A Combination of A Simple Sweep Heuristic and Exact Method to Solve Vehicles Routing Problem Under Uncertainty of Demand and Service Time Interval: Case Study in Rainbow Water Delivery Service, Thailand

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Abstract

This research aims to use simple heuristic to solve a case study of vehicle routing problem under uncertainty of demand and required service time interval (RSTI). Rainbow water delivery service (RWDS) is the company that delivers two types of water to all 101 customers. It has two major uncertainty properties. The uncertainty of demand changed over the planning horizon, we present three strategies which are : delivery water to customers according to their (1) minimum, (2) maximum and (3) average demand that customers buy water from RWDS. The second uncertainty is number of days that the customers did not buy water from RWDS is not stable depending on the usage of water during the period we call this uncertainty required service time interval (RSTI) we use average RSTI to manage the uncertainty. Average RSTI will be use to fulfill the shipping plan of all customers over 32 days planning horizon. Firstly, the customer will be cluster into two group (1st and 2rd) using sweep algorithm. Then each customer will fulfill the plan with average RSTI time until it reach end of planning horizon. Next step, each day in planning horizon will be clustered according to truck capacity limitation (each customer has different demand according to the strategies that we use to manage uncertainty demand). Finally, each cluster will be routed by CPLEX. After we get solution of transportation route we apply routing and number of load in each truck to the case study (only mean strategy). We found that the company can reduce 13.85% of transportation distance. 92.68% of number of times that RWDS visits the customers but the customer does not want the service. Reduce 84-85.14% number of products that have to delivery back to the depot after all customers are visited.

***Keywords*:** Sweep algorithm, Vehicle Routing problem, Traveling Salesman Problem, exact method, Uncertainty

1. Introduction

Rainbow water delivery service (RWDS) is located in Nakornpanom province which is in the North Eastern part of Thailand. RWDS delivers two types of product which are 5 liters buckage (5B) and a box which contain 24 bottles of 0.5 liters of water (0.5B). It has 101 customers to service. Customers have different demands and required service time interval (RSTI) . The example of RSTI is as follows: on Monday customer A need 5 buckages of water then customer A want again water on Tuesday 3 buckages, then 4 buckages on Friday. This example make it is very hard to find appropriate the right number to load , right time to deliver and right route to transport products to all customers with the good customer satisfaction.

Recently there is plenty of researches have been done in area of finding good solution for VRP problem such as Dantzig and Ramser [1] presents Vehicle routing problem since then 45 years, tons of research have been proposed to solve VRP problem in various disciplines.

Golden et.al. [2] presents problem and methodology to solve VRP problem with different demand of customer in constraint of maximum tour length (Standard Vehicle Routing Problem: VRP)

Clark and Wright [3] presents a classic saving method to solve VRP which is one of the most popular heuristic that use as the starting point of a lot of powerful metaheuristic approaches. Later on, Gillett and Miller [4] proposes Sweep approach which is used as the clustering method in more recent articles involved in VRP and so do we.

Holmes and Parker [5] develops algorithm base on saving algorithm to solve VRP problem under vehicle load capacity both symmetric and asymmetric distance metric.

Chen and Chai [6] presents hybrid Metaheuristic by applying two metaheuristics which are Simulated Annealing (SA) and Tabu Search (TS) to solve vehicle routing problem with simultaneous Pick-up and Delivery :VRPSPD). Later on, in 2007, Bianchessi and Righuni [7] presents heuristic which base on Tabu Search technique then includes Arc-exchange-based and Node-exchange-based in constructing Tabu list.

Kima, Kimb and Surya [8] Benjamina, and Beasley [9] study the waste collection routing problem with time windows (VRPTW). Normally, the time window in waste industry is neglected if we consider on residential collection, but in commercial waste collection the appropriate period of collecting time is very important aspects. Both of these articles also have the driver rest period as one of their constraints too. The first paper solves the problem with a capacitated clustering-based algorithm. Their proposed algorithm has been successfully implemented in one of the biggest waste collection company in America. The latter paper use Tabu search and Variable Neighbourhood Search and can produce better solutions than previous studies with the problems involving over 2,000 customers

The problem that Tan, Cheonga and Goha [10] study is similar to our problem due to the actual demand is revealed only when the vehicle arrives at the customer. They solved this stochastic demand problem with a multi-objective evolutionary algorithm. They also validated their algorithm with a few of other type VRP benchmark problems too.

Repoussis and Tarantilis [11] use Adaptive Memory Programming (an Iterated Tabu Search algorithm with intense local search and frequency-based memory structures) to solve the Fleet Size and Mix Vehicle Routing Problem with Time Windows or FSMVRPTW. This method improves the best results over most benchmark instances with reasonable time.

One of unfamiliar variants of VRP is Open VRP (OVRP). The unique aspect is the vehicles are not required to return to the depot after completing their service. Salaria, Toth and Tramontani [12] present a heuristic for OVRP based on Integer Linear Programming (ILP) techniques and their proposed algorithm is able to find the new best known solution for the considered instances. Moreover, the solving procedure can be extended to cover other variants of VRP as well.

Emmanouil E. Zachariadis and Chris T. Kiranoudis [13] present the interesting topic about complexity reducing of local search-based methods for the VRP. They introduced the Static Move Descriptor (SMD) data structures, which encode local search moves in a systematic and independent manner base on the concept that only a limited part of the solution is modified when a local search is applied. The proposed method was tested on very large scale and real-world VRP instances and produced fine results.

In case study, we separated our problem into three sub problems which are (1) problem that deal with the uncertainty in service time interval of each customers in order to reduce number of customer that reject the delivery and number of products that have to return to depot (2) problem that we should find a good route for each customer in order to generate the minimum transportation cost (3) problem of loading the product into truck in order to have suitable amount to deliver to all customer which we expect the same result as (1)

2. Management of Uncertainty

2.1 Current position of the case study

RWDS has 101 customers to be deliveried. 56 customers have demand on both 5B and 0.5B while 30 customers need to be delivery only 5B and 15 remaining customers want only 0.5B products. In preliminary data collection we found that the longest time interval of each customer will accept the delivery in 16 days interval. Thus in order to let all customers be checked in demand and time interval we decide to have 32 days experiments to collect current position of the case study.

We found that in 32 days, 5B product has been loaded in the truck 2,114 buckages but can sales only 1,562 buckages while 0.5B has been loaded 907 boxes and return home 400 boxed which is rather high when comparing with the sales volume. We found that in 1680 times of the truck that visit customer it has 314 times that the customer rejects or 18.69% of all visits is rejected from the customers. It has tour length of 946.36 km to transport water to all customers in 32 days.

Besides the data addressed above we found the case study has managerial problems as following:

(1) In each route there is no pre specific number of customers.

(2) The transportation routes are decided by the driver which employ common sense to design the route.

(3) Customers have uncertainty demand and service time required interval for example customer A001 which want only 5B products has been decide to visit by the driver in day 1, 3,4,5,6 and 7 and customer A001 decides to buy water in day 1,4,5 and 7 in amount of 8,2,2 and 5 buckages respectively as shows in Table 1.

Table 1: Number of 5B product delivered to customer A001

Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Number of 5B accepted	8	-	0	2	2	0	5

From this data we found that customer A001 has first service time required interval of 3 days (1^{st} and 4^{th} day) The second time interval is 1 day (4^{th} and 5^{th} day) and the last time interval is 2 days (5^{th} and 7^{th}) and each time interval has different demand as well. Due to this data has no specify format we decide to use average number of time interval to solve the first uncertainty which is occurs in our preliminary result. From Table 1 it has several uncertainty which clearly see which are:

(1) Required service time interval (RSTI). In Table 1 customer A001 buy 4 times, each time has time interval (days) of 3,1,2 days respectively. We present the simple way to deal with this problem. Firstly, every product will be inspected to discover RSTI along the planning horizon. Then, for each product, the average RSTI is calculated. For example, product A001 has average RSTI equals to (3+1+2)/3 or equals to 2. This number will be use to find shipping plan which will be explained in section 2.2

(2) Demand uncertainty of the customer, each customer has different demand for example customer A001 buy 4 times of water out of 6 times of visits each time has 8 ,2,2 and 5 buckages accepted respectively. We can see that it is demand uncertainty. Dealing with this problem we design 3 strategies to cove with this problem which are:

(a) Deliver as minimum numbers of product that has been accepted by specified customer so far, this strategy decides based on idea to get rid of all products that have been return to depot. As shows in table 1, if we use this strategy 2 buckages of 5B will be calculated as demand of customer A001

(b) Deliver as maximum number of product that has been accepted by specified customer so far, this strategy decides based on idea to generate maximum number of sales volume. As shows in table 1, if we use this strategy 8 buckages of 5B will be calculated as demand of customer A001

(c) Deliver as average number of product that has been accepted by specified customer so far, this strategy decides based on idea to generate maximum number of sales volume while keep idea of reducing product return . As shows in table 1, if we use this strategy (8+2+2+5)/4 which equal to 4.25 or 5 buckages of 5B will be calculated as demand of customer A001

From these three strategy we use demand at each node (customer) to find the route of transportation. We draw all customers into the map which generated from Google map as shows in Figure 1.

2.2 Heuristics Approach for the case study

We use cluster first route second algorithms base heuristics to fine a good solution for the routing problem. Firstly, all 101 customers will be clustered into two groups in order to let all customers be serviced in the first two days (due to all 101 customers can not be served in 1 day). For example in Figure 1 show the first line of angle 0 to 180 degree will be selected to be served in the first day (top part of the line) and customers which are located between 181 degree to 360 degree will be served in the second day.

Fig.1 Position of 101 customers of Rainbow water delivery service [source: http://maps.google.co.th/]

In the algorithm, this angle will be iteratively random selected. Next step, assign the service day for each customers by predefined service time required interval as we have discussed in section 2.1. Thus, all customers will be on our plan for 32 days (planning horizon). Each day all customers will be clustered and designed route by using cluster first route second algorithm. In all transportation planning firstly, we use sweep heuristic to cluster customers under limited truck load after we get clusters of customers then we apply exact method, commercial optimization software (CPLEX) to fine transportation route.

In optimization software we firstly formulate mathematical model and then program in CPLEX to find the optimal route for all clusters. The mathematical model used will be explained later. The solution of each cluster will be integrated as the part of global solution of the transportation plan for arbitrary iteration. Then the algorithm will be re-run again until the stopping criteria are met.

From Table 2, customer A001 to A0012 have demand of 5,3,4,2,6,1,2,3,3,2,7 and 8 and have service time required interval of 2,3,4,1,2,1,3,2,5 and 4 days respectively. In Table 2 shows delivery plan of one truck of RWDS respectively. Customer A001 , A002, A004,A005,A006,A007 and A0010 are clustered in the first group of first two days clustering (using sweep method) while others customers is clustered into second day group. Number of delivery of customer A001 is 5 (from section 2.1) and the next delivery of customer A001 will be in the 3rd day due to the time interval of A001 is 2 days this mechanism will be applied to all customer in the list (as shows example in Table 2).

Table 2: Shipping plan of customer A001-A0012

Day	1	2	3	4	5	6	7	8	9
A001	5		5		5		5		5
A002	3			3			3		
A003		4				4			
A004	2	2	2	2	2	2	2	2	2
A005	6					6			
A006	1	1	1	1	1	1	1	1	1
A007	2		2		2		2		2
A008		3	3	3	3	3	3	3	3
A009		3			3			3	
A0010	2		2		2		2		2
A0011		7					7		
A0012		8				8			

Next step, customers which appears in each day, for example in day 3 has 6 customers which are customers A001,A004,A006,A007,A008 and A0010 will be re-clustered according to the truck capacity. Customer A001, A004, A006, A007, A008 and A0010 have demand 5, 2, 1, 2, 3 and 2 buckages respectively. If one truck has load of 9 buckages, when we sweep first cluster we get customer A001 (5), A004 (2), A006 (2) in the cluster which has 9 buckages to carry (full capacity). While, the second cluster we have A007 (3) and A008 (2) which has 5 buckages to carry. Then A001, A004 and A006 will employ CPLEX to find the optimal route, for example we design route of Depot-A001-A006-A004 for the first transportation plan. Then we do the same for customer A007 and A008. In each cluster, we use CPLEX to find the optimal route by applying mathematical model of simple TSP problem. When all clusters have been solved to find transportation route, the integration of solution from all sub-problems (all clusters) which are solved will be the result of the algorithm

Mathematical model formulation

Indices

i = customer (1..n)

j = customer (1..n)

n = number of customers

Decision variable

$$X_{ij} = \begin{cases} 1 & if\ there\ is\ travel\ route\ between\ i\ and\ j \\ 0 & otherwise \end{cases}$$

Parameters

$$d_{ij} = distance\ between\ i\ and\ j$$

Objective function

$$Minimize \quad z = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}X_{ij}$$

Subject to

$$\textstyle\sum_{i=1}^{n} X_{ij} = 1 \qquad \forall\ j = 1 \dots n \qquad (1)$$

$$\textstyle\sum_{j=1}^{n} X_{ij} = 1 \qquad \forall\ i = 1 \dots n \qquad (2)$$

$$\sum_{i\in S}\sum_{j\in \bar{S}} X_{ij} \geq 1 \qquad for\ every\ subset\ S \qquad (3)$$

$$\sum_{i\in S}\sum_{j\in S} X_{ij} \leq |S| - 1 \qquad for\ every\ subset\ S \qquad (4)$$

Objective function of this model is to minimize total distance traveled in all customers link. (1) guarantee that there is at least one travel to a customer while (2) prove that only one time that a customer can travel to another customer while (4) and (5) is sub-tour elimination constraints under circumstance that *S* is a set of customers. CPLEX will be used to solve each cluster by using addressed mathematical model formulation (formula (1)-(4)).

The algorithm that we explained will be employed in everyday in planning horizon (32 days). After we finished first Sweep result for all 32 days we will re-Sweep again for each day which different starting point of sweep then we re-do Lingo v.11 for each cluster in each day. We will re-do this step until no improvement in tour length for 50 iterations. After that we will come back to re-do step one and we set our stopping criteria as 10 minutes using Compaq Presario B1200. Flow chart for proposed algorithm shows in Figure 2.

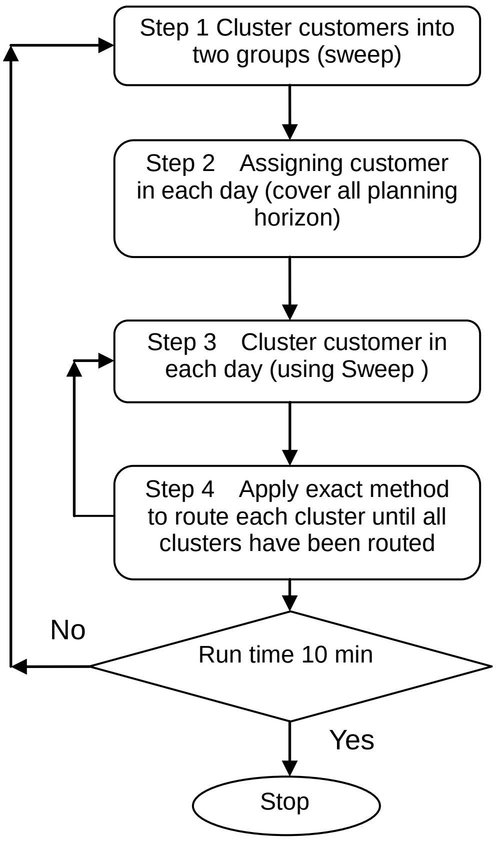

Fig. 2 Flow chart of proposed algorithm

Step 1 is to cluster all customers into two groups, because of from preliminary test we found that all customers demand and number of trucks that the company has it is possible to visit all customers in two days.

Step 2 is to integrate the service time required interval with the clusters that we have done in step 1 then, we get the shipping plan to whole planning horizon.

Step 3 is to cluster customers in each day using sweep method under truck capacity.

Step 4 is to route all cluster by exact method, in the case study we use CPLEX to route the transportation plan then we redo step 3 until no improvement occurs between 50 iterations then we move to re-do step 1until the time constraint is violated (10 minutes)

We applied the algorithm that we have propose to find the best route according to the simulation framework as we discuss before and result regards to the simulation is shown in Table 3

Table 3: Simulation result of the proposed algorithm

Strategies	**Cluster/Saving**	**Cluster/CPLEX**
Min	1004.98	851.79
Max	1151.69	1022.46
Mean	990.03	815.25

From Table 3, besides CPLEX that we use to optimize the tour in each cluster we also apply simple saving algorithm instead of CPLEX. In both algorithms we limit computational time as 10 minutes and total distance of all clusters are show in Table 3 (km). We can clearly see that in the same computational time cluster and then use CPLEX generates better solution than cluster and then use saving heuristic as the optimization tool for each cluster in all presented policy.

2.3 Evaluating the strategies

The evaluating of the strategy should be done after we have tested the route that we plan in section 2.2 but the RWDS allow us to try only one strategy thus we need to select one out of three strategies. We decide to use Delphi method to evaluate. Factors that we use as the criteria to evaluate the strategies (min, max and mean number of items that will be shipped to customer) are:

(1) Distance to customers
(2) Expected sales volume
(3) Expected Number of items returned
(4) Expected Customers satisfaction

These factors, we conclude from the discussion to owner of RWDS and owner of 8 others water-delivery-service companies. After we get factors that necessary to evaluate the strategies we let the experts give weight for each factors and also give score for each strategy resulting in Table 4.

Table 4: Result of the evaluating of the strategies

Factors	**weight**	**Min**	**Max**	**Mean**
Distance to customers	0.35	95	70	93
Expected sales volume	0.35	65	93	90
Expected Number of items returned	0.10	99	78	90
Expected Customers satisfaction	0.20	70	90	85
Total score	1.00	**79.9**	**82.85**	**90.05**

Resulting from the evaluating of strategy we will use Mean strategy to implement in the case study.

3. Result of the experiment

We implement strategy which is selected in section 2.3. Before the experiment we have determined the transportation route and send to the experts to evaluate the strategy (as shows in section 2.3). The determination of the transportation route we use algorithm as show in Figure 2. When we implement the route and number of shipping in each day in 32 days planning horizon, result of the experiment is shown in Table 4

Table 5: Result of experiment compare with current position of the customer

Key performance indicators (KPI)	**Current position**	**Experiment result**
Sales Volume of 5B (buckages)	1,562	1,628
Sales Volume of 0.5B (boxes)	507	655
Returned items of 5B (buckages)	552	82
Returned item of 0.5B	400	64
Number of time that customer reject the delivery	314	23
Total distance	946.36	815.25

From Table 5, number of sales volume increase from 1,562 to 1,628 of 5B and 0.5B increase from 507 to 655 boxes or for 5B increase 4.22% and 0.5B increase 29.12%. Besides that 5B can decrease number of returned items 85.14% and 0.5B decrease 84% while number of time that customer reject the delivery reduce 92.68%

4. Discussion and conclusion

From the experiment result we can clearly see that in all KPIs new transportation route together with the implemented strategy outperform the current situation of the company. Transportation distance reduces from 946.36 to 815.25 or 13.85% of the current distance. As we know from section 3 that number of customers that reject the service reduce 92.68% which can increase level of customer satisfaction. Customer satisfaction is the indicators of sale volume as we can see in number of product that have been sold is increase for product 5B and 0.5B around 16.78% in average of two products.

The experiment of our algorithm and strategy generate lower transportation cost, more sales volume, less product that has to deliver back to the company and less number of customer that reject the service. We still have some problems that to be solve in future research. Due to the uncertainty and nature of the company, number of customers rises everyday and also have different in demand but our algorithm is designed only for the case study thus we need to develop decision support system which has algorithm to solve like in our proposed heuristics but can be used when customer is changed in number and demand average. The new and more effective algorithm need also to be developed in later research in this case study in order to reduce transportation distance. From our knowledge we know that the managerial of service time interval which is require of each customer plays important role for the sale volume and other KPIs. In this research we use average time interval to manage it which can be improve so that the KPI's can improve in the next research such as use more stochastic involved strategy.

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