Decision Support for Location Routing with Relocation Aspects

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1 Introduction

Due to drops in orders and decreasing production rates, demand is declining seriously in many logistic sectors like e.g. air cargo, ship and less-than-truckload (LTL) transports. Hence, logistic companies are looking for new ways to improve their transportation network efficiency. On the operational level, costs depend mainly on planned delivery tours. In our current research project *KolOptNet*[1] (Schwind and Kunkel 2009), we focus mainly on this aspect and develop an integrated software system which determines optimal delivery tours. The system exploits historical data as well as the demand information of the current day to calculate sorting plans for the packages and the delivery tours. The historical data is used to develop a prognosis function that analyzes changes in demand over a given period of time in order to forecast the future delivery volume of each geographical area.

Moreover, our software automatically transfers sorting plans and vehicle routes to wireless mobile package delivery scanner devices which in return provide our system with collected data about the delivery process.

In the long term, the location of a depot is a critical success factor because it strongly affects delivery costs. Therefore it is advisable to evaluate and improve depot locations before the route planning process. To this end, we integrate a *relocation decision support system (RDSS)* into our software. This tool analyzes the existing depot structure, i.e. location of depots and allocation of customers to depots, and checks if a relocation of existing depots would enhance the cost-efficiency of the delivery network. Besides this one-time determination of optimal depot locations, the relocation tool is coupled with our operational routing module to allow continuous verification of the network efficiency. As soon as changes in demand make modifications of the network structure reasonable, the system will suggest benefi-

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[1] www.koloptnet.de

cial location changes. To obtain distances between customers and visualize the existing network structure and recommended location changes, we make use of Microsoft MapPoint[2], a tool for viewing, editing and integrating maps.

The determination of optimal depot locations is achieved using a complex mathematical optimization model. In this context, *location-routing problems (LRP)* have attracted a great deal of attention among researchers and practitioners over the last two decades. An LRP solves three interdependent tasks with the objective of cost minimization (cf. Chien 1993; Perl and Daskin 1985):

1. *Location:* Determining the optimal number, capacity and location of depots.
2. *Allocation:* Assigning each customer to one depot.
3. *Vehicle routing:* Determining the optimal number and type of vehicles as well as the optimal pickup and delivery tours.

Simultaneous consideration of the vehicle routing aspect provides important input data for the location decision. In this way, the solution quality of LRPs significantly exceeds that of traditional location-allocation problems (LAP), which assume direct connections to each customer (cf. Salhi and Rand 1989).

The number of articles dealing with LRPs is tremendous. For an extensive literature review, we refer the reader to Min et al. (1998) and Nagy and Salhi (2007). Due to our focus on practical LRP applications, we are interested in research that emphasizes the characteristics of real-world *courier, express and parcel delivery (CEP)* networks. For example, Jacobsen and Madsen (1980) study the case of a newspaper distributor who faces an LRP with two facility layers and consequently two different types of tours and vehicles. Small trucks (primary vehicles) serve several transfer points (secondary facilities) from the printing office (primary facility). Vans or cars are used on secondary tours to deliver the newspapers to sale points or customers. Perl and Daskin (1985) consider a two facility layer structure in their warehouse location routing problem, but they assume the primary facilities to be fixed. They include the fixed costs of establishing a distribution center (depot location) as well as linear variable costs in order to implicitly determine the optimal number of depots. Wu et al. (2002) enhance this model by introducing a heterogeneous vehicle fleet, which is common in real-world applications. Moreover, most LRP papers deal with *capacitated location-routing problems (CLRP),* i.e. they consider capacity constraints on vehicles and depots. To the best of our knowledge, Lopes et al. (2008) present the only decision support tool for a CLRP. However, research on the LRP still has one major shortcoming from a practical viewpoint: all previously published work presents greenfield approaches, i.e. planning does not consider existing distribution networks. Disregarding established sites leads to suboptimal planning results since modifications of existing networks cause significant cost. This paper makes the following contributions:

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[2] www.microsoft.com/germany/mappoint

1. We analyze the costs incurred when an existing delivery network is restructured.
2. We describe possible reorganizational moves in a distribution network and situations in which these moves are appropriate.
3. We develop a new formulation for the location routing problem which pays attention to relocation aspects.

The remainder of this paper is structured as follows. In Section 2, we describe relocation costs and restructuring moves. We present a mathematical formulation of our relocation-oriented LRP in Section 3. Finally, we give a conclusion and an outlook over our future work in Section 4.

2 Location planning in established networks

For CEP service providers, depot locations generally result from long-term strategic decisions and are thus fixed for several years. In many real-world CEP systems, the existing network structure has never been analyzed, planned and optimized as a whole. Instead, companies adapt their current network in a stepwise manner, i.e. opening or closing one single depot, based on changes in demand. This leads to suboptimal network designs. The existing literature on LRP models used for determining the optimal depot locations is extensive. Practically all models are based on the assumption that the optimization task is to plan an entirely new delivery network, neglecting the currently established network. As a first step, Wasner and Zäpfel (2004) analyze the effects of depot closings on network efficiency in their many-to-many LRP formulation. However, they do not calculate any restructuring costs. In reality, CEP service providers cannot ignore existing networks due to the costs that occur when closing established sites. To the best of our knowledge, none of the published LRP formulations considers these closing costs, which contribute a great deal to the total costs incurred by relocation decisions.

Greenfield LRP models are inappropriate for making relocation decisions in an existing network. Clearly, we can use the optimal greenfield solution in some heuristic to support such decisions. However, this is guaranteed to lead to globally suboptimal solutions. To avoid this, relocation costs have to be considered.

In Section 2.1, we describe the relocation cost factors of a CEP service provider. Section 2.2 analyzes possible reorganizational moves in a distribution network and situations in which these moves are appropriate.

2.1 Relocation Costs

Several major CEP service providers, like UPS, operate a major part of their depots themselves and perform the delivery tours on the last mile. Therefore, transactions costs C_{trans} and establishing costs C_{estab} occur if a depot location is changed.

Transaction costs arise for:

1. Collecting information about potential buyers C_{col1}
2. Negotiating with the potential buyers C_{neg1}
3. Closing a contract with the buyer C_{deal1}
4. Collecting information about potential locations C_{col2}.
5. Negotiating with the property owner or landowner C_{neg2}.
6. Closing a contract with the owner C_{deal2}.

The costs for establishing a depot include all costs which arise when a new depot opens. Besides the construction and installation costs, delivery processes between hubs and depots have to be designed. Furthermore, training courses for the employees might be necessary.

Additionally, we have to pay attention to the opportunity costs (C_{opp}) of the location decision. For example, changing a depot location seriously influences the costs of the delivery tours as driver learning is neutralized. The drivers employed initially have no knowledge of their tours and the new delivery area. This fact leads to increased delivery costs, which have to be considered in the LRP. The total relocation costs can be stated as follows:

$$\begin{aligned} C_{relocation} &= C_{trans} + C_{estab} + C_{opp} \\ &= [c_{col1} + c_{neg1} + c_{deal1} + c_{col2} + c_{neg2} + c_{deal2}] + c_{estab} + c_{opp} \\ &= [c_{col} + c_{neg} + c_{deal}] + c_{estab} + c_{opp} \end{aligned}$$

The integration of relocation costs into a mathematical LRP model is described in Section 3.

2.2 Reorganizational Moves

As input for the reorganization of a distribution network, the current network structure, i.e. a given set of depot locations and allocated customers, is provided by the company. From there, the following reorganizational moves are possible:

1. Add: open one additional depot
2. Drop: close one existing depot
3. Shift: move one depot to a new location
4. Join: replace two (or more) depots by one new depot

We give a detailed qualitative description of each of these moves and identify situations that suggest each move. Note that the moves are not a description of a solution method. We are aware that the moves Add and Drop suffice to represent all possible moves from an algorithmic viewpoint.

Add

In general, the network design of a CEP service provider is based on expectations calculated several years ago. If the real growth in customer numbers or volume exceeds what was projected, the number of depots may not be sufficient or cost-efficient. In this case, it is reasonable to add a new depot location. We distinguish between:

- *Rural areas,* in which the distances between two arbitrary customers are usually quite large. A growing number of customers might lead to very large tour lengths, which are unprofitable, especially in the express delivery industry. Adding a new, small depot might be profitable.
- *Metropolitan areas,* which are characterized by high volumes, i.e. many customers in a small area. The average tour length is usually very short, i.e. a driver has many stops which are time-consuming. If new customer locations are beyond the tight delivery radius of the existing depots, we have to add a new depot to ensure on-time delivery. Figure 1 illustrates an example of this case.

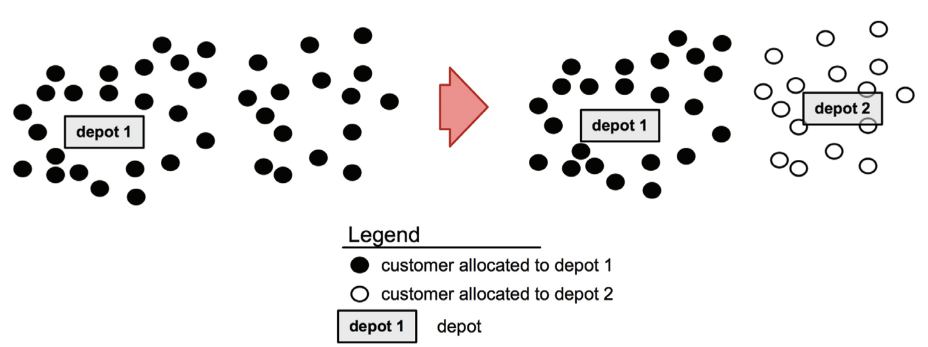

Figure 1: Add a new depot location

Drop

The growth prognosis of a company can also be too optimistic, resulting in unused depot resources. Let us consider a company that plans to expand their business into a new geographical area. In order to serve the customers there, the company opens at least one new depot with capacity suited to their expectations. If these expectations are not met, the depot location is inefficient and should be closed. An example is shown in Figure 2.

Also, the installed capacity of a depot can depend strongly on the volume of a few large customers. Once too many of them cease doing business, it might be favorable to close the depot and serve the previously allocated customers from remaining depot sites.

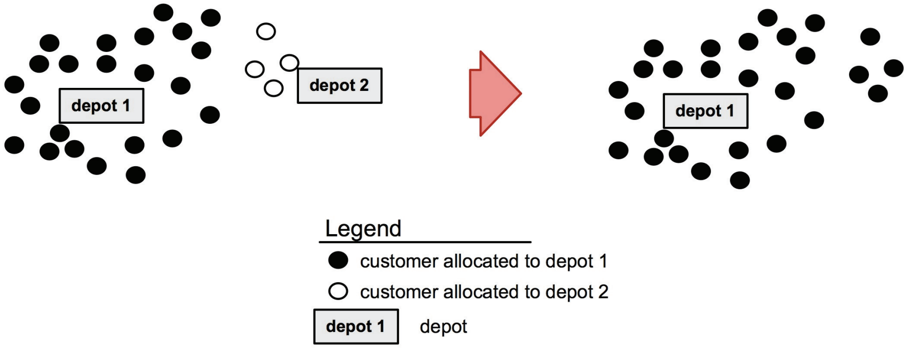

Figure 2: Drop an existing depot location

Shift

After some time, the set of allocated customers can drift away from the current depot location. Due to the fact that delivery costs account for the biggest portion of the total costs of a CEP service provider (Wasner and Zäpfel 2004), it is reasonable to close the existing depot in such a case. Instead, a new location that reduces tour lengths is opened. Figure 3 demonstrates a case in which a depot is shifted to a new and more profitable location.

Furthermore, imagine that some new customers with high daily package volumes are allocated to a certain depot. Due to the high volume, they have significant influence on the delivery costs. If the sites of these customers are not situated close to the existing depot, shifting the depot location may result in reduced total costs.

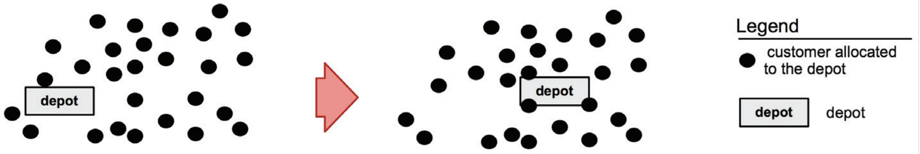

Figure 3: Move a depot to a new location

Join

Consider two depots with a low or medium utilization ratio which are additionally located close to each other. It is possible to replace them by one new depot and the two formerly independent sets of customers are joined and allocated to the new depot (see Figure 4). In this way, appropriate capacity utilization can be ensured. However, one has to trade off between lower depot operational costs and higher delivery costs due to longer delivery tours.

Moreover, consolidating depot locations always harbors the risk of not delivering on time due to larger depot-customer distances. Let us consider a customer at the farthest point of the delivery area who orders a pre-nine delivery. If the distance to this customer is too far, an exclusive trip is necessary to achieve on time delivery.

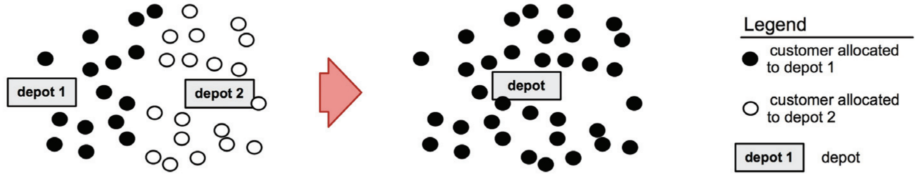

Figure 4: Join two depot locations

3 Relocation-oriented model

In this section, we present the mathematical model of our *relocation-oriented location routing problem (RLRP),* which is based on the modified WLRP of Perl and Daskin (1985). Our model simultaneously determines the optimal location of depots, the optimal allocation of customers to depots and the optimal delivery tours which account for the currently established network.

In our RLRP, we consider a network of $N+M$ nodes, N being the number of customers and M the number of potential depot sites. The distance between two nodes i and j is d_{ij}, where $i,j \in \{1,..,N+M\}$. Demand from customer i is denoted by q_i. Furthermore, we consider capacitated depots and assume that each depot may have a different size, and hence an individual maximal throughput T_j. The vehicle fleet is homogeneous with a capacity CAP. The variable delivery costs per km c_k of a tour k are proportional to the distance. K denotes the maximum number of vehicles.

Many researchers simply integrate the fixed costs of establishing a depot in their LRP formulation. In contrast, we use four types of depot costs which can vary among different locations j:

1. Fixed costs of establishing a new depot CE that combines the transaction costs c_{col2}, c_{neg2} and c_{deal2} as well as the establishing costs c_{estab}. In order to consider the current network design, we set $CE_j = 0$ for all existing depots, otherwise $CE_j \neq 0$.
2. Fixed costs of operating a depot during the planning period CO_j.
3. Fixed costs of closing an existing depot CL_j that combines transaction costs c_{col1}, c_{neg1} and c_{deal1} as well as opportunity costs c_{opp}. In order to consider the current network design, we set $CL_j \neq 0$ for all existing depots, otherwise $= 0$.
4. Variable costs of operating a depot cv_j.

The planning period is set to 3 years in order to represent a real-world strategic planning horizon of location decisions.

We use the following decision variables:

$$X_{ijk} = \begin{cases} 1 & \text{if node } j \text{ follows node } i \text{ on tour } k \\ 0 & \text{otherwise} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if customer } i \text{ is allocated to depot } j \\ 0 & \text{otherwise} \end{cases}$$

$$Z_{j} = \begin{cases} 1 & \text{if depot } j \text{ is opened} \\ 0 & \text{otherwise} \end{cases}$$

The RLRP can then be written as follows:

$$\begin{aligned} \text{Min}\, C(X,Y,Z) = & \sum_{j=N+1}^{N+M} \left[\left(CE_j + CO_j \right) \cdot Z_j + (1 - Z_j) \cdot CL_j \right] \\ & + \sum_{j=N+1}^{N+M} cv_j \cdot \left(\sum_{i=1}^{N} q_i \cdot Y_{ij} \right) \\ & + \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \sum_{k=1}^{K} c_k \cdot d_{ij} \cdot X_{ijk} \end{aligned} \tag{1}$$

Subject to:

$$\sum_{j=1}^{N+M} \sum_{k=1}^{K} X_{ijk} = 1 \ \forall i = 1, \ldots, N \tag{2}$$

$$\sum_{i=1}^{N} q_i \sum_{j=1}^{N+M} X_{ijk} \leq CAP \ \forall k = 1, \ldots, K \tag{3}$$

$$\sum_{i \in S} \sum_{j \in S} \sum_{k=1}^{K} X_{ijk} \geq 1 \ \forall (S, \bar{S}), \tag{4}$$

$$S \subset \{1, \ldots, N + M\} \wedge S \supseteq \{N + 1, \ldots, N + M\}$$

$$\sum_{i=1}^{N} \sum_{j=N+1}^{N+M} X_{ijk} \leq 1 \ \forall k = 1, \ldots, K \tag{5}$$

$$\sum_{i=1}^{N+M} X_{jik} - \sum_{i=1}^{N+M} X_{ijk} = 0 \ \forall \begin{Bmatrix} k = 1 \ldots K \\ j = 1, \ldots, N + M \end{Bmatrix} \tag{6}$$

$$\sum_{i=1}^{N} q_i Y_{ij} - T_j Z_j \leq 0 \;\; \forall j = N+1,...,N+M \tag{7}$$

$$\sum_{j=1}^{N+M} X_{ijk} + \sum_{i=1}^{N+M} X_{jik} - Y_{ij} \leq 1 \;\; \forall \left\{ \begin{array}{c} i = 1,...,N \\ j = N+1,...,N+M \\ k = 1,...,K \end{array} \right\} \tag{8}$$

$$X_{ijk} \in \{0,1\} \;\; \forall i = 1,...,N+M; \;\; j = 1,...,N+M; \;\; k = 1,...,K \tag{9}$$

$$Y_{ij} \in \{0,1\} \;\; \forall i = 1,...N; \;\; j = N+1,...,N+M \tag{10}$$

$$Z_j \in \{0,1\} \;\; \forall j = N+1,...N+M \tag{11}$$

The objective function (1) minimizes the total expenses of a CEP service provider. The first term evaluates the fixed costs which arise if a depot is established and operated in the planning period (Z_j=1) and, at the same time, the fixed costs of closing an existing depot (Z_j=0). The second term calculates the variable operating depot costs. These costs are calculated by multiplying the cost factor cv_j by the total volume of demand from all customers allocated to the corresponding depot. The last term determines variable delivery costs, which depend on the distances between the nodes and the delivery costs per km c_k.

Constraints (2) ensure that each customer is served by one vehicle, i.e. each customer is assigned to one single route. Constraints (3) restrict the total volume of a delivery tour to the vehicle capacity *CAP*. Subtour elimination constraints are presented in (4). Operating a route from multiple depots is prohibited by Constraints (5). Constraints (6) require that vehicles have to leave all nodes that have been entered previously. Constraints (7) limit the maximum throughput at a depot to *Tj*. Due to Constraints (8), the allocation of a customer *i* to a depot *j* requires an established delivery tour *k* from depot *j* through the customer *i*. Finally, Constraints (9)-(11) define the binary variables X_{ijk}, Y_{ij} and Z_j.

4 Conclusion and Outlook

Existing mathematical LRP models are not applicable to real-world problems since they consider *greenfield planning* optimization tasks. These models disregard any established structure such as depot or hub sites. In real-world applications, the closing of sites leads to high costs which have to be considered in the optimization model. Hence, including relocation aspects in the formulation as presented in our RLRP is the right approach. Our model incorporates all costs that arise if a real-world CEP service provider reorganizes its delivery network. As a result, the solution of our RLRP is able to suggest location changes. These changes happen if the costs arising from closure are amortized by savings in variable delivery costs during the planning period.

However, location changes eliminate the positive effects of driver learning. Instead of doing their regular tours, drivers have to acquire knowledge about serving new customers. It takes several weeks or months until they achieve reasonable knowledge of a new delivery area and are able to provide good service at low cost. This learning effect has a strong influence on delivery costs and should not be neglected (Zhong et al. 2007). Due to this relevance to real-world applications, we consider learning-based opportunity costs in our RLRP.

Driver learning is also a major topic in the operational route planning of KolOptNet. Since KolOptNet incorporates tour planning as well as location decisions, we have to investigate appropriate ways to trade off relocation benefits and driver losses incurred by neutralizing driver knowledge.

Furthermore, the applicability of our decision support system will be tested on the business data of a mid-sized French CEP service provider. This provider is a typical example of a CEP company with a three facility layers network. Besides hubs and depots, the CEP service provider additionally owns agencies, which are connected to the hubs and serve the depots by direct transport. In a first step, we extract the historical delivery data for the last two years from their current planning tool and import the information into our system. Second, we provide our RDSS with data from currently established depot locations and the allocation of customers to these depots. We have to select all potential depot locations in a third step, which is done with the visual support of Microsoft MapPoint. For each depot, cost factors are adjusted separately. Based on this input data, our RDSS finally calculates the optimal depot locations based on the integrated RLRP. The actions recommended by RDSS, i.e. relocation of depots and reallocation of customers to depots, are again visualized using MapPoint.

Last, investigating the applicability of relocation factors to hub location problems is another research goal in KolOptNet.

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