The tactical two-echelon inventory routing problem

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1 Introduction

Transport and inventory management activities have a great impact on each other. Ensuring an ideal inventory level can require frequent deliveries, leading to high logistics costs. To optimize the trade-offs between inventory and transportation costs, VMI (Vendor Managed Inventory) systems have been developed to manage inventory and transportation operations together. Given a set of customers with demands over a time horizon, the problem of determining routes and delivery quantities to meet customer demands at a minimum inventory holding and transportation costs is known as Inventory Routing Problem (IRP) [1].

Two-echelon systems have also been studied to improve the freight vehicle flow inside urban areas. As new management policies have emerged, with the goal of limiting the traffic of large vehicles and their speed in urban centers, Distribution Centers (DCs) are introduced to coordinate freight flows inside and outside the urban areas [2]. Products are then delivered from the suppliers to the customers through the DCs. The stock of products in DCs has also the advantage of reducing the transportation cost due to the reduced number of trips to suppliers. Recently, a two-echelon multi-depot IRP has been investigated by [3].

In the context of a two-echelon IRP, two important decisions have to be taken in addition to route and quantity delivery decisions: from which DC will be supplied each customer and using which vehicles? Answering these questions is extremely difficult as it implies being able to minimize operational costs for a a two-echelon VMI delivery system on a long term (several months) and with uncertain demands. In order to deal with this, we introduce the Tactical Two-Echelon Inventory Routing Problem (T-2E-IRP) that optimizes the decisions based on a short-term horizon and a scenario for the demands.

2 Problem description and solution methods

In the T-2E-IRP, the first echelon involves deliveries from a single supplier to DCs, while the second echelon concerns the flows between DCs and customers. A fleet of homogeneous primary vehicles is available for deliveries on the first echelon and a different fleet of homogeneous secondary vehicles is available for deliveries from DCs to customers. Each customer must be served by the supplier through the DC to which the customer is assigned in order to meet its demands over a given long time horizon. Each secondary vehicle is assigned to a DC so that its routes have to start and finish at this DC over the time horizon. Customers and secondary vehicles must be assigned to the same DC throughout the entire time horizon. The T-2E-IRP has as main objective to solve the tactical problem of assigning each customer and secondary vehicle to one DC, so that the transportation total cost of the entire time horizon is minimized.
Usually, the supplier is located far from customers. The supplier receives the products to meet the demands of the customers at a constant rate per time period. The inventory levels of the supplier, DCs and customers at the beginning of the time horizon are known in advance. We assume that the supplier inventory capacity is not restrictive. Each DC strictly meets demands of the subset of customers assigned to it. The inventory capacity of each DC and customer must be respected and each customer has a deterministic demand per time period according to a specific scenario. In the first echelon, primary vehicles provide a single DC by time period, so that vehicle and inventory capacities are respected. Thus, each primary vehicle makes at most one direct delivery to a DC per time period, starting and ending at the supplier. Differently, secondary vehicles can supply several customers in a route, starting and ending at a DC, respecting routes duration and vehicle and inventory capacities.

We propose the Full Vehicle (FV) replenishment policy in which, each time a DC is supplied, a full primary vehicle is shipped, as long as the inventory capacity of the DC is respected. An Order-Up-to level policy (OU) is considered for customers. Thus, whenever a customer is replenished, its inventory level is raised to the maximum allowed, i.e, to its capacity. We also consider the Maximum inventory Level (ML) policy, in which the only constraints on the delivered quantities are that inventory and vehicle capacities are respected.

To tackle the T-2E-IRP, we propose a Mixed Integer Linear Programming (MILP) formulation based on flow variables (FI) and a route index MILP formulation (FII) with undirected variables for routing decisions. As, to the best of our knowledge, the T-2E-IRP is a new problem, we propose a set of randomly generated instances with 6 periods, where: 5 instances with 3 DCs and 15 customers; and 5 instances with 6 DCs and 30 customers. The following combinations of replenishment policies, respectively for the first and second echelon, have been analyzed: ML-ML, FV-ML and FV-OU. While the model FII was not able to find feasible solutions for any instance and inventory policy configuration, the FI did not find feasible solutions only for one instance, thus confirming that the T-2E-IRP is a very challenging problem.

3 Conclusions and further research

We proposed a new tactical assignment problem for a two-echelon system, which is inserted in a current context due to the interest of managing the supply chain in an integrated way. Three inventory management policies have been modeled and applied at one or both levels. The problem was proposed based on a real-life problem faced by a multinational distribution company. The mathematical model used to solve the problem is effective for small-scale instances.

The next step of this research will consist in the evaluation of the decisions provided by this model on the long term. We are currently developing a simulation tool for this purpose. Without modifying the problem definition (a time horizon of several months with uncertain demands), we also intend to develop other models and solution approaches, by playing on the number of time periods and the presence or not of stochastic data, and the use of exact or heuristic solution methods. A comparison of the results obtained by the proposed model with those obtained by solving a decomposition of the problem would be interesting.

References


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