Synchronizing inventory and transport within supply chain management

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PROBLEM DEFINITION

The practical problem considers synchronized optimization of inventory and transport, and focuses on producer-distributor relations. A producer has signed a contract with a distributor that guaranties exclusivity for sales in a certain region/country.

Given a region/country with its road network, historical data about sales, and all relevant costs (facilities, vehicles, workers, and haulage), it should be provided a way for a distributor to organize his sales/distribution network.

Since goods are owned by the distributor as soon as they leave production facility, and since stock out results in lost sales, the distributor's cash flow highly depends on inventory control. Given sales forecasts, should be found methods how the producer can manage its inventories. Finally, some suggestions about contracting models that lead to more profitable supply chains should be given.

Introduction

The problem of synchronizing inventory and transport within supply chain management attracts attention and has been studied for many years [1, 3, 5, 7]. The supply chains of large corporations involve hundreds of facilities (retailers, distributors, plants and suppliers) that are globally distributed and involve thousands of parts and products. The goals of corporate supply chains are to provide customers with the products they want in a timely way and as efficiently and profitably as possible. Fueled in part by the information revolution and the rise of e-commerce, the development of models of supply chains and their optimization has emerged as an important way of coping with this complexity. Indeed, this is one of the most active application areas of operations research and management science today. This reflects the realization that the success of a company generally depends on the efficiency with which it can design, manufacture and distribute its products in an increasingly competitive global economy [1].

Supply chain management is a dynamic operation research problem where one has to quickly adapt according to the changes perceived in environment in order to maximize the benefit or minimize the loss. Supply chain management can be defined as ”a goal-oriented network of processes and stock points used to deliver goods and services to customers” [6]. Science of supply chains deals with an array of suppliers, plants, warehouses (WHs), customers, transportation networks and information systems that make up actual supply chains.

Many companies search for efficient distribution alternatives, as the lead times for customer order fulfillment need to be shorten while the costs and risks of warehousing need to be minimized. Cross-docking is an operation strategy that moves items through consolidation centers or cross docks without putting them into storage [3]. In our case we have one supplier that should provide some products through a network of shops. This scheme includes wide variety of problems, such as transportation scheduling problems and warehouse location problems. These problems are independently defined as optimization problems, and algorithms have been proposed for each problem. There are different approaches that have already been proposed for solving similar kind of problems. Some of them are using genetic algorithm [4], gravitational search algorithm [2], heuristic methods and also simulation based algorithms [7].

The main purpose in our work is to optimize the distribution network of MPC Holding Mercata that has a pioneer role in domestic wholesale development for Serbia and is committed to the wholesale and distribution of tobacco products and consumer goods.

The Warehouse Location Problem (WLP)

The (uncapacitated) WLP is a problem to minimize the sum of the transportation cost and the fixed cost of warehouses. Let S be the set of shops, W be the set of candidate locations for warehouses, f_j be the fixed cost for opening a warehouse $j \in W$, and c_{ij} be the cost to supply shop i from warehouse j. The WLP is defined as follows:

$$WLP(x, y) = \sum_{i \in S} \sum_{j \in W} c_{ij} x_{ij} + \sum_{j \in W} f_j y_j \rightarrow min_{x,y} \qquad (1)$$

subject to $\sum_{j \in W} x_{ij} = 1$ for each $i \in S$

$x_{ij}, y_j \in \{0, 1\}$ for each $i \in S$, $j \in W$

$0 \leq x_{ij} \leq y_j \leq 1$ for each $i \in S$, $j \in W$

where x and y are decision variables ($x_{ij} = 1$ decides if store i is supplied from warehouse j, $y_j = 1$ decides if warehouse j is open).

The first term of $WLP(x, y)$ represents the transportation cost between warehouses and shops and the second one represents the fixed cost of the warehouses. The first constraint means that each shop must be supplied by only one warehouse. The second constraint means that the shops must be supplied by open warehouses. The last constraint means that the variables are zero-one. For this problem, Beasley proposed a Lagrangian relaxation algorithm which can find optimal or near optimal solutions quickly [5].

Our approach

At the moment, the distribution network of MPC Holding Mercata in Serbia is:

- One factory (in Senta);
- Currently 5 WHs (Novi Sad, Beograd, Pozharevac, Kragujevac, Nish) for whole Serbia;
- Different numbers of cross-docking points (CDPs) supplied from a given WH;
- Different numbers of shops supplied from a given CDP (by smaller transport vehicles) or directly from the corresponding WH

To optimize the network it is possible to open new WHs/CDPs and change the position of any WH/CDP. Also, some WHs/CDPs can be closed.

We have to consider the following constraints (based on the received data by the contact person from the company):

- The transport vehicles from given WH are trucks and vans;
- The transport prices are: for 5 ton (capacity) truck 0.35 Eur/km; for 3.5 ton truck 0.30 Eur/km; for a van 0.20 Eur/km.
- One truck supplies up to 4 vans;
- The rental cost of CDP is up to 100 Eur per month (that is negligible).

For these reasons we do not need to consider the Traveling Salesman Problem. Instead of it we can apply the Dijkstra's algorithm to compute the lengths of the shortest paths and the tree of these paths (the root of the tree is a given WH).

In order to get an optimized solution we make the following:

- Redefine the terms of WLP depending on the possibility to add the intermediate level of CDPs (one possible way to do that is to define 2-stage WLP: 1'st stage "factory-WHs" and 2'nd stage "WH-CDPs");

- Decide WLP for WHs by Simplex Algorithm for 0-1 Integer Linear Programming (or by the algorithm suggested in [5]). Generally, it is NP-complete problem but for practical goals it is possible to get a solution in polynomial time. Also, the current positions of the WHs can be taken as initial;

- Split the region supplied from a given WH to the smallest possible parts. In our case, these are the territories supplied by the smallest used transport vehicle (vans), as in Figure 1 (a);

- Estimate the values of distances from any territory to the corresponding WH (this estimation is based on the road network of Serbia).

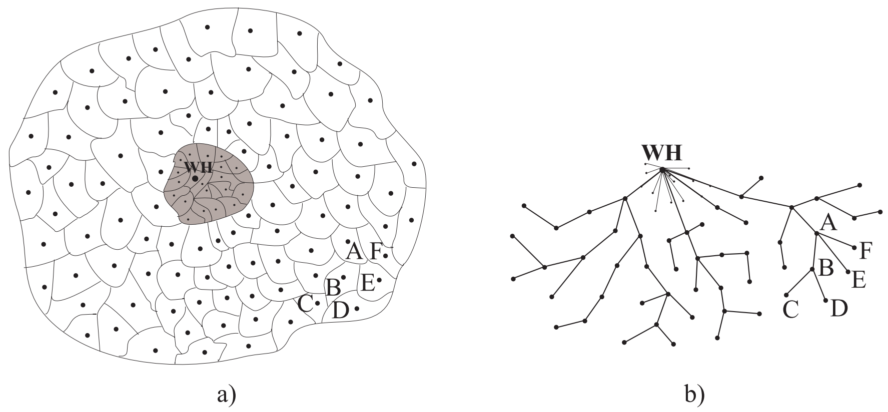

Figure 1: a) The WH area; b) A part of the computed tree of the shortest paths

Figure 2 represents the two possibilities for a given smallest part that we consider. First, it can be a set of small towns and villages (a). In that case we choose one town (or village) to be a 'center' of this territory and we calculate the distance from this point to the WH. In the second case this is a big town or city and we can assume that the distances from WH to all van's territories are the same (b). So, all these vans are associated with the same 'center' – this big town or city. The borders and the dots inside (in Figure 2) denote the shops supplied by the corresponding van, i.e. its territory. We assume that each van supplies its territory in a way near to the optimal one.

Let V be the set of all centers, including WH. We define a weighted graph $G = (V, R)$ where V is the set of vertices of G, R is the set of all edges between two adjacent

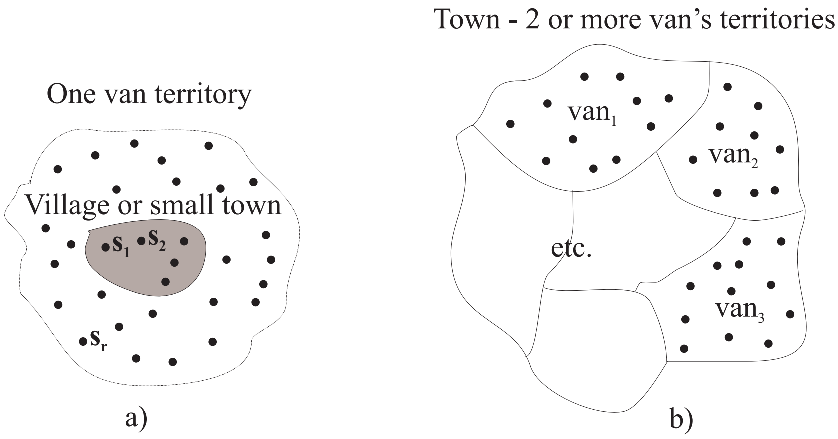

Figure 2: The smallest possible part

vertices (when there is a direct route between them), and L is the set of all weights of the edges in R.

By the defined graph we can apply the following method:

1. Use Dijkstra's algorithm to obtain the tree of the shortest paths (the root is that WH);
2. Choose the outermost leaves of the obtained tree and compute where to place CDP more efficiently;
3. Place CDP that supply some centers that are leaves of the tree;
4. Cut (exclude) already supplied centers (by the last placed CDP);
5. If there are nonsupplied centers go to Step 2;
6. End.

It can be seen that the optimization depends on:

- The distances from the WH to each center (so at any step we choose the longest path).
- The type of the territories $A, B, \ldots, F$ and the number of vans that supply them.
  - Figure 3 illustrates Step 2 in more details if the center is of type shown in Figure 2 (a). The optimization in this case can be computed as follows:

$$p_1 = (2(l_1 + \cdots + l_5) + 2(l_1 + \cdots + l_4 + l_6) + 2(l_1 + \cdots + l_4))p_v,$$

where p_v is the price of van per km. Here p_1 is the transport price for supplying the centers B, C, D by vans.

$$p_2 = 2(l_1 + \cdots + l_4)p_{bt} + 2(l_5 + l_6)p_v,$$

where p_{bt} is the price of big truck per km. Here p_2 is the transport price if we place a CDP in center B.

$$p_{opt} = p_1 - p_2 = 2(l_1 + \cdots + l_4)(3p_v - p_{bt})$$

Here p_{opt} is the value of the obtained optimization. This value is positive because $3p_v > p_{bt}$ (as it was shown above).

– If the center is of type shown in Figure 2 (b) then this center becomes a CDP. Obviously, in this case the optimization is maximal.

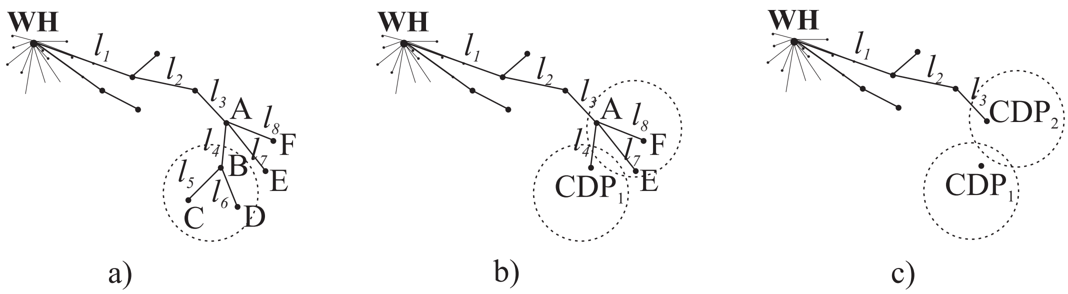

Figure 3: a) No placed CDP; b) One placed CDP; c) Two placed CDPs

Conclusions

By using the proposed model the distribution network can be optimized in general. The main advantage of this model is that (once computed) the tree of the shortest paths can be used many times until some change of the road network happens. Also, this model can be used in case of occasional supplies (after excluding the centers without demands).

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