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An Optimization Model for Cold Chain Food Distribution

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A B S T R A C T

Food product has a characteristic of continuous quality deterioration until the food is consumed. Cold chain distribution can improve the sustainability of the product quality but requires a more significant investment for storage facilities and vehicles as well as higher operation cost to control the temperature. This research focuses on a distribution problem faced by an ice cream distributor. In this paper, we developed a mixed-integer non-linear programming model to minimize the total cost, which consists of fixed cost, transportation cost of the vehicles, energy cost to keep the cold storage temperature, and inventory cost. The model considers the vehicle characteristics and hard time-windows for the distributor and all the stores. The implementation of this model demonstrates that the proposed route is able to reduce the total cost.

Keywords: Frozen food, Cold chain, Perishable, Distribution, Integer programming, Time-windows.

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1. Introduction

The competition has imposed pressure on product and service providers to emphasize short delivery lead times, flexibility, low cost, and high quality [1]. Food product distribution differs from other types of products. Food product has a characteristic of continuous quality deterioration until the food is consumed [2]. Physical, chemical, and biological factors cause deterioration which happen along the food supply chain. This deterioration affects the quality and safety of the product, reduces the lifecycle of the product, and changes the product appearance. We already know that keeping the right temperature of the storage throughout the supply chain will help to reduce the quality deterioration and increases the food product lifecycle. Therefore, temperature control is one of the critical factors in food product distribution. With relation to temperature

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control, Akkerman et al. [2] identified three types of food supply chains: frozen, chilled, and ambient. The frozen chain commonly operates at -18 °C, although several products like ice cream require an even lower temperature. For the chilled chain, the temperature ranges from 0 °C for fresh fish to 15 °C for potatoes and bananas. Finally, ambient chain concerns products that do not require temperature control.

Jackson et al. [3] mentioned that on average, European customer grocery bag contains more than 60% of frozen food. One of the critical factors in the chilled and frozen foods distribution is the time and temperature control, which leads to the need for cold chain management [4-7]. According to Bogataj et al. [8], the Cold Chain Management (CCM) is defined as "the process of planning, implementing and controlling efficient, effective flow and storage of perishable goods, related services and information from one or more points of origin to the points of production, and distribution and consumption in order to meet customers' requirements on a worldwide scale". An ability to implement a complete cold chain can generate significant time and cost saving for commercial companies [9]. Some researchers who have also discussed the studies related to cold chain can be found in [10] and [11]. Ndraha et al. [10] reviewed temperature abuse in food cold chains that operate in different countries. While, Zhao et al. [11] investigated the present situation of the cold chain in China.

Distribution planning is the main activity in CCM. The complexity of this activity increases because services have to serve the expected food quality within an acceptable time-windows [12]. Cold chain distribution can improve the sustainability of the product quality but requires more significant investment for storage facilities and vehicles as well as higher operation cost to control the temperature. Therefore, the cold chain distribution has to be configured to minimize the cost of storage and transportation and to meet the requirements of product quality.

The studies on the subject of cold chain distribution planning are limited. One of the focus of those studies is to consider cost and the effect of food quality deterioration during distribution [12-21]. Chen et al. [12] proposed a non-linear mathematical model to optimize production scheduling and vehicle routing for perishable food. Zhang et al. [13] proposed a tabu search algorithm that optimizes the structure of the cold chains for distribution of chilled or frozen food. Hsu et al. [14] focused on perishable goods, whose value function decreases throughout their lifetime. They proposed the basic model with hard time-windows and revised model with soft time-windows having time-dependent temperature and travel. In the second model, they considered deterministic and stochastic travel time. Osvald and Stirn [15] studied the fresh vegetable distribution where the loss of quality and the perishability of goods are considered as part of overall distribution cost. They defined their problem as a VRP with soft and hard time-windows and time-dependent travel times over a homogenous fleet of vehicles. Zhang and Chen [16] proposed an optimization model that manages the delivery of a variety of frozen foods, by considering loading volume as constraint beside time-windows and loading weight.

Amorim and Almada-Lobo [17] proposed a new formulation for a vehicle routing problem dealing with perishability issues based on multi objectives of the decision-maker. The first objective is to minimize tangible operational costs. The second objective is the maximization of the freshness intangible value. Wang et al. [18] proposed a Multi-Objective Vehicle Routing Problem with Time-Windows dealing with Perishability (MO-VRPTW-P). Song and Ko [19] considered a vehicle routing problem with both cold-storage and general *m* type vehicles for multi-commodity perishable food product delivery. The objective was to maximize the total sum of customer satisfaction, which is dependent on the freshness of the delivered food products. Hsio et al. [20] modeled a distribution planning for cold chain food problem, aiming to generate a distribution plan for fulfilling customer requirements for various foods with pre-appointed quality levels at the lowest distribution cost. The quality level was defined based on the estimated shelf life, which varies by food type and storage temperature, and is characterized by a stepped decrease as time goes on. Trihardani and Dewi [21] developed a mathematical model and particle swarm optimization algorithm to resolve perishable product delivery routing. The model and algorithm considered perishability and time-windows.

This research focused on a real case of PT Lukindari Permata Malang as the ice cream distributor for the stores in Malang Raya area. The company uses cold storage vehicle to store the ice cream at -18^{o}C, which consumes energy to maintain the temperature. The ice cream has to be delivered from the distributor to the stores between the opening and closing hour, thus the complexity of the distribution increases. If the vehicle arrives before store opening hour, the driver has to change the route and return to that store at another time, which increases the fuel and energy cost consumed by the cold storage. Additionally, ice cream has a perishability characteristic that will decrease the quality during the delivery process and affect the inventory cost. The company currently relies on the driver experience to determine the route, which means it will not consider the energy cost and product quality loss yet.

Based on the previous studies, a Mixed-Integer Programming model (MIP) developed by Hsu et al. [14] is the closest model to the company distribution characteristic. Therefore, this research will propose an optimization model in the form of mixed-integer non-linear programming model. The objective is to minimize the total cost, which consists of fixed cost, transportation cost of the vehicles, the energy cost to keep the cold storage temperature, and inventory (quality loss) cost. The model considered the vehicle characteristics such as cold storage capacity, vehicle speed, and the costs (i.e. fixed cost, transportation cost, and energy cost). Moreover, the model considered the opening and closing (time-windows) of the distributor and all the stores. As the result, it will propose a route for ice cream distributor that is able to minimize the total costs.

The remainder of the paper is organized as follows. Section 2 describes problem definition and model formulation. Section 3 explains computational results from model implementation. Section 4 summarizes the result and proposes some future research directions.

2. Research Method

2.1. Problem Definition

The problem is defined as symmetric graph G = (N, A) whereas N = {0, 1, …, n} is a set of nodes and A is a set of arc with arc (i,j): i,j $\in$ N, i$\neq$j. Customer index is presented by i, i = 1, 2, …,n whereas n is the number of customer and i=0 represents distributor. Product demand and service time on each customer are presented as d_i and u_i. Then l is vehicle set, l = 1, 2, …, m, whereas m is the total number of vehicles. Each vehicle has limited cold storage capacity and is defined by K^l. The traveling time at arc (i,j) using vehicle l is assumed deterministic and is defined by t_{ij}^l and $t_{ij}^l = t_{ji}^l$. The transportation cost at arc (i,j) using vehicle l is defined as c_{ij}^l and $c_{ij}^l = c_{ji}^l$. The traveling time and transportation cost is linear to traveling distance by vehicle l at arc (i,j). Next, the vehicle has to visit the distributor and all the customers within their time-windows and presented as [r_i, s_i]. In other words, this is hard time-windows for the distributor and all the customers.

The total cost consists of vehicle fixed cost, transportation cost, inventory cost, and energy cost. The fixed cost for delivery using a vehicle can be expressed as $\sum_{l=1}^{m} f^l v^l$ where f^l is the fixed cost for vehicle l and v^l= 1 when the vehicle l is chosen to perform the delivery. The transportation cost is expressed as $\sum_{l=1}^{m}\sum_{i=0}^{n}\sum_{j=0}^{n} c_{ij}^l X_{ij}^l$, where X_{ij}^l= 1 for vehicle l traveling via arc (i,j). The inventory cost is shown as $P\ \sum_{l=0}^{m}\ \sum_{i=0}^{n} z_i^l \bar{b}_i$. P is the purchase cost per item product, $z_i^l = 1$ for vehicle l serving customer i, and $\bar{b}_i$ represents the expected inventory loss or the amount of food deterioration on the way to customer i. This inventory cost formulation refers to [14], in which the loss of food caused by time accumulation during delivery process depends on the frequency of cold storage opening every time food is being offloaded to serve the customer. The energy cost for each vehicle depends on the total energy loss caused by thermal conduction and convection during the delivery process, total traveling time, and the energy cost per calorie (q) [14]. Next, the energy cost is expressed as $\sum_{l=1}^{m}[\overline{q^l}\ (y_f^l - y_s^l)]$ whereas $\overline{q^l}$ is the energy cost per hour for vehicle l, y_f^l is the arrival time of vehicle l at distributor after the delivery process, and y_s^l is the departure time of vehicle l from the distributor to start the delivery process to the customer. The difference between y_f^l and y_s^l presents the total traveling time of vehicle l.

Hsu et al. [14] assumed that food deterioration is caused by the duration of the cold storage opening. The duration will increase along with customer demand. G(d_i) is the probability of food deterioration caused by opening the cold storage as the function of customer demand d_i for i = 1, 2, …,n. d_0 is the total food loaded to the vehicle in the distributor, and assuming that food deterioration does not yet happen at the distributor, then G(d_0) = 0. Let f(y) represents the probability that food deterioration at time y and F(.) is the cumulative probability density function of f(y). Then the variables y_i, u_i, and L^l represents the arrival time at customer i, service time for customer i, and vehicle load l. Thus, the expected inventory loss incurred on the way to customer i, $\bar{b}_i$ is presented in ***Eq. (1)***.

$$x_0^l \overline{b_i} = x_{0i}^l L^l x[F(y_i - y_s^l + u_i) + G(d_i)], \quad i = 1,2,...,n, \; l = 1,2,...,m. \qquad \textbf{\textit{(1)}}$$

The study conducted by Hsu et al. [14] assumed that the vehicle is homogenous, delivers the same type of food so that the volume and temperature in the cold storage remain the same for all vehicles. They also assumed that the operator has already planned the delivery route as such that it satisfies the time-windows limit agreed with the customer. Therefore, the frequency of cold storage opening on each vehicle can be represented with the expected value of $\overline{\beta}$. The thermal load generated from the thermal convection while opening the cold storage was calculated on ***Eq. (2)*** [22]. In this equation, Qs is the thermal load per hour (kcal/h), V_1 is the cold storage volume, T_0 represents the outside temperature, T1 represents the inside temperature and β as the indicator that reflects the cold storage opening. Next, the thermal load generated from the thermal conduction was caused by the temperature difference between outside and inside to keep the cold storage temperature and is estimated using ***Eq. (3)*** [22]. Q_T shows the thermal load per hour (kcal/h), U is the cold storage conductivity (kcal/h m^2 ^oC), A_1 is the inside surface, and A_0 is the outside surface of the cold storage. The thermal load on each vehicle (α^l) is the addition of Qs and Q_T. Given q^l as the energy cost per kcal on each vehicle, then the energy cost per hour per vehicle is $\overline{q^l} = q^l\alpha^l$.

$$Q_s = (0.54V_1 + 3.22)(T_0 - T_1)x\overline{\beta}. \qquad \textbf{\textit{(2)}}$$

$$Q_T = U\sqrt{A_1A_0}(T_0 - T_1). \qquad \textbf{\textit{(3)}}$$

2.2. Model Formulation

The mixed-integer non-linear programming model proposed in this paper uses the base model formulated by Hsu et al. [14]. The vehicle characteristics such as cold storage capacity, vehicle speed, and the costs (i.e. fixed cost, transportation cost, and energy cost) will determine whether the vehicle is to be used or not. So, we introduced new decision variables which are v^l and y_i^l since there could be more than one vehicle arriving at the distributor. Also, this model uses new decision variable notation X_{ij}^l to replace $x_{i(i+1)}^l$ and g_{ij}^l, which has the same meaning. The changes in parameter and decision variables in this model are shown in bold typeface.

Parameters

d_i =demand at customer i.
u_i =service time at customer i .
r_i =lower bound time-windows of customer i.
s_i =upper bound time-windows of customer i.
K^l =cold storage capacity of vehicle l.
f^l =fixed cost of vehicle l.
c_{ij}^l =transportation cost at arc (i,j) with vehicle l.

t_{ij}^{l} = traveling time at arc (i,j) with vehicle l.

P = purchase cost per item product.

$\overline{q}^{l}$ = energy cost per hour for vehicle l.

$G(d_i)$ = function that states the probability of food deterioration caused by opening the cold storage is the function of customer demand d_i.

$F(.)$ = probability cumulative density function of $f(y)$ where $f(y)$ shows the probability of food deterioration over time y.

Decision variables

X_{ij}^{l} = 1 if vehicle l performs the traveling via arc (i, j), otherwise 0.

v_l = 1 if vehicle l is used, otherwise 0.

y_i^l = arrival time of vehicle l at distributor before loading and delivery process.

z_i^l =1 if vehicle l serves customer i, otherwise 0.

y_i = arrival time at customer i.

y_s^l = departure time of vehicle l from distributor to deliver to the customer.

y_f^l = arrival time of vehicle l at distributor after delivery to the customer.

b_l = expected inventory loss on vehicle l.

$\overline{b_i}$ = expected amount of food deterioration incurred during a traveling to customer i.

Hsu et al. [14] developed a model where the distributor was visited m times by the number of homogenous vehicles available. While in this model, the distributor (i=0) will be served minimum one vehicle as shown in ***Eq. (4)***. If the vehicle l will serve distributor then the decision variable v^l is chosen, as shown in ***Eq. (5)***.

$$\sum_{l=1}^{m} z_i^l = \begin{cases} \geq 1 & i = 0 \\ 1 & i = 1,\ldots,n \end{cases} \tag{4}$$

$$v^l \geq z_i^l, \quad i = 0,1,2,\ldots n, \quad l = 1,\ldots,m. \tag{5}$$

In this model, we introduced the constraint to guarantee that the arrival time of vehicle l at a distributor (y_i^l) is within the time-windows, or otherwise it will be 0, as shown in ***Eq. (6)***. Additionally, we also introduced ***Eqs. (7)*** and ***(8)*** to guarantee the departure time from the distributor (y_s^l) and the arrival time after the delivery process (y_f^l) will be 0 if the vehicle l is not chosen. Both of those times have to be ensured to be 0 since the difference between them represents the total traveling time, which will impact the energy cost for vehicle l, as explained before.

$$y_i^l \geq r_i z_i^l, \quad y_i^l \leq s_i z_i^l, \quad i = 0, l = 1,\ldots,m, \tag{6}$$

$$y_i^l = y_s^l - u_i z_i^l, \quad i = 0, l = 1,\ldots,m, \tag{7}$$

$$y_f^l \leq s_i z_i^l, \quad i = 0, l = 1,\ldots,m. \tag{8}$$

Lastly, we also added one fundamental constraint in the vehicle routing problem model to ensure the balance between inflow and outflow on each vehicle for each customer to maintain the loop. If the customer *i* is visited by vehicle *l*, then vehicle *l* has to leave from the same customer after delivering the service. ***Eq. (9)*** shows this inflow and outflow balance.

$$\sum_{j=0}^{n} X_{ij}^{l} = \sum_{j=0}^{n} X_{ji}^{l}, \quad j = 0,1,\dots,n,\ l = 1,\dots,m,\ i \neq j. \tag{9}$$

The complete MINLP model is presented in ***Eqs . (10)*** to ***(26)***.

$$\text{Minimize} \sum_{l=1}^{m} f^{l} v^{l} + \sum_{l=1}^{m} \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij}^{l} X_{ij}^{l} + P \sum_{l=1}^{m} \sum_{i=1}^{n} z_{i}^{l} \overline{b_{i}} + \sum_{l=1}^{m} \overline{q^{l}} (y_{f}^{l} - y_{s}^{l}), \tag{10}$$

S.t.

$$\sum_{l=1}^{m} z_{i}^{l} = \begin{cases} \geq 1 & i = 0 \\ 1 & i = 1,\dots,n \end{cases}, \tag{11}$$

$$v^{l} \geq z_{i}^{l}, \quad i \forall N, \quad l = 1,\dots m, \tag{12}$$

$$\sum_{j=0}^{n} X_{ij}^{l} = z_{i}^{l}, \quad i = 0,\dots,n,\ l = 1,\dots,m,\ i \neq j, \tag{13}$$

$$\sum_{j=0}^{n} X_{ij}^{l} = \sum_{j=0}^{n} X_{ji}^{l}, \quad i = 0,1,\dots,n,\ l = 1,\dots,m,\ i \neq j, \tag{14}$$

$$y_{j} \geq y_{i} + u_{i} + t_{ij}^{l} - (1 - X_{ij}^{l})M, \quad i = 1,\dots,n,\ j = 1,\dots,n,\ l = 1,\dots,m, \tag{15}$$

$$y_{j} \geq y_{s}^{l} + t_{ij}^{l} - (1 - X_{ij}^{l})M, \quad i = 0,\ j = 1,\dots,n,\ l = 1,\dots,m, \tag{16}$$

$$y_{f}^{l} \geq y_{i} + u_{i} + t_{ij}^{l} - (1 - X_{ij}^{l})M, \quad i = 1,\dots,n,\ j = 0,\ l = 1,\dots,m, \tag{17}$$

$$r_{i} \leq y_{i} \leq s_{i}, \quad i = 1,\dots,n, \tag{18}$$

$$y_{i}^{l} \geq r_{i} z_{i}^{l},\ y_{i}^{l} \leq s_{i} z_{i}^{l}, \quad i = 0,\ l = 1,\dots,m, \tag{19}$$

$$y_{i}^{l} = y_{s}^{l} - u_{i} z_{i}^{l}, \quad i = 0,\ l = 1,\dots,m, \tag{20}$$

$$y_{f}^{l} \leq s_{i} z_{i}^{l}, \quad i = 0,\ l = 1,\dots,m, \tag{21}$$

$$\sum_{i=1}^{n} z_{i}^{l} d_{i} + b^{l} \leq K^{l}, \quad l = 1,\dots,m, \tag{22}$$

$$L^{l} = \sum_{i=1}^{n} z_{i}^{l} d_{i}, \quad l = 1,\dots,m, \tag{23}$$

$$X_{ji}^{l} \overline{b_{i}} = X_{ji}^{l} L^{l} x [F(y_{i} - y_{s}^{l} + u_{i} + G(d_{i})], \quad j = 0,\ i = 1,\dots,n,\ l = 1,\dots,m, \tag{24}$$

$$X_{ij}^{l},\ z_{i}^{l},\ v^{l} \in \{0,1\}, \tag{25}$$

$$y_{i},\ y_{i}^{l},\ y_{s}^{l},\ y_{f}^{l},\ b^{l},\ \overline{b_{i}} \geq 0. \tag{26}$$

Eq. (10) states the objective function to minimize the total cost that consists of fixed cost, transportation cost, inventory cost, and energy cost. ***Eq. (11)*** ensures that a minimum one vehicle will visit the distributor and the customer will be visited only by one vehicle. ***Eq. (12)*** provides customer i will be served by vehicle l if vehicle l is chosen. ***Eq. (13)*** ensures that arc (i, j) can be formed from customer i to any customer j if customer i will be served by vehicle l. ***Eq. (14)*** is the inflow and outflow balance of each vehicle at each customer. ***Eq. (15)*** guarantees that arrival time at the next customer will be at least the same with an arrival time of the previous customer added with serving and traveling time. ***Eq. (16)*** ensures that arrival time at the customer has to be later than departure time from the distributor added with traveling time from distributor to customer. ***Eq. (17)*** ensures that arrival time at the distributor is later than arrival time at the customer added with service time and traveling time from customer to distributor.

Eq. (18) ensures that arrival time at each customer is within its time-windows. ***Eq. (19)*** provides that arrival time at the distributor is within its time-windows. ***Eqs. (20)*** and ***(21)*** guarantees that the vehicle's departure time from the distributor and arrival time after the delivery process at the distributor only has value if the vehicle is used. ***Eq. (22)*** states that total customer demand added with expected inventory loss must not higher than the vehicle capacity. Total customer demand is the same as vehicle load is indicated in ***Eq. (23)***. ***Eq. (24)*** shows the product loss or deterioration to serve customer i with vehicle l. ***Eq. (25)*** states that the decision variable x_{ij}^l, z_i^l, and v^l is integer binary. ***Eq. (26)*** states those decision variables $y_i, y_i^l, y_s^l, y_f^l, b^l, \overline{b}_i$ is greater than zero.

3. Result and Analysis

The formulation model that has been explained in Section 2.2 was used to solve the ice cream distribution problem at Klojen district Malang. There were 48 stores visited in one day and the data related to the demand, service time, and time-windows of each store are available in the research done by Khoidir [23]. The company's initial route used 2 Mitsubishi Colt L300 vehicles having 135 x 215 x 135 cm cold storage with 3,243,375 cm^3 load capacity. Khoidir [23] proposed route determination with two time-windows limitations that is 07.00-11.00 AM and 13.00-18.00 PM to deliver the ice cream to the stores. This research considers the energy spent to keep the cold storage temperature and ice cream deterioration risk during the traveling caused by opening the cold storage door. Therefore, the calculation for the energy per hour on each vehicle and deterioration of the ice cream quality during the traveling was added.

The vehicle requires fuel to run and keep the cold storage temperature. One liter of fuel generated 9,240 kcal and was priced at IDR 10,200/litre. Thus the energy per calory (q) cost is IDR 1,104/kcal. Then thermal load per hour (Q_s) was calculated by ***Eq. (2)***; cold storage volume is 3.918375 m^3, box opening frequency at average is 2, average outside temperature is 29 ^{0}C, average cold storage temperature is at -18 ^{0}C, and Q_s can be obtained as ((0,54 x 3,918375) + 3,22) x 2 x (29-(-18)) = 501,577 kcal/h. The thermal conduction (Q_t) is obtained using ***Eq. (3)***. It is known that the conductivity of cold storage insulated material using high-pressure polyurethane is 0.02 W/mK or equals to 0.0017 kcal/h m C, the surface area inside the cold storage is 2.29025 m^2, and the outside area is 3.492 m^2, thus Q_t is obtained as $0.017\ x\ \sqrt{2.9025 \text{ x } 3.492}\ x(29+18)$= 2.544 kcal/h. Having Q_s, Q_t, and q, then the energy cost per hour per vehicle is calculated as 1.104 x (501.577 + 2.544) = IDR 556.5496/hour or equals to IDR 9.276/minute.

The service time per customer function (u_i) is estimated using a customer demand function and expressed as $u_i = d_i$ x 0.0004 minutes/cm^3. The deterioration can happen for 24 hours thus $G(d_i) = u_i/1{,}440$ or d_i x 0.000000278 and F(.) = Δ y/1440. Lastly, the purchase price per ice cream (P) is IDR 36/cm^3 from averaged from several popular ice cream prices. On the initial route, vehicle 1 and 2 visited 27 stores, respectively. The combined total cost of both vehicles is IDR 1,767,453.2944.

The proposed route was obtained after running the model using LINGO software, and the result is available in ***Table 1***. There are two vehicles used to deliver to 48 stores. Vehicle 1 visited 34 stores and vehicle 2 visited 14 stores. Another information taken from this research is that the arrival time at the distributor and at each store is within their respective time-windows. The departure time of vehicle 1 from the distributor (y_s^1) was at the 510th minute and back at distributor after the delivery process (y_f^1) was at the 978.47th minute (16.18 PM). Thus the total energy cost for vehicle 1 is IDR 9.276/minute x (978.47 minute - 510 minute) = IDR 4,345.57. Other information that can be obtained is the expected ice cream quality deterioration during the traveling of vehicle 1 to customer K001 of IDR 22,859.433 cm^3. This expected loss is then multiplied by the average product price of IDR 36/cm^3 to obtain estimated inventory cost of vehicle 1 for IDR 822,939.59. For the vehicle 2, the expected ice cream deterioration during the traveling to customer K031 is at IDR 7,720.9302 cm^3, and the estimated inventory loss is at IDR 277,953.49. The total cost of vehicle 1 and 2 is at IDR 958,737.124 and IDR 399,248.46, respectively; the total combined cost is at IDR 1,357,985.6 for the proposed route.

Based on the total combined cost of initial and the proposed route, it can be concluded that the proposed route was able to reduce the cost by IDR 409,467.71 or saving of 23.17% for one day of delivery. The saving was obtained from the reduction of total transportation, energy, and inventory cost, each of IDR 21,055.2, 320.08, and 388.092.4323. Meanwhile the total fixed cost remains the same as both routes are using two vehicles. This saving demonstrated that the proposed route was able to produce a more optimal ice cream distribution plan by considering the quality deterioration of the ice cream and allowed time-windows and minimizing the vehicle investment and energy cost to keep the cold storage temperature.

4. Conclusion

This research developed an optimization model in the form of mixed-integer non-linear programming model to resolve the issue of cold-chain food distribution. The objective is to minimize the total cost consisting of fixed cost, transportation cost, inventory cost, and energy cost. The model considered the vehicle characteristics such as cold storage capacity, vehicle speed, and the costs. In this paper, we introduced new decision variable that is, the number of the vehicle to be used. Additionally, the model has constraints to ensure opening and closing of the distributor and all the stores. The proposed model was proven able to solve the distribution problem at PT Lukindari Permata Malang and reducing the cost by IDR 409,467.71 or saving of 23.17% in one day of delivery. The drawback of this optimization model is the long computation time to obtain a globally optimal solution. Therefore, a metaheuristic method can be explored to resolve the problem of cold-chain food distribution with reasonable computation time.

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References

[1] Tunali, S., & Oztuzcu, G. (2018). A two-phase approach for supply chain network design: a real-world case study from automotive industry. *International journal of research in industrial engineering*, *7*(1), 1-18.
[2] Akkerman, R., Farahani, P., & Grunow, M. (2010). Quality, safety and sustainability in food distribution: a review of quantitative operations management approaches and challenges. *Or spectrum*, *32*(4), 863-904.
[3] Jackson, V., Blair, I. S., McDowell, D. A., Kennedy, J., & Bolton, D. J. (2007). The incidence of significant foodborne pathogens in domestic refrigerators. *Food control*, *18*(4), 346-351.
[4] Montanari, R. (2008). Cold chain tracking: a managerial perspective. *Trends in food science & technology*, *19*(8), 425-431.
[5] Aiello, G., La Scalia, G., & Micale, R. (2012). Simulation analysis of cold chain performance based on time–temperature data. *Production planning & control*, *23*(6), 468-476.
[6] Laguerre, O., Hoang, H. M., & Flick, D. (2013). Experimental investigation and modelling in the food cold chain: Thermal and quality evolution. *Trends in food science & technology*, *29*(2), 87-97.
[7] Defraeye, T., Cronjé, P., Berry, T., Opara, U. L., East, A., Hertog, M., ... & Nicolai, B. (2015). Towards integrated performance evaluation of future packaging for fresh produce in the cold chain. *Trends in food science & technology*, *44*(2), 201-225.
[8] Bogataj, M., Bogataj, L., & Vodopivec, R. (2005). Stability of perishable goods in cold logistic chains. *International journal of production economics*, *93*, 345-356.
[9] Badia-Melis, R., Mc Carthy, U., Ruiz-Garcia, L., Garcia-Hierro, J., & Villalba, J. R. (2018). New trends in cold chain monitoring applications-A review. *Food control*, *86*, 170-182.
[10] Ndraha, N., Hsiao, H. I., Vlajic, J., Yang, M. F., & Lin, H. T. V. (2018). Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations. *Food control*, *89*, 12-21.
[11] Zhao, H., Liu, S., Tian, C., Yan, G., & Wang, D. (2018). An overview of current status of cold chain in China. *International journal of refrigeration*, *88*, 483-495.
[12] Chen, H. K., Hsueh, C. F., & Chang, M. S. (2009). Production scheduling and vehicle routing with time windows for perishable food products. *Computers & operations research*, *36*(7), 2311-2319.
[13] Zhang, G., Habenicht, W., & Spieß, W. E. L. (2003). Improving the structure of deep frozen and chilled food chain with tabu search procedure. *Journal of food engineering*, *60*(1), 67-79.
[14] Hsu, C. I., Hung, S. F., & Li, H. C. (2007). Vehicle routing problem with time-windows for perishable food delivery. *Journal of food engineering*, *80*(2), 465-475.

[15] Osvald, A., & Stirn, L. Z. (2008). A vehicle routing algorithm for the distribution of fresh vegetables and similar perishable food. *Journal of food engineering*, *85*(2), 285-295.
[16] Zhang, Y., & Chen, X. D. (2014). An optimization model for the vehicle routing problem in multi-product frozen food delivery. *Journal of applied research and technology*, *12*(2), 239-250.
[17] Amorim, P., & Almada-Lobo, B. (2014). The impact of food perishability issues in the vehicle routing problem. *Computers & industrial engineering*, *67*, 223-233.
[18] Wang, X., Wang, M., Ruan, J., & Zhan, H. (2016). The multi-objective optimization for perishable food distribution route considering temporal-spatial distance. *Procedia computer science*, *96*, 1211-1220.
[19] Song, B. D., & Ko, Y. D. (2016). A vehicle routing problem of both refrigerated-and general-type vehicles for perishable food products delivery. *Journal of food engineering*, *169*, 61-71.
[20] Hsiao, Y. H., Chen, M. C., & Chin, C. L. (2017). Distribution planning for perishable foods in cold chains with quality concerns: Formulation and solution procedure. *Trends in food science & technology*, *61*, 80-93.
[21] Trihardani, L., & Dewi, O. A. C. (2017). Pengembangan Algoritma Hybrid Metaheuristik Untuk Penentuan Rute Pengiriman Produk Perishable. *Jurnal teknik industri*, *18*(2), 191-206.
[22] MOEA-IDB. (2001). *A handout of training class for industry technology talent in 2001*. Taiwan.
[23] Khoidir, A. (2018). *Vehicle routing problem with multiple time windows untuk mengoptimalkan rute distribusi ice cream (PT. Lukindari Permata Malang)* (Doctoral dissertation, University of Muhammadiyah Malang).