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A survey on two-echelon routing problems

R. Cuda [a], G. Guastaroba [b,*], M.G. Speranza [b]

[a] Departement of Management, Economics and Quantitative Methods, via dei Caniana 2, University of Bergamo, Bergamo, Italy
[b] Department of Economics and Management, C.da S. Chiara 50, University of Brescia, Brescia, Italy

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ABSTRACT

The delivery of freight from its origin to its destination is often managed through one or more intermediate facilities where storing, merging and consolidation activities are performed. This type of distribution systems is commonly called multi-echelon, where each echelon refers to one level of the distribution network. Multi-echelon distribution systems are often considered by public administrations when implementing their transportation and traffic planning strategies as well as by private companies in their distribution networks. City logistics and multi-modal transportation systems are the most cited examples of multi-echelon distribution systems. Two-echelon distribution systems are a special case of multi-echelon systems where the distribution network comprises two levels. This latter type of distribution systems has inspired an ever growing body of literature in the last few years. This paper provides an overview of two-echelon distribution systems where routes are present at both levels. We consider three classes of problems: the two-echelon location routing problem, the two-echelon vehicle routing problem, and the truck and trailer routing problem. For each class we provide an introduction and survey the foremost related papers that have appeared in the operations research literature.

1. Introduction

Transportation of freight occurs from the freight *origin* (e.g., the supplier or the production plant) to its *destination* (e.g., the wholesaler, the retailer or the final customer). A supply chain may be seen as composed by *stages* (also called layers or tiers). Transportation occurs between each pair of stages. Each pair of stages represents one level of the distribution network and is usually referred to as an *echelon*. Freight transportation is a key driver for many companies since it considerably affects both the product costs and the customer experience. Chopra and Meindl [9] highlight that distribution-related costs make up about 10.5% of the US economy and about 20% of the cost of manufacturing. It is therefore not surprising that such topic has attracted considerable efforts from the operations research community aimed at developing effective optimization models and solution algorithms capable of providing support to decision makers.

Freight transportation can be broadly categorized into two classes according to the presence of one or more intermediate facilities. Direct shipping takes place when freight is delivered directly from its origin to its destination. Conversely, *indirect shipping* takes place when freight, or part of the freight, is moved through some *intermediate facilities* (e.g., cross-docks or distribution centers) before reaching its destination. Two-echelon distribution systems are a special case of multi-echelon systems where the network is composed of two echelons. In this case, after leaving its origin, freight is first delivered to an intermediate facility where storage, merging, consolidation or transshipment operations take place. The freight is then moved from the intermediate facility towards its destination. Given this framework, the flow of freight in one echelon must be coordinated with that in the other echelon. As a consequence, routing problems arising in two-echelon distribution systems cannot be merely decomposed into two sub-problems and then solved separately.

We define as *two-echelon routing problems* a class of problems that study how to optimally route freight in two-echelon distribution systems, possibly considering also location decisions.

Area covered. In recent years, a considerable number of papers focusing on two-echelon routing problems have been published. Some of them tackle variants of the same basic problem, while others propose different solution methods for the same problem. Two-echelon routing problems can be classified according to the type of decisions involved. We consider

- *strategic planning decisions*: they include decisions concerning the infrastructure of the network, typically the number and the location of the facilities;
- *tactical planning decisions*: they include the routing of freight through the network and the allocation of customers to the intermediate facilities.

* Corresponding author. Tel. +39 30 2988588.
E-mail addresses: rosario.cuda@unibg.it (R. Cuda), guastaro@eco.unibs.it (G. Guastaroba), speranza@eco.unibs.it (M.G. Speranza).

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This survey aims at providing a classification and a systematic overview of the foremost contributions in the operations research literature on two-echelon routing problems. We survey the literature dealing with two-echelon routing problems where strategic and/or tactical planning decisions are taken into consideration. In particular, we consider the following three classes of two-echelon routing problems.

We refer to the Two-Echelon Location Routing Problems (*2E-LRPs*, hereafter) when the problem definition involves both strategic and tactical planning decisions, and routes are present at both echelons. Specifically, in a 2E-LRP goods available at different origins (called *depots* or, sometimes, platforms) have to be delivered to the respective destinations moving mandatorily through intermediate facilities called *satellites*. An opening cost is associated with each depot and each satellite. The depots, as well as the satellites, to be opened have to be selected from a set of possible depot (satellite) locations.

We refer to the Two-Echelon Vehicle Routing Problems (*2E-VRPs*, from now on) when the problem definition involves only tactical planning decisions, and the routing is present at both echelons. In a 2E-VRP the set of depot and the set of satellites to use is given, and no cost is associated with the use of any depot and any satellite.

Finally, we consider the Truck and Trailer Routing Problems (*TTRPs*, henceforth). In a TTRP freight transportation is managed by means of a set of trucks and trailers with the following restrictions. A subset of customers have to be served by a truck alone, whereas the remaining customers can be served either by a complete vehicle (i.e., a truck pulling a trailer) or by a truck alone. The nature of the TTRPs is different from the above two classes of problems. However, TTRPs are two-echelon routing problems since in a feasible solution a two-level route may be present with the following characteristics: the first level route is traveled by a complete vehicle, whereas the second level route, starting and ending at a vertex visited in the first level tour, is traveled by the truck alone.

Applications. Due to the many real-life problems that can be modeled as two-echelon distribution systems, an increasing number of examples of design and implementation of this type of distribution system appears in the literature. We mention, among other applications, city logistics, multi-modal transportation, postal and parcel delivery, milk collection, press and grocery distribution.

City logistics is probably the most frequently cited application. Crainic et al. [18] claim that "city logistics aims to reduce the nuisances associated to freight transportation in urban areas while supporting their economic and social development". Indeed, freight transportation in urban areas is one of the main reasons of congestion, disorder, pollution emissions and noises. Implementing a two-echelon distribution system could be an effective response to these issues. In such systems each satellite corresponds to a facility located, usually, on the outskirts of the city where large trucks are allowed to arrive and where goods headed to different destinations are unloaded, sorted and consolidated. Goods are then loaded onto smaller and environment-friendly (also called eco-friendly) vehicles that are allowed to travel in the city center and can serve the final customers. Several papers cited in this survey are related to this particular application.

Although multi-modal transportation is not as cited as city logistics, it represents a relevant application of freight distribution systems involving two or more echelons. In recent years the number of intermodal logistic centers in Central and South-West European countries has increased significantly (e.g., see [28]). As an example we mention the ship-road multi-modal distribution system (e.g., see [27]) where the freight travels from the supplier to a satellite by ship (i.e., the first echelon) and then is loaded onto a truck that delivers it to its final destination (i.e., the second echelon).

Surveys for related problems and structure of the paper. Among the related classes of problems we mention the Location Routing Problem (LRP) and the Vehicle Routing Problem (VRP). For an overview on LRPs we refer the interested reader to the surveys by Nagy and Salhi [40] and, more recently, by Prodhon and Prins [48], whereas the paper by Laporte [33] provides a summary of the most important studies on the VRP. Two-echelon freight transportation optimization problems are analyzed in González Feliu [23] that aims at identifying the main concepts and issues. Papers dealing with the presence of intermediate facilities in distribution

Table 1
A summary of the abbreviations used in the paper.

Optimization model	Heuristic and exact algorithm
ILP: Integer linear programming MILP: Mixed integer linear programming	ALNS: Adaptive large neighborhood search B&C: Branch-and-cut B&P: Branch-and-price GRASP: Greedy randomized adaptive search procedure ILS: Iterated local search SA: Simulated annealing TS: Tabu search VND: Variable neighborhood descent VNS: Variable neighborhood search

Problem
2E-(C)LRP: Two-echelon (capacitated) location routing problem
2E-CLRPSD: Two-echelon capacitated location routing problem with a single depot
2E-(C)VRP: Two-echelon (capacitated) vehicle routing problem
CFLP: Capacitated facility location problem
(C)LRP: (Capacitated) location routing problem
(C)TTRP: (Capacitated) truck and trailer routing problem
CTTRPTW: Capacitated truck and trailer routing problem with time windows
(C)VRP: (Capacitated) vehicle routing problem
CVRPTW: Capacitated vehicle routing problem with time windows
GTTRP: Generalized truck and trailer routing problem
MDVRP: Multi-depot vehicle routing problem
SDVRP: Split delivery vehicle routing problem
STTRPSD: Single truck and trailer routing problem with satellite depot
TSP: Traveling salesman problem

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