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Source: *Journal of the Transportation Research Forum*, Vol. 51, No. 1 (Spring 2012), pp. 93-109
Published by: Transportation Research Forum
Stable URL: http://www.trforum.org/journal

Freight Distribution Systems with Cross-Docking: A Multicisciplinary Analysis

by Jesus Gonzalez-Feliu

Freight transport 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 in this field. This paper presents the main concepts of multi-echelon distribution with cross-docking through a multidisciplinary analysis that includes an optimization study and an interview-based analysis. The optimization analysis uses both a geographic approach based on the concept of accessibility and a scenario simulation analysis for collaborative freight transportation. The interview-based analysis includes a conceptual framework for logistics and transport pooling systems and a simulation method for strategic planning optimization.

INTRODUCTION

The freight transport industry is a major source of employment and supports the economic development of a country. However, freight transport has many adverse effects including congestion and environmental disturbances that affect quality of life (Brewer et al. 2001). In recent years, companies have adapted their logistics strategies to changing demand leading to the development of multi-echelon transport schemes in which two or more connected transportation schemes are linked by one or more transshipment operations (Gonzalez-Feliu 2011). A wide variety of fields have developed multi-echelon transportation approaches with cross-docking; for example, the press (newspapers and magazines), spare parts supply, postal and urban freight distribution systems, intermodal transportation, and grocery distribution (Gonzalez-Feliu 2008). A cross-docking operation is a form of consolidation (Beuthe and Kreutzberger 2001) of specific road and railroad freight transportation. In a multi-echelon transportation system, cross-docking operation consists of transshipment of one or more freight units from an incoming vehicle into an outbound vehicle with little or no storage in between (Gonzalez-Feliu 2008).

According to Brewer et al. (2001), cross-docking and warehousing are used in multi-echelon systems. However, multi-echelon transportation with cross-docking differs from that with warehousing in that there is no stocking on intermediary platforms though consolidation and transshipment operations are allowed (Beuthe and Kreutzberger 2001). Because these two concepts are studied separately by different disciplines, the relationships between them are less understood. This paper contributes to understanding this relationship. It uses a multidisciplinary framework to conceptualize and study multi-echelon transport systems with cross-docking by focusing not only on their theoretical and technical aspects but also on their applicability and general feasibility.

The paper is organized as follows. First, a review of the relevant literature on multi-echelon systems with cross-docking is presented. It is followed by mathematical models that conceptualize multi-echelon transportation cost optimization with cross-docking, and assess a two-echelon transport system for a single carrier, and three collaborative freight transportation scenarios to assess the potentials of collaboration among carriers to optimize transportation costs. In both models the practical implications of the results are examined rather than computational effectiveness. Next is a section on interview-based analysis that identifies the benefits and limitations of multi-echelon transportation systems, followed by a conclusion section.

LITERATURE REVIEW

In freight transport, decisions on transport networks have a direct impact on service quality and costs. Consequently, it is important to adapt transport networks to economic, geographic, organizational, and quality constraints. In the past, several strategies and logistics models have been developed to increase the effectiveness of freight transport systems (Beuthe and Kreutzberger 2001). Multi-echelon systems with cross-docking are among the most popular because they reduce logistics costs by avoiding inventories (Lambert 2008). Moreover, they are the base of most collaborative transportation systems (Gonzalez-Feliu and Morana 2011). In the scientific literature, several disciplines and researches deal with multi-echelon transportation with cross-docking including operations research, business, management, economics, and transport engineering.

In transport engineering, the main research related to multi-echelon distribution is vehicle management at terminals (Wang and Regan 2008) and infrastructure management and not transportation itself. Also in operations research, such works relate to terminal management (Soltani and Sadjadi 2010, Larbi et al. 2011) and infrastructure (Klose and Drexl 2005). These categories of research will not be detailed here because they are technical and unrelated to multi-echelon transportation management.

In the past, tactical and operational issues in multi-echelon transportation were the focus in major research. For example most operations research works in freight transport management derived from the vehicle routing problem and sought to minimize the total transportation cost of delivering to a number of customers with a fleet of vehicles that are based at one or more depots (Toth and Vigo 2002). In comparison, multi-echelon vehicle routing aims to minimize the costs of both locating intermediate facilities and delivering to several final destinations using cross-docking platforms. According to Jacobsen and Madsen (1980), there are four phases in multi-echelon vehicle routing. First, customers are grouped and assigned to vehicles using cross-docking platforms. Second, one transshipment location for each vehicle is determined. In the third and last stages, all routes are determined by heuristics methods that assign each destination to a suitable route.

Besides the heuristics approach, Semet and Taillard (1993) develop an algorithm which initially solves the route selection problem using a procedure similar to those above, and improves the solution by reallocating customers onto routes. Gerdessen (1996) used an algorithm that finds an initial solution by a combination of heuristics like those of Jacobsen and Madsen (1980), and improves it by reallocating the destinations using iterative local search heuristics (Toth and Vigo 2002). Nguyen et al. (2011) used a constructive heuristics approach that builds each echelon's routes separately and a post-optimization algorithm based on route reallocation. These route selection studies have been complemented by studies focusing on managerial issues in multi-echelon distribution related to interactions between transportation and supply chain management. Most of these works, however, deal with multi-echelon system optimization in the general contexts of supply chains defined as an integrated set of processes related to product manufacturing and distribution. These supply chains cover all the operations from raw material collection to final product delivery to customers and product returns. According to Brewer et al. (2001), a supply chain consists of three integrated parts, which are raw material collection and production supply, production planning and inventory, and distribution to the final destination. To this must be added transportation, information, and financial flow activities, which are important aspects of supply chain management. In global supply chain works, decisions on supply, production, and inventory are internal to the company, whereas, distribution and transportation are usually externalized using third-party companies. Therefore, many works in supply chain management focus on factors internal to the company and include transportation as additional costs without taking into account transport management and optimization analysis (Lambert 2008)

In distribution logistics, most works deal with multi-echelon distribution systems with warehousing, focusing on inventory management rather than on transportation planning (Lambert

2008). Regarding multi-echelon distribution with cross-docking, most works focus on production-distribution coordination (Galbreth et al. 2008). In these works, distribution costs are mainly associated with transport demand and cross-docking platform management costs, and not to traveled distances or chosen transport strategies. In addition, there are qualitative studies that deal with supply chain management and can be related to multi-echelon transportation with cross-docking. Yang et al. (2010) analyze the factors affecting cross-docking in a terminal management perspective, including the impacts on other supply chain echelons such as delays in production and distribution. Concerning relational aspects of collaboration, Newbourne (1997) defines the main principles of a logistics partnership and the differences between other forms of inter-enterprise relationships, while Lambert (2008) presents a model to analyze the feasibility of collaboration from a management viewpoint. These works are mainly related to production and warehousing and in general involve multiple participants.

While these studies continue, there is very little done in terms of the acceptability and limits of multi-echelon transportation with cross-docking. Beuthe and Kreutzberger (2001) analyze different multi-echelon schemes and estimate the changes in their costs. Simonot and Roure (2007) examine the typologies of transport networks regarding their constitution, objectives, and organizational behavior. From their results they suggest that transport management and modal split are less used in multi-echelon transportation because of several limitations in terms of relationships between stakeholders and transportation carriers. Gonzalez-Feliu and Morana (2011) make a case study for press (newspaper and magazine) distribution to examine the limits to possible changes in their distribution schemes.

To summarize, several works deal with multi-echelon transportation with cross-docking in related disciplines and can be broken into two streams: (1) optimization methods related to computer science and applied mathematics, and (2) works from economics, business, and management focusing on business relationships and not on transportation management. These disciplines seldom collaborate to provide multidisciplinary analyses. In an applied research subject like multi-echelon transportation, it is essential to deal with realistic and applicable methods and analysis. To deal with this question, an optimization analysis focusing on practical and applicability aspects of multi-echelon transportation with cross-docking is presented below followed by a socio-economic feasibility study.

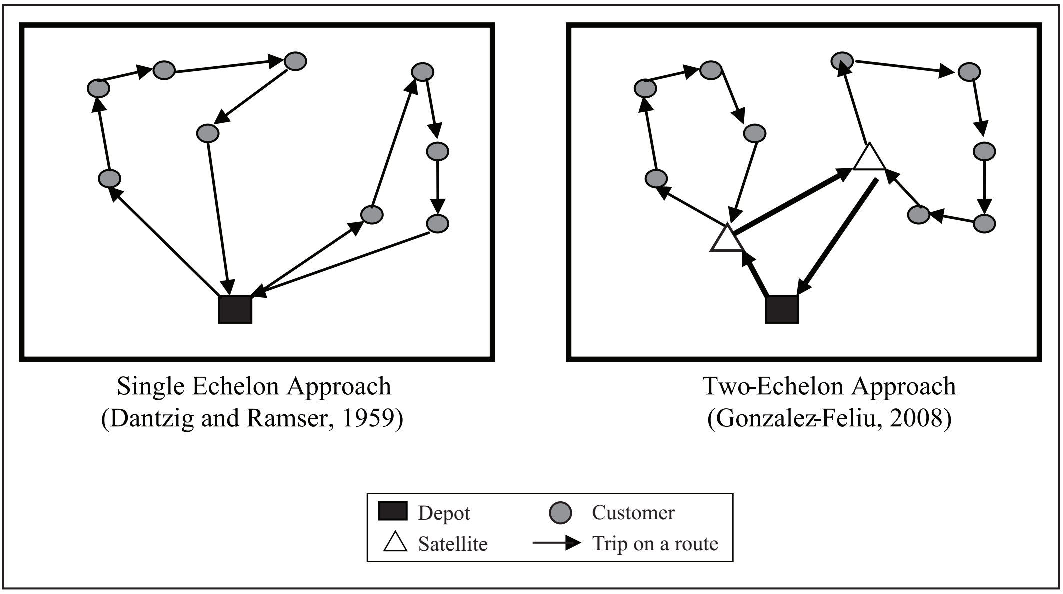
OPTIMIZATION ANALYSIS

Two analyses are used to show the potentials of multi-echelon distribution systems. These analyses are based on transportation cost optimization and are mainly related to travel distances (Gonzalez-Feliu 2011). The first is an analysis from the viewpoint of a single carrier, and the second is the possibility of collaboration among various operators.

Issues for a Single-Carrier Transportation System.

The first considers the viewpoint of a single transportation operator who has both possibilities of delivering freight directly using less-than-truck load routes without cross-docking, or using intermediate platforms to develop a two-echelon transportation system. In this context, one-echelon distribution results in direct routes from the depot to a set of customers, and a two-echelon transportation uses intermediary cross-docking platforms (see Figure 1). The details of the mathematical formulations of this problem and a solution are in Appendix A.

Figure 1: Single-Echelon and Two-echelon Vehicle Routing Schemes



Accessibility is used to study the impacts of multi-echelon transportation with cross-docking compared to one-echelon transportation systems. Following Geurs and van Wee's (2004) accessibility is the extent to which transport systems enable individuals to reach their destinations. According to them there are four categories of accessibility indicators. The first consists of infrastructure-based indicators, largely used in transport planning studies. These measures deal with service levels of transport infrastructure, for example, congestion or average travel speed (Ewing 1993). The second includes location-based measures, which analyze accessibility on a macroscopic scale and describe access to spatially distributed activities, and are used largely in urban planning and geography. Two main groups of indicators in this category are distance-based and potential accessibility measures. The distance-based measures (Pirie 1979) represent the degree to which two locations are connected. Several distance measures can be defined, for example, the linear distance between two points and travel time or transport cost to access a number of opportunities (Geurs and van Wee 2004). Potential accessibility, also called gravity-based measures of accessibility, estimates access to opportunities in zone *i* by all other zones. These measures take into account both the number of opportunities and the transportation costs to reach them (Hansen 1959) and can be generalized as follows:

(1) $$A_i = \sum_j D_j . f(c_{ij})$$

where A_i is the potential accessibility of zone *i*, D_j are the opportunities at each destination zone *j*, and $f(c_{ij})$ a function of c_{ij}, the transportation cost between zone *i* and zone *j*.

The third category defines accessibility at the individual level (Burns 1979). This measure is based on space-time geography following Hägerstrand (1970) and measures limitations on an individual's freedom of action in the environment. The main measures are related to travel budgets and are difficult to define precisely with standard survey techniques (Geurs and van Wee 2004). The fourth includes utility-based measures derived from the benefits of having access to spatially distributed activities. For example, utility-based accessibility can show benefits in terms of travel time for users of a transport system or network. This type of measure has its origin in economics and considers accessibility as the outcome of a set of transportation choices. Two main types of measures are used for this accessibility. One is a log-sum indicator (Ben-Akiva and Lerman 1979), which is a summary measure of the desirability of a full choice set. This indicator is included in the multinomial logit models of discrete choice commonly used in the four-step transportation models. The other is derived from Williams' (1976) integral transport-use benefit measure defined as an integral function of cost and transport demand. For more details about the four types of accessibility, see Geurs and van Wee (2004).

In the context of the proposed analysis, personal indicators do not seem useful because carrier-oriented transportation planning often refers to facility location and fleet management. Moreover, in multi-echelon freight transportation systems the main cost optimization issues are total traveled distances related to the geographic configuration of the transportation network. For these reasons, location-based indicators seem the most reasonable to use in this study since they take geographic contexts of networks into account and can use both costs and access opportunities as their main variables.

A two-echelon transportation system is defined by two connected transportation systems, each assigned to an echelon. For the first echelon, the freight is not pre-assigned to each intermediary facility. Although capacity and other operational data of these facilities are available, demand is strongly dependent on each final destination and on the second echelon. Therefore, two indicators are defined. First, a gravity model-based accessibility measure is defined for the second echelon following the general definition presented above. This accessibility is related to both customer demand and distance to a chosen satellite. Thus, a freight transportation trip is more attractive when large freight can be delivered to a customer's location, and a customer is less accessible when the distance from the customer's location to the starting point of the route increases. An exponential cost function is used to accentuate the role of increasing distances. To compare test cases of different sizes and scales, a normalized accessibility indicator whose value range is independent of its size (number of satellites and customers) and distance is used (Gonzalez-Feliu 2008). This measure is defined as follows:

(2) $$A_k = \sum_{i \in V_c} \frac{q_i}{q_{\max}} \exp\left(-\beta \left[\frac{c_{ki} - c_{\min}}{c_{\max} - c_{\min}} \right] \right)$$

Where q_i is customer *i's* demand, q_{max} the maximum overall demand for customers, c_{ki} is transport cost between satellite *k*, and the customer *i*, c_{min} and c_{max} the minimum and maximum values of the second-echelon transport costs, respectively, and β is a given parameter representing traveling impedance. Following Bertuglia et al. (1987), it is assumed that β is 0.1 in Eq. (2). Concerning transportation cost, c_{ki} accounts for travel distance between *k* and *i*. This distance can be Euclidean or not and it is not always symmetric, i.e., c_{ki} can be different from c_{ik}.

A second measure of accessibility derived from average distance ratios is used to complement the accessibility indicator in Eq. (2). More precisely, it is desired to measure how long it takes to deliver to a customer by passing through a satellite and using a direct transportation path from the depot to the customer. This indicator is denoted as first-echelon distance ratio and it is defined for each satellite *k*, as follows:

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

Where c_{0i} is the distance between a depot and customer *i*, c_{0k} the distance between a depot and satellite *k*, c_{ki} transport cost between the satellite *k* and customer *i*, and n_c the total number of customers.

The accessibility analysis is carried out for 80 test cases for which a global optimum was found by solving the combinatorial optimization problem in the appendix. This optimization considers four sets consisting of 66 test cases with 12 customers, six test cases with 21 customers and a central depot, another six with 21 customers and a peripheral depot, and two with 32 customers. Each set is from Christophides and Eilon (1965) and it is compared to basic one-echelon cases. Note that the original single-echelon test cases with 12 customers have non-Euclidean distances, whereas all the others have Euclidean distances (Christofides and Eilon 1965).

Overall transportation cost is calculated for each two-echelon test case and compared to the corresponding single-echelon benchmark case. Then, the quartiles (first quartile, median, third quartile, fourth quartile) are calculated respectively for the second echelon accessibility and the first echelon cost ratio. This division of the data leads to 16 homogeneous classes, each containing five values. Table 1 shows for each class the number of test cases where a two-echelon system results in a lower travel cost compared to a single-echelon scheme.

Table 1: Impacts of Accessibility and Transportation Cost Ratio

Quartile		Transportation Cost Ratio				
		First quartile	Second quartile	Third quartile	Fourth quartile	**Total**
Mean 2nd-echelon accessibility	First quartile	3	4	3	0	**10**
	Second quartile	4	3	3	0	**10**
	Third quartile	5	5	2	3	**15**
	Fourth quartile	5	4	3	3	**15**
	Total	**17**	**16**	**11**	**6**	**50**

This table can be read as follows. For example, for the third quartile of the transport cost ratio and the second quartile of accessibility, three test cases result in a cost reduction. Although the sizes of the test cases in terms of the number of customers are small, the comparison is between exact optima and as such it provides information about the travel costs impacts of multi-echelon distribution with cross-docking. Indeed, the table shows that multi-echelon distribution leads to a cost reduction in 50 (63%) of the test cases. On the average, the range of the decrease/increase is -23% to 21% of the transport cost of a single-echelon system resulting in an average cost decrease of 5% as shown in Table 2.

Table 2: Average Percent Gain/Loss Compared to the Single-Echelon Optimum

Quartile		Transportation Cost Ratio				
		First quartile	Second quartile	Third quartile	Fourth quartile	**Average**
Mean 2nd-echelon accessibility	First quartile	-23%	-13%	-1%	14%	**-6%**
	Second quartile	-20%	-13%	-7%	11%	**-7%**
	Third quartile	-11%	-12%	-4%	9%	**-5%**
	Fourth quartile	-9%	-15%	-4%	21%	**-2%**
	Average	**-16%**	**-13%**	**-4%**	**14%**	**-5%**

Examining these results further, Table 2 shows the average cost increases or decreases compared to the single-echelon approach. This table considers only the cases where two-echelon distribution leads to a cost reduction. It is observed from the second echelon accessibility mean value that when it increases, two-echelon systems are less costly than one-echelon schemes. This, however, is not the case for average cost decreases. For example, when the second-echelon accessibility is in the fourth quartile (i.e., when it reaches its highest values), 75% of the two-echelon cases result in cost reductions in Table 1 but the average cost reduction is only 2% in Table 2. Focusing on the fourth quartile of accessibility, when the transport cost ratio is low (the two first quartiles), nine test cases result in cost reductions in Table 1, ranging from 9% -15% in Table 2. Each of the third and fourth quartiles has three cases resulting in cost reductions. However, the third quartile has an average cost reduction of 4%, and the fourth, an average cost increase of 21%. To summarize, cost reductions are found for the first three quartiles of transport cost ratio in Table 2. However, the effect of accessibility is less evident. Indeed, only for the first quartile of the transport cost ratio is it observed that the number of cases resulting in cost reductions increases with accessibility. This result is not confirmed in terms of average cost reduction (Table 2).

From this analysis, accessibility and cost ratio can be used to study the potential of two-echelon transportation systems with cross-docking. In this analysis, only transportation cost directly related to travelling distances has been taken into account to produce a homogeneous comparison between single- and two-echelon transportation schemes. However, no investment costs have been taken into account, especially those related to the financing of infrastructures and vehicles needed in two echelon schemes. Therefore, issues concerning investments and financing will be considered in the socioeconomic analysis further presented.

Comparison of Single-Echelon and Collaborative Multi-echelon Systems

A scenario analysis is used to compare single-echelon and multi-echelon strategies with data from Fisher (1994), who proposed three real-life test cases. Each test case can be seen as an optimization problem for a transport company. Complementary information is assigned to each test case to allow the company to use a single- or a two-echelon transportation system. Each company's characteristics are summarized in Table 3.

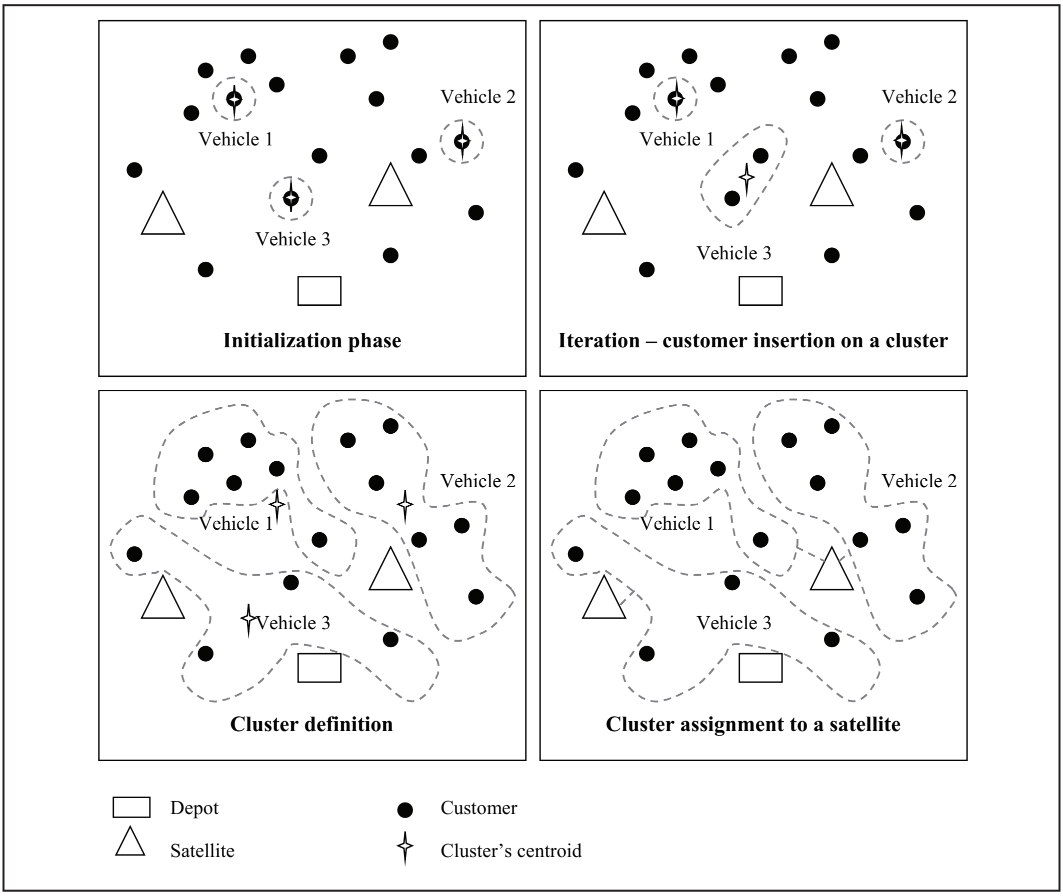
Table 3: Main Characteristics of Each Carrier (Adapted from Fisher 1995)

Transport Carrier Number	Number of Customers	n_s	n_c	m_1	m_2	C_1	C_2
1	71	2	71	2	6	7800	3000
2	44	2	44	2	6	6500	2500
3	136	3	136	3	10	6500	2500

n_s: Number of cross-docking platforms (also known as satellites); n_c: Number of customers; m_1: Number of first-echelon vehicles; m_2: Number of second-echelon vehicles; C_1: Maximum capacity of first-echelon vehicles (in kg); C_2: Maximum capacity of second-echelon vehicles (in kg)

From the test cases, four scenarios are defined. The first is where each company has a single-echelon transportation system. In the second, each carrier develops its own two-echelon distribution strategies. The third assumes a form of collaboration involving companies sharing cross-docking platforms. The fourth assumes complete collaboration among partners involving sharing both vehicles and facilities. Because it is of interest to present realistic situations and solve the optimization problem quickly, each carrier's route is simulated using a two-step algorithm (Jacobsen and Madsen 1980, Nguyen et al. 2011). The first is clustering, where customers are assigned to each second-echelon vehicle, then to a satellite using an adapted Forgy and Random Partition method (Hamerly and Elkan 2002). To initialize this algorithm, m_2 observations are chosen randomly from the data set (i.e., a number of customers equal to the number of second-echelon vehicles). Each customer becomes the centroid of a cluster. Then, each customer is assigned to a cluster using a k-means algorithm. This algorithm is an iterative procedure that assigns each customer to a cluster to minimize the mean distance among customers in that cluster. Here, the mean distance to minimize is the Euclidean distance between each customer and the cluster's centroid. Each cluster contains customers whose overall demand does not exceed the capacity of the second echelon vehicle to which the cluster is associated. In order to take into account the two-echelon nature of the problem, once the clusters are defined, each is assigned to a satellite using the same principle as shown in Figure 2.

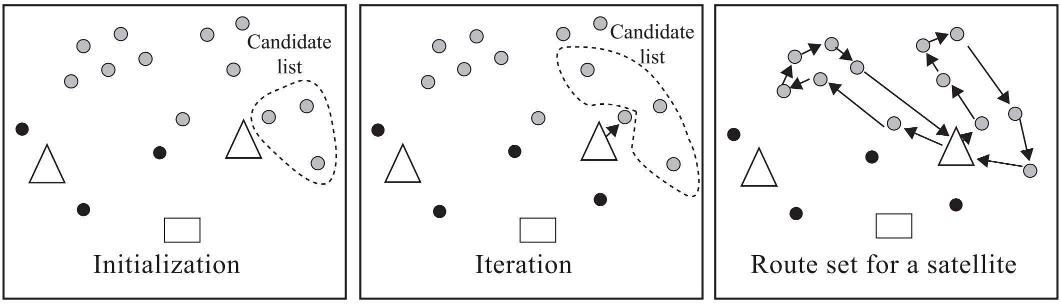
Figure 2: An Example of the Clustering Phase



The second phase is route construction. Given the satellite clusters defined in the first phase, a semi-greedy algorithm (Toth and Vigo 2002) is used. In the initialization phase of the algorithm each customer is assigned to a satellite following the results of the clustering phase. Then, for each satellite, account is taken of the maximum number of routes, which is equal to the number of clusters assigned to it in the clustering phase. Routes are generated following an iterative procedure that adds each customer to a route in the following manner. Given each iteration and incomplete route, a list of candidates is defined by taking the n closest customers to the last point on the route as shown in Figure 3. This is done by defining a distance threshold δ. Customers whose distances to the last point of the route are less than δ are included in this list, which will be called Restricted Candidate List (RCL). Then, the customer to be added to the route is chosen at random from the RCL customers. Finally, the first-echelon routes are built following the same principle and knowing the load that will transit in each satellite from the second-echelon routes. Since the number of intermediary facilities is small, all feasible first-echelon routes can be easily identified, and the optimal solution obtained by combining the routes iteratively until all the satellites are served by at least one echelon route, and the vehicles have adequate capacity to deliver the required freight. The algorithm solves optimization problems of more than 200 destinations and five satellites in less than one second.

To adapt the algorithm to a single-echelon system, this scheme is represented by a two-echelon system with one satellite whose distance to the depot is equal to zero. The different scenarios have been tested by programming the simulation in Python. This analysis identified the main cost sources,

Figure 3: Schema of the Semi-Greedy Algorithm for the Second-Echelon Routes



traveled distances, the number of open cross-docking platforms, and the number of vehicles used. A generalized cost function is not used but the method analyzes these three variables and deduces their main implications taking into account that each affects a carrier differently.

It is observed that all scenarios result in decreases in distances and a larger number of vehicles. In Table 4, scenario one gives a small reduction of about 5% in total travel distance and uses a larger number of vehicles. In this scenario, each carrier needs to almost double its number of vehicles and all available vehicles are used. This is due to the algorithm and the assumptions assigning vehicles to each satellite and not using the same vehicle on more than one route. The number of open platforms is seven, i.e., each carrier uses all the satellites it has and employees to perform different operations related to consolidation and transshipment.

Table 4: Scenario Simulation Results

	First-echelon vehicles	Second-echelon vehicles	Used satellites	First-echelon vehicle variation	Second-echelon vehicle variation	Distance variation
0	0	15	0	-	-	-
1	7	22	7	+7	+7	-5%
2	7	21	7	+7	+6	-10%
3	5	14	4	+7	-1	-22%

A similar situation is observed in scenario two. If only platforms are shared, transportation costs can only be improved by using more platforms, which is not the best for the number of satellites and vehicles used. Indeed, the number of open satellites is also seven (see the fourth column of Table 4) but they are used by all three carriers. This leads to a small reduction in the number of second-echelon vehicles because one carrier can, by using a satellite not belonging to it, group a set of customers to gain one vehicle. The overall transportation costs in the last column of Table 4 in terms of travel distances are reduced about 10% compared to scenario zero or one-echelon schemes for each company.

Finally, the third scenario which involves collaboration among all the carriers to share vehicles leads to a reduction of about 22% in travel distance and a better usage of vehicles. In this scenario Table 4 shows 19 vehicles are used (five for the first and 14 for the second echelon), which is the best taking capacity constraints into account. Note that in these simulations, account is taken of the fact that one route is served by only one vehicle. The cost reduction in terms of distance traveled by the vehicles remains however small if it is considered that other costs mostly related to consolidation and vehicle driving have not been considered in this study. To complete the study, an interview-based analysis on major limitations to transport sharing and collaboration is presented in next section.

Interview-Based Analysis

From the simulation multi-echelon transport can be useful in reducing transport cost. However, these cost reductions do not ensure the successes of these schemes because they are a part of a socio-economic system and are influenced by it. To study the limitations to multi-echelon transportation with cross-docking, 25 companies and their contact persons were randomly identified to be surveyed about their experiences with multi-echelon distribution. The number of interviews was limited to 25 for the following reasons. First is the nature of the analysis. A qualitative analysis needs long interviews, and data processing times are significant. Second, it is important to use many companies to show diverse use of multi-echelon transportation. Third, the 25 interviews are more than the 20 Raux et al. (2007) consider appropriate for a qualitative exploratory analysis. Questions for the survey came from existing literature on multi-echelon transportation and several professional documents containing the experiences of companies regarding multi-echelon distribution. Then, a face-to-face interview was conducted with each contact person following the approach in Gonzalez-Feliu and Morana (2011). Missing information was collected by phone interviews.

Each interview was organized in three parts. First, a questionnaire that identified the main logistics schemes and flows of the company was completed by company contacts. In many cases, the questionnaire was sent prior to the interview to decrease interview time. Next, a set of questions about how the company should change its logistics systems in relation to different external factors was developed. Third, an open-phase interview was conducted that consisted of making the contact person identify the main advantages and disadvantages of managing multi-echelon transportation systems with cross-docking. More precisely, the respondent was asked to define a list of factors that help or work against multi-echelon transportation systems. For confidentiality reasons, the companies' identities are kept anonymous. The interviews were done with six grocery distribution companies, four automotive and spare part industry companies, three press distribution companies, three urban consolidation centers, four parcel and postal distribution companies, and five transport operators. Except the urban consolidation centers the interviewed stakeholders work for global companies or operate on different continents (Europe, North America, or East Asia).

The interview questions sought information on different socio-economic and legislative factors that could affect multi-echelon transportation with cross-docking. Three types of factors derived from the model were identified in each interview, and then synthesized to generalize the findings of Lambert (2008) and Gonzalez-Feliu and Morana (2011) about multi-echelon transportation with cross-docking. The first factor is that of motivators, defined as the factors that contribute to the development of a transportation system with cross-docking. The interviewed stakeholders indicate that these motivators derive from the socio-economic and legislative contexts of their practices and can be grouped into the following sub-categories. First, are the economic, environmental, and value motivators, which from the interviews can be defined as the factors related to economic efficiency, prestige of partners, and image. For example, the need for just-in-time deliveries to deal with service quality targets is one of the main factors that defines the press and spare parts distribution systems, and which leads to a network of consolidation platforms connecting different transportation networks. In addition are logistics performance-related to the optimal use of resources in terms of costs and revenues mentioned by all stakeholders, and sustainable performance in terms of the minimization of environmental impacts. The latter was mentioned by 76% of the company representatives interviewed who believe that environmental factors can motivate the use of multi-echelon systems. The existence of social policies as motivators was mentioned by 24% of those interviewed. Also mentioned are legislation and jurisprudence aspects of transport collaboration, which seem to affect transport management. Transportation carriers, postal and parcel delivery operators, and urban consolidation centers state that existing legislation compels them to develop new forms of organizations, including multi-echelon transportation. The most important aspects of this latter category are different local laws that help develop multi-echelon transportation systems in urban and regional freight transportation.

Relationship motivators are closely related to habits and interpersonal relations, and are the most difficult to identify. Those interviewed were not always forthcoming about their relationships with direct competitors. But when they have collaborated in such schemes, which as was found is common in the automotive and spare parts industry, collaboration is taken into account more naturally than when there is no such prior experience. Last, there are financial motivators, which according to those interviewed, are related to subsidies and financial help that can come from public, private, or mixed companies. However, of note is that multi-echelon distribution is seen by transport carriers and parcel distribution operators as resulting in direct cost increases. As well, changing their logistics systems to accommodate multi-echelon transportation is seen by 84% of those interviewed as costly and slow. Therefore, financial support is seen by those interviewed as a factor that can make them develop new organizational concepts.

The second category of factors is that of facilitators, which are the conditions and situations that have positive impacts on the daily operations of multi-echelon transportation schemes. They are similar to collaboration and logistics partnerships (Lambert 2008) and will not be analyzed indepth. These factors are not only related to the logistics organization but also to the evolution of strategic relationships between partners. A history of relationships can facilitate a durable partnership, as shown by the urban consolidation centers that persist in the automotive industry. The boundary between motivators and facilitators is not always clear, as revealed by the interviews. Indeed, several companies did not see clearly the difference between these two categories of factors. For this reason, it is important to explain here the main differences between them. The motivators have an impact on strategic decisions before a project's experimentation and deployment, i.e., in strategic planning, and the facilitators have impacts that are observed at tactical and operational levels.

Closely related to the facilitators, the study identified limitations and obstacles which consist of the factors that can become impediments to the successful development of strategies concerning multi-echelon transportation with cross-docking. These factors constitute a third category and are seldom studied in the logistics literature (Lambert 2008). For this reason, they are the focus of the analyses. From the experiences and feedbacks, several types of limitations and obstacles have been identified and are synthesized as follows.

First, there are commercial strategies. Each enterprise has its own commercial interests, which are not the same for loaders and transport operators. In general, producers aim to sell products and transport is seen as a cost and/or a constraint but seldom as an opportunity to improve performance. This derives from the fact that transport is carried out by third parties. Transport carriers see transport management as a leverage to improve their performance, as stated by all considered urban consolidation centers and transportation companies, as well as four of the six grocery distribution companies. However, each sector has its specific characteristics and constraints. For example, transport demand for press distribution is fixed by publishers and the benefits of the distribution company depend on sales. Also, for the press companies whose representatives were interviewed, distribution by transport and route selection are planned six months ahead and this makes it difficult to optimize. Aggressive strategies and disregard of transport plans to favor "friends" or customers were identified by many transport operators as a problem in the development of collaborative multi-echelon networks. Since multi-echelon transportation affects the transportation field directly, producers and distribution companies that subcontract transportation are less concerned about it.

Another limitation identified in the interviews concerns the financial aspects of implementation of a multi-echelon system, more precisely, investment costs of construction or adaptation of cross-docking platforms, depots or other infrastructures. This is an important limitation to the development of urban consolidation centers and is one of the main factors that define grocery distribution supply chains. Yet another limitation, especially for parcel distribution companies and transportation carriers, is the ownership of these infrastructures or managerial issues related to them once they are operational. Also, the logistics strategies of each stakeholder as well as the potential or real changes that a multi-echelon system would introduce are a source of obstacles to their development. Most transport carriers, postal and parcel delivery companies, and urban consolidation centers state that the physical and organizational conditions for freight compatibility such as dimensions, type of freight, type of packaging, loading unit, and loading requirements are important and are not only related to legislation but also to organizational type, equipment, and habit. Another limitation identified by 92% of those interviewed is acceptability of organizational changes.

Two other important limitations identified by those interviewed are responsibility transfer and confidentiality. Although the main transactions in freight transportation are regulated by several commercial contracts, the responsibilities of sub-contractors are not always well defined (Simonot and Roure 2007). Moreover, not all transport operators use subcontractors if responsibility issues are not well defined. And as found, none of the transportation and parcel distribution carriers would give freight to another operator without well defined responsibility transfer rules. In cases of conflicts, the responsibility transfer clause of a contract plays an important role because it defines liability. For this reason, transportation carriers are reticent to organizational changes that imply collaboration with other carriers. Moreover, confidentiality was mentioned as an obstacle to multi-echelon systems when two competing companies decide to collaborate to reduce their transport costs. Since information flow is the basis of good collaboration, if one or more partners manage confidential information that they do not want to share for competitive reasons, the efficiency of multi-echelon approaches can decrease considerably. These issues come to light in most of the initiatives involving competing enterprises that are not supported by public entities.

CONCLUSION

This paper presents a multidisciplinary analysis to study multi-echelon transport with cross-docking using both engineering and social science approaches. Two optimization analyses were undertaken to study the potentials of these systems as well as their main limits. The first, based on the notion of accessibility, shows that the physical and geographical characteristics of a network have important impacts on the development of transportation systems with cross-docking. Such systems are useful if they group delivery points to use small vehicles to make short distance deliveries, but are disadvantageous if the distances to reach cross-docking platforms are long. The second analysis explores the possibility of collaboration between transport carriers to optimize vehicle loads. This analysis leads to two main conclusions. The first is that significant cost reductions can be obtained only by sharing vehicles. However, other costs will appear mainly related to the introduction of new vehicles and the use of cross-docking facilities. This leads to the second conclusion, which is that it is important to have enough freight to put on the vehicles feeding the satellites. In this respect, collaboration seems a good way to increase vehicle load.

To complete these analyses, an interview-based analysis of 25 companies was undertaken. Several factors that can be considered incentives and limitations to multi-echelon transportation with cross-docking were identified. These factors are related to commercial strategies, financing, organization, and legislation. Since transport is used by humans, the social aspects of human interactions are important and can be its keys to success. For these reasons, optimization methods are useful but have to meet operational needs and limits, most of them related to habits that are often difficult to change.

In conclusion, multi-echelon transport has potential and can be well accepted by practitioners and public authorities, but structural changes have to be implemented in a medium term perspective, after identifying and analyzing the potential obstacles to its development to ensure its continuity from an economic point of view. Finally, some future extensions to this study can be done in two complementary directions. One is to provide more realistic simulation tools, by adding a cost function that takes into account not only traveled distances but other costs related to vehicle usage, crew scheduling, platform management, and maintenance issues, among others. The other is to include qualitative variables in the simulation approaches to develop integrated decision support systems to help planners and practitioners in their strategic or tactical decisions related to multi-echelon transportation with cross-docking.

APPENDIX: The two-echelon vehicle routing problem

Consider a transportation carrier that has to deliver to a set of N_C destinations, called customers (Fisher 1994). To each customer i is associated a quantity of freight q_i to be delivered, called demand. The carrier has one depot and N_S intermediate facilities, or satellites (Nguyen et al., 2011) where cross-docking operations can take place. The company has two fleets of homogeneous vehicles, m_1 and m_2, assigned respectively to the first and the second echelon. These vehicles have a maximum capacity of C^1 and C^2 respectively. Two types of routes are then defined, one for each echelon. A first echelon route starts and finishes in a depot and visits the satellites. At the satellites, the freight is transshipped into the second echelon vehicles. Each of them makes a round trip to deliver to one or more customers.

Define three sets of nodes: V_0 includes the depot, V_S the satellite nodes and V_C the customers. Then define an arc (i,j) to link node i and node j. Cost c_{ij} is defined as the travel distance associated with arc (i,j). The decision variables are the following: x_{ij} is an integer that represents the number of first echelon vehicles traveling on arc (i,j); y_{ij}^k is a binary variable equal to one if a second echelon route starting from satellite k travels on arc (i,j) otherwise it is zero. Also define z_{kj} as a binary variable equal to one if the freight to be delivered to customer j is transshipped at satellite k, otherwise it is zero. Finally define a set of variables that represents the quantity of freight loaded into a vehicle passing through each arc. These variables are real and can be noted as Q_{ij}^1, Q_{ij}^{2k} respectively, for each subset, k representing the satellite where the second echelon route starts. The corresponding optimization problem can be written as follows (Gonzalez-Feliu 2008):

$$(A.1) \quad \min \sum_{i,j \in V_0 \cup V_S} c_{ij} x_{ij} + \sum_{k \in V_S} \sum_{i,j \in V_S \cup V_C} c_{ij} y_{ij}^k$$

Subject to

$$(A.2) \quad \sum_{i \in V_S} x_{0i} \le m_1$$

$$(A.3) \quad \sum_{j \in V_S} x_{j0} = \sum_{i \in V_S} x_{0i}$$

$$(A.4) \quad \sum_{k \in V_S} \sum_{i,j \in V_c} y_{ij}^k \le m_2$$

$$(A.5) \quad \sum_{i,j \in V_C} y_{ji}^k = \sum_{i,j \in V_C} y_{ij}^k \ \forall k \in V_S$$

$$(A.6)\quad \sum_{i\in V_S} Q_{ij}^{1} - \sum_{k\in V_S} Q_{jk}^{1} = \begin{cases} \sum_{h\in V_C} q_h z_{jh} & \text{if } j \text{ is not the depot} \\ \sum_{i\in V_c} -q_i & \text{if } j \text{ is the depot} \end{cases}$$

$$\forall j \in V_0 \cup V_S, k \neq i, k \neq j$$

$$(A.7)\quad \sum_{i\in V_c} Q_{ij}^{2k} - \sum_{l\in V_c} Q_{jl}^{2k} = \begin{cases} z_{kj} q_j & \text{if } j \text{ is not a satellite} \\ -\sum_{h\in V_C} q_h z_{jh} & \text{if } j \text{ is a satellite} \end{cases}$$

$$\forall j \in V_S \cup V_C, \forall k \in V_{S,}\ l \neq i, k \neq j$$

$$(A.8)\quad \sum_{i\in V_S} Q_{i0}^{1} = 0;$$

$$(A.9)\quad \sum_{i\in V_C} Q_{ik}^{2k} = 0 \qquad \forall k \in V_S$$

$$(A.10)\quad Q_{ij}^{1} \leq C^1 x_{ij} \quad \forall i, j \in V_S \cup V_0, i \neq j$$

$$(A.11)\quad Q_{ij}^{2k} \leq C^2 y_{ij}^{k} \quad \forall i, j \in V_S \cup V_0, \forall k \in V_S, i \neq j$$

$$(A.12)\quad y_{ij}^{k} \leq z_{kj} \quad \forall i, j \in V_S \cup V_C, \forall k \in V_S$$

$$(A.13)\quad y_{ij}^{k} \leq \sum_{h\in V_{S\cup\{0\}}} x_{hk} \quad \forall i \in V_S, \forall j \in V_C, \forall k \in V_S$$

$$(A.14)\quad \sum_{k\in V_S} z_{kj} = 1 \quad \forall j \in V_C$$

Where x_{ij} is integer; y_{ij}^{k} and z_{k} are binary; Q_{ij}^{1} and Q_{ij}^{2k} are real.

The objective function (A. 1) seeks to minimize the overall transportation cost. Equations two and four impose the maximum number of routes. Constraints (A.2) to (A.5) balance the number of vehicles entering and leaving each node. Equations A.6, A.7, A.8, and A.9 ensure that each route returns to its departure point and each node receives its corresponding demand. Vehicle capacity constraints are expressed by equations A.10 and A.11. Constraints (A.12) and (A.13) ensure the connection between the two echelons. Constraint (A.14) assigns each customer to one and only one satellite.

To test the two-echelon model, four test cases are adapted from Christofides and Eilon (1969). These test cases represented as 12, 21, 32, and 50 customers, respectively. Then, 102 two-echelon test cases were created in the following way. Given a reference dataset (one of the chosen Christofides and Eilon's test cases), two satellites are added. The second-echelon vehicle fleet is taken from the reference and then the first echelon vehicles are added. The number of such vehicles is two, and their capacity is 2.5 times the capacity in the reference. After creating the test cases we solve them using XPress 2006 (see Gonzalez-Feliu 2008 for the detailed computational issues). All test cases up to 21 customers, and two having 32 customers, were solved to optimality. The Xpress solver thus gives the global optimum solution. The other test cases were not solved to optimality in the given time (45 minutes), but at least one solution was provided by the solver in less than 20 minutes. Although there is a gap between the best solution and the best lower bound (i.e., a bound lower than the optimum calculated by Xpress solver), only test cases with 50 customers and a central depot present solutions too far from it. In the other cases, on average a gap of less than 10% was obtained between the best solution and its best lower bound found with Xpress solver, which is considered as a good result (Toth and Vigo 2002).

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Acknowledgement

The author would like to acknowledge Christian Ambrosini, Mathieu Gardrat, Aurélie Mercier, Joëlle Morana, and Jean-Louis Routhier (Laboratoire d'Economie des Transports, France) for their suggestions as well as Carlos Peris Pla (TComm, Spain) for his help in algorithmic development. The author would also like to acknowledge the co-editors in chief, as well as the two anonymous reviewers, for their suggestions to improve the paper.

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