An Algorithm Model for Solving the Single-Period Inventory Transportation Problems in the Construction Industry

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***Abstract* --- Vendor managed inventory (VMI) is an illustration of effective partnering and collaboration practices between upstream and downstream points in a supply chain. VMI policy is an integrating decision between a supplier and the customers in which the supplier takes the accountability of sustaining the customers' inventory while confirming that no stock-out. The supplier indicates when each delivery time takes place, so that the customers are no longer responses to the customers' orders. Under the VMI system, the planning is proactive as it is based on the available information rather than reactive to customers' orders. Consequently, in this paper, we expected that the demand at the construction sites are constant and stationary, and the construction consolidation centre (CCC) is implementing a VMI system. The concentration of this paper is to minimize the transportation and inventory holding costs of the customers for a two-stage supply chain system in the construction industry. The problem is to identify what is the delivery quantities to the construction sites, what is delivery times and which routes should be used to deliver products to the customers at the construction site for the single-period deterministic inventory routing problem (SP-DIRP) in the construction sector. Furthermore, realistic side-constraints such as driving time restrictions, storage capacities constraints and constant replacement intervals are considered. Results of a simplified real-life case implementing the proposed linear mixed-integer program are shown and discussed in detail.**

Keywords--- *vendor managed inventory, inventory routing problem, single-period, deterministic demand, construction.*

1. Introduction

The construction sector has an important fragment to play within the overall economy of any given country in the world. This sector is one of the most complicated industries. Thus, the construction procedure and process consist of some stages where various players are involved during each stage. The distinctiveness of this sector is that it is a project-based industry, where every project in construction development could be measured as a temporary organization. However, this construction sector has a similarity with other industries as well, which is concentrating on high production performance while keeping the lowest possible overall costs [1].

In the construction project, firstly the acquired materials will be delivered to the construction site before any construction developments can carry out. When all the required material gathered on-site, it represents the concept of inventory management should be applied to avoid shortage, spoilage or even wastage. Moreover, the construction industry varies from other manufacturers in several aspects comprise each project in construction is various, the final product is one-of-a-kind, there are a lot of staff and firms working at each construction site. So that the production of the construction firm takes place in several different locations. Therefore, it is the best way to discover the possible solution for managing inventory and transportation logistics of the construction projects.

Also, the information flow in construction is complicated and the process is affected by numerous issues. One of these issues is logistics which is defined as the management of the equipment and flow of materials, starting from the point of release to the point of use. The construction industry suffers logistics problems regarding handling the building materials and other products used during the construction period, and one of the most common problems in the construction industry is the incapability of the main contractors to deliver materials or products at the right location and at the right time [2].

Authors [3], identify that any purchase routines, in which usually massive numbers of urgency orders, need to

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be measured carefully once exploring the source of low productivity in the construction segment, subsequently it logically causes extra costs and delays for projects. Therefore, in this paper, we study the issues of managing inventory and transportation problems in construction projects using a concept of vendor managed inventory (VMI).

VMI is an effective method or technique to solve logistics and transportation problems and could be a future direction of the construction supply chain management's innovation. Researchers [4] describe that VMI as an approach to inventory and order fulfilment whereby the supplier is accountable for handling and replenishing customers' inventory at the construction site. With VMI implementation, the suppliers will take over the power and the responsibility of planning and requiring orders for the customers according to the actual condition of inventories. Furthermore, the suppliers could also optimize their production and transportation systems [5].

In the VMI system, quantities and delivery times to distribute to a customer is no longer done after the customer's order, the supplier determines what is the quantity and when the delivery takes place. Customers just provide consistently with enough inventory information, inventory access and the confirmation of order initiated by suppliers. So that the replenishment is proactive as it is based on the available inventory information instead of being reactive in response to the customer's order. This VMI policy has many benefits for both the customers and the supplier. One of the advantages is the supplier has the possibility of integrating multiple tours to optimize the vehicle capacity and the routing cost. Additionally, as the deliveries become more stable, the amount of inventory that must be held at the supplier can be drastically reduced. On the other hand, the customers need no longer to dedicate resources to the management of their inventories.

One reason the VMI system gains more popularity is the current enabling technologies to monitor customer inventories in an online and cost-effective manner. Inventory data can be made available much easier. However, implementing VMI does not in all cases lead to improved results. For instance, failure can also happen due to the unavailability of the essential and important information or the incapability of the supplier to make the correct decisions. The huge amount of data makes it tremendously hard to improve the problem. It involves managing distribution and inventory in a supply chains system which is two particularly challenging problems.

Therefore, the motivation of this paper is to analyse the impact of deterministic demand on a two-stage supply system implementing VMI. An approach is proposed to minimize overall transportation and inventory costs. Hence, the problem is tackled as describe below. The construction consolidation centre (CCC) is presented, which is a centre that is used to distribute products to several construction sites. This CCC provides efficient material flows to the customers from the supplier which makes it an effective supply chain management solution. Then, CCC will distribute acquired products in the required quantity, at the right time and to the right location. This is possible due to goods being combined from multiple part-loads to single shipments. This further contributes to better certainty of supply, reduced number of deliveries to site, reduced amount of stored materials and finely reduced waste. Figure 1 shows the concept of the CCC model in the construction project.

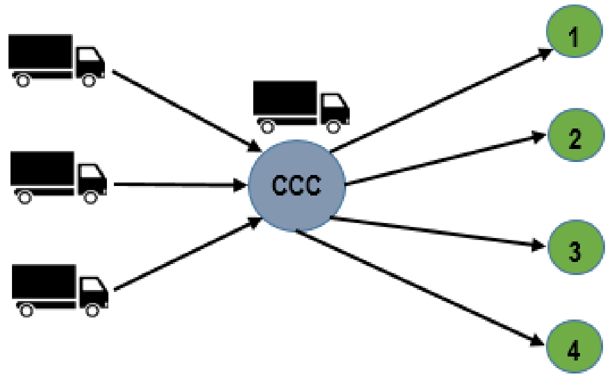

Figure 1. Construction Consolidation Centre (CCC) Model

The remaining of the paper is organized as follows. In section 2, we review some papers and researches regarding the modelling of deterministic inventory routing problem. Then, we develop a linear mixed-integer formulation for the SP-DIRP in Section 3. We provide some illustrative example of the SP-DIRP problem in Section 4. Lastly, in Section 5, we make some concluding remarks of the research.

2. A Brief Literature

In the previous study, [6] among the first explored the problem of the integration between vehicle scheduling and inventory management, diverse versions of the inventory routing problem (IRP) have been approached by many researchers. A huge variation of solution methods has been developed to solve these problems. The IRP problem can be approached and modelled in many styles depending on the features and characteristics of its parameters. For example, different models can be attained, when customers consume the product at a variable or at a stable rate; when demands at the customer are considered to be stochastic or deterministic; when the planning horizon is infinite or finite, when the vehicle used is homogenous or heterogenous and so on. Moreover, [7] made a classification of IRP models in details and during the last thirty years, [8] organised current informative literature reviews on IRPs.

Furthermore, [9] studied the combined vehicle routing problem and inventory allocation. They considered a single period IRP with random demands and fixed fleet size. Thus, [10] studied the problem of constant demands and then compared and proposed two solution methods for the resulting single period problem. This was supported by another study by [11] solved the same problem with the variability of demand rates. Additionally, [12] worked where the decisions on multi-period IRPs are implemented over a finite planning horizon. However, if demand at the customer is constant and deterministic, cyclic solution methods are more suitable, because of their stability and predictability. Thus, [13] proposed a model that produces optimal robust delivery plans in the case of a cyclic IRP where travel times and demand rates for the product are random but stationary. For recent research devoted to the multi-period IRPs, we referred to [14] and [15]. These papers considered periodic demands which are not constant over time. Another exploration, [16] developed a robust mixed integer program and solved the IRP problem when the probability distribution of the customers is not fully specified. [17] formulated a dynamic program of stochastic IRP and solved it by using a hybrid rolling horizon algorithm.

Recently, in a previous work by [18], they focused in the manufacturing industry, which is the single-warehouse, multiple-retailer vendor managed inventory (SWMR-VMI), in which the customers' appearance constant and deterministic demand rate. Accordingly, [19] considered a two-level supply chain system where a supplier distributes from a single warehouse to a set of customers using a homogenous vehicle with restricted capacity. Their objective is to optimize the total transportation and inventory costs of the SWMR system implementing VMI. Then, they proposed a two-stage optimization method for integrating the deliveries in the VMI system. The solutions of the SWMR-VMI problem predicted that demand rates at customers were static and constant. However, in real-life applications, we know that demand rates are not usually constant and are variable or stochastic.

Hence, in this paper, we concentrate on a single-period deterministic inventory routing problem (SP-DIRP) in the construction sector, where the customers who are contractors at the construction site request the product at a constant demand rate. More specifically, we consider a delivery system in which a homogeneous vehicle fleet is used to allocate some products from a construction consolidation centre (CCC) to a set of customers consuming it at constant demand rates, during a finite planning horizon. Based on the recent papers established by [20] and formulation of the multi-period IRP by [21], we formulate a linear mixed-integer model for solving the SP-DIRP problems in the construction industry.

3. Modelling of the SP-DIRP

The SP-DIRP model involves a single construction consolidation centre (CCC) using a homogeneous vehicle to distribute a product to a set of geographically customers which are scattered around the CCC over a given planning horizon. It is presumed that customer-demand rates are constant and static, and that travel-times are constant over time. The objective of the SP-DIRP model is to find the delivery time and optimal quantities, and vehicle delivery routes, so that to optimize the total transportation and inventory costs in the VMI system. To formulate the SP-DIRP model, the following assumptions need to be considered:

- Inventory capacities at the construction consolidation centre (CCC) and construction sites are supposed to be large enough so that the capacity constraints are omitted in the model.
- The time necessary for unloading and loading of the vehicle is disregarded in this deterministic model.
- Split deliveries are not permitted; such that a customer is always completely reloaded by a single vehicle on the same tour.
- Transportation costs of the vehicles for delivery of the products are assumed to be directly proportional to the travel times.
- Driving times for the truck drivers are restricted to eight hours per day.

Let τ_t be the planning horizon size in time units of period 1, in this research, we are using eight working hours per day as a driving time restriction. Let S be the set of customers located in the construction site in which denoted by i and j; and $S^+ = S \cup \{r\}$, which represents the CCC. A homogenous fleet of vehicles V is used to distribute these customers. In this study, we consider an overall cost structure, comprising of the following four cost components:

- φ_j : The fixed handling cost per shipment at location $j \in S^+$ (CCC and customers);
- ψ_v : The fixed operating and maintenance cost of vehicle $v \in V$ (in RM per hour);
- η_j : The holding cost of the product per unit per period at location $j \in S^+$;
- δ_v : Travel cost for the vehicle $v \in V$ (in RM per kilometer);

The relevant additional model parameters, as well as the model variables, are described in the following subsections below:

Model parameters:

- κ_v : The capacity of vehicle $v \in V$;
- ν_v : Average speed of vehicle $v \in V$;
- θ_{ij} : Duration of a journey from customer $i \in S^+$ to customer $j \in S^+$;
- d_j : The constant demand rate at customer j .
- Ij_0 : The initial inventory levels at each customer $j \in S$.
- Q_{ij}^{v}: The quantity of product outstanding in vehicle $v \in V$ when it travels exactly to location $j \in S^+$ from location $i \in S$. This quantity product equals zero when the trip (i, j) is not on any tour of the route travelled by vehicle $v \in V$;
- q_j : The quantity distributed to location $j \in S$, and 0 otherwise;
- I_j : The inventory level at location (CCC and customers) $j \in S^+$;

Model variables:

- x_{ij}^{v} : A binary variable is set to 1 if location $j \in S^+$ is visited immediately after location $i \in S^+$ by vehicle $v \in V$, and 0 otherwise;
- y^{v} : A binary variable is set to 1 if vehicle $v \in V$ is being used, and 0 otherwise.

Therefore, if we let I_{jr} be the initial inventory level at the CCC, the following linear mixed-integer program provides a feasible formulation of the single period DIRP is given:

SP-DIRP: Minimize

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

Subject to:

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

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

$$\sum_{i \in S^+}\sum_{j \in S^+}\theta_{ij} x_{ij}^v \le \tau_t, v \in V \quad (4)$$

$$\sum_{v \in V}\sum_{i \in S^+} Q_{ij}^v - \sum_{v \in V}\sum_{k \in S^+} Q_{jk}^v = q_j, \ \forall j \in S \quad (5)$$

$$Q_{ij}^v \le k^v x_{ij}^v, \forall j \in S^+, v \in V \quad (6)$$

$$I_j + q_j - I_j = d_j \tau_t, \forall j \in S \quad (7)$$

$$I_{jo} \le I_j, \forall j \in S \quad (8)$$

$$x_{rj}^v \le y^v, \forall j \in S^+, v \in V \quad (9)$$

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

The main objective function (1) comprises four cost components, in which total fixed operating and maintenance cost of the vehicles, total delivery handling cost, total transportation cost, and lastly total inventory holding cost at the CCC and customers. Constraint (2) approves that each customer at the construction site is visited at most once. Constraint (3) promises that if a vehicle arrives at a customer at a specific location, it must leave after it has delivered it to the next customer or to the CCC. Constraint (4) is to ensure that vehicles or trucks complete their routes within one travel period, so the total travel time of a vehicle should not exceed the total working hours. Constraint (5) determines the quantity needs to be delivered to a customer at the construction site. The vehicle capacity constraints are given by (6) and to assure that the variables Q_{ij}^{v}, cannot carry any cumulated flow unless x_{ij}^{v}, equals 1. Constraint (7) is the inventory balance equations at the customers at the construction site. Constraint (8) designates that the final inventory level at customer *j* at the end of the period is of the same magnitude as its initial inventory. Constraint (9) indicates that a homogenous vehicle cannot be used to deliver any customer unless it is designated.

4. An Illustrative Case for the SP-DIRP Problem

To illustrate the performance of the proposed model, we consider the following a small example case with 15 sets of contractors or customers for the single-period deterministic inventory routing problem (SP-DIRP) system in the construction sector. In this example case, each of the customers at the construction site which is scattered around the construction consolidation centre (CCC) as shown in Figure 2. We are generated randomly demand rates of customers d_j are between 1 and 3 tons per hour. A vehicle *V* with a capacity of truck κ^v 80 tons is available for product replenishment from the CCC. For simplicity, we assume that the unloading and loading times of the vehicle are negligible and customers at the construction site have no storage capacity restrictions. Then, the fixed operating and maintenance cost of the vehicle ψ^v is RM 50 per vehicle. We assume that the truck's average speed v_v is constant at 50 km per hour, and the travel cost δ_v is RM 1 per km. Travel times can be calculated from the distances (in km) by considering an average speed of 50 km/hour for each vehicle. Finally, we also consider that the fixed delivery handling cost φ_j of RM 25 is the same for all customers and the size in time units τ_t is set to be 8 hours per day. The values of the parameters to each of the customers are then showed in Table 1.

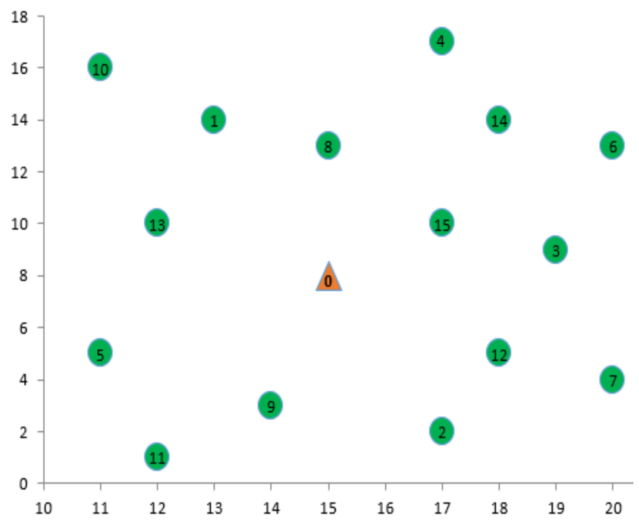

Figure 2. A simple example case with 15 customers with deterministic demand rates

The generated 15 customers instance of the SP-DIRP is solved by A Mathematical Programming Language (AMPL), with CPLEX 12.2 solver. The optimal solution of the 15 customers is graphically demonstrated in Figure 3 and the quantities that are delivered to each of the customers are presented in Table 1.

Table 1. Parameters and delivery quantity to each of the customers for the SP-DIRP

Customer	Demand rate (ton/hour)	Delivery cost (RM)	Delivery (ton)
1	2.23	25	40.88
2	2.54	25	37.04
3	2.99	25	23.92
4	1.58	25	22.48
5	1.31	25	10.48
6	2.60	25	20.80
7	1.35	25	27.68
8	2.71	25	21.68
9	1.97	25	15.76
10	1.95	25	15.60
11	2.09	25	16.72
12	2.05	25	16.40
13	2.94	25	23.52
14	1.88	25	15.04
15	1.50	25	12.00

For the solution, we can see that only one vehicle is applied to replenish the product to each customer. As illustrated in Figure 3, the customers are allocated to four routes. Vehicle V_1 makes multiple deliveries consisting of the following tours to route C_1 (2, 9, 11, 5), route C_2 (6, 14, 4, 8), route C_3 (12, 7, 3, 15), and route C_4 (13, 10, 1).

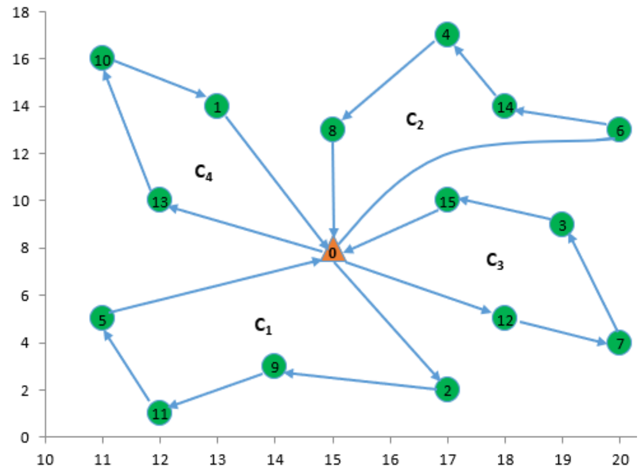

Figure 3. An optimal solution of the 15 customers

Table 2. Vehicle load for the different tours

Tour	Vehicle load (ton)
C_1 (2-9-11-5)	37.04 + 15.76 + 16.72 + 10.48 = 80.00
C_2 (6-14-4-8)	20.80 + 15.04 + 22.48 + 21.68 = 80.00
C_3 (12-7-3-15)	16.40+ 27.68 + 23.92 + 12.00 = 80.00
C_4 (13-10-1)	23.52 + 15.60 + 40.88 = 80.00

For this illustrative example, the solution gives the optimum value of RM 1500. From Table 2, we can compute the vehicle load for each of the tours. Based on the delivery quantities to each customer at the construction site, we can recognize that the capacity of the vehicle is optimized efficiently. For instance, vehicle 1 distributes 80 tons to each of the routes. Route C_4 {(13, 10, 1)} delivers 23.52 tons product to customer 13, 15.60 tons product to customer 10 and 40.88 tons product to customer 1, with a total demand rate of 80 tons, which is similar with the vehicle capacity being used for the delivery of the materials or products. Same situation to route C_1 (2, 9, 11, 5), route C_2 (6, 14, 4, 8), and route C_3 (12-7-3-15). A vehicle has delivered to all these routes exactly in a total of 80 tons of products to the customers at the construction sites. Thus, it demonstrates that the vehicle loading capacity is fully utilized precisely with the capacity consumption for all routes is about 100%.

4. Concluding Remarks

The use of multi-tours in VMI policy, to design the distribution of the product and manage inventories at the customers which are located at the construction sites. This makes management of replenishment and distribution relatively optimize efficiently. In this paper, we have explored the single-period deterministic inventory routing problem (SP-DIRP) in which a single construction consolidation centre (CCC) is distributing the product to a set of customers at the construction site. Thus, we proposed a model for solving the problem in which demand rates are constant, using a fleet of homogeneous vehicles over a given finite planning horizon. The main objective of the research is to optimize the total transportation and inventory costs in the construction industry. We then proposed a formula for a linear mixed-integer program for solving the SP-DIRP problems. The proposed model needs to find the optimal quantities to be distributed to the customers, the delivery time, and to design routes of the vehicle delivery. The initial analysis from the case shows that our model performs better. The computational results that we attained with the approach are very promising.

However, for further research approach, we will be extending our model to the medium and large example cases. Also, we need to apply the existing model to real-life problems, including a very large set of customers at the construction sites. Finally, many issues need to be tackled and some extensions are currently examined to see how the existing approach can be explored to the multi-period stochastic and deterministic case.

Acknowledgments

This research was sponsored by Universiti Utara Malaysia (UUM) through Geran Penjanaan Universiti, under SO Code No. 14585.

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