Performances of Heuristic Algorithms for Consolidated Transportation with Weight and Volume Constraints

Suk-Chul Rim, Nae-Heon Kim, Youngjin Yoo

Dept. of Industrial & Information Systems Eng., Ajou Univ., Suwon 442-749, Korea

Abstract

Since the transportation cost takes about two thirds of the logistics cost of Korean firms, significant reduction of business logistics cost can hardly be achieved without effectively reducing the transportation cost. Although consolidated transportation has been regarded as the most promising strategy for reducing the transportation cost, it has not been successful in practice. In this paper we consider a consolidated transportation for the factories located in a limited area such as industrial complexes, where loads of various volume and weight are consolidated. We want to group the loads to assign to a truck of various size such that the total transportation cost is minimized, while the maximum volume constraint and weight constraint of each truck are satisfied. We suggest four heuristic algorithms to efficiently determine the groups of loads; and conduct a computer simulation to evaluate the performances of the algorithms.

1. Introduction

In Korea, companies are concerned about reducing the total logistics cost as we consider logistics as the most promising area to improve the profitability. The logistics cost, however, is 12.9% of GDP that is higher than others such as Japan(8.8%), USA(7.&%), and Europe(5.8%). Especially, the transportation cost amounts to two thirds of the total logistics cost; and the trucking cost is 69.5% of the transportation cost in Korea [8].

It is reported that use of 1-ton trucks takes about 80%; and empty vehicle ratio of company-owned trucks is 49%, which is much higher than that of commercial trucks (36.4%). It seems to be due to lack of systematic consolidated transportation and distribution systems [7]. Consolidated transportation is believed to reduce the transportation cost mainly because it achieves the economy of scale.

Consolidated transportation among the manufacturers is basically a difficult task because it often requires the changes of logistics processes of the participating companies; the benefits are often ambiguous; the leading institution must have a strong leadership and credibility; many details such as rates and regulations must be established; and it will not be as flexible as using private trucks. Furthermore, participants are concerned about their confidential business data to be exposed to the competitors. One promising case is the small to medium sized factories located in a very limited area such as industrial complexes.

In this paper, we propose a consolidated transportation model; suggest four heuristic algorithms; and estimate the performances of the algorithms by using the computer simulation.

2. Problem Definition

Consider small to medium-sized manufacturers located in a geographically limited area such as industrial complexes who ship their products to their customers located around the country everyday. Shipment of large truckload is of no problem, but less-than-truckloads (LTL) cause significant costs increase.

By the end of work hours every day, the shipment requirements including item code, weight, and volume of the loads to be shipped on the next day are collected via communication network. Among many destinations, consider n loads to be shipped from the region to another region on a day, whose weight and volume are given as w_j and v_j for j=1, 2, ..., n, respectively. There are m types of trucks available whose weight capacity and volume capacity is denoted as c^w_i and c^v_i for i=1, 2, ..., m, as shown in Figure 1.

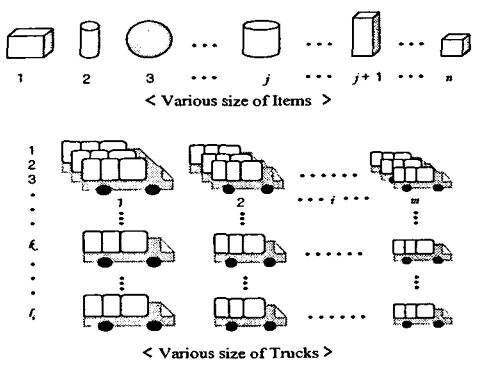

Figure 1. Illustration of the problem

Each truck of capacity t-ton costs r_t as the base fare once the truck is used for the day, regardless of the utilization. Note that base fare *per ton* is cheaper for larger truck due to the economy of scale. We consider the multiple picking and delivery, as shown in Figure 2. Let a_t denote the additional charge for each additional stop for a t-ton truck. Then, the problem is to determine the best grouping of loads to be assigned to the trucks of various size such that the total cost (which is the sum of base rate and additional charges) is minimized. That is also called multiple stop truckload or shipment consolidation. This consolidated transportation model is more economical than those which require central warehouse to collect loads. Some local transportation companies have already provided such services, but they often lack systematic operational procedures, thereby fail to lower the cost.

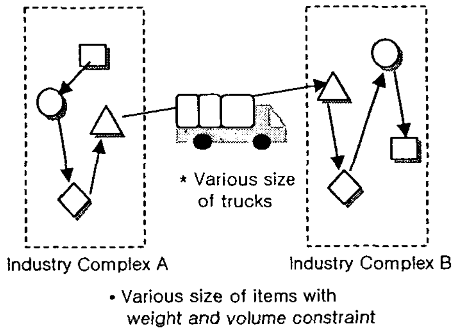

Figure 2. Consolidation model

We consider the weight and volume constraints at the same time. That is, during the grouping of loads, if either the total weight or the total volume reaches the maximum capacity of the truck, then no additional loads can be added to the group. In the following sections, we will consider four types of truck sizes (11t, 8t, 5t, 2.5t); and the maximum number of stops for each truck is limited to four places in a same region due to practical loading and unloading time requirements.

Although the problem can be formulated as an integer programming problem, we propose a few heuristic algorithms for their simplicity.

3. Literature Review

The most relevant research is proposed by Hall[5], in which several loads located at different areas are shipped between different areas that are beginning and finishing points

Pooley and Stenger[4] studied a shipment consolidation model where shippers can choose to use a mix of multiple stop truckload(TL) carriers and less-than-truckload (LTL) carriers. The authors consider five factors that may influence the performance of the shipment consolidation. Empirical demand data from two shipper companies are analyzed. Cooper[1] compared two alternative strategies, freight consolidation and decentralized deployment of inventory using a combination of facility location and dynamic simulation models. Sheffi[6] presented a general framework for examining and analyzing the freight transportation and logistics market. Carriers and shippers are viewed as suppliers and customers of transportation service, respectively. The author pointed out that the carriers and shippers face essentially the same problem of minimizing the total transportation cost and inventory cost. Jackson[2] reported the survey results from fifty three U. S. business firms regarding the eight important factors about freight consolidation. Pooley[3] presented a heuristic vehicle routing algorithm for the less-than-truckload vs. multiple-stop truckload problem. A recent report[6] provides the detailed interest conflicts among the manufacturers, truck owners, and freight agents who link freights to trucks. Although there have been many research results about consolidated transportation, the problem we defined in the previous chapter has not been studied in the literature.

4. Heuristic Algorithms

In this section, four heuristic algorithms are proposed and their performances are compared by using computer simulation.

(1) Brutal algorithm

We arrange n loads in decreasing order of weight and volume, respectively. We put the heaviest load into the largest truck up to its weight limit, during which volume constraint is only a feasibility constraint. Secondly, we put the largest load into the largest truck up to its volume limit, during which weight constraint is only a feasibility constraint. Finally we choose the better result in terms of the total cost between the two.

(2) Steepest Algorithm

Two utilization of a truck is considered; weight utilization and volume utilization. Steepest algorithm is that we select as the next load the one which improves the weight utilization or volume utilization whichever is larger.

(3) Dominance-based Algorithm

Loads are grouped into two disjoint groups, namely, weight dominating group and volume dominating group, defined as follows: for the truck type i. a load j is called "weight dominating" if

$$w_j / c^w_i > v_j / c^v_i \qquad (1)$$

otherwise it is called "volume dominating". Loads in the weight(volume)-dominating group are arranged in non-increasing order of weight(volume). At first the largest load in either group is selected and assigned to the largest available truck of type i. If the ratio of remaining weight capacity to c^w_i is greater (smaller) than the ratio of remaining volume capacity to c^v_i, then the heaviest (largest) among the remaining weight (volume) dominating loads is assigned to the truck. If the selected load exceeds the remaining capacity, then the next largest load in the same group is examined until a feasible one is selected.

(4) Density based Algorithm

Let d_{ij} denote the "density" of load j when assigned to a truck of type i. as defined in (2):

$$d_{ij} = \frac{w_j / c^w_i}{v_j / c^v_i} \qquad (2)$$

If the current weight utilization is lower (greater) than the current volume utilization, then the load with largest (smallest) density is assigned to the truck, as long as the weight and volume constraint permits.

5. Computer Simulation

In order to compare the performance of the four heuristic algorithms defined in the previous section, we conduct computer simulation. We assume that weight and volume of the loads follow uniform distribution between 0.5 ton and 10 ton; and between $1.5m^3$ to $32m^3$, respectively. Fifty loads a day is simulated for 90 days. To reflect the current law, loading up to 110% of the weight capacity is allowed to all types of truck. For each type of truck, parameters including volume constraints, regular and additional fare are summarized in Table 1.

Table 1. Cost parameters for each truck type

weight capacity	volume capacity	base fare	charge for additional stops
11t	36 m^3	₩ 320,000	₩ 40,000
8t	32 m^3	₩ 280,000	₩ 35,000
5t	15 m^3	₩ 240,000	₩ 30,000
2.5t	10 m^3	₩ 210,000	₩ 25,000

Simulation results indicate that, compared with the individual transportation. the total cost is reduced by as much as 32.5% using the proposed Dominance heuristic; reduction of 27.2% achieved by Brutal heuristic is the lowest improvement, as shown in Figure 3. Note that, the two leftmost columns of Figure 3 indicate the reduction of total cost in relaxed problems where only weight and volume constraint is considered, respectively. Figure 4 shows the average improvement of weight and volume utilization for each algorithm compared to the case of assigning each load to the most efficient truck type.

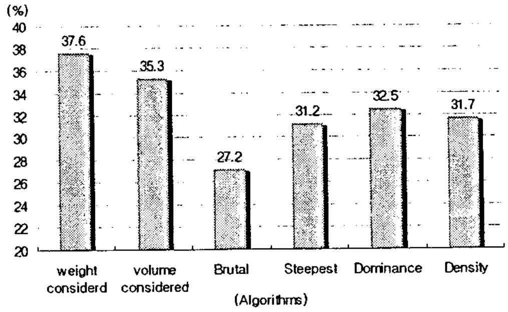

Figure 3. Reduction of the total cost

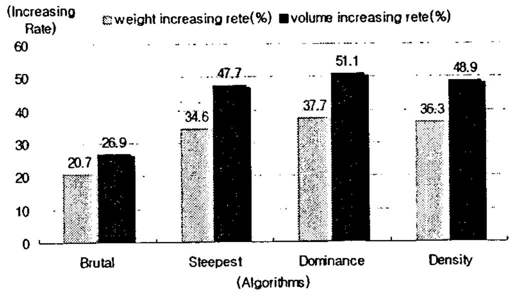

Figure 4. Increasing rate of utilization

Average number of loads assigned to each truck for each heuristic algorithms is shown in Figure 5. Note that most trucks are assigned of at most two loads which is acceptable in practice. It is noteworthy that the most efficient algorithm (dominance rule) has the largest portion of two loads.

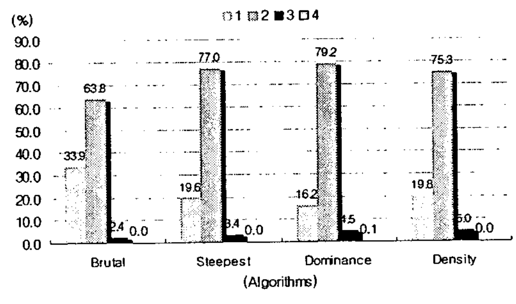

Figure 5. Average stop ratio per day

Out of ninety day simulation, the lowest cost is achieved by Dominance rule (70.1%), Density rule (26.7%), and Steepest rule (20%). Note that the sum exceeds 100% because there are many ties. Figure 6 shows the changes of total cost for ninety days.

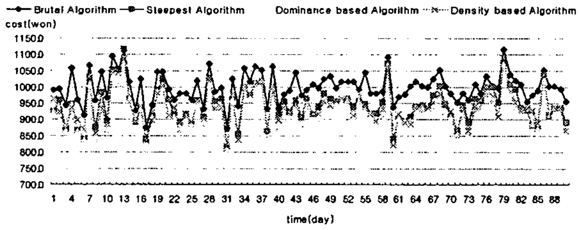

Figure 6. Variation of the total cost over 90 days

6. Summary and Conclusions

In this paper, we address a practical problem of consolidating loads for minimizing the total cost. Since trucks have limited weight and volume capacity, assigning a group of loads to a truck must meet both constraints. We present four heuristic algorithms to determine which group of loads to be shipped by which type of truck. The objective function is to minimize the total cost, which is the sum of base fares of the trucks used and additional stopping charges proportional to the number of loads assigned to the trucks.

Simulation results show that the total cost can be saved by 27% to 32% compared to the individual transportation. Among the four proposed algorithms, dominance-based one yields the largest improvement. Such heuristics can be used at the consolidation station for practical operations of daily decision making.

References

[1] Cooper, M., "Freight Consolidation and Warehouse Location Strategies in Physical Distribution System", Journal of Business Logistics, Vol.4, No2, pp.53-74 (1983)

[2] Jackson, G. C., A Survey of Freight Consolidation Practices , Journal of Business Logistics, Vol.6, No.1, pp.13-34 (1985)

[3] Pooley, J, A Vehicle Routing Algorithm for the Less-Than-Truckload vs. Multiple-Stop Truckload Problem , Journal of Business Logistics, Vol.13, No.1, pp.239-258 (1992)

[4] Pooley, J. and Stenger, A., "Modeling and Evaluating Shipment Consolidation in A Logistics System", Journal of Business Logistics, Vol.13, No.2, pp.153-175 (1992)

[5] Randolph W. Hall, Consolidation Strategy: Inventory, Vehicles and Terminals , Journal of Business Logistics, Vol.8, No.2, pp.57-73 (1987)

[6] Sheffi, Y., "Carrier/Shipper Interactions in the Transportation Market: An Analytic Framework", Journal of Business Logistics, Vol.7, No.1 (1986)

[7] "Competitiveness Enhancement of Traditional Industry using EC", Korea Information Society Development Institute, Report #99 (December 1999)

[8] "Status Report on Business Logistics Management in Korea", Korea Chamber of Commerce (1999)