

Product Distribution Optimization in Food SMEs with Integer Linear Programming

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Abstract. Efficient product distribution is a key driver of the overall profitability of a company. The high cost of product distribution in food SMEs is caused by the absence of a proper distribution cost calculation to obtain optimal distribution decisions. This research aims to provide SMEs with a product distribution model with the lowest cost. A Heterogenous Fleet Vehicle Routing Problem (HVRP) for SMEs product distribution is modeled in the form of Integer Linear Programming and solved using branch-and-bound algorithm to obtain an optimal route and vehicle assignment with the lowest cost. The result of this research is a model that can be used by SMEs to make daily product distribution decision.

1 Introduction

Small Medium Enterprises (SMEs) is the largest business actor in Indonesia. SMEs contribute about 60% of Gross Domestic Product (GDP) and absorb 96,99% of the total workforce [1]. The competitiveness of Indonesian food SMEs is still low compared to other ASEAN countries. The increase of product price due to the distribution in Indonesia is 15% which is much higher compared to the average 7% increase in ASEAN [2]. Distribution is a major driver of the overall profitability of a company because it directly affects supply chain costs and customer experience. SMEs as the largest business actor in Indonesia requires a proper calculation of optimal distribution costs to improve competitiveness.

2 Literature Review

Logistics is defined as the full process of materials and products movement into, within, and out of a business [3]. Distribution management refers to the physical flow and product storage from the final production point to the customer or end user [4]. Distribution management can be divided into three levels of decision planning: distribution network design, distribution network planning, and transportation planning [5]. Transportation planning involves short-term distribution operations planning and related to delivery planning to different customers. The general decision in transportation planning is to find the shortest route, time, and minimum cost [6].

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Vehicle routing problem (VRP) aims to obtain routes for homogeneous vehicles to fulfill the demand of customers. Each customer is visited only once by one vehicle, each vehicle route begins and finishes at the depot [7]. Heterogeneous Fleet Vehicle Routing Problem (HVRP) is a type of VRP in which the vehicle is characterized by different capacities and costs [8]. Previous studies on HVRP aims to minimize the logistics cost that includes the manufacturing capacity and driver work time using branch-and-bound algorithm [9].

Integer linear programming is a mathematical programming problem where a linear objective function is optimized while satisfying a linear constraint and decision variables are integer values. Branch-and-bound (B & B) is a method where a branching and pruning process is used to solve sub-problems in ILP. Upper and lower bound is tightened progressively to the objective value of ILP [10].

3 Problem Formulation

SMEs have different types and number of vehicles, some of them have only one type of vehicles and others have more than one type of vehicles. Graphic $G = (V, A)$ is given, where $V = \{0, 1, \dots, n\}$ is a set of node n and A is set of arc. Node 1 represents the factory and node set $V' = V \setminus \{1\}$ represents n customers. Every customer $i \in V'$ demands a certain amount of product Q_i from the factory ($Q_0 = 0$). Heterogeneous vehicles are stationed in the factory and used to deliver the products to customers. Vehicles consist of different vehicle type m , with $M = \{1, \dots, k\}$. For each vehicle type $k \in M$, the vehicle has a capacity of Q_k . Each type of vehicle has a fixed cost F_k of vehicle depreciation and driver wage. For each arc $(i, j) \in A$ and for each vehicle type $k \in M$, routing cost C_{ijk} is given. Routing cost is calculated by multiplying vehicle variable cost C_k with the distance traveled. The vehicle variable cost consists of fuel cost and vehicle maintenance cost. The route is defined as (R, k) , where the route is a circuit in G that contains the factory and k is a type of vehicle that is used in the route. R represents the visiting sequence and a set of customers (including factory) in the route. Route (R, k) is feasible if the total customer demand does not exceed capacity Q_k . Distribution cost is the sum of arc sets that build the route and the total cost of vehicles used in the route. HVRP aims to create a feasible set of routes with minimum distribution cost where every customer is visited in a route and a route is assigned for one vehicle k .

4 Mathematical Model

$$\text{Min } \sum_{k \in M} F_k \sum_{j \in V'} X_{0jk} + \sum_{k \in M} \sum_{\substack{(i,j) \in V \\ i \neq j}} c_{ijk} \cdot X_{ijk} \quad (1)$$

$$\sum_{k \in M} \sum_{j \in V} X_{ijk} = 1, \forall i \in V' \quad (2)$$

$$\sum_{k \in M} \sum_{i \in V} X_{ijk} = 1, \forall j \in V' \quad (3)$$

$$\sum_{\substack{(i,j) \in V \\ i \neq j}} q_i \cdot X_{ijk} \leq Q_k \cdot X_{0jk}, \forall k \in M \quad (4)$$

$$\sum_{i \in V} X_{ipk} - \sum_{j \in V} X_{pjk} = 0, \forall p \in V', \forall k \in M \quad (5)$$

$$y_{ik} - y_{jk} + Q_k \cdot X_{ijk} \leq Q_k - q_j, \forall i, j \in V', i \neq j, \forall k \in M \quad (6)$$

$$q_i \leq y_{ik} \leq Q_k, \forall i \in V', \forall k \in M \quad (71)$$

$$C_{ijk} = D_{ij} \cdot C_k, \forall i, j \in V, i \neq j, \forall k \in M \quad (82)$$

$$y_{ij} \geq 0, \forall i, j \in V, i \neq j \quad (93)$$

$$C_{ijk} \geq 0, \forall i, j \in V, i \neq j, \forall k \in M \quad (104)$$

$$X_{ijk} \in \{0, 1\}, \forall i, j \in V, i \neq j, \forall k \in M \quad (11)$$

$$X_{ojk} \in \{0, 1\}, \forall k \in M \quad (12)$$

This model have an objective to minimize the total distribution cost that consist of vehicle k fixed cost and routing cost. Constraint (2) and (3) ensure that every customer is visited exactly once. Constraint (4) ensure that the total customer demand distributed by vehicle k in one route that does not exceed the capacity of vehicle k that is assigned in the route. Constraint (5) ensure that a vehicle enters and leaves a customer. Constraint (6) and (7) ensure that there is no subroutine formed in the route. Constraint (8) calculates the routing cost based on the distance travelled and vehicle variable cost. Constraint (9) – (12) is the integrality and non-negative restriction towards the variable.

5 Implementation

The mathematical model is modeled with Lingo 11 with a branch-and-bound algorithm to obtain the product distribution decision with the lowest cost for food SMEs. This model is verified because it succeeds to run without error and generated the desired outcome. This model is validated by comparing the outcome of Lingo and manual calculation.

Data needed for the model are customers and factory addresses, customer demands, drivers wages, vehicle maintenance costs, and vehicle characteristics (type, capacity, amount, initial cost, fuel consumption). The addresses are used as an input to generate the coordinates for obtaining distances between locations with Bing Maps embedded in Ms. Excel VBA. In this model, the fixed costs used are drivers wages and vehicle depreciation costs calculated with straight line depreciation. The variable costs used are fuel costs and vehicle maintenance costs.

This model is implemented in 5 food SMEs in Indonesia. VB SME distributes burgers to 6 customers, J distributes biscuits to 7 customers, S and KGG distributes potato chips to 6 customers each, and MK distributes noodles to 14 customers. Vehicle information in each SMEs are presented in Table 1.

Table 1. Vehicle information in each SMEs

SME	VB		J	S	MK	KGG
Type	Motorcycle	Pick-up	Pick-up	Motorcycle	Motorcycle	Motorcycle
Amount	1	1	1	2	3	2
Capacity	250	2100	2500	50	90	50
Fixed cost (Rp)	131,393	226,712	196,233	114,110	140,088	128,196
Variable cost (Rp)	124	387	402	124	122	124

6 Results and Discussion

Food SMEs in this research differs in product, vehicle characteristics, and customer. The product distribution in these SMEs has been optimized and the total distance, route, vehicle assignment with the lowest distribution cost is generated from the model. The distribution decision result for each SMEs are presented in Table 2. The route and vehicle assignment result for MK SME is shown in Figure 1.

Market fluctuation will affect food SMEs daily product distribution activities. Scenarios with a different number of customers and demands are implemented in each SMEs. The scenarios are: (1) if the number of customers increased by 50%, (2) if the number of customers decreased by 50%, (3) if demand increased by 50%, (4) if demand decreased by 50%, (5) if the number of customers and demand increased by 50%, (6) if the number of customers and demand decreased by 50%, (7) if the number of customers increased by 50% and demand decreased by 50%, and (8) if the number of customers decreased by 50% and demand increased by 50%. The results showed that a change in customer amount and demand would change the product distribution decision with the lowest cost.

Table 2. Model implementation result for each SMEs

SMEs	Distance (km)	Distribution Cost (Rp)	Vehicle used	
			Type	Amount
VB	169.91	Rp 387,539	Motorcycle	1
			Pick-up	1
J	195.67	Rp 302,435	Pick-up	1
S	64.69	Rp 236,241	Motorcycle	2
MK	81.28	Rp 430,342	Motorcycle	3
KGG	144.21	Rp 274,274	Motorcycle	2

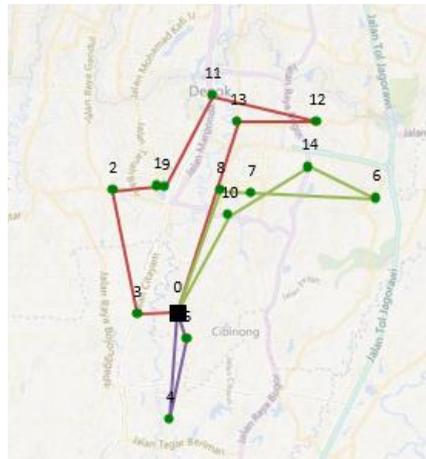


Fig. 1. Visualization of MK SME distribution decisions

7 Conclusion

In this research, food SMEs product distribution is formulated as a heterogeneous fleet vehicle routing problem in the form of integer linear programming. Product distribution optimization is implemented in 5 food SMEs in Indonesia and distribution decisions regarding the routing and vehicle assignment with the lowest cost were obtained. A distribution cost calculation tool is developed and could be used by food SMEs for daily product distribution decisions in the future.

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