A Network Design Problem with Location, Inventory and Routing Decisions

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ABSTRACT

We consider the design of a supply chain network for a blood bank system to satisfy the needs of hospitals in a certain region, by integrating strategic, tactical and operational decisions. In the current blood distribution network, hospitals keep their own inventory and procure bloods from a main blood bank. We propose an alternative model, in which, some of the hospitals are selected as local blood banks (LBBs) and serve the hospitals that are assigned to them. Thus, we try to solve a complex problem which aims to find optimal number and locations of LBBs, assignment of hospitals to opened LBBs and the weekly and daily routes between the facilities. We formulate a mixed integer nonlinear programming model to combine these decisions to minimize total system cost and propose a simulated annealing heuristic approach to find near optimal solutions. We analyze the performance of the heuristic via detailed numerical studies.

CCS CONCEPTS

• **Theory of computation → Routing and network design problems**; **Network optimization**;

KEYWORDS

Facility Location, Routing, Inventory, Simulated Annealing

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1 INTRODUCTION

We aim to design a blood bank network for distribution of blood by considering facility location, inventory and vehicle routing decisions. Blood is generally collected at blood centers and blood stations spread over a region and then it is processed at the blood banks or at donation centers. Then blood banks supply hospitals within their regional area. Blood bank sends several vehicles with different routes and fulfill the demand of the hospitals. Hospitals generally keep a certain level of their own inventory of blood that might lead to overstock and stockout risks. Furthermore managing inventory and maintaining a high service level is a problem for the entire system. Thus, we suggest localization of blood banks to increase efficiency, and benefit from risk pooling advantages. In the proposed distribution network, some of the hospitals will be selected as local blood banks (LBBs) to monitor and serve the nearby hospitals. The daily demand of hospitals will be consolidated and satisfied by these local centers via daily shipments.

The framework of the blood bank distribution system is also applicable, with some modifications, to the optimization of other supply chain network design problems (SCNDPs). Our problem can be considered as a SCNDP with a goal to find the optimal number and locations of distribution centers, assignment of retailers to the distribution centers (DCs), inventory levels that at the DCs and the routes of the vehicles to supply the facilities. Even though location, inventory and routing decisions are generally analyzed separately in literature, there are various studies analyzing inventory-routing (see Moin and Salhi [3]), location-routing (e.g. Wu et. al. [4]) or location-inventory (e.g. Diabat et. al [1]) decisions simultaneously. Hiassat et. al. [2] is one of the few studies that consider location, inventory and routing decisions at the same time.

In this study, we formulate a mixed integer nonlinear programming (MINLP) model to combine the strategic (optimal number and location of distribution centers), tactical (assignment of the retailers to DCs and inventory levels in the DCs) and operational level decisions (daily and weekly transportation route decisions) for finding an optimal network design. Our study differs from the literature by combining these decisions in a complex supply chain network. Since the complex nature of the problem makes it impossible to solve medium and large sized instances, we also develop an efficient heuristic method to solve this problem.

2 MODEL

We consider a blood network distribution system in which there exists a main blood bank and N different hospitals. In the current system, each hospital keeps their own inventory and receive shipments directly from the main blood bank in a weekly basis. Our new model aims to change the current system by adding a new layer (local blood banks) in order to decrease the total system cost and increase the responsiveness of the system for blood demand. In the new system, the main blood bank acts as the supplier in the network and ships blood to local blood banks (LBBs) and then the local blood banks serve the hospitals on a daily shipment basis. The inventory will be pooled at the LBBs instead of keeping them at each hospital separately.

We develop a MINLP model to determine which hospitals should be selected as LBBs, how to allocate hospitals to LBBs, what are the

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optimal routing decisions and what are the optimal inventory levels at LBBs. We model this problem using a mixed integer nonlinear program to find the optimal number and locations of local blood banks, assignment of hospitals to the local blood banks, inventory levels at the local blood banks and routes of the vehicles which supply the local blood banks and hospitals.

3 SOLUTION METHODOLOGY

The problem in this study is a combination of location, inventory and routing problems and thus is more complex than these NP-Hard problems. Finding an exact solution to these problems in a reasonable time is seen to be very difficult in literature for medium and large sized instances. Moreover, our model has non-linear terms which make it more difficult to solve. We use GAMS/BARON solver to solve small sized instances of this problem and use simulated annealing (SA) heuristic to find good solutions to mid and large sized problem instances. We design the SA algorithm in a way that it uses four consecutive phases to find the best solution to our problem. These are Initialization, Location-Allocation, Weekly Route Improvement and Daily Route Improvement phases.

The initialization phase of our SA algorithm starts with the "Random facility open" procedure to open LBBs randomly with respect to minimum facility limitation. Then, "Allocation" procedure assigns the hospitals to opened LBBs based on shortest distances. Then, "Big Route Algorithm" and "Small Route Algorithm" construct the initial routes for weekly and daily vehicle routes, respectively. Finally, "Savings Algorithm" and "2-Opt Algorithm" are applied to weekly and daily routes to have better initial solutions.

In the location-allocation phase, first SA parameters are set and initial solution from the first phase is accepted as current and best solution. Then, initial solution is improved by searching the neighborhood solutions through different moves such as Add-Drop, Swap, Insert etc. At each iteration one of the moves are selected and applied upon the dynamic probability selection rule. Probability of the moves are close to each other at the beginning of the iterations, but probabilities change dynamically at upcoming iterations. If the selected move is applied and current solution is improved, then the probability of the move increases and vice versa. Best solution found during the iterations are recorded and becomes the input for the next phases.

In the third phase, optimal number and location of LBBs and hospital assignments are taken as inputs and "Big Route Algorithm" constructs the best weekly distribution routes from main blood bank to opened LBBs. Then, "2-Opt Algorithm" is applied until there is no more improvement in the solution. In the final phase, daily route improvements are considered. At each iteration, an insertion move is applied after the feasibility check and best daily distribution route found during the iterations is returned as the final solution.

4 COMPUTATIONAL STUDIES

For numerical experiments, we create different instances with different problem sizes. We collect and use real life data about the parameters in this problem considering the hospitals in the Asian side of Istanbul. In order to test the effectiveness of heuristic parameters, we first made test runs and the final parameter values are selected based on the results of these test runs. Moreover, current distribution system is also studied and total system costs are compared with the proposed system costs. Solutions obtained by the exact method and the heuristic algorithm are represented in Table 1. For problems with 20 or more hospitals, we applied 8 hour time limit for the exact solution method, however we could not find any feasible solution within this time.

Table 1: Test Results for the Base Case

	Exact Solution		Heuristic Solution		Current System	
Problem Size	Cost	CPU time	Cost	CPU time	Cost	% Improvement
10x10	2624.67	3240	2624.67	0.03	2865.19	8.39%
20x20	-	-	4463.09	0.21	5658.00	21.12%
50x50	-	-	14204.24	1.63	23607.73	39.83%
75x75	-	-	22846.87	7.12	39232.07	41.76%
100x100	-	-	31195.36	27.23	57446.91	45.70%

For the medium and large sized problem instances we use the heuristic method to find solutions. The costs of the current distribution network is also calculated to compare with the proposed new system. As Table 1 indicates, significant cost improvements over the current system can be achieved by using the proposed model. The improvement percentage increases as the problem size increase. Thus, we conclude that risk pooling advantage for this problem is greater than the cost disadvantage caused by the daily routing for this instance. Cost improvements change from 8.39% to 45.70%. We also do a sensitivity analysis by introducing different problem instances and observe that the proposed system is better than the current system in almost all of these instances, where the improvement percentages are seen to be up to 59.12%. Improvements are seen to increase as the number of hospitals in the system increases.

5 CONCLUSION

Supply chain network design problems traditionally have strategic, tactical and operational decision levels. In this study, we aim to integrate these three different decision levels and design a complex supply chain network for blood distribution in Istanbul. For the proposed system, we develop a mixed integer nonlinear programming model that finds optimal number and locations of LBBs, assign hospitals to open LBBs, decide safety stock levels in opened LBBs and routes weekly and daily distributions together. We use two different methods to solve our model. Firstly, we use the exact solution method by using commercial solvers like GAMS/Baron. Since exact methods can only solve the small size problem instances, we also provide a simulated annealing based heuristic to solve the model for mid and large sized problem instances. The performance of the heuristic is evaluated with computational experiments and is seen to provide improved solutions compared to the current system.

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