A Single Period Deterministic Inventory Routing Model for Solving Problems in the Agriculture Industry

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This paper constructs the problem of dealing inventory and the transportation in the supply chain in the agriculture industry, also to investigate the capabilities of the distribution process of perishable products (vegetables) from the distribution centre (DC) to a set of customers to minimize the total operational cost. This research proposed an optimisation model to present the actual problem that happened in a real-life situation. The simulation of the transportation problem was developed using an algebraic modelling language which is called a mathematical programming language (AMPL) to determine an optimal solution. Thus, by setting the delivery routes for DC, based on the number of products that have been set for each customer, it helps to find an optimal inventory routing problem (IRP). As a result, an optimization model developed, it is predicted that agriculture firms can achieve an optimal solution by reducing their operational cost, especially on the inventory and transportation cost.

Keywords: Supply Chain Optimization, Agriculture, Inventory Routing Problem, Operations Research, Sustainability

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1. Introduction

Nowadays, most industries focus on strategies that can improve their efficiency and effectiveness of supply chain management (SCM). SCM is a policy that manages the flow of products from the supplier to a set of customers. In this paper, we provide a case study of SCM based on the Federal Agriculture Marketing Authority (FAMA). FAMA is an established agency under the Ministry of Agriculture and Food Industries (MOA) that manage, control and develop product marketing in Malaysia and also expand market access to the foreign market.

Since the 1990s, a lot of improvements have been done to sustain the SCM for the agriculture sector but there is still some lack in terms of logistics activities. Therefore, this research proposed a mathematical model to solve the problem on the inventory routing problem (IRP) in FAMA located in the northern part of Malaysia, which is in Alor Setar, Kedah. Fig. 1 shows the supply chain system for FAMA, they use a collection centre (CC) by collecting the fresh product from farmers before distributing it to the distribution centre (DC) and then delivering it to customers.

The amount of product delivery between CC to DC must be enough to avoid the stockout. One of the main concerns is how to minimize the total operational costs which consist of inventory and transportation costs. Thus, agriculture companies need to focus on how to maximize their output and also can optimize the total cost of the inventory and transportation costs. Moreover, companies should have the right schedule flow for transportation to minimize the operations and the delivery costs.

Therefore, the objective is to find the optimal solution for transportation costs from FAMA's distribution centre also called as operation centre (OC) to deliver the product to a set of customers that can minimize the total operational costs. Consequently, in this research, we proposed linear mixed-integer programming to solve the problems,

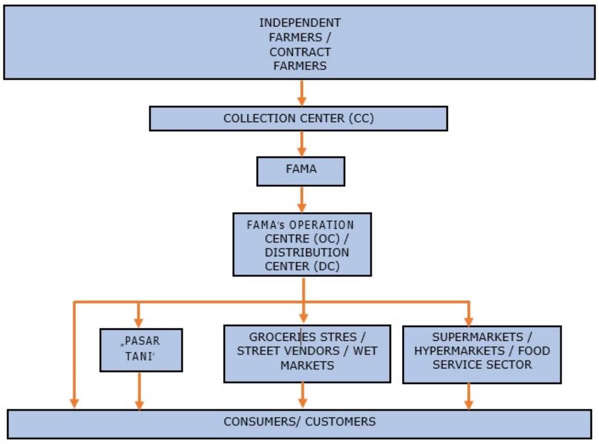

Fig. 1. FAMA's supply chain system in Kedah

by adopting a related constraint for optimization and then used a mathematical programming language (AMPL) software and analyse the results.

2. A Brief Literature Review

The IRP is an important optimization model that catches the fundamental qualities of vendor managed inventory (VMI) arrangement such as inventory control and transportation planning. The IRP is an extremely difficult problem that emerges in different distribution systems. There is a various version of the deterministic inventory routing problem (DIRP) that have been explored to investigate the inventory management and vehicle routing problem. In this section, we have focused specifically on the DIRP literature in the agriculture industry.

[1] have deliberated the overview of the fruit supply chain. They described the structure of the supply chain in the agriculture industry by using CC and DC as a medium to deliver the product to the customers. The DC is also called an OC and CC is a venue where functions as a daily temporary depositary before distributing to the customers.

[2] studied the integration of food distribution networks. They proposed a schematic illustration of the distribution scenarios that happen. In their paper, they used only one DC as a medium to deliver the product to the customers.

[3] focused on inventory replenishment and transportation schedule. The analytical model was presented in their paper to coordinate the inventory and transportation decisions in VMI systems. They considered that each customer has a random demand rate in each location. They also computed the optimum replenishment quantity and delivered the demand simultaneously to reduce the operational costs.

[4] have studied the IRP on a single period with deterministic demand rates. They focused on the optimization of the inventory and transportation costs of the two-stage of supply chain system under the VMI policy. They solved the problem by defining the quantity of deliveries, the time need to deliver and delivery routes to serve the customers.

[5] studied the transportation network for fresh inventories in Bangkok, Thailand. Due to increasing demand for high-quality fresh products, the main factor that has to be developed is the distribution network which is focused on transportation. They proposed an illustrative with some situations based on the mathematical model of fresh inventories transportation and distribution network.

A recent study by [6] considered minimization of the transportation and inventory holding costs. They measured the two-stage supply chain system used in the construction company. Then, they defined the delivery quantities that should be delivered to the construction sites, what are delivery times and what delivery routes should the vehicle take to distribute the products to the customers for a single period deterministic inventory routing problem (SP-DIRP).

[7] studied on the agri-food supply chain with a single fresh food supplier with one warehouse to serve several retail centres. They considered that the IRP is known as perishable IRP that needs to deliver to each of the retailers with stochastic demand rates. They proposed the mixed-integer program and sim-heuristic algorithm to solve the problem.

In addition, the proposed of this paper is to extend the study made by [8] and [9] on the characteristic of the IRP under the VMI policy. Consequently, this paper focuses on the optimization of IRP in the SP-DIRP. This paper aims to minimize the total inventory and transportation costs in the agriculture sector.

3. Connection scenario that interlinks DC and CC

In this paper, we present the scenario that usually happened in the distribution process in the food supply chain proposed by [10] and [11]. The proposed scenarios are set carefully the relations between the suppliers, CC, DC and delivery routes. They also considered the delivery frequency and quantity per tour based on the available data.

In Fig. 2, suppliers deliver the products to their customers by having a single or more delivery route depending on the demand and the location of their customers. Since the data is only the location of the customers are available, the delivery route must be generated. To generate the vehicle route planning, they assumed that the distribution process can be done to the customers who are located close to each other on the same route.

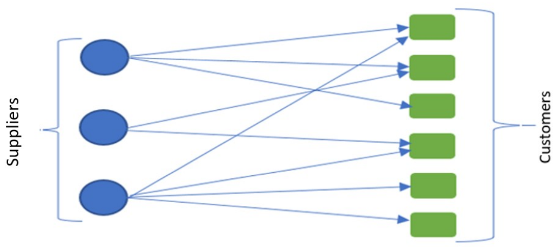

Fig. 2. Basic distribution of the products

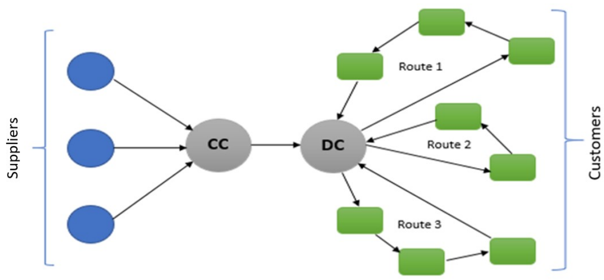

Fig. 3. Collection by CC and distribution by DC

Fig. 3 shows the delivery process starting from supplier to CC, followed by CC delivering to DC and finally from DC delivering the product to a set of customers. An integrated distribution was considered as the products could be delivered by maximizing the vehicle capacity.

Therefore, in this paper, we focus on the distribution process starting from the DC then delivering the products to the customers (refer to Fig. 4). We try to solve the SP-DIRP for the DC to deliver the products to each of the customers.

4. Mathematical Model

Let τ_t be a time period and in this paper, we consider that 8 hours per day for the working hours. Let the set of customers S denoted by i and j; and $S^+ = S \cup \{r\}$, and r

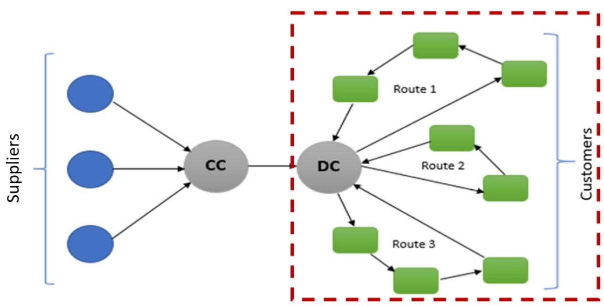

Fig. 4. Focus area on the distribution process starting from DC to the customers

represent the DC. To serve the customers, we use a fleet of the homogeneous vehicle V. There are some other parameters and variables used in developing this model which is given in Table 1 and Table 2 below:

So that, we consider that I_{jr} be the level of initial product at the DC. The linear mixed-integer formulation for the SP-DIRP shows below:

SP-DIRP minimize

$$CV = \sum_{v\in V}\left[\psi^v y^v + \sum_{i\in S^+}\sum_{j\in S^+}\left(\delta_v v_v \theta_{ij} + \varphi_j\right) x_{ij}^v\right] + \sum_{j\in S^+} \eta_j I_j \tag{1}$$

Subject to

$$\sum_{v\in V}\sum_{i\in S^+} x_{ij}^v \leq 1, \quad \forall j \in S \tag{2}$$

$$\sum_{i\in S^+} x_{ij}^v - \sum_{k\in S^+} x_{jk}^v = 0, \quad \forall j \in S^+, v = V \tag{3}$$

$$\sum_{i\in S^+}\sum_{j\in S^+} \theta_{ij} x_{ij}^v \leq \tau_t, \quad v = V \tag{4}$$

$$\sum_{v\in V}\sum_{i\in S^+} Q_{ij}^v - \sum_{v\in V}\sum_{k\in S^+} Q_{jk}^v = q_i, \forall j \in S \tag{5}$$

$$Q_{ij}^v \leq k^v x_{ij}^v, \quad \forall i,j \in S^+, v \in V \tag{6}$$

$$I_{j-1} + q_r - I_r = d_j \tau_t, \quad \forall j \in S \tag{7}$$

$$I_{j0} \leq I_j, \quad \forall j \in S \tag{8}$$

$$x_{rj}^v \leq y^v, \quad \forall j \in S, v \in V \tag{9}$$

$x_{rj}^v, y^v \in \{0,1\}, I_{j0}, I_j \geq 0, Q_{ij}^v \geq 0, q_j \geq 0, \forall i,j \in S^+, v \in V$

The objective function (Eq. (1)) comprises four cost components (total vehicle's fixed operating, total transportation cost, total delivery handling cost and total inventory holding cost at the DC and customers. Constraints (Eq. (2)) contain the vehicle surely to visit each customer at only once. Constraints (Eq. (3)) confirm that the vehicle must leave after it has been served and then go to the next customer or return to the DC. Constraints (Eq. (4)) is to make sure that vehicles complete their routes within one travel period so that the total vehicle's travelling time should not exceed the total working hours. Constraints (Eq. (5)) indicate that the quantity needs to be distributed to a customer. Constraint (Eq. (6)) is the vehicle capacity and guarantee that the variables cannot carry any cumulated flow unless equals 1. The product balance equation at the customers is presented in constraints (Eq. (7)). To indicate the final

Table 1. Parameters

Label	Explanation
φ_j	The fixed handling cost per delivery (in RM) at location $j \in S^+$(customers and DC)
n_j	The products holding cost per period at location $j \in S^+$(in RM/kg)
ψ^v	The vehicle's fixed operating cost $v \in V$ (in RM/vehicle)
δ_v	The vehicle's travelling cost $v \in V$ (in RM/km)
k^v	The vehicle's capacity $v \in V$ (in kg)
v_v	The vehicle's average speed $v \in V$ (in km/ hour)
θ_{ij}	Trip duration from customer $i \in S^+$to customer $j \in S^+$(in hour)
d_j	The constant demand rate at customer j (in kg/hour).
I_{j0}	The levels of the initial product (in kg) at each customer $j \in S$

Table 2. Variables

Label	Explanation
Q^v_{ij}	The product quantity remaining (in kg) in vehicle $v \in V$ when the vehicle travels directly to location $j \in s^+$ from location $i \in s^+$ The quantity will become zero (0) when the trip (i, j) is not having a tour by the vehicle v ∈ V
q_j	The delivery quantity (in kg) to the location $j \in S$, and 0
I_j	The level of the product at the location (customers and DC) $j \in S^+$
x^v_{ij}	If location $j \in s^+$ is visited immediately after location $i \in s^+$ by vehicle $v \in V$, and 0 (a binary variable set to 1)
y^v	If vehicle $v \in V$, and 0 (a binary variable set to 1)

Table 3. Coordinate and demand rates for each customer

Label	x	y	Demand Rate/hour
DC	15	8	0
1	10	12	3.83
2	17	1	3.84
3	19	9	4.55
4	15	16	5.35
5	11	5	3.62
6	20	14	5.51
7	20	4	3.41
8	11	16	4.31
9	14	5	3.88
10	21	7	4.07

level of product at customer j at the end of the period is of the same magnitude as its initial product is shown in constraints (Eq. (8)). Constraints (Eq. (9)) ensure that a vehicle cannot be used to serve any customer only if the customers are selected.

5. Analysis of IRP example

In this paper, we propose an example situation to solve the SP-DIRP. For this case, we consider that the DC should serve all 10 customers as shown in Fig. 1. All the customers are disseminated with a coordinate (x, y) with the demand rate assumed to be constant. We assume that DC should serve use only one vehicle for products replenishment from the DC.

Fig. 5 illustrated the location of the DC and 10 sets of

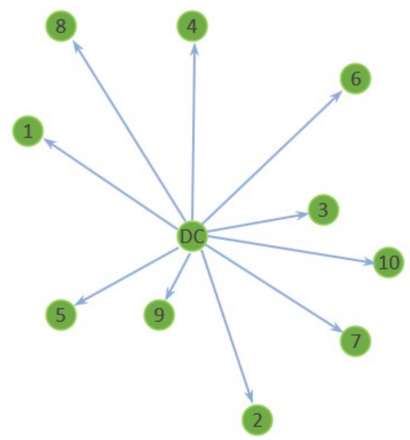

Fig. 5. Location and the direct delivery route taken by the vehicle (10 customers)

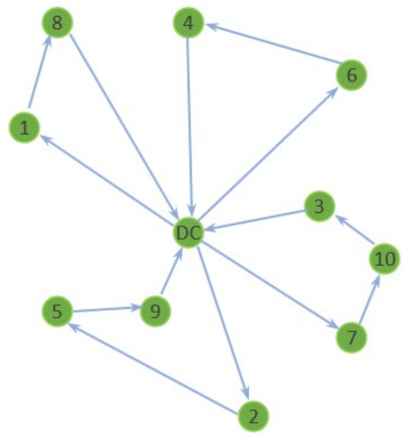

Fig. 6. A delivery tour (100 kg vehicle capacity)

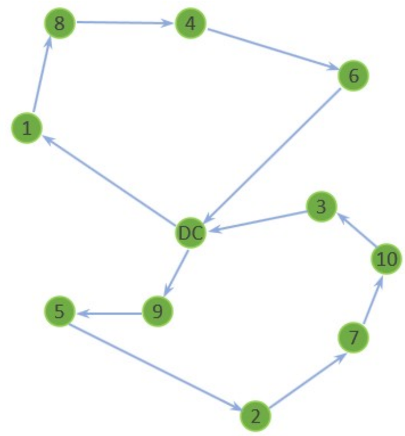

Fig. 7. A delivery tour (200 kg vehicle capacity)

Table 4. Delivery routes for DC

DC Route	Customers
Route 1	$\{1,8\}$
Route 2	$\{6,4\}$
Route 3	$\{2,5,9\}$
Route 4	$\{7,10,3\}$

Table 6. The example of changing the vehicle capacities

Instance	100 kg (RM)	200 kg (RM)	300 kg (RM)
R10-0-T1	1498	1412	1406
R10-1-T1	1508	1432	1422
R10-2-T1	1486	1414	1400
R10-3-T1	1540	1440	1408
R10-4-T1	1526	1416	1416

customers according to each coordinate in Table 3. The customers are located around the DC in a square and the customer demand rate are known and created randomly between 0 to 6 kg per hour. A fleet of homogeneous vehicles is utilized to restock the product to each of the customers. We assumed that the vehicle speed is 50 km per hour. By using a CPLEX solver, the allocation of products can be illustrated as below:

Fig. 6 above shows the computational result for the distribution process using 100 kg of vehicle capacity. In the solution, only one vehicle is allowed to be used to deliver the product to the customers. For instance, Table 4 shows a fleet of homogeneous vehicles with 100 kg capacity makes the tour $V_1 = \{(1,8),(6,4),(2,5,9),(7,10,3)\}$ with the total cost is RM1498.00.

In addition, Fig. 7 above shows the results for the distribution using a fleet homogeneous vehicle with 200 kg vehicle capacity to deliver the product. For this instance, we are using only a vehicle to make replenishment the product to a set of customers. The results from Table 5 show that the route is decreased to be only two routes

Table 5. Delivery route for DC

DC Route	Customers
Route 1	$\{1,8,4,6\}$
Route 2	$\{9,5,2,7,10,3\}$

$V_1 = \{(1,8,4,6),(9,5,2,7,10,3)\}$ with the total cost is RM1412.00.

From these computational results, we can see that the change in the capacity of the vehicle would affect the cost to replenish the product. In this paper, we proposed the example of using 100 kg and 200 kg of vehicle capacity to compare the effect that can happen. It shows that the decrease in total cost from RM1498.00 (100 kg) to RM1412.00 (200 kg) which is cheaper. Therefore, we can estimate that the bigger the capacity of the vehicle, the smaller route should be taken for the vehicle to replenish the product to each customer.

6. Additional instances of changing the vehicle capacity

Table 6 above shows the comparison in changes in vehicle capacity. We develop the data where the location of the DC and the customers are different respectively. According to Table 6, the instance is denoted as a (R10-0-T1) which R10 refer to the 10 customers, 0 is the number of instances and T1 refers to the time period which is only one period. As we can see, the increase in vehicle capacity affects the cost to become lower compared with the small capacity. By using a bigger capacity, the vehicle can deliver the product to the customers directly without returning to the DC frequently.

In that case, we can understand that adding the vehicle capacity can reduce the route taken and automatically reduce the transportation cost-effectively.

7. Conclusion

The paper was initiated to investigate the capabilities of FAMA's SCM in the northern part of Peninsular Malaysia which is located in Alor Setar, Kedah. To minimize the total operating costs in allocating the product to a set of customers, the amount of transportation must be optimized efficiently. In that case, the optimal solution for the problem consisted of how to determine the number of products that needed to deliver to a set of customers, where is the location to deliver and which customers need to assign. We can identify that how many products are carried from DC to distribute to the customers to reduce the shipping cost and also to find the shortest routes. AMPL solution may solve which delivery routes have to go from DC to 10 locations located on the map.

The complexity of problems in the area of supply chain optimization is becoming more challenging, so wide knowledge is very important and needs to use different tools and techniques to solve the crucial problems. Finally, this paper has so many characteristics to be explored for future study. In that case, it is suggested to continue on further research by adding a stochastic element in the model which is reasonable with demand in a real-life and can be extended from the single-period setting to the multi-period optimization problem.

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