelon, where the freight is delivered from the $(N-1)^{th}$ 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.

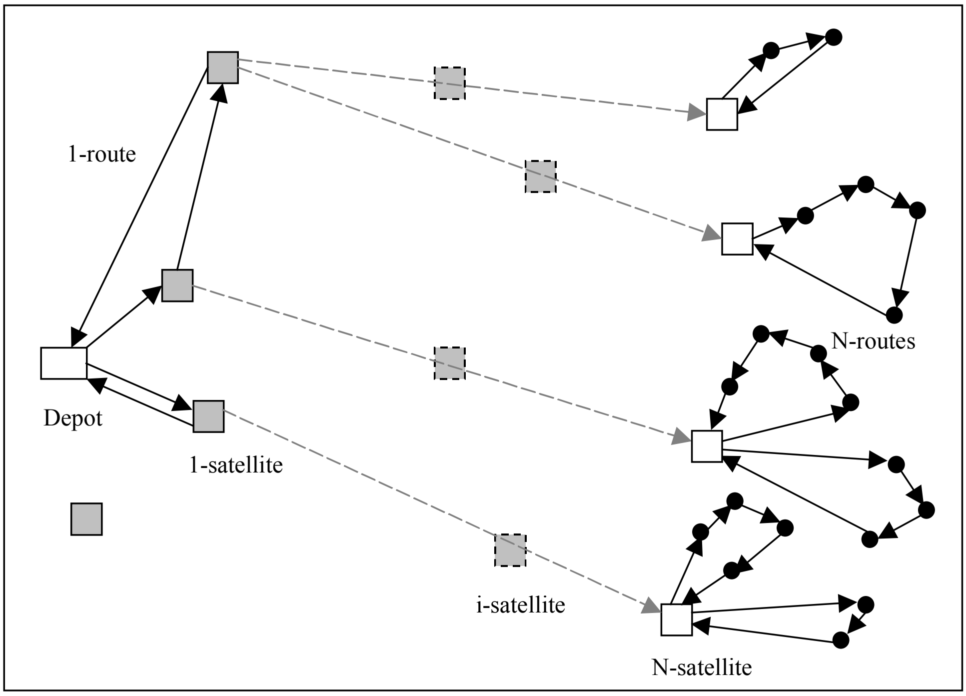


Fig. 1 Example of a N-echelon distribution network

The main question when modelling N-echelon transport networks is how to connect the different echelons and to manage the dependence of each e^{th} echelon from its predecessor. It is difficult to mathematically represent a N-echelon problem. Moreover, for practical issues, the two-echelon variant is both illustrative and common in practice. For these reasons, we propose to focus on this type of problems.

In a two-echelon system only one intermediary level is used. In this context, an exact solution can be obtained solving a mixed integer problem (MIP model). The capacity of reaching the optimality very limited for this type of models (only instance up to 30 customers can be solved to optimality according to Gonzalez-Feliu, 2008) but the interest of this approach is that it can show the advantages in terms of cost of using multi-echelon strategies if the demand is important (loading rates of the second level vehicles near to 80%).

In order to produce a first analysis for optimisation issues in multi-echelon transport systems, we solved 78 instances up to 30 customers using a mathematical model and the linear programming solver Xpress. For more details on the method, see Gonzalez-Feliu (2008). We present here a geographic analysis, based on the notion of freight accessibility. We can then define a freight accessibility index analogously to the classical gravity accessibility indicator (Hansen, 1959):

$$A_k = \sum_{i \in V_c} \frac{d_i}{d_{\max}} e^{-\beta \frac{c_{ki} - c_{\min}}{c_{\max} - c_{\min}}}$$

where d_i is the demand of the customer i, d_{max} the maximum demand overall the customers, c_{ki} the transport cost between the satellite k and the customer i, c_{min} and c_{max} the minimum and maximum values of the second-echelon transport costs, respectively, and $\beta>0$ a given parameter (we have assumed $\beta = 0,1$ following Hansen's considerations). The Accessibility is not the only measure we need for the analysis. Indeed, we also propose the notion of transport cost ratio of each satellite k, given by:

$$r_k = \frac{\sum_{i \in V_c} \frac{c_{0k} + c_{ki}}{c_{0i}}}{n_c}$$

In the following we discuss advantages and disadvantages of the proposed two-echelon distribution system, by considering all the instances of Gonzalez-Feliu (2008) up to 30 customers comparing the results with the optimal solution of the original VRP instances with optimal solutions. In order to make the accessibility analysis, we propose three ranges of accessibility and transportation cost ratio. The mean accessibility is split into three sets: low (L), medium (M) and high (H) accessibility as follows:

- Low: mean accessibility in the interval $[A_{min}, \{33\% \text{ of } [A_{min}, A_{max}]\}[$.
- Medium: mean accessibility in the interval $[\{33\% \text{ of } [A_{min}, A_{max}]\}, \{67\% \text{ of } [A_{min}, A_{max}]\}[$.
- High: mean accessibility in the interval $[\{33\% \text{ of } [A_{min}, A_{max}]\}, A_{max}]$.

where $A_{min} = \min_k \{A_k\}$ and $A_{max} = \max_k \{A_k\}$.

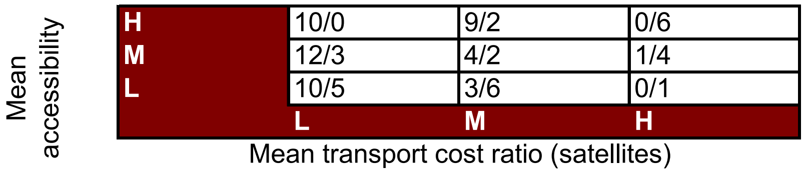
Analogously to the accessibility, the transport cost ratios have been categorised in three sets:

low (L), medium (M) and high (H) as:

- Low: mean transport cost ratio of the satellites in the interval $[r_{min},\{50\%\ \text{of}\ [r_{min}, r_{max}]\}[$.
- Medium: mean transport cost ratio of the satellites in the interval $[\{50\%\ \text{of}\ [r_{min}, r_{max}]\}, \{67\%\ \text{of}\ [r_{min}, r_{max}]\}[$. [.
- High: mean transportation cost of the satellites in the interval $[[\{67\%\ \text{of}\ [r_{min}, r_{max}]\}67, r_{max}]$.

We report the synthesis of the results on Table 1. We observe that multi-echelon systems can present some advantages in terms of transportation cost (reduction of the number of km. and vehicles used) and, although the number of customers is small, the analysis is interesting because the comparison takes place between exact optimums.

Table 1 – Synthesis of the optimisation analysis on small instances



Mean accessibility	L	M	H
H	10/0	9/2	0/6
M	12/3	4/2	1/4
L	10/5	3/6	0/1

Mean transport cost ratio (satellites)

Multi-echelon distribution leads to a smaller cost in 49 of the 78 instances (almost 63% of the cases), while the decreasing/increasing of the costs is in average between –25% and +25% of the transport cost of a single-echelon system. The mean decrease in the 49 instances that present transport cost reductions is about 15%, which should balance the costs due to the loading/unloading operations at the satellites. Therefore, issues concerning investments and financing will be taken into account in the socio-economic analysis further presented.

3.2. Comparison of single-user and collaborative multi-echelon systems

In order to make a comparison of multi-echelon strategies, we propose four contrasted scenarios, built from the instances proposed by Fisher (1994) for the Capacitated Vehicle Routing Problem that can be used to reproduce hypothetical transport plans. The first scenario represents the case where each company follows a direct shipping distribution schema. To estimate the transport costs, we use the simulation method on a CVRP for each company and we calculate the overall transport cost resulting as the sum of each company's cost.

The second scenario is that of a two-echelon distribution system, but with separate infrastructures and vehicle fleets. The companies are not collaborating, but follow a cross-docking strategy. To estimate the transport costs, we use the simulation method on a 2E-CVRP for each company and we calculate the overall transport cost resulting as the sum of each company's cost. The third scenario present a first form of collaboration, that of sharing the cross-docking facilities. To estimate the transport costs, we use the simulation method on a 2E-CVRP for each company but with common satellites, then we can calculate the overall transport cost as the sum of each company's cost.

The fourth scenario supposes a complete collaboration among partners. To estimate the transport costs, we create a multi-depot 2E-CVRP instance resulting of the aggregation of the three companies into the same system then we solve it to obtain the transport cost.

In order to make the comparative analysis, a solving algorithm has to be chosen. Because we want to represent realistic situations, and also solve the optimisation problem in an approximate but quick way, we propose a GRASP-derived algorithm. The gap between the optimal solution and the algorithm's costs remains similar for each simulation. The comparison between the scenarios will be homogeneous, so the accuracy of the method is less important than the speed in the present study.

The algorithm work as follows: given a set of destinations, a set of cross-docking facilities and a set of depots, the algorithm has to construct the overall routing schema in order to deliver all the customers passing through intermediary facilities. First, a clustering phase will group the destinations and assign them to a second-level vehicle. For this, we will use a k-means algorithm (Hartigan 1975). The second phase (routing) will use a randomised greedy algorithm (Resende and Ribeiro 2003), i.e. a procedure that, starting from an intermediary facility, assigns a destination to the route, randomly chosen among the 5 closest customers. Then, in an iterative way, each destination is assigned to a second echelon route. The first echelon routes are then build using dynamic programming (Gonzalez-Feliu 2008), since the number of intermediary facilities is small. The procedure solves instances of more than 200 destinations and 5 satellites in less than 1 second.

The different scenarios have been tested using our simulation approach programmed in Python. From the synthesis of the results (Table 2), we observe that two-echelon systems lead to an increase on the number of vehicles. In these approaches, if transport is not shared, we observe that the number of vehicles does not change. When the three companies share their vehicles, they can be better optimised, and we observe an important gain in the number of vehicles. In scenarios 2 and 3, the algorithm finds a first solution that uses many satellites and routes, but after a small post-optimisation phase the costs decrease. Two echelon strategies are efficient if there is freight rationalisation, and to do this it is important to have important volumes to transport. We observe also that only when a vehicle sharing approach is used, the platforms are better used, and we find three unused cross-docking facilities.

Table 2 – Number of vehicles, cross-docking platforms and transport costs (km) gain of each scenario respect to the reference situation

	Vehicles	Platforms	Gain
0	15	0	-
1	22	7	-5%
2	21	7	-10%
3	14	4	-22%

The cost gains, which are related to the kilometres travelled by the vehicles, remain however small, if we consider than other costs, mostly related to consolidation, are added but have not been considered in this study. Future developments of the simulation approach will take into account these costs, as well as the costs of opening a new logistics platform or adapting the existing facilities to develop sharing approaches.

In order to complete the study, a socio-economic analysis on the main limits to transport sharing and collaboration is proposed in next section.

4. Socio-economic analysis

As we have seen from simulation, multi-echelon transport can be an interesting approach to reduce the transport cost. However, it is not always possible to follow this type of logistics schemas in an economical and social continuity. We define the limitations and obstacles as those factors that can become an impediment to the successful development of a multi-echelon system optimisation approach.

In order to study these limitations, we propose a quick study on 20 experiences' feedbacks. As it is not always easy to identify the best stakeholders to interview (mainly because of the lack of information and people availability reasons), we have made a preliminary documentary study based on both scientific literature and specialised publishing analysis (Roy et al. 2006; Simonot and Roure 2007; Gonzalez-Feliu 2008; Bestufs 2009; TL&Associés and LET 2009). We have identified 25 interesting cases, and we have completed the missing information by semi-directive and open interviews to the main stakeholders involved in collaborative transport planning. In this way, 15 "loaders" (expeditors or receivers) and 10 "transport operators" have been identified and studied in order to produce one "experience's feedback table" for each case. These tables have been compared in order to obtain the following qualitative results. From these experiences' feedbacks, we have identified several types of limitations and obstacles, which can be synthesised as follows:

First, we can find the *commercial strategies.* Each enterprise has its own commercial interests, which are not the same for loaders than for transport operators. If they are not a major source of conflicts among producers, retailers and logistics operators, they can become an important handicap for the transport operators. In fact, aggressive strategies and the non-respect of the transport plans to advantage the "friends" or their own customers have been identified by many transport operators as a brake to the development of collaborative multi-echelon networks.

Another important element is that of the *financial aspects* related to the implementation of a multi-echelon system, more precisely to the investment costs for the construction or adaptation of crossdocking platforms, depots or other infrastructures. Another source of disagreement is usually related to the "ownership" of them (or the management issues related to them) once they are operative.

Also the *logistics strategies* of each stakeholder, as well as the potential or real changes that a multi-echelon system organisation should introduce, are a source of obstacles to their development. The physical and organisational conditions for freight compatibility, like dimensions, freight, type of packaging, loading unit and loading operations main characteristics are important, and they are not only related to legislation but also to organisational, equipment and habitude reasons. Another organisational factor is the acceptability of the organisational changes, which also has to be taken into account when defining the main characteristics of the multi-echelon system, and they can derive into dysfunctions, delays or employees strikes and complaints, that can impact on the image and reputation of the system.

Two other important elements are *responsibility transfer* and *confidentiality.* Although often regulated by the transport contract, it is important to note that not all the transport operators agree to give the freight to other companies than the final destination customer because of responsibility issues. In case of conflicts, the responsibility transfer clause of the contract plays an important role because it can define the physical and the moral responsible(s) of the product's loss or damage, and determine who has to pay for them. Moreover, confidentiality that can become an obstacle to multi-echelon systems when two competing actors decide to collaborate to reduce their transport costs. Since information is the base of good collaboration, if one or more partners manage confidential information that they don't want to share for competition reasons, the efficiency of the sharing approach can decrease considerably. These issues are seen in most of the initiatives involving competing enterprises that do no have the support of public entities.

Moreover, other factors have to be explored. For example, the transport cost optimisation is seen by the loaders as a competence of the transport operator. Moreover, in multi-echelon systems, several operators are participating, so a coordinated optimisation is not easy to carry away.

5. Conclusion

In this paper we have presented a multidisciplinary analysis to study multi-echelon transport with cross-docking using both engineering and social sciences approaches. The optimisation analysis show the potential of these systems, as well as the main limit: it is important to have enough freight to put on vehicles feeding the satellites, in order to better organise the distribution operations. Moreover, collaboration seems a good way to increase the vehicles' loads, as seen in the second optimisation study.

To show the limits, 25 experience's feedback tables have been completed and compared. In this preliminary study, we observe than commercial strategies, financing, organisation and habits, confidentiality and responsibility are the main obstacles to multi-echelon and collaborative transport. Since the transport is made by humans, social aspects are important and can be the keys of success of a transport system.

Finally, we have to note that not all the drivers follow all the instructions written in the transport plans (Deflorio et al. 2009). For these reasons, optimisation methods are useful but have to meet the operational needs and limits, most of them related to habitude, which is difficult to change.

In conclusion, multi-echelon transport has a big potential and can be well accepted by practitioners and public authorities, but the structural changes have to be implemented in a middle-long term perspective, after individuating and analysing the potential obstacles to the development of a project in order to ensure its continuity at an economic point of view.

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References

ASKEN, C.H. (1985). Facility location models for distribution planning, *European Journal of Operational Research*, 22 (3), p. 263-279.

BESTUFS (2009). *BESTUFS II Bibliografic Overview*, BESTUFS, Rijswijk, Pays-Bas.

CRAINIC, T.G. (2000). Service network design in freight transport, *European Journal of Operational Research*, Vol. 122, p. 272-288.

CRAINIC, T.G. (2008). City Logistics. In CHEN, Z.L. and RAGHAVAN, S. (eds.). *Tutorials in Operations Research 2008. State-of-the-Art Decision Making Tools in the Information-Intensive Age*. INFORMS, p. 181-212.

CHRISTOFIDES, N. and EILON, S. (1969). An algorithm for the vehicle dispatching problem, *Operations Research*, 20, p. 309-318.

DEFLORIO, F.P., GONZALEZ-FELIU, J., PERBOLI, G. and TADEI, R. (2009). Transportation cost estimation in freight distribution services with time windows: application to an Italian urban area, *Proceedings of the VI International Conference on City Logistics*, Puerto Vallarta, Mexico.

FERREIRA, L. and SIGUT, J. (1995). Modelling intermodal freight terminal operations, *Road and Transport Research*, 4 (4), p. 4–15.

FISHER, M. (1994). Optimal solution of vehicle routing problems using minimum K-trees, *Operations Research*, 42, p. 626-642.

GONZALEZ-FELIU, J. (2008). *Models and methods for the City Logistics : The Two-Echelon Vehicle Routing Problem*. PhD. Thesis, Politecnico di Torino, Turin, Italy.

GONZALEZ-FELIU, J. and MORANA, J. (2010). Collaborative transportation sharing: from theory to practice via a case study from France. In YEARWOOD, J.L. and STRANIERI, A. (eds.). *Technologies for Supporting Reasoning Communities and Collaborative Decision Making: Cooperative Approaches*, IGI Publising, Forthcoming.

GOLDEN, B.L., RAGHAVAN, S. and WASIL, E.A. (2008). *Vehicle routing: Latest advances and challenges*, Kluwer, Boston.

HANSEN, W.G., (1959). How accessibility shapes land use, *Journal of the American Institute Planners*, 25, p. 73-76.

HARTIGAN, J.A. (1975). *Clustering Algorithms*, Wiley.

JACOBSEN, S. and MADSEN, O. (1980). A comparative study of heuristics for a two-level routing-location problem, *European Journal of Operational* Research, 5, p. 378–387.

LAPORTE, G. (1988). Location-routing problems. In GOLDEN, B.L. (ed.). *Vehicle routing: methods and studies*, North-Holland, Amsterdam, p.163–197.

PARTYKA, J. and HALL, R. (2010). On the road to connectivity, *OR/MS Today*, 37 (1), p. 42-49.

RESENDE, M.G.C. and RIBEIRO C.C. (2003). Greedy randomized adaptive search procedures. In GLOVER, F. and KOCHENBERGER, G. (eds)., *Handbook of Metaheuristics*, Kluwer, p. 219–249.

ROY, J., LANDRY, S. and BEAULIEU, M. (2006). Collaborer dans la chaîne logistique : où en sommes nous? *Gestion, revue internationale de gestion*, 31 (3), p. 70-78.

TOTH P. and VIGO D. (2002). *The vehicle routing problem*, SIAM Society for Industrial and Applied Mathematics, Philadelphia, USA.

TL&ASSOCIÉS and LET (2009). *FIDES* - Flexibilité *et impact de la demande de transport des différents secteurs économiques et simulation de scénarios d'évolution. Rapport final,* PREDIT-ADEME, Paris, France.

WEN, M., LARSEN, J., CLAUSEN, J., CORDEAU, J.F. and LAPORTE, G. (2007). Vehicle Routing with cross-docking, Working Paper Technical University of Denmark.

WIEBERNEIT, N. (2008). Service network design for freight transport: a review, *OR Spectrum*, 30, p. 77-112.