VEHICLE ROUTING AND SCHEDULING PROBLEMS:

A CASE STUDY OF FOOD DISTRIBUTION IN GREATER BANGKOK

By

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Abstract

Vehicle routing problem (VRP) and its extension is an area of importance to Operation Research theoreticians as well as very useful for real world applications. Recent research in this field has provided significant breakthroughs in problem formulation and in the design and analysis of algorithms. This study attempts to develop a daily truck routing and scheduling software, which will improve the efficiency of the perishable distribution in Bangkok of the food company. The scheduling will be done in such a way that it can satisfy all of the orders, while in the mean time, will attempt in order to improve the total distribution distance.

The software program was developed from the algorithm of Tillman and Cochran Algorithm (1968), which extended from Clarke and Wright Algorithm (1964). It is hopeful that this study can be used as scheduling software to schedule the distribution routing in any production fields.

Based on the results, the following can be concluded. The total distribution distance of the generated Vehicle Routing and Scheduling Software (VRASS) schedule is decreased from the present schedule between 11% and 27% without additional cost. Moreover, VRASS can generate the schedule in various routes in any tour. It is noticed that using VRASS make the schedule more flexibility to select and allocate the appropriate route and choosing the appropriate truck. Furthermore, the utilization of resources was better than the present schedule. In addition, VRASS Schedule was also consumed a shorter planning time. And last but not least, VRASS can be used as a tool to predict the future expansion requirement of the fleet size.

Introduction

Background

Decisions making problems related to distribution management are classified into three levels (1) Strategic level for decision-making relates to the location of facilities (plants, warehouses, or depots). The decision in this level is very important because the locations of the facilities have many effects on the costs of various operations in lower levels. (2) Tactical level relates to the problem of fleet size and mix determination: The decision in this level will be made based on the given facilities and demand. (3) Operational level relates to the problem of routing and scheduling of the existing vehicles and staffing of such vehicles. This decision should be made on day-to-day basis.

In this study, the decision-making problem involving the operational planning is to be analyzed; namely the study will cover the development of the routing and scheduling software. The study is done on the section of perishable food distribution of the restaurant business company, particularly on the problem of daily scheduling of food deliveries.

At present the food is distributed from the central depot in Bangkok to the branches in Greater Bangkok Area (GBA). The company has already fixed an existing route of perishable food delivery trucks that is available for scheduling based on past experience of the staff. These delivery tasks have to be assigned to the trucks on a daily basis. The scheduling tasks are currently done manually and the drivers assign the deliveries routing, however, the company is thinking about computerization. As a result, this routing and scheduling problem has to be analyzed and a software program that can improve the efficiency of the operations should be developed. The developed program shall be coded in conventional programming language.

Statement of the problem

The company faces the problem of scheduling and routing the trucks with several orders for several types of food everyday. They categorize foods into two groups (1) perishable food: around 80 types (2) non-perishable food: around 200 types. This task has been done manually using the experience of the staff person, so the optimality may not be achieved, which also implies that the company may not operate at the optimal level.

As mentioned before, the decisions about the distribution function are made using the past experience of the staff. For example, the delivery routes are chosen by the staff, as well as the matching of branches to be on the same tour, the allocation of delivery tasks to trucks, and the sequence of tasks on each truck and so on.

The problem is defined as follows: Given a set of expiratory food orders that have to be done and a set of available trucks; a software program have to developed schedules for task sequencing, trucks routing, and route description individually.

The trucks can categorize into four groups as follows:

Table 1: Type of Available Truck

Group	Type	Quantity (truck)	Capacity (ton)
1	Freezing Truck	3	1
2	Cooling Truck	6	1.5
3	Regular Truck	2	N/A
Spare	Regular Truck	1	N/A

This problem will concentrate in the whole problem into two sub problems. One is the freezing truck problem. Another one is cooling truck problem. Both of them have different characteristics as described as follows:

Freezing Truck Problem

There were 3 identical trucks with 1.0-ton capacity each. They operated this truck based on the basis of two-day time horizon. They used these trucks for delivering only fresh meat that ordered from branches in 6 different routes depend on which time horizon and which tour considered. Since meat orders were heterogeneous demand, but the company's policies for delivery a raw materials allowed only this type of trucks to deliver the meat product. And the packaging of all meats was doing in the same way. Thus, we can relax this constraint to become a homogeneous demand. According to the first day period, these trucks were assigned to deliver through a big tour (around 8 branches per trip that served all famous branches and not too famous branches in the same geographical location). And for the second day period, these trucks are assigned to deliver through a small tour (around 4 branches per trip only for a famous branch). At present, they assigned 8&4 branches ordered to each truck for big & small tour based on which time horizon is. Therefore, they fixed branches and routes for each truck two-day basis repeatedly.

Cooling Truck Problem

There were 6 identical trucks with 1.5-ton capacity each. They operated this truck on the basis of one-day time horizon. They used these trucks for delivering vegetables and sauces (but majority for vegetables; sauces can load to the available space in the truck) in 6 different routes. Since vegetable orders were also heterogeneous demand but in this case the company's policy were same as the freezing trucks. Thus its demand becomes homogeneous demand with one-day time horizon. At present, they assigned 4 branches ordered to each truck daily. Therefore, they fixed branches and routes for each truck one-day basis repeatedly.

Objectives of the study

The main purpose of this study is to develop a daily truck routing and scheduling software, which will improve the efficiency of the perishable distribution in Bangkok of this company. The scheduling will be done in such a way that it can satisfy the orders, while in the mean time, will attempt in order to improve the total distribution distance.

Scope and limitation of the study

The study concentrates on the development of the routing and scheduling software only for Freezing Trucks and Cooling Trucks, which develop tasks sequencing, trucks routing to deliver perishable foods from central depot to all branches in order to minimize the total distribution distance.

Problem Classification

The problem in this studied has the following characteristics: multiple vehicles with identically properties, single use (trip) of vehicles, single type of vehicles, single depot, deterministic with homogeneous demands, undirected network (symmetric distances), delivery operations only, single period of time horizon within soft constraints and fleet size is large enough to handle all demands. The objective of this study is to minimize total distribution distance.

Literature Review

Vehicle routing problem (VRP) and its extension is an area of importance to operations research theoreticians as well as very useful for real world applications. Recent research in this field has provided significant breakthrough in problem formulation and in the design and analysis of algorithms.

It consider the distribution problem in which vehicles based at a central facility (depot) are required to visit during a given time period geographically dispersed customers in order to fulfill known customer requirements. The problem appears in a large number of practical situations concerning the distribution of commodities and is known by the generic name: the vehicle routing problem (VRP). The VRP is also known in the literature as the 'vehicle scheduling' [Clarke & Wright, 1964; Gaskell, 1967], 'truck dispatching' [Dantzig & Ramser, 1959; Christofides & Eilon, 1969; Krolak, Felts & Nelson, 1972] or simply 'delivery problem' [Hays, 1967], and appears frequently in situations not related to the delivery of goods. For example, the collection of mail from mail boxes or coins from telephone boxes, house call tours by a doctor, salesman routing, preventive maintenance inspection tour, etc. [Stern & Dror, 1979] are all VRPs in which the 'delivery' operation may be a collection and/or delivery or neither, and in which the 'customer requirements' and 'vehicles' can take variety of forms, some of which may not even be of a physical nature.

In view of the enormous number of practical situations which give rise to VRPs, one can only hope to study the basic problem which is at the core of all vehicle routing problems. It calls this core problem as the basic VRP.

VRP classification

Dantzig and Ramser (1959) originally proposed VRP. Since then, VRP has been extensively studied. Bodin et al. (1983) has been presented the most general bibliography. According to its characteristics, VRP can classify into follow classes which described in Table 2:

Table 2: Classifications of VRP

	Characteristics	Options
1	Size of fleet	One vehicle Multiple vehicles
2	Type of fleet	Homogeneous Heterogeneous Special vehicle
3	Housing of vehicle	Single depot Multiple depot
4	Nature of demand	Deterministic demand Stochastic demand
5	Nature of product	Homogeneous Heterogeneous
6	Underlying network	Undirected-Directed Mixed
7	Operations	Pick-ups only Deliveries only Pick-ups and deliveries on one trip
8	Costs	Variable cost Fixed cost
9	Time windows	Soft constraint Hard constraint
10	Horizon	Single period Multiple period
11	Objectives	Minimize total distribution time or distance Minimize sum of fixed cost and variable cost Minimize number of vehicles required Minimize total routing cost Maximize utility function based on service or convenience

The basic VRP and its extensions

The customers are indexed $i = 1,…, n$ and $i = 0$ refers to the depot. The vehicles are indexed $k = 1,…, m$. A customer i has a demand of q_i. The travel cost between customer i and j is c_{ij}. The capacity of vehicle k is Q_k. It will assume that all customers and vehicles are ordered in descending order of q_i and Q_k respectively.

The basic VRP is to route the vehicles (one route per vehicle, starting and finishing at the depot), so that all customers are supplied with their demands and the total travel cost is minimized.

The basic VRP ignores a large number and variety of additional constraints and extensions that are often found in real-world problems. Some of these constraints and extensions are [IBM, 1970; Christofides, Mingozzi & Toth, 1982]:

(i)   Each vehicle can operate more than one route, provided the total time spent on these routes is less than a given time T (which is related to the operating period). Note that such a constraints-in common with many of the ones listed below-requires the knowledge of travel time (t_{ij}) between every pair of customers.

(ii)   Each customer must be visited only at a time that lies in one of a given number of working time windows during the period.

(iii) The problem may involve both deliveries to and collections from customers. In addition, it may be possible to mix deliveries and collections on a single route, or alternatively, it may be required for a vehicle to first perform al the deliveries in the route before performing the collections. This latter case is often referred to as backhauling.

(iv)   Just as in (ii) above (every customer has working time windows), vehicles (in fact their drivers) may also have working time windows during the period. The vehicle can then only operate during the specified time windows.

(v)   Time-consuming activities other than the travel times (t_{ij}) mentioned above must also be considered. These include: unloading times (or loading times for the case of collections) at the customer premises; loading times of the vehicles at the depot-both for first and for any subsequent routes; queuing times of vehicles for loading at the depot if the number of available loading bays is limited; etc.

Although the constraints and extensions listed above are only a small fraction of those found in practice, it does not change the essential nature of the basic VRP and can be incorporated in quite a number of the heuristic methods for solving the problem. On the other hand, there are some other practical considerations that also arise frequently, and which do not fit neatly into the basic VRP framework.

Heuristics for the basic VRP

A great deal of work has been done devising heuristics for the VRP, although much less effort has been spent comparing and drawing conclusions. The possibilities are virtually limitless and the purpose of the present section is not to list them all, but simply to provide an outline of some of the best known.

Constructive methods

Constructive methods can be further classified according to:
(a) The criterion used to expand the routes, and
(b) Whether the routes are constructed sequentially or in parallel.

Saving methods

   Clarke and Wright (1964): suggested a simple method for optimum routing of a fleet of trucks of varying capacities from a central depot to a large number of delivery points. This heuristic is one of the earliest ones and is without doubt the most widely known heuristic for the VRP. Clarke and Wright have modified the original method by Dantzig and Ramser. The procedure is simple but effective in producing a near-optimal solution. It is an "*exchange*" procedure in the sense that at each step one set of tour is exchanged for a better set. First of all, each tour simply connects depot and 1 customer. Then it combines any 2 customers into 1 route if total demand does not exceed vehicle capacity. The saving cost due to combination is calculated and the largest is selected. When a combination cannot reduce the total distance, it tries to exchange 2 customers in 2 routes by breaking 2 links and setting 2 new links. The saving distance due to exchanging is calculated and the move corresponding to the largest saving is selected if it does not violate capacity or time constraints.

   In the method of Clark and Wright, saving of combining 2 customers' i. and j into one route is calculated as:

$$S_{ij} = d_{0i.} + d_{0j} - d_{ij}$$

   Where d_{ij} denotes travel distance from customer i. to j. Customer "0" stands for the depot.

   Tillman and Cochran (1968): developed an algorithm to solve this kind of problem. The proposed method is heuristic and is an extension of the method of Clark and Wright. The essential differences of the two methods are that the present method allows for the inclusion of restrictions on the system and will in some cases yield a better answer. It is noted that neither method of Clark and Wright (1964) nor method of Tillman and Cochran (1968) guarantees and optimal solution. And both methods require the distance matrix to be symmetric. This current method allows for restrictions on the system whereas the previous method does not. Their concept is the selection criterion, which requires looking at the effect of two choices in sequence could be extended to looking at three, and so on, but the computation becomes extensive in large problems.

Methodology

Mathematical Model Approach

These model used for described the structure of the problem in mathematical ways. The objective function of this kind of problem is non-linear function, which difficult to achieve the optimal solution by mathematical approach.

Notation

Let
- i = Job that assign on truck; $i \in \{1,2,3,\ldots, rm\}$
- l = Position that job occupied in a tour; $l \in \{1,2,3,\ldots, r\}$
- k = Truck number; $k \in \{1,2,\ldots, m\}$
- m = Number of truck;
  - For Freezing Truck = 3 trucks
  - For Cooling Truck = 6 trucks
- n = Actual number of locations; $n \in \{23\}$
- r = Upper bound of number of locations visited daily

- $d_{i,j}$ = Distance between node i to node j
- w_i = Weight of order for i; unit: kg.
- W = Truck capacity;
  - For Freezing Truck = 1000 kgs.
  - For Cooling Truck = 1500 kgs.

Then
- Total number of jobs (dummy and non-dummy) = rm
- Total number of dummy locations located at the depot = rm-n

The decision variables:
- $x_{i,k}$ = 1; if node i assigned to truck k
  = 0; otherwise
- $y_{i,l,k}$ = 1; if node i occupies position l in the tour for truck k
  = 0; otherwise

<u>Mathematical model</u>

Objective function:

The objective of this study is to minimize the total distribution distance of overall trucks which is as follows:

$$\text{Min} \sum_{i=1}^{rm} \sum_{j=1}^{rm} \sum_{l=1}^{r-1} \sum_{k=1}^{m} d_{i,j} \, y_{i,l,k} \, y_{j,l+1,k} + \sum_{i=1}^{rm} \sum_{k=1}^{m} d_{0,j} y_{i,r,k} + \sum_{i=1}^{rm} \sum_{k=1}^{m} d_{0,i} \, y_{i,l,k}$$

Subject to:

Constraint 1: Capacity constraint; the load of any truck k does not exceed its capacity

$$\sum_{i=1}^{rm} \sum_{l=1}^{r} w_i \, y_{i,l,k} \le W; \qquad \text{for } 1 \le k \le m$$

Constraint 2: Assignment constraint; job i is assigned to precisely one truck at a time

$$\sum_{k=1}^{m} x_{i,k} = 1; \qquad \text{for } 1 \le i \le rm$$

Constraint 3: Assignment constraint; every job i assigned to truck k, occupies precisely one position l in the tour that truck k performs

$$\sum_{i=1}^{rm} \sum_{k=1}^{m} y_{i,1,k} = 1; \qquad \text{for } 1 \le l \le r$$

Constraint 4: Assignment constraint; every job i occupies precisely one position in the tour performed by truck k

$$\sum_{l=1}^{r} \sum_{k=1}^{m} y_{i,1,k} = 1; \qquad \text{for } 1 \le i \le rm$$

Constraint 5: Assignment constraint; if job i is assigned to truck k, the job i occupies a position in the tour performed by truck k

$$\sum_{l=1}^{r} y_{i,1,k} \le x_{i,k}; \qquad \text{for } 1 \le i \le rm \text{ and } 1 \le k \le m$$

Heuristic Approach

As mentioned above, the mathematical model proposed is nonlinear objective function, which difficult to find the optimal solution in shortens time. Heuristic approach is therefore proposed which can yield quickly and acceptable solution for this problem.

Tillman and Cochran (1968) had introduced their heuristic to solve this problem effectively by developed an extension of the method of Clark and Wright. Their heuristic allows for the inclusion of restrictions on the system. This current method allows for restrictions on the system whereas the previous method does not. Their concept is the selection criterion, which requires looking at the effect of two choices in sequence could be extended to looking at three, and so on, but the computation becomes extensive in large problems.

The Algorithm of Tillman and Cochran (1968)

Step1: Assigning of Identification numbers to the demand points
Step2: Initial allocation of trucks to demand point
Step3: Computation & Seeking the desire node (Find Maximum Saving)
Step4: Feasible Check
Step5: Attempt to join the better point (Find the next Maximum Saving)
Step6: Test for restriction constraint
Step7: Update indicator (Update t)
Step8: Update Order Remaining
Step9: Update Capacity Remaining
Step10: Return to Step5, until no feasible joint

Since the Tillman and Cochran (1968) had developed the algorithm to solve these kinds of problems, following their heuristic, the algorithm for coding the program was show in Figure 1 below; it is recommended by the author that setting the find maximum saving's iteration count equal to 16 is appropriate to get the feasible maximum saving from the distance matrix within shorter time. The program will order the saving in decreasing order starting from the highest first.

After the flow chart created, then coding the program in Delphi Borland 5 language is now coded. It is named as "Vehicle Routing and Scheduling Software (VRASS)". The source code of the program will show in detail in Appendix C.
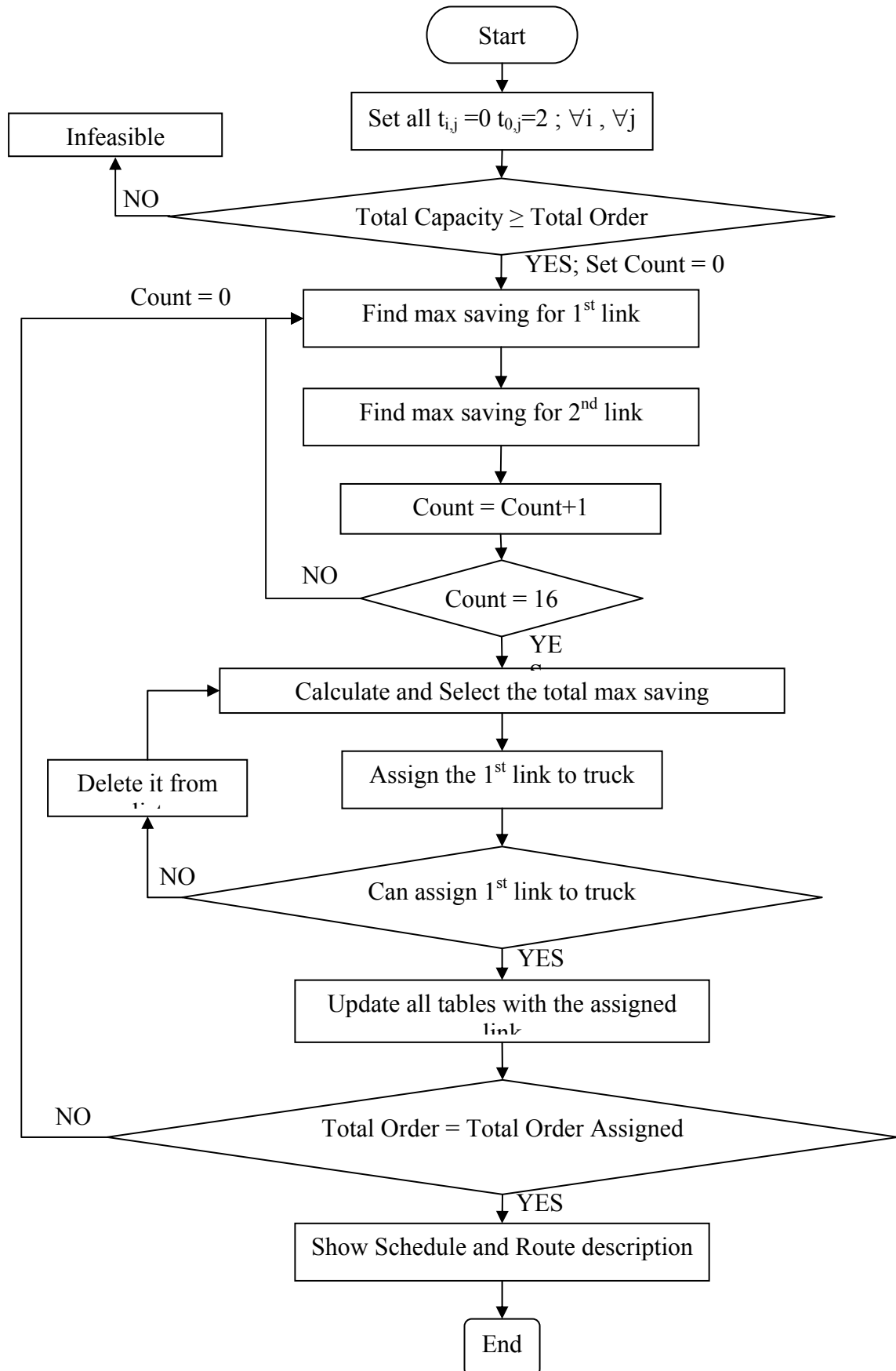
Figure 1: Flow chart of VRASS

Results

After Vehicle Routing and Scheduling Software (VRASS), which coded by using Borland Delphi5 language, was completed. It was recommended to test the program with the real situation data.

The Average Demand which came from the demand of all branches at the working day period was choose to be tested. It was noticed that not only Average Demand which was chosen to test VRASS, but also the Peak Demand which came from all branches at the weekend period needed to be test too.

The comparison data between the present schedule and the generated schedule, which show in Table 3, was described and showed the improvement of the generated schedule from VRASS compare with the present schedule.

From Table 3, it could be concluded that the generated schedule from VRASS was improved the total distribution distance of the Freezing Truck Schedule by 10.9% and 13.2% for average demand and peak demand. Furthermore, the total distribution distance of the Cooling Truck Schedule was also improved from the present schedule by 23.4% and 26.7% for average demand and peak demand. In addition, the VRASS schedule for Cooling Truck was assigned only five trucks to serve all demands daily. Then the surplus truck can be assigned to do another job. And also, the VRASS schedule was better than the present schedule in terms of capacity utilization on Cooling Truck.

It was noticed that the VRASS Software program can generate the schedule on daily basis within shorten time. The computation time was around 20 minutes on average (when applies 23 branches, 23 orders; with Pentium4 Processor 1.8 GHz. Ram 256 MB). It is competitive in terms of speed and the variety of routes construction when compare with the present schedule.

Table 3: Conclusion Table of Present Schedule compare with the VRASS Schedule

Type	Present Schedule				VRASS Schedule						% Improve	
	Present		Order		Avg. Demand		Peak Demand		Order		Distance	
	Saving	Distance	Avg.	Peak	Saving	Distance	Saving	Distance	Avg.	Peak	Avg.	Peak
Freezing												
F1	327	104.7	830	913	384	95	384	95	830	913	9.2646	9.2646
F2	140.9	109	680	748	234.5	76.4	249.3	111.2	730	946	29.9083	-2.0183
F3	222.1	88.9	730	803	109.5	98.3	101.8	56.4	680	605	-10.5737	36.5579
Total	690	**302.6**	2240	2464	728	**269.7**	735.1	**262.6**	2240	2464	**10.8724**	**13.2188**
Cooling												
C1	93.8	69.9	380	456	396.5	111.2	414.1	96.9	1360	1488	-59.0844	-38.6266
C2	149.3	64.7	490	588	202.7	58.2	202.7	58.2	760	912	10.0464	10.0464
C3	104.7	58.4	500	600	35.2	41	35.2	41	200	240	29.7945	29.7945
C4	34.5	65	480	576	31.2	68.4	31.2	68.4	380	456	-5.2308	-5.2308
C5	170.5	84.9	560	672	15.8	21.4	27.3	22.6	190	372	74.7939	73.3804
C6	48.2	48.8	480	576	0	0	0	0	0	0	100.0000	100.0000
Total	601	**391.7**	2890	3468	681.4	**300.2**	710.5	**287.1**	2890	3468	**23.3597**	**26.7041**

Conclusion

The objective of this study was to generate the scheduling software program for schedule the deliveries route to vehicles in order to minimize the total distribution distance of all fleet. To generate the schedule, the constructive heuristic method of Tillman & Cochran was chose to schedule. Then, following the constructive heuristic method, Delphi Borland 5 language was chose to code the program.

From all of schedule in Result Session, it showed that the new schedule which was generated from VRASS had improved the total distribution distance by decreasing the overall distance that is satisfy the objective function of this study. And it was also utilized the capacity better than the present schedule indeed.

Since the Conclusion Table 3, then it can be concluded that using the VRASS can improved the result by decreasing the total distribution distance, which was satisfied the objective function, by 10.9% and 13.2% of the present schedule on average demand and peak demand of Freezing Truck without any additional cost. Moreover, the result schedules of cooling truck were proposed in the same direction. It was 23.4% and 26.7% improved from the present schedule for average demand and peak demand of cooling truck. In addition, it was noticed that the company can assigned cooling truck only 5 trucks to serve all orders demand at present time, which mean that they was over fleet size for cooling truck nowadays.

Furthermore, there are some more additional advantages when using VRASS as described as follows.

First, the existing schedule, which was scheduled by the experience of the company officer, was fixed for any tour at present time. It has not flexibility in terms of route selection in any tour. But VRASS can generate the schedule in various routes in any tour. It showed that using VRASS make the schedule more flexibility to select and allocate the appropriate route in any tour. And it is another alternative for choosing the suitable truck. Furthermore, the utilization of resources was better than the present schedule. Moreover, VRASS Schedule was also consumed more shorter planning time. And last but not least, VRASS can be used as a tool for predict the future expansion requirement of the fleet size.

Future Study

From Tillman and Cochran (1968) assumption, they assume that the distance and route between each pair of node is symmetric. But it may not be assume that way in Metropolitan city with unpredictable traffic. Moreover, it is recommended that travel time and workload balancing should be concern. Furthermore, the selection criterion which requires looking at the effects of two choices in sequence could be extended to looking at three, and so on, but the computation becomes extensive in large problems. And ultimately, the cost function should be considered in the future study, but the computation become very complex.

Literature Cited

Baker, K.R. (1974), Introduction to sequencing and scheduling, Wiley, Chichester.

Bodin, L.E., Golden, B., Assad, A. and Ball, M. (1983), Routing and Scheduling of Vehicles and Crews: The State of the Art, Computer and Operations Research, Vol. 10, No. 2, p. 67-211.

Christofides, N. and Eilon, S. (1969), An algorithm for the vehicle-dispatching problem, Operation Research, Vol. 20, p. 309-318.

Christofides, N., Mingozzi, A. and Toth, P. (1982), MOVER (Modeling and Optimization of Vehicle Routing) - A user manual, Imperial College of Science and Technology, London.

Clarke, G. and Wright, J.W. (1964), Scheduling of Vehicles from A Central Depot to A Number of Delivery Points, Operations Research, Vol. 12, p. 568-581.

Dantzig, G.B. and Ramser, J.H. (1959), The Truck Dispatching Problem, Management Science, Vol. 6, p. 80-91.

Gaskell, T.J. (1967), Bases for vehicle fleet scheduling, Operation Research, Vol. 18, p. 281-295.

Hays, R. (1967), The Delivery Problem, Report 106, Department of Management Science, Carnegie Institute of Technology, Pittsburgh, PA.

Kamlesh, M. and Daniel, S. (1994), Management Science The Art of Decision Making, Princtice Hall, New Jersey.

Krolak, P.D., Felts, W., Nelson, J.H. (1972), A man-machine approach toward solving the generalized truck dispatching problem, Transportation Science, Vol. 6, p. 49-170.

Lawler, E. L., Lenstra, J.K., Rinnooy Kan, A.H.G., Shymoys, D.B. (eds.) (1987), The Traveling Salesman Problem A Guided tour of Combinatorial Optimization, Wiley, Chichester.

Michael, P. and Xiuli, C. (1999), Operations Scheduling with applications in manufacturing and services, McGraw-Hill,

Stern, H.I., Dror, M. (1979), Routing electric meter readers, Computer & Operation Research, Vol. 6, p. 209-223.

Tillman, F.A. and Cochran, H. (1968), A Heuristic Approach for solving the Delivery Problem, The Journal of Industrial Engineering, Vol. 19, No. 7, p. 354-358.