A Practical Heuristic for Economic Truck Selection: A Case Study of Paper Wholesaler in Bangkok

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Abstract

This article outlines a practical heuristic for selecting trucks and allocating customer orders for daily paper distribution in Bangkok. A binary linear program was first developed. The objective function was to minimize the total rental cost subject to daily customer orders and truck capacities. Solving the model could give truck selection and order assignment for each truck simultaneously. Nevertheless, solving the proposed model was not practical because the computation runtime was too long. Thus, a practical heuristic was then proposed and used to obtain a truck selection/order assignment plan. A numerical example modified from a real-world case was used to demonstrate the mechanism of the proposed heuristic. Finally, its performance was evaluated by numerical simulations.

Keywords: Logistics Problem; Binary Linear Programming; Heuristic; Numerical Simulations.

1. Introduction

This paper revisits a case study presented in Monthatipkul [1]. The author proposed a method to determine the most appropriate approximate location of the 2nd distribution center for a paper distributor in Bangkok. By using the same case, this paper focuses on another main concern of the paper distributor. It is truck selection and order assignment planning in each day so as to minimize the distribution cost subject to all concerned constraints. The necessary background of the case study is explained in Monthatipkul [1]. The current paper will start by summarizing all necessary conditions related to the present study.

The company in the case study buys many types of papers from many suppliers and distributes its products to customers using trucks from 3rd party service providers. Currently, the company has about 1,000 customers (such as printing, retailers, and copier centers, etc.) whose shops are dispersed throughout Bangkok. The annual sale volume reaches roughly 50 million kilograms of papers. Figure 1 as first displayed in Monthatipkul [1] is redisplayed to show the coverage area of customers (represented by the square). The company distribution center is at the southern part of Bangkok. Four dots in Figure 1 show the farthest customer in each direction. Daily, the company receives customer orders by phones and has a cut-off time at 4 p.m. The planner needs to prepare a truck schedule and finish all pre-loading jobs including document preparation before 7 p.m. The trucks are physically loaded the next morning. They must depart from the distribution center before 8.30 a.m. and make a round trip with

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approximate 5 - 15 drops. The trucks must return to the distribution center in order to finish their jobs. It is also possible for some trucks to make the 2nd round trip in some days, but this event rarely occurs.

A main concern of the company is to decrease the total distribution cost in each day. Thus, the planner needs to select the most appropriate trucks by considering their rental prices and capacities such that all customer orders can be delivered with the lowest cost. This paper proposes a practical heuristic to determine the truck selection/order assignment plan so as to minimize the total rental cost in each day.

Fig.1. The coverage area of customers [1].

To simplify the analysis without loss of generality, the following concepts and assumptions are made:

- The case study uses all trucks from 3rd party service providers and pays for those services on a daily basis. The daily rental price is fixed and mainly based on the type of the truck and its capacity. The transportation distance for those daily services is limited to 200 kilometers. The driver and fuel costs are already included.
- The case study uses area zoning to divide its customers into several groups. Trucks must be selected on the basis of zoning. Transportation across zones by one truck is not allowed because of the distance limitation issue.
- There are normally 20-50 orders per day per zone. All of them must be fulfilled. Each order cannot be separated and a single sales unit of papers (package or unit) is deployed.
- Each customer order is always less than the truck capacity. The customer order which is more than the truck capacity is very rare and will be ignored.

2. Literature Review

The concerned problem can be considered as a subset of the general Bin Packing (BP) problem. The original BP problem can be stated as determination of the minimum number of bins which can be used for packing different volumes of all given objects. The mathematical representation of the original problem can be stated as follows, [2].

minimize $bin = \Sigma_t \, T_t$ (1)

subject to

$\Sigma_t \, K_{tk} = 1$ for all k (2)

$\Sigma_k \, s_k \, K_{tk} \leq V_t$ for all t (3)

T_t, K_{tk} are binary (4)

where t is the bin index, T_t is a binary variable representing if bin t is selected or not, k is the object index, K_{tk} is also a binary variable representing if object k is packed into bin t or not, s_k is the size (volume) of object k, and V_t is the volume of bin t.

So far, there have been many variations of the BP problem such as 2-dimensional or 3-dimensinal Bin Packing, Bin Packing by weight, Bin Packing by cost, etc. And its applications [3, 4] have existed in many areas, for example, filling up containers, loading trucks with weight capacity constraints, etc. Also, it has been well-known that this problem class belongs to the NP-hard problem. Many heuristics and algorithms have been developed, for example, the First Fit algorithm [5], the FFD bin-packing algorithm [6], etc. Xia, B. and

Tan, Z. [7] further investigated the tighter bounds of the First Fit algorithm for the Bin Packing problem. Lewis, R. [8] proposed a general-purpose hill-climbing method to solve a Bin Packing problem of a case study. Various interesting approximate algorithms can also be seen in [9, 10, 11].

This paper has applied the main idea of the BP problem to a particular truck selection problem of a paper distributor in Bangkok. The main contribution is to propose an efficient heuristic which can be practically used in the case study.

3. Problem Description

The following notations are used to describe the main problem of the case study.

Notation:

i customer index (i = 1, 2, 3, …, I)
j truck index (j = 1, 2, 3, …, J)
O_i order of customer i (unit)
P_j daily rental price of truck j (baht/day)
C_j capacity of truck j (unit)
M a large positive number

Main decision variables:

X_{ij} a binary number representing if order i is selected to truck j or not (if order i is selected to truck j, $X_{ij} = 1$, otherwise $X_{ij} = 0$)
Y_j a binary number representing if truck j is selected or not (if truck j is selected, $Y_j = 1$, otherwise $Y_j = 0$)

The objective function is expressed as (5).

minimize *total rental cost* $= \Sigma_j P_j Y_j$ (5)

subject to

$\Sigma_j X_{ij} = 1$ for all i (6)

$\Sigma_i O_i X_{ij} \leq C_j$ for all j (7)

$\Sigma_i X_{ij} \leq M Y_j$ for all j (8)

$X_{ij}, Y_j \geq 0$ for all i, j (9)

X_{ij}, Y_j are binary (10)

The above problem can be stated as "For each customer zone, determine X_{ij} and Y_j so as to minimize the total rental cost per day subject to truck capacities and fulfillment of all orders." Equation (5) is the total rental cost per day. It is the sum of prices of all trucks which are selected. Equation (6) forces all orders to be fulfilled and delivered by only one truck. The partial shipment is not allowed. Constraint (7) is to ensure that each truck capacity is not violated. Constraint (8) is the Big-M constraint. It is to ensure that truck j will be selected ($Y_j = 1$) if there are customer orders assigned to it ($\Sigma_i X_{ij} > 0$ for truck j). If there are not customer orders assigned to truck j ($\Sigma_i X_{ij} = 0$ for truck j), truck j will not be selected automatically ($Y_j = 0$). Constraint (9) is the non-negativity constraint. Constraint (10) states that all decision variables must be binary.

4. Solution Approach

Solving the binary linear program as presented in Section 3 will give a truck selection/order assignment plan for all customer orders. However, solving the model is not practical since it takes much time (a non-polynomial problem). To confirm the impractical issue, some numerical experiments were conducted. Fifty customer orders were randomly generated. Four different types of truck were defined and all necessary parameters were assumed. By using the Microsoft Excel Solver, it was found that the computational runtime was always over 1 hour. Those time periods are not practical for daily truck selection/order assignment planning because the determination of such a plan must be completed within a reasonable time period. Thus, there is a need to develop a heuristic algorithm which can give the solution within a short period of time. The following details present a proposed heuristic algorithm.

The proposed heuristic algorithm

Step 1 Prepare a list of all orders and determine the total quantity of all orders (the total quantity $= \Sigma_i O_i$)

Step 2 Determine all possible solutions (alternatives) by finding all possible combinations among the truck capacities.

Step 3 Determine the daily rental price for each alternative in step 2.

Step 4 Sort all alternatives from the lowest rental cost to the highest rental cost.

Step 5 Select the cheapest alternative which has sufficient capacity for all orders first.

Step 6 Select truck j which has the maximum capacity in the selected alternative first. Then, use the following mathematical model to assign orders to the selected truck. Delete all assigned orders from the order list.

The mathematical model to assign orders to truck j

For each truck j, determine X_{ij} for all i by

maximize $volume = \Sigma_i O_i X_{ij}$ (11)

subject to

$\Sigma_i O_i X_{ij} \leq C_j$ (12)

$X_{ij} \geq 0$ for all i (13)

X_{ij} is binary (14)

Step 7 Select the next truck in the selected alternative and repeat solving the proposed mathematical model in Step 6 until all orders are assigned.

Step 8 If all orders cannot be assigned to the selected alternative (an infeasible solution), select the next cheapest alternative in Step 4 and repeat Steps 5, 6 and 7 until a feasible alternative is found.

5. Numerical Example

This section contains a numerical example to demonstrate the mechanism of the proposed algorithm. Tables 1 and 2 present all given parameters used in the example. There are 20 customer orders (I = 20) whose quantities are uniformly distributed between 20 to 120 units. There are four types of truck (J = 4). Their daily rental prices and capacities are displayed in Table 1. Table 3 demonstrates the proposed algorithm mechanism and the solution of the example. The step-by-step explanation of using the algorithm is presented subsequently**.**

Table1. Given parameters to demonstrate the heuristic algorithm.

Parameters	Values
I	20 (20 customer orders)
J	4 (4 types of truck)
O_i	Uniform from 20 to 120 (unit)
P_j	$P_{j=1}$ = 700, $P_{j=2}$ = 200, $P_{j=3}$= 140, $P_{j=4}$ = 1000
C_j	$C_{j=1}$ = 705, $C_{j=2}$ = 202, $C_{j=3}$= 150, $C_{j=4}$ = 980
M	10,000

Table 2. Example of Customer orders.

Parameters	Values (I = 20)			
O_i	54	57	89	55
	52	90	42	120
	91	117	55	54
	112	40	115	25
	111	71	65	129

The step-by-step explanation

Step 1 Table 3 shows the list of all orders vertically and the total amount is 1320 units.

Step 2 Determination of all possible solutions (alternatives) is presented in Table 4. For this example, there are four types of truck. Thus, all combinations among the truck capacities are 15 as shown in Table 4.

Step 3 The daily rental price of each alternative is then determined (summation of all truck prices in each alternative) and presented in Table 4.

Step 4 Sorting all alternatives from the cheapest one to the most expensive one is shown in the last column of Table 4.

Step 5 The cheapest alternative which has sufficient capacity for all orders (1320 unit) is the alternative 14. It has the total capacity of 1332 units and its price is 1340.

Step 6 The truck j = 4 is then selected because it has the maximum capacity among all trucks in the alternative

14. Then the mathematical model is applied to assign orders to the selected truck. The results are shown in Table 3. The total amount of orders assigned to truck j = 4 is 973 which is less than the truck capacity itself. All assigned orders are deleted from the order list.

Step 7 The truck j = 2 is selected next. Solving the mathematical model in Step 6 is repeated to further assign the remaining orders to the new truck. Finally, the last truck (j = 3) is selected and all remaining orders are assigned. The final solution is presented in Table 3.

Table3. Demonstration of the proposed algorithm mechanism to obtain the truck selection plan.

Customer (i)	Orders (Unit)	X_{ij}				$\Sigma_j X_{ij}$ Equation (6)
		j=1	j=2	j=3	j=4	
1	44				1	1
2	47				1	1
3	79		1			1
4	45				1	1
5	42		1			1
6	80		1			1
7	32			1		1
8	98				1	1
9	81				1	1
10	107				1	1
11	45				1	1
12	44			1		1
13	102				1	1
14	30				1	1
15	105				1	1
16	15			1		1
17	99				1	1
18	61				1	1
19	55			1		1
20	109				1	1
		Y_j				Total Price 1340
		0	1	1	1	
Total	1320	0	201	146	973	
Truck Capacity (Unit)		705	202	150	980	
Truck Price (Baht)		700	200	140	1000	

Table4. All possible alternatives (The proposed algorithm: Step 2).

Alternative	Truck				Total Capacity	Total Price	Sorting
	j=1	*j*=2	*j*=3	*j*=4			
Cases of only one truck in each alternative (there are four alternatives)							
1	Yes				705	700	4
2		Yes			202	200	2
3			Yes		150	140	1
4				Yes	980	1000	7
Cases of only two trucks in each alternative (there are six alternatives)							
5	Yes	Yes			907	900	6
6	Yes		Yes		855	840	5
7	Yes			Yes	1685	1700	12
8		Yes	Yes		352	340	3
9		Yes		Yes	1182	1200	10
10			Yes	Yes	1130	1140	9
Cases of only three trucks in each alternative (there are four alternatives)							
11	Yes	Yes	Yes		1057	1040	8
12	Yes	Yes		Yes	1887	1900	14
13	Yes		Yes	Yes	1835	1840	13
14		Yes	Yes	Yes	1332	1340	11
Case of four trucks in each alternative (there is only one alternative)							
15	Yes	Yes	Yes	Yes	2037	2040	15

Step 8 The alternative 14 is a feasible solution. Thus, the algorithm stops. The truck selection plan is concluded as shown in Table 3.

6. Numerical Simulations

To evaluate the effectiveness of the proposed algorithm, numerical simulations were conducted using the Microsoft Visual Basic 6.0 and the Microsoft Excel Solver 2013, run on a Dell Inspiron N5110. The results of the simulation run were compared against the optimal solutions obtained from solving the binary linear program. Simulations were run daily, and in each day ten customer orders were generated according to historical data, which was represented by a statistical distribution function. Four types of trucks as presented in Section 5 were reused. It was noted that all parameters were set in a similar way to those presented in Section 5 except for the number of orders. It was decreased from 20 to 10 due to the computation runtime issue. The simulations were run for 1000 days. The daily total rental costs (DRC) were recorded. They were then compared to the optimal solutions. %GAPs were calculated and the average value was presented in Table 5. It was noted that %GAP was equal to $\{100 \times (DRC_{optimal} - DRC_{algorithm}) / DRC_{optimal}\}$. Table 5 shows that the algorithm was able to give solutions equivalent to the optimal solutions based on the numerical experiments.

Table 5. Results from the numerical simulations.

	Average of %GAP
Daily rental cost	0.00%

In order to verify the practical use of the proposed algorithm, various sets of the problem were designed, 1000 simulations were run, and results were recorded and shown in Table 6. Customer order O_i, daily rental price P_j, and truck capacity C_j were generated by using the uniform distribution function. $O_i \sim U(10,120)$, $P_j \sim U(200,1000)$, and $C_j = P_j \pm diff$, where $diff \sim U(0,10)$. From Table 6, it was shown that the proposed algorithm was really practical since it took less time.

Table6. Computation runtime of the algorithm.

Truck (*J*)	Average computation runtime (second)				
	I=10	*I*=20	*I*=30	*I*=40	*I*=50
4	2.5	3.5	4.5	NA	NA
6	4.1	5.1	6.1	7.1	NA
8	10.5	11.5	12.5	13.5	14.5
10	36.1	37.1	38.1	39.1	40.1

7. Summary

This paper addresses a general order-assignment problem of a paper distributor in Bangkok. The daily order assignment and truck selection are considered simultaneously. First, a binary linear program is formulated. It aims to minimize the total daily rental price of all trucks subject to truck capacities and order fulfillment completeness. A heuristic algorithm applying the optimization technique is then proposed and its mechanism is also presented. To guarantee the effectiveness of the proposed algorithm, numerical experiments have been conducted.

Since truck selection/order assignment planning in this paper is performed based on the zone-by-zone concept, the proposed method must be repeatedly used until all customer zones are considered. This assumption is reasonable because the total distance of each truck can be within 200 kilometers due to suitable size (not too large) of each customer zone. Thus, routing of each truck can be excluded from the model and determined afterward by solving the original Travelling Salesperson Problem (TSP).

From the proposed algorithm, Step 2, it is noted that the planner must determine all possible combinations among truck capacities. Even though this task is cumbersome due to an increasing number of trucks, it is still practical because it is done infrequently. It will be repeated only if a new truck is provided.

Since the decisions to select trucks and to assign orders for trucks are quite general tasks in transportation management, an appropriate practical method is very necessary. This paper presents a proposed method for this general problem. Nevertheless, it can be further studied in several ways as follows:

- The time window can be considered, if some orders must be transported due to time sensitivity.
- Other types of truck capacities, weights for instance, can be further embedded to the model. This extension can change the problem into a more-than-one dimensional order assignment problem.
- Since it is assumed that a shipment of each truck must be within one customer zone only, a further study should investigate if a shipment across customer zones will be beneficial or not. To do this, a new version of the binary linear program considering the distance constraint and routing must be formulated.

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9. References

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