An Application of Immune Algorithm for the Periodic Delivery Planning of Vending Machines

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***Abstract*—This paper investigates the periodic delivery planning of vending machine problem (PDPVMP). The problem is a periodic vehicle routing problem (PVRP), which is also an extension of the typical vehicle routing problem (VRP). The considered PDPVMP contains multiple vending machines with periodic demands. For each vending machine, its replenishment frequency is either once per two days or twice per two days, i.e., once per day. In the PDPVMP, there are multiple vehicles to deliver goods for vending machines. The objective of the considered problem is to minimize the total length of routes for all vehicles during the time horizon such that all demands for vending machines are delivered. In this paper, based upon a new coding procedure, we apply an immune based algorithm to solve the PDPVMP. A case of Taoyuan county in Taiwan is considered and solved. Numerical results show that the studied immune algorithm can effectively solve this PDPVMP.**

***Index Terms*—periodic vehicle routing problem, immune algorithm, vending machine**

I. INTRODUCTION

With the rapid economic development, the number of convenience stores increases drastically during the past years. However, it usually requires considerable funds and a suitable location for a new convenience store. Thus, more and more vending machines appear on most of the streets in cities. In the early 19th century, the first vending machine appeared in Japan. But vending machines became popular after World War II. In 2003, The annual report of the Japan Vending Machine Manufacturers Association shows that there are more than 5.5 million vending machines to serve 126 million people in Japan. Japan has the highest density of vending machine in the world. As known, most vending machines sell beverages (47.3%), cigarettes (11.3%) and foods (2.2%). For the beverage, most vending machines sell soft drinks (83.7%), while the others sell milk (7.0%), coffee and chocolate drink (6.1%), and alcoholic beverages (3.2%) [1].

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Vending machine is a non-store business machine without time and space constraints and can operate twenty-four hours per day. Moreover, it does not require the store space and the salesperson costs. In addition, its set-up costs and operating costs are relatively low. Unlike the convenience stores, the vending machines sell few types of goods, such as beverage and biscuits etc. Convenience stores have warehouses for inventory, however, vending machines have no warehouses. Thus, vending machines require replenishment frequently to insure that customers can buy products at any time. As known, the routing cost is the main part of replenishment cost for vending machine industry. Thus, reducing the cost of replenishment is equivalent to finding a good delivery route of replenishment for vending machines.

In this paper, we consider the periodic delivery planning of vending machine problem (PDPVMP) which contains multiple vehicles to deliver goods for vending machines. In addition, it is assumed that the replenishment frequency of each vending machine is either once per two days or twice per two days (i.e., once per day). Note that we use "day" as a general time unit throughout this paper. The objective of the PDPVMP is to minimize the total length of routes for all vehicles such that all periodic demands of goods for vending machine are delivered. In this paper, based upon a new coding procedure, we develop an immune based algorithm to solve the PDPVMP. A case of Taoyuan county in Taiwan is considered and solved. Numerical results show that the studied immune algorithm can effectively solve this PDPVMP.

II. PERIOD VEHICLE ROUTING PROBLEM

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A. Typical Period Vehicle Routing Problem

The PVRP was introduced by Beltrami and Bodin in 1974 and has several exciting variants and applications arising in recent years. The PVRP is a generalization of the classic vehicle routing problem (VRP) in which vehicle routes must be constructed over multiple days. During each day within the planning period, a fleet of capacitated vehicles travels along routes that begin and end at a single depot (Francis et al. [2]). There are many variants for PVRP, e.g., (i) MDPVRP (Multiple-Depot PVRP): Cordeau et al. [3], Hadjiconstantinou and Baldacci [4], Angelelli and Speranza [5], (ii) PVRPTW (PVRP with Time Windows): Cordeau et al. [6], (iii) PVRP-SC (PVRP with Service Choice): Francis et al. [7].

There are several applications of PVRP, e.g., courier services, elevator maintenance, waste collection, lottery sales representatives visiting, interlibrary loan etc., see Banerjea-Brodeur et al. [8], Blakely et al.[9], Hemmelmayr et al. [10], Parthanadee and Logendran [11], Jang et al. [12], Gaur and Fisher [13], Claassen and Hendriks [14], Mourgaya and Vanderbeck [15], Teixeira et al. [16], Baptista et al. [17].

Many approaches have been proposed to solve PVRP, including, (i) Classic Heuristics: Russell and Gribbin [18], Gaudioso and Paletta [19], (ii) Metaheuristics: Cordeau et al. [3], Drummond et al. [20], (iii) Mathematical Programming Based Approaches: Francis et al. [7], Mourgaya and Vanderbeck [15].

B. Periodic Delivery Planning of Vending Machine Problem (PDPVMP)

In 2005, Rusdiansyah and Tsao [1] considered an inventory routing problem encountered in vending machine supply chains. The objective of their problems is to minimize the sum of the average inventory holding and traveling costs during a given *m*-day period. The visit frequency is treated as a decision variable, and they attempted to optimize the visit frequency of each retailer and to build vehicle tours simultaneously in order to find the best trade-off between the inventory holding and traveling costs.

The considered PDPVMP is an application of PVRP which is different to that of Rusdiansyah and Tsao [1]. In practice, the replenishment frequency of a vending machine should depend upon the current sale condition, but not a decision variable. For example, the vending machine on the street with more residents will usually sell more products than those on streets with few residents. Hence, in this paper, we assume that the replenishment frequency of a vending machine is given. In practice, the replenishment frequency of a vending machine can be predicted based upon the past sales data. The assumptions and the objective of the considered PDPVMP are presented in the next session.

III. Problem and Method

A. Assumptions

The main assumptions of the considered GDRPVM problem are listed below.

(1) Each vending machine has various demands of goods and its replenishment frequency is given.
(2) There are two vehicles to deliver goods for vending machines.
(3) Each vehicle departs from the parking lot to warehouse for uploading goods, and then deliver these goods to vending machines.
(4) Each vehicle has to go back to warehouse for uploading goods when it has no sufficient goods for vending machines.
(5) Once all vending machines are replenished, the vehicles will return to parking lot.
(6) For simplicity, the replenishment time is ignored. The replenishment frequency of each vending machine is either once per two days or twice per two days, i.e., once per day. Note that we use “day” as a general time unit throughout this paper.
(7) The objective of the problem is to find the best routes, i.e., the total routing length of vehicles is minimized such that all vending machines are replenished based upon their demand frequency and quantity.

B. Immune System

The natural immune system of all animals is a very complex system for defense against pathogenic organisms. The references related to the immune system are referred to Huang [21], Weissman and Cooper [22], Jerne [23], and Huang [24].

C. Procedure of Immune Based Algorithm

The main steps of the proposed immune based algorithm are as follows.

Step 1. Generate an initial population of strings (antibodies) randomly.
Step 2. Evaluate each individual in current population and calculate the corresponding fitness value for each individual.
Step 3. Select the best s individuals with highest fitness values.
Step 4. Clone the best s individuals (antibodies) selected in Step 3. Note that the clone size for each select individual is an increasing function of the affinity with the antigen.
Step 5. The set of the clones in Step 4 will suffer the genetic operation process, i.e., crossover and mutation (Michalewicz [25]).
Step 6. Calculate the new fitness values of these new individuals (antibodies) from Step 5. Select those individuals who are superior to the individuals in the memory set, and then the superior individuals replace the inferior individuals in the memory set. While the memory set is updated, the individuals will be eliminated while their structures are too similar.
Step 7. Check the stopping criterion, if not stop then go to Step 2. Otherwise go to next step.
Step 8. Stop. Report the optimal or near optimal solution(s) from the memory set.

D. The Coding Procedure

Our coding of string is based upon the permutation of $\{1,2,\ldots,n*\max|v_i|\}$, where n is the number of vending machines in the network and $\max|v_i|$ is the maximal total number of replenishment times for vending machines in the network. In our assumption, we set $\max|v_i|=2$. Once a permutation of $\{1, 2,\ldots, n*\max|v_i|\}$ is given, we may use the following efficient coding procedure to convert the permutation into the routes of vehicles. The main steps of the coding procedure are as follows.

Step 1. Generate an initial permutation of string P randomly from $\{1, 2,\ldots, n*\max|v_i|\}$.

Step 2. Divide P into n parts equally, and then rank the numbers (R) for each part.

Step 3. Shade the first v_i rank numbers (R) of vending machine i for each part, i=1, 2,…,n. Let j=0, $S_{t,1}=\ldots=S_{t,C_t}=\phi$, t=1,2, where C_t is the number of cars in day t.

Step 4. Compute all R_new by the following two rules.

(a) Rule1: R_new=1 if its corresponding C_R is 1 or R is not shaded.

(b) Rule2: $R\_new=k+1$ if (i) R is shaded, (ii) its corresponding $C_R>1$, and (iii) its corresponding $\mathrm{mod}(P,C_R)=k$.

Step 5. $j=j+1$. Find i such that P(vending machine i)=j, then append vending machine i into S_{R,R_new} when its corresponding R is shaded, where S_{R,R_new} is the sequence of vending machines on the Rth day on vehicle R_new. Ignore this step when its corresponding R is not shaded. Repeat Step 5 until $j=n*\max|v_i|$. Finally, append the starting/end points in every S.

IV. Numerical Results and Discussion

A. Test Problem

The network of test problem is from Chung-Li, Taoyuan county in Taiwan which is shown in Fig. 1. As shown in Fig. 1, the network contains 212 nodes, where P (node 209) is the parking lot, W (node 117) is the warehouse, nodes with circle 1 (vending machines) in green have replenishment frequency once per two days, and nodes with circle 2 in orange have replenishment frequency twice per two days. Therefore, there are 20 demand nodes (i.e., vending machines) for the test problem. Table I illustrates the demand quantity for each vending machine. In addition, the vehicle capacity is set to 15 and 25, respectively.

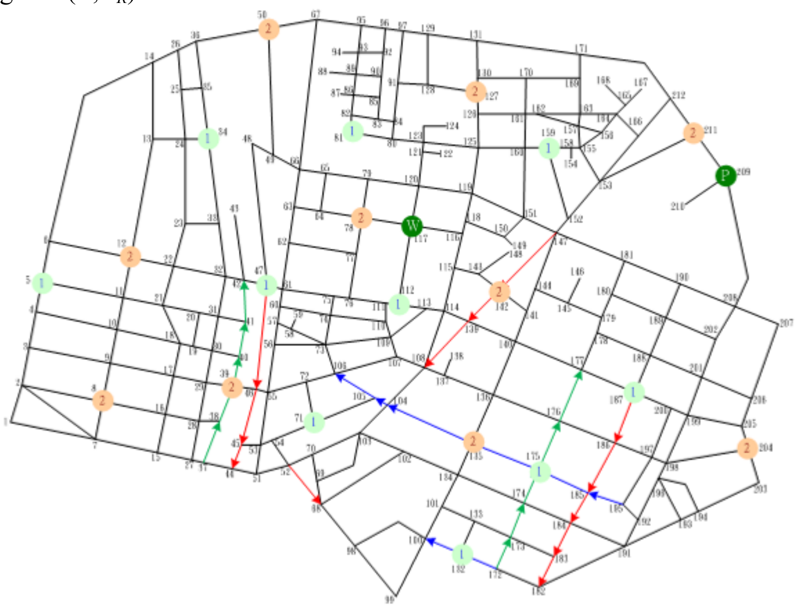

Figure 1. The simplified network of Chung-Li in Taoyuan county, Taiwan.

For the test problem, we set the parameters in the immune algorithm as: the initial population=100, the exchange rate=0.96, mutation rate=0.01, the maximum generation=1000. The termination condition is the maximum number of generation. In this study, we test 1000 times of the applied immune algorithm and record the results. Our algorithm is coded in MATLAB R2009a and executed by a PC (Intel Core i7-2600 CPU3.4GHz with 3.16GB RAM).

B. Numerical Results and Discussions

We set vehicle capacity = 15 and 25, respectively, and test 1000 times by our immune algorithm. The numerical results are summarized in Table II. The best routes under various vehicle capacities are illustrated in Table III and Table IV. From Table II to Table IV, we observe that:

(1) When the vehicle capacity is smaller, the vehicle requires more times back to the warehouse (W) for replenishment. Thus the route length will increase. For example, when the vehicle capacity = 25, the vehicle will back to the warehouse (W) once, and the total length of the route is 672.9 (= 124.7 +234.3 +138.1 +175.8). When the vehicle capacity = 15, the vehicle will back to the warehouse (W) twice, and the total length of the route is 852.7 (= 207.2 +166.2 +146.8 +332.5).

(2) The problem with lower vehicle capacity will require less CPU time for the algorithm. For example, when

the vehicle capacity = 15, the average CPU time of the algorithm is 362.24, and when the vehicle capacity = 25, the average CPU time of the algorithm is 373.02.

Based upon 1000 numerical results, we further test the following hypotheses with α=0.05:

(i) H_0:There is no significant difference between the vehicle capacity and total route length of vehicles.
H_1:There is significant difference between the vehicle capacity and total route length of vehicles.

(ii) H_0:There is no significant difference between the vehicle capacity and CPU time of algorithm.
H_1:There is significant difference between the vehicle capacity and CPU time of algorithm.

The results show all p-values < 0.05. That is, there is significant difference between the vehicle capacity and total route length of vehicles, and there is significant difference between the vehicle capacity and CPU time of algorithm.

TABLE I.
THE DEMAND QUANTITY AND REPLENISHMENT FREQUENCY FOR VENDING MACHINES

Frequency	vending machine (demand quantity)
Once per 2 days	5(8), 34(8), 47(4), 71(10), 81(6), 112(4), 132(6), 159(7), 175(5), 187(8)
Twice per 2 days	8(7), 12(5), 39(7), 50(3), 78(6), 127(7), 135(4), 142(5), 204(5), 211(8)

TABLE II.
NUMERICAL RESULTS OF 1000 TESTS UNDER VARIOUS VEHICLE CAPACITIES

Solution	capacity=15		capacity =25	
	objective	CPU (sec)	objective	CPU (sec)
Max	970.4	418.41	853.3	433.5
Min	852.7	276.8	672.9	258
μ	892.06	362.24	735.16	373.02
σ	18.36	24.49	23.95	28.33

TABLE III.
THE BEST REPLENISHMENT ROUTE (VEHICLE CAPACITY=15)

Day	Vehicle	Route length	The best replenishment route (R) and quantity for vehicle (Q)	
1	1	207.2	Route	P→W→50→12→8→W→135→132→204→P
			Quantity	0→15→12→7→0→15→11→5→0→0
	2	166.2	Route	P→W→142→71→W→78→39→W→127→211→P
			Quantity	0→15→10→0→13→7→0→15→8→0→0
2	1	146.8	Route	P→W→50→34→47→W→78→112→W→159→211→P
			Quantity	0→15→12→4→0→10→4→0→15→8→0→0
	2	332.5	Route	P→W→81→127→W→5→12→W→39→8→W→142→175→135→W→187→204→P
			Quantity	0→13→7→0→13→5→0→14→7→0→14→9→4→0→13→5→0→0

P=parking lot, W=warehouse

TABLE IV.
THE BEST REPLENISHMENT ROUTE (VEHICLE CAPACITY=25)

Day	Vehicle	Route length	The best replenishment route (R) and quantity for vehicle (Q)	
1	1	124.7	Route	P→W→78→39→71→W→127→159→211→P
			Quantity	0→23→17→10→0→22→15→8→0→0
	2	234.3	Route	P→W→50→5→8→12→W→142→135→132→175→204→P
			Quantity	0→23→20→12→5→0→25→20→16→10→5→0→0
2	1	138.1	Route	P→W→81→50→34→47→112→W→127→211→P
			Quantity	0→25→19→16→8→4→0→15→8→0→0
	2	175.8	Route	P→W→78→12→8→39→W→142→135→187→204→P
			Quantity	0→25→19→14→7→0→22→17→13→5→0→0

P=parking lot, W=warehouse.

V. CONCLUSIONS

In this paper:

(a) We have studied a periodic delivery planning of vending machine problem (PDPVMP). The problem is a periodic vehicle routing problem, and is also an extension of the typical vehicle routing problem.

(b) We have applied the immune algorithm (IA) to solve the PDPVMP. In addition, a new coding procedure has been proposed to convert any random permutation into a feasible route for vehicles to delivery goods for vending machines.

(c) We have applied the immune based algorithm to solve the test problem in Chung-Li, Taoyuan county in Taiwan. Numerical results show that the applied IA can effectively solve this PDPVMP.

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