A Mathematical Model for Vehicle Routing of Used-oil Collection in Bio-diesel Production Using Visual Basic Interface: Village Bank and Bio-diesel Project

Srisawat Supsomboon [*]

Abstract

Village Bank and Bio-diesel Project: Project initiated by His Majesty King Bhumibol Adulyadej has conducted a project named Used-oil donating and purchasing for bio-diesel production project. The purpose of this project was to obtain used-oil by donating or purchasing from the members in Bangkok area and neighbourhood to produce bio-diesel in the Village Bank and Bio-diesel Project bio-diesel plant in Pranakorn-sri-ayutthaya province. Since there have been an increasing numbers of members all over the pilot district, Thaweewattana district, logistics management has been brought into account. An efficient logistics system would be able to reduce fuel cost as well as labour cost. This study presented a method and a computer-aid tool to help solving vehicle routing problem of used-oil collection for bio-diesel production at the plant of Village Bank and Bio-diesel Project. A mathematical model, Binary Integer programming, were developed by using LINGO software solver. The objective was to find optimal routes of shortest distance in order to minimize logistics or transportation cost. Visual Basic was used to create user interface for both input and output parts to assist users.

Keywords: Vehicle Routing Problem (VRP), Truck Dispatching, Mathematical Model, Optimization Model, Binary Integer Programming

[*] Assistant Professor, Industrial Engineering Department, Khon Kaen University, Khon Kaen, 40002,
E-Mail: srisawat@kku.ac.th

1. Introduction

His majesty the King's speech given to those who attended His birthday anniversary on December 4, 2005 at Dusit Palace (translated from Thai) was "I have done it; it means that I am not in trouble. When I am 118 years old, I will use my fuel. Others will not do, they will not have. But I have because I am able to search for the methods of making alternative fuel. Unless I produce alternative fuel I am in trouble, I am worried. Unless others produce it, they will have no bio-diesel, but I do have since I myself make it". His majesty the king's speech reflected his concern toward his people regarding alternative energy, especially bio-diesel. Therefore, Village Bank and Bio-Diesel Project; Project initiated by His Majesty King Bhumibol Adulyadej, has responded to his majesty the king's speech by conducting many significant researches to develop the entire bio-diesel production. For the past few years, they have accomplished by being able to produce high quality bio-diesel, B-100, and able to install a bio-diesel plant with capacity of 3,000 litters/day (or about 1,200 litters per 12 hours). The second-phase plant of the extension capacity up to 5,000 litters per day has been under construction. The plant is located at Lard-loom-kaew sub-district, Lard-loom-kaew district, Pranakorn-sri-ayutthaya province. Moreover, Village Bank and Bio-diesel project have established campaigns of using jatropha curcus and used-oil as raw materials rather than using any other oil plants. They have conducted many programs to encourage communities, villagers as well as government organizations and private enterprises to realize the importance of producing alternative energy and to be a part of the project. For Bangkok area, the project committees emphasized on gathering used-oil all over Bangkok area and its neighbourhood as raw material to produce bio-diesel. Not only because used-oil is plentiful in Bangkok area, but using used-oil would also reduce misusing it. Many studies presented that misusing used-oil causes terrible problems to human health. Not only that used-oil has been misused to feed animal directly, such as marine animals, but also used as raw material of pet's food. These would cause human cancer by producing carcinogens. Draining used-oil into culvert or disposing it onto the ground also causes pollutions. Moreover, reusing used-oil by filtering and bleaching it also incurs human caseinogens. Another case, if used-oil is used to produce low quality bio-diesel for automobile, it would also make engine damage or tumble.

Acknowledging problems occurred by used-oil misusing mentioned above, the Village bank Bio-diesel project has constituted a project called Used-oil donating and purchasing for bio-diesel production project. Its purpose was to obtain used-oil in Bangkok area and its neighbourhood by donating or purchasing from project's members to produce bio-diesel at Village Bank and Bio-diesel project plant in Pranakorn-sri-ayutthaya province. Thaweewattana district was chosen to be a pilot district. After about 1 year of operation, there have been a lot of members who are interested to join the program and to donate as well as to sell their used-oil to produce bio-diesel. Since the locations of members were scattered all over the district, unless there was an efficient logistics system, logistics cost would be respectively high. In the past, when the operation of picking up used-oil took place, the only thing that was used to assist planning truck routes was an experience of the truck driver. The truck driver was the one who decided his truck route.

Many times, there was back and forth turning or repeating ways. In another word, the truck driver was unable to identify his shortest route. It wasted time and increased transportation cost due to the unnecessary repeating travelling paths. As the number of members has been increasing, the system getting larger and more complicated, it was impossible for a truck driver to decide the best route. Therefore, effective tools that could assist an operator to make the best decision are necessary. With an effective tool, logistics cost is expected to decrease. In order to help the project to effectively manage used-oil purchasing system and to reduce logistics cost, this study was proposed to help solving vehicle routing problems of used-oil collection for bio-diesel production by using binary integer programming with LINGO software solver. Visual Basic program was used to create user interface for both input and output parts to ease operators. The objective was to find optimal routes with minimum distance. By using the shortest distance, logistics or transportation cost, therefore, will be minimized.

2. Reviewed Literature

Vehicle routing problems related literatures were reviewed and presented as followed.

Sung Chul Hong and Yang Byung Park (1999) studied vehicle routing with time constraints to minimize total distance and total customer waiting time. Heuristic called bi-object vehicle routing with time window constraints (BVRPTW) which used Linear Goal Programming (GP) to find an initial solution and developed it to Sequential linear goal programming (SLGP) to find the best solution. Heuristic was used in two steps. The first step was Clustering stage to increase number of points into the routing. After that, the second step called Routing stage would combine points to form routes using Goal programming model and adapted it to be Sequential linear goal programming (SLGP) to minimize total waiting time.

Barrie M. Baker and M. A. Ayechew (2003) developed the method of arranging vehicle route by using Genetic Algorithm to give the shortest total distance with 3 major conditions. The three conditions were truck capacity, distance limitation and a customer was allowed to deliver product to one truck. Two steps Heuristic with Genetic algorithm were applied.

Hoog Chuin, et.al. (2003) developed a method to solve vehicle routing problem with limited number of vehicles with time window to find the best route that minimized cost. Two steps of heuristic were used. The first step was used to find maximum number of vehicle (Upper bound) by MATLAB. Then, Tabu Search was used to find vehicle routes. Vehicle routing had two basic steps. The fist one found initial solution and the second one used algorithm to find the best solution.

Ruben Ruiz, et.al. (2004) developed a decision support system to solve vehicle routing problem using Decision Support System: DSS. The Decision Support System was created to find optimal route that gives minimum total distance and minimum cost. Two steps of heuristic were used to find solutions. The first step used implicit enumeration algorithm to find vehicle route and the second step used Integer Programming to find the optimal route.

S.C. Ho and D. Haugland (2004) studied a method of vehicle routing by using Tabu search to find the minimum number of vehicle and minimum total transportation distance. They considered ordering time in order to deliver products to customer in time. One customer could receive products from not more than one vehicle. They used a mathematical model to find an initial solution and improved it by Tabu search to find better solutions.

Chi Guhn Lee, et. al. (2006) studied to find the shortest route for merchandise transportation problem of multiple suppliers. Some of the suppliers may transport their products to more than one depot. The objective of the study was to reduce transportation cost. The mathematical model called mVRPSP was created by using CPLEX/AMPL program to find the optimal solutions.

Ana Osvald and Lidija Zadnik Stirn (2008) developed a mathematical model for vehicle routing problem with time windows and time-dependent travel-times (VRPTWTD) to solve transportation problem of fresh vegetable and similar perishable food. The objective was to reduce cost of the system. The major factor was to deliver products at the right time and right quantity according to customer's needs regarding quality of products in terms of freshness, nutrition and taste.

In the past several years, vehicle routing problems has been brought significantly into the interests of many researchers. Some studies used mathematical model approach, and some heuristic such as Tabu search, Genetic algorithm, or other new-developed heuristic methods. This study used a mathematical model (Binary Integer programming) as the problem of the beginning phase is not so large and there are various solvers to choose. In case that the model would be extended (more number of points or customers) in the future, other effective tools which could handle larger model like heuristic should be brought into account.

3. A Mathematical Model

After having meetings with the project personnel and observing workers' operations, essential information was collected and summarized as followed. For the first phase of the project, there was one plant with 29 enterprises or customers who applied to be members and were willing to sell and donate used-oil to the project. Only 4-wheel pick up truck with the capacity of 95 containers was used. One container contained about 16-17 litters and weighted about 17-18 kilograms. Each round of service, the operator knew the amount of used-oil by checking with customers and making appointment with them 1-2 days ahead. A truck was allowed to travel only one time for each round and it could travel at most 8 hours from departing until returning to the plant. For each round, if there was more than one truck, a customer could deliver used-oil to one truck only. After knowing the amount of used-oil from customers, the operator would decide the number of truck according to the amount of used-oil. The smallest number of truck of each round of service was desirable.

According the information illustrated above, mathematical model was created under those conditions. As working hour of each truck was assigned to be less than 8 hours for one round service, processing time and transportation time were brought into account. Waiting time was ignored since pick-up appointments were made ahead of time. Processing time is the time of passing used-oil containers onto the truck as well as arranging them. As observed, on the average, two workers took about 1-2 minutes to process one container. Transportation time is travelling time a truck used to travel from one point to another. Processing time together with transportation time must not greater than the maximum time allowed for a truck to use from departing the plant until entering it. Therefore, maximum time is 8 hours (480 minutes).

Considering all conditions mentioned above, a mathematical model was created as shown below.

Define

n = number of points

Point 1 denotes the plant (depot)

k = truck number (k =1,…,NV)

Parameters

NV = number of truck

C_k = capacity of truck k

Q_i = demand quantity at point i

d_{ij} = shortest distance from point i to j

p_{ij} = processing time at point i

t_{ij} = transportation time from point i to j

T_k = maximum time allowed for truck k

Variables

x_{ij}^k = truck k travel from point i to j

x_{ip}^k = truck k travel from point i to p

x_{pj}^k = truck k travel from point p to j

x = a compound matrix $x_{ij} = \sum_{k=1}^{NV} x_{ij}^k$,

defines connections of route

U_i ,U_j = variables created to prevent subtour at

points i and j, respectively.

$S = \{(x_{ij}) : \sum_{i \in Q} \sum_{j \notin Q} x_{ij} \geq 1$, for appropriate set Q}

An objective function could be either minimize total transportation distance only or minimize the sum of total transportation distance and total transportation time. It depends on users. The following objective shows the first case; minimize the total transportation distance.

Minimize
$$Z = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{NV} d_{ij} x_{ij}^k \qquad (1)$$

Subject to

$$\sum_{i=1}^{n} \sum_{k=1}^{NV} x_{ij}^k = 1 \qquad j = 2,\ldots,n \qquad (2)$$

$$\sum_{j=1}^{n} \sum_{k=1}^{NV} x_{ij}^k = 1 \qquad i = 2,\ldots,n \qquad (3)$$

$$\sum_{i=1}^{n} x_{ip}^k - \sum_{j=1}^{n} x_{pj}^k = 0 \quad p = 1,\ldots,n; k = 1,\ldots,NV \quad (4)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} Q_i x_{ij}^k \leq C_k \qquad k = 1,\ldots,NV \qquad (5)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} p_i x_{ij}^k + \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} x_{ij}^k \leq T_k \quad k = 1,\ldots,NV \quad (6)$$

$$\sum_{j=2}^{n} x_{1j}^k \leq 1 \qquad k = 1,\ldots,NV \qquad (7)$$

$$\sum_{i=2}^{n} x_{i1}^k \leq 1 \qquad k = 1,\ldots,NV \qquad (8)$$

$$x_{ij}^k = 0 \quad k = 1,\ldots,NV; i = j \text{ where} \begin{cases} i = 1,\ldots,n \\ j = 1,\ldots,n \end{cases} \qquad (9)$$

$$U_i - U_j + S x_{ij}^k < S - 1$$
$$i \neq j; i = 2,\ldots,n; j = 2,\ldots,n; k = 1,\ldots,NV \quad (10)$$

$$\forall x_{ij}^k \in \{0,1\} \qquad (11)$$

Equation (1) is the objective function that minimizes the total transportation distance. Equation (2) shows that only one truck can enter point j. Equation (3) shows that only one truck can depart from point i. Equation (2) and (3) define that only one car can reach each point to take demand of that point at each round and depart it. Equation (4) represents the continuality of routes. The truck entering one point must also depart it. Equation (5) illustrates truck capacity. Each truck can carry containers not more than its capacity. Equation (6) shows that the sum of total processing time and total transportation time cannot exceed maximum time allowed for each truck in each round. Equation (7) shows that one truck can leave plant (depot) only one time. Equation (8) shows that one truck can enter plant (depot) only one time. Both equation (7) and (8) illustrate that a truck can leave and enter depot only one time of each round. Equation (9) presents the forbidden of a truck travel to the same point to which it just enter. Equation (10) is used to avoid subtour of each truck. No subtour is allowed to take place within each route of feasible routes. Equation (11) illustrates that all variables x are binary which can only be 0 or 1.

4. Data Collection

From the above model, many data sets of parameters should be collected. It is known that to acquire some parameters, such as shortest distance and transportation time, is not easy. It would consume much time and money. Therefore, applying assisting tools like Google Earth and Google Map programs was taken into consideration. Some real data, both shortest distance and transportation time, were collected to compare with the data obtained from Google Earth and Google Map programs. By a method of statistical hypothesis testing, it was found that the distances obtained by Google Earth and Google Map programs did not differ from the real data with 0.05 significant level as so the transportation time. Therefore, in this study, shortest distance and transportation time data were taken from Google Earth and Google Map programs.

5. An Example

The model was tested with the information of real operation on January 22, 2009 in order to compare the original route the driver decided with the result from the mathematical model. In that round, there were 89 containers of used-oil from 7 restaurants. Number of demand quantity (number of used-oil containers) is presented in Table 5.1. As mentioned earlier that the average processing time is about 1-2 minutes, in this example the approximated processing time of 2 minutes per container was assumed. It is also shown in Table 5.1.

Table 5.1 *Demand quantity and approximated processing time*

No.	Enterprise	Demand (Containers)	Processing Time (Min.)
1	Plant	0	0
2	Hua-pla-chongnonsee	16	32
3	Klua-ban-sai	2	4
4	White Cottage	2	4
6	Ka-moo-chula	4	8
7	Pet-toon-han-palo	5	10
5	Ruan-kaew	24	48
8	Ban-hai-kwam-rak	36	72
	Total	89	178

The original route the truck driver used was shown as followed.

<u>Original route</u>:

Plant→Hua-pla-chongnonsee→Klua-ban-sai→White Cottage→Ruan-kaew→Ka-moo-chula→Pet-toon-han-palo→Ban-hai-kwam-rak→Plant

The total transportation distance of the original route was 137.32 kilometres with 137.32 minutes of total time. With demand quantity of 89 containers, only one truck of one round travel was required. Table 5.2 and 5.3 present shortest distance and transportation time matrix of those 8 points from Google Earth program. For some paths, the distance of its reverse path are different due to dissimilar road conditions such as u-turn, one way, or altered entrance and exit ways of some places.

Table 5.2 *Shortest distance matrix*

Enterprise	Shortest Distance (Kilometers)								
	No.	1	9	10	12	13	14	16	28
Plant	1	M	56.5	56.7	56.2	58.3	58.3	55.5	61.9
Huapla-chongnonsee	9	58.3	M	0.2	1.3	3.3	3.3	2.1	6.9
Klua-ban-sai	10	58.3	3.6	M	1.4	3.4	3.4	2.1	6.9
White Cottage	12	59.0	3.5	3.7	M	2	2	2.7	5.6
Ka-moo-chula	13	60.9	8.6	8.8	10.0	M	0.02	7.8	3.6
Pet-toon-han-palo	14	60.9	8.6	8.8	9.9	11.9	M	7.8	3.6
Ruan-kaew	16	56.4	3.6	3.8	4.9	6.9	6.9	M	10.2
Ban-hai-kwam-rak	28	66.0	10.4	10.6	11.7	13.8	13.8	9.6	M

Table 5.3 *Transportation time matrix*

Enterprise	Transportation Time (Minutes)								
	No.	1	9	10	12	13	14	16	28
Plant	1	M	52	53	51	54	54	51	59
Huapla-chongnonsee	9	53	M	0.3	2	4	4	3	10
Klua-ban-sai	10	53	6	M	2	5	5	4	10
White Cottage	12	54	5	6	M	2	2	4	8
Ka-moo-chula	13	62	12	13	14	M	0.02	11	5
Pet-toon-han-palo	14	62	12	13	14	17	M	11	5
Ruan-kaew	16	51	5	6	7	10	10	M	15
Ban-hai-kwam-rak	28	64	14	15	16	19	19	13	M

The mathematical model gave the optimal value of 129.72 kilometres shortest transportation distance. It was 7.6 kilometres less than the original route. The shortest route is shown below. When considering transportation time, the optimal route provided 125.32 minutes, which yielded the reduction of 12 minutes transportation time.

<u>Optimal route</u>:

Plant→Hua-pla-chongnonsee→Klua-ban-sai→White Cottage→ Ka-moo-chula→Pet-toon-han-palo→Ban-hai-kwam-rak→Ruan-kaew→Plant

The model was used to test with more cases from real information of 7 service rounds. The result showed that total distance of all 7 original routes was 1,022.72 kilometres, while the optimal value from mathematical model was 958.44 kilometres, which reduced 64.28 kilometres. Considering transportation time, the original 7 routes gave 1,020.68 minutes of total transportation time, while the optimal solutions gave only 956.12 minutes, which is 64.56 minutes decreased.

Another objective function which minimized the sum of total transportation distance and total transportation time was also tried. The results were the same as of the previous model. Relationship of distance and transportation time was suspected to be dependent. Scatter diagram was brought to find the pattern of their relationship. 25 samples were taken. The result of a scatter diagram in Figure 5.1 obviously illustrates linear relation of the two parameters. The optimal value of the second model was 255.04, where optimal transportation distance was 129.72 kilometres and the optimal transportation time was 125.32 minutes.

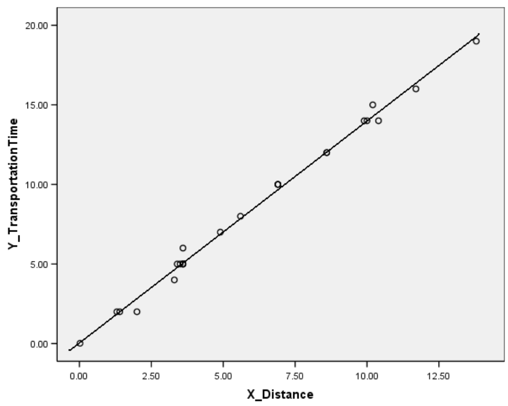

Figure 5.1 *Scatter diagram of distance and transportation time*

Furthermore, the model was tested with larger scenarios by assuming more demand quantity and more number of customers for each round, which required more number of truck in the system. The results showed that for the number of containers less than 95 (one car needed), the model worked well for 29 customers (points) in one round, for the number of containers less than 190 (two cars needed), the model worked efficiently with 20 customers, and for the number of containers less than 285 (three car needed), the model still worked well with 15 customers.

6. Visual Basic Window

The window of visual basic created to receive parameters input and to show run results of mathematical model is shown in Figure 6.1. The model shown in Visual Basic window was the first model with objective function of minimizing total transportation distance. To input each parameter, a user could click on the blank area of each parameter. Number of points should be assigned first so that it would define matrix size of other parameters. After that, if clicking on the button "Define Connection", the dialog box would pop up to ask for number of points to which each point is allowed to travel. Number of vehicle, vehicle capacity, and maximum time could also be defined by clicking on the blank area and enter the corresponded numbers. Demand quantity and processing time of each point could be defined as matrices. Their sizes were 1xnumber of points. Shortest distance and transportation time matrix sizes were number of pointsxnumber of points. For each matrix, there was a dialog box asking for each input number. Figure 6.2 shows dialog boxes of some parameters. Figure 6.3 represents the window after defining all parameters and displays optimal solutions of January 22, 2009 operation.

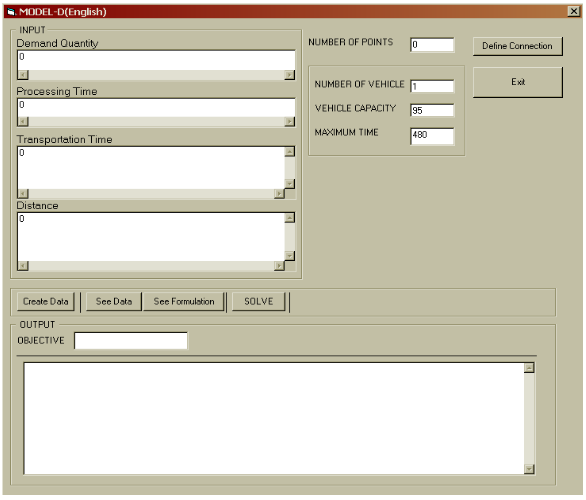

Figure 6.1 *Working window of Visual Basic*

Figure 6.2 *Dialog boxes of parameter input*

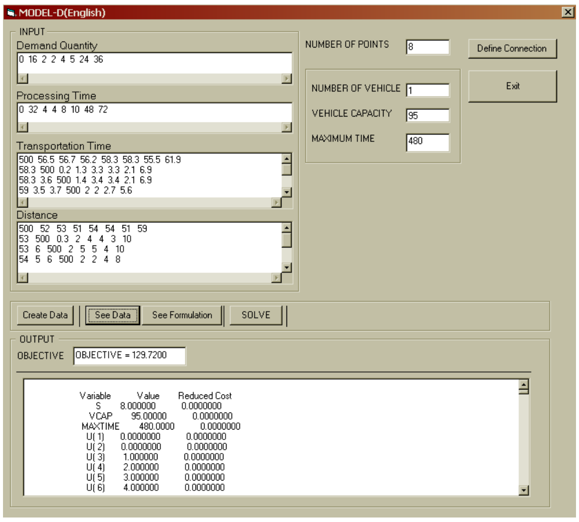

Figure 6.3 *Parameter input and solutions window*

As Visual Basic was used to receive input and presented the output results from LINGO solver, both optimal value and optimal solutions shown in Visual Basic window were all the same value and solutions as given by LINGO program. Runtime of the program using Visual Basic was very close to the runtime using LINGO alone.

7. Conclusions

This study presented a tool for solving vehicle routing problems of collecting used-oil from customers to the bio-diesel plant in bio-diesel production of the Village Bank and Bio-diesel Project initiated by His Majesty King Bhumibol Adulyadej. The tool was easier to use for users who had low computer skill. The objective of the model was to minimize the total transportation distance in order to reduce transportation cost. The mathematical model created was a Binary Integer Programming. Visual Basic was used to assist user to input all parameters for LINGO software to solve problem as well as to show the output of results. The optimization model gave better solutions in every case compared to the original drivers' decisions based one their own skills. Using Visual Basic to create user interface for input and output eased the users who had low computer skill and it helped to find the best solutions under complicated conditions. In case that the project would be extended to have more number of points (customers) and more concerned factors, which would be more complicated and difficult to solve, a computer-aided tool with its helpful advanced applications or another alternative of solving methods such as heuristic would be able to assist operator to increase level of management as well as reduce logistics cost.

Acknowledgments

This research was financially supported by the Faculty Engineering Research Fund, Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand.

Reference

Ana Osvald and Lidija Zadnik Stirn. (2008). A vehicle Routing Algorithm for the distribution of fresh vegetables and similar perishable food, Journal of Food Engineering, 85, page 285-295.

Barrie M. Baker and M. A. Ayechew. (2003). Genetic algorithm for the vehicle routing problem, computer and Operations Research, 30, page 787-800.

Chi Guhn Lee, et.al. (2006). A shortest path approach to the multiple-vehicle routing problem with split pick-ups, Transportation Research Part B, 40, page 265–284.

Hoong Chuin Lau, et.al. (2003). Vehicle routing problem with time windows and a limited number of vehicles, European Journal of Operational Research, 148, page 559-569.

Ruben Ruiz, et.al. (2004). A decision support system for a real vehicle routing problem, European Journal of Operational Research, 153, page 593-606.

S.C. Ho and D. Haugland. (2004). A Tabu search heuristic for the vehicle routing problem with time windows and split deliveries, Computer and Operations Research, 31, page 1947-1964.

Sung Chul Hong and Yang Byung Park. (1999). A Heuristic for bi-objective vehicle routing with time window constraint, International Journal Economics, 62, page 249-258.