THE STUDY OF OPTIMAL VEHICLE ROUTES FOR COLD DELIVERY AT NIGHT IN THE URBAN AREA

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Abstract: In recent years, frozen food market has being expanding in Taiwan. To transport low-temperatured food, air conditioned trucks are used. The customers of Distribution Center (D.C.) have extended from firms to families and individuals. The importance of urban distribution has been noticed. To avoid the deteriorating traffic condition, this research assumes D.C. makes delivery at night to ignore intersection delay. This research develops an algorithm to determine the optimal delivery sequence with minimal logistics cost under the factors of real-time traffic light, maximal vehicle capacity, gasoline fee and so on. This algorithm has ten main steps by modifying the cyclic algorithm. The output of the algorithm includes the optimal delivery sequences, the corresponding logistics cost and the optimal speed range between any two consecutive customers. In this research, a distribution example in the urban area of Taichung, Taiwan is used to demonstrate the process of the proposed algorithm.

1. INTRODUCTION

With increasing demand for frozen and low-temperatured food in Taiwan, certain equipments such as frozen machine and thermometer, etc. will be installed in delivery vehicles, so as to be adapted to the requirements of cold delivery and ensure freshness and sanitary of frozen products. However, the delivery cost of using such delivery vehicles will be much higher than that of using vehicles with normal temperature. The delivery of low-temperatured food relies on effectiveness and efficiency of adequate transportation. Shortening the operational time of frozen equipments can lower the cost. Besides, in order to maintain the optimal circulation of cold air in vehicles, products accommodated in the vehicles can not be too crowded. Therefore, an overall study on the load and delivery routes of vehicles should be investigated in advance. When the delivery operation is proceeded at night, the delivery vehicles can pass each road section within the estimated time due to the light traffic. Comparing with that on the long-distance transportation in the rural area, the study on delivery routes in the urban area tends to be more complicate. Nevertheless, in order to improve the efficiency of the short-distance delivery operation of low-temperatured food in the urban area, this study develops an algorithm which considers the capacity per vehicle, delivery distance, gasoline consuming rate and dynamic data of each node of the road network such as traffic signal lights at each intersection, characteristics of one-way and two-way drive lanes, driving speed and time for passing through each road section, so as to determine the optimal delivery sequence with the minimal cost for the delivery between multiple customers and the optimal speed range in each road section.

2. LITERATURE REVIEW

A transportation network is known as a system consisted of different nodes through roads (Bae, 1986). So far, the shortest path theory is able to determine the shortest path from the starting node to the ending node in a transportation network. As far as the long-distance transportation is concerned, the delivery time and distance constitute of a direct-proportion relationship; therefore, most of time the shortest path is portrayed in the form of distance. However, due to the traffic condition in the urban area, the shortest distance does not guarantee that the corresponding delivery time will be minimal. Hence, delivery time is a better indicator than distance to show the real traffic situation in the urban area. Since the background of this study is based on the urban area, delivery time is adopted as an indicator to represent the shortest path. There are two famous algorithms in determining the shortest path, which are the acyclic algorithm and cyclic algorithm. The basic concept for these two algorithms is based upon recursive computations of the dynamic programming, i.e. the top-down thinking and bottom-up calculation. In the real world, loops or cycles always exist in the transportation network. Therefore, the cyclic algorithm will be more applicable to the real situation than acyclic algorithm, and the heuristic algorithm will be developed from the concept of cyclic algorithm.

In general, transportation equipment depends in the types of products delivered. Basically, there are three delivery types, i.e. the normal temperature, constant temperature and low temperature deliveries. The normal temperature delivery means that it is not necessary to maintain products at a specific temperature during the distribution operations. The constant temperature delivery means that it is necessary to maintain products at the same temperature in the course of transportation; otherwise, it is highly likely that the product quality will be damaged. The low temperature delivery includes to delivery cold-storaged food and frozen products. The cold-storaged food means that the temperature of products must be maintained at the temperature degree between $0^{\circ}C$ and $7^{\circ}C$, while the frozen product means that the temperature of products must be maintained at the temperature degree below $-18^{\circ}C$. In order to ensure the product quality, frozen equipment must be installed in the course of transportation in order to control temperature. The consumption of frozen food in Taiwan has shown a steady growth in recent year (Taiwan Development Association of Frozen Food Industries, 1996). It is anticipated that once Taiwan joined in WTO (Wang, 1998), the demand for low temperature delivery, due to heavy importation of agricultural products, will be increased at least five times and the market value will be about 7 billion NT dollars.

The investigation conducted by ILDM (1992) shows that the transportation costs of food, drink and tobacco industries occupy about 50% of the logistics cost. The logistics cost mentioned in this study is based on the calculation of distribution gasoline fees which are determined by the vehicle capacity and the distance. The distribution system usually can be broken down into three sub-systems including procurement logistics, internal logistics and logistics physical distribution. The vehicle routing and scheduling functions are parts of the logistics physical distribution. The sub-systems are all related. Any changes occurring in the supply chain may bring certain impact to some parts thereof. For the sake of signifying the control on cost and the importance of the productivity, Peter (1994) explained that the use of computer software can manage the vehicle routing and scheduling more efficient by utilizing a wine-making industry as an example. The result has revealed that the use of computer software not only reduced the cost of direct transportation but also upgraded the

sale volume.
Robert (1991) used the LP relaxation algorithm to determine the amount of each product type should be loaded in which vehicle to minimize the cost. This policy will influence the transportation cost of each vehicle. Chen (1991) adopd the weighted A* algorithm to solve the large scale of shortest path problem. His study calculated the cost based on the distance without taking the time window into account. Mario (1995) proposed an algorithm to solve the vehicle routing problem of after-sales servicing. His algorithm built the path by utilizing the saving method, to determine the shortest traveling time and sequence of customers whom the servers need to visit and the number of servers. Lee (1996) mentioned that since agricultural products decay easily, they are often damaged by the traffic condition. Therefore, the highway network is usually taken as the transportation channel of agricultural products for the long-distance transportation. Besides, Lee's study employed the cyclic algorithm to determine the optimal transportation route. The goal for selecting routes in Lee's study is seeking the shortest distance. Lee's study assumed that the long-distance transportation is on the highway, while this study focuses on delivery in the urban area by taking dynamic traffic information such as traffic signal lights into account. To sum up, factors for selecting the shortest path in Lee's study are not considered as thoroughly as those in this study.

Chen (1997) developed a fast spontaneous system based on the generic algorithm to distribute the decay-prone products conducted by a distribution center.

Lee (1998) determined the optimal routes in the transportation network of the urban area in Taichung, Taiwan based on the dynamic information of each intersection such as change of traffic signal lights. Unfortunately, optimal logistics cost and delivery sequence has not discussed in his paper. In addition to the above dynamic network information, this study also involved logistics cost, vehicle capacity and delivery sequence to make the result of this paper more practical.

Most of the above literatures did not include the impact to vehicles brought by the change of traffic signal lights in a real traffic network. This study incorporates not only the above factors into the vehicle routing decisions but also the real-time information such as the constraint of one-way or two-way drive direction and driving speed, as well as the calculation of logistics cost to complete the programming process.

3. CONSTRUCTION OF AN ALGORITHM

The main object of this study refers to the scheduling distribution between a distribution center and multiple customers. There are 4 assumptions: 1. there is only one delivery vehicle which is equipped with frozen facility, for each delivery sequence, the vehicle starts from the distribution center and distributes products to customers. 2. If customers' total demand quantity is more than the vehicle capacity, the same vehicle will go back to the distribution center to resume the distribution task. 3. Customers' demand is expressed in terms of weights. 4. Delivery time is a better indicator than distance to represent the real traffic situation in the urban area. Since the distribution is based upon multiple customers, the shortest distribution path determined by the least delivery time between a customer and another one must be found in the first place, and then distribution routes among all customers will be connected subsequently. Therefore, one of the functions of the proposed algorithm is to determine the minimum delivery time and optimal speed range between any two consecutive customers. For each delivery route, the logistics cost of this delivery will be calculated. The optimal delivery sequence will be created after finding the lowest corresponding logistics cost among all possible delivery sequences. The logistics cost mentioned in this study is based on the calculation of distribution gasoline fees which are determined by the vehicle capacity and the distance.

Due to the vehicle capacity, the number of distribution times must be determined first. However, it is not easy to get actual information of the gasoline consumption rate of vehicles, this study can be only perceived through professional experience under the occupied and vacant conditions. Thereafter, this study estimates the logistics cost through weight tonnage and delivery distance, which is expressed as equation (1).

$$X = 0.88 \times Y \times Z \qquad (1)$$

Where X = logistics cost
Y = weight tonnage
Z = distance

As far as the transportation network is concerned in this study, arcs mean road sections while nodes mean intersection, all customers are set on the nodes. The proposed algorithm aims to seek the minimal total logistics cost among all possible delivery sequences and optimal speed range between two consecutive customers. There are three constraints in this research, which are (1) customers' demands must be satisfied, (2) the accumulated demand quantity must not exceed the vehicle capacity and (3) delivery time between any two nodes must be the shortest. The constraints (1) and (2) can be easily met. Since the constraint (3) makes this problem with the NP Hard characteristic, it means that the calculating time and memory space required by computer will be increased in the exponential rate in the increase of the number of network nodes. This study will seek the shortest path within reasonable time by developing an algorithm, to improve the efficiency of solving problems. The cyclic algorithm published by Dijkstra in 1959 is currently the most efficient solution for determining the shortest path between any two nodes. Nevertheless, in view of the bottleneck of computer capability, this study develops a new solution by the concept of the cyclic algorithm and this new solution takes the traffic signal lights for each intersection into account. This study assumes that the distribution center undertakes delivery operation at night due to the low traffic load. By doing so, the vehicle is able to pass through each road section within the expected time and no delay in the intersection will occur. The binary search will serve as the guideline for determining the average vehicle speed.

This study uses VBA (Visual Basic for Application) (Lee, 1996) to develop computer programs. The procedure of the algorithm developed by this study is shown as Figure 1. Its major steps are explained as follows:

Step 1: Inputting the starting distribution time of the vehicle, initial average vehicle speed range and convergent value (α)

Step 2: Determining a delivery sequence, so as to use the next steps to compute the logistics cost

Step 3: Taking N_1 as the initial node and N_2 as the first delivery customer

Step 4: Determining the number of distribution times for serving all customers:

Since there is only one delivery vehicle, this step aims to compute number of distribution times of the vehicle in the delivery operation. This number can be

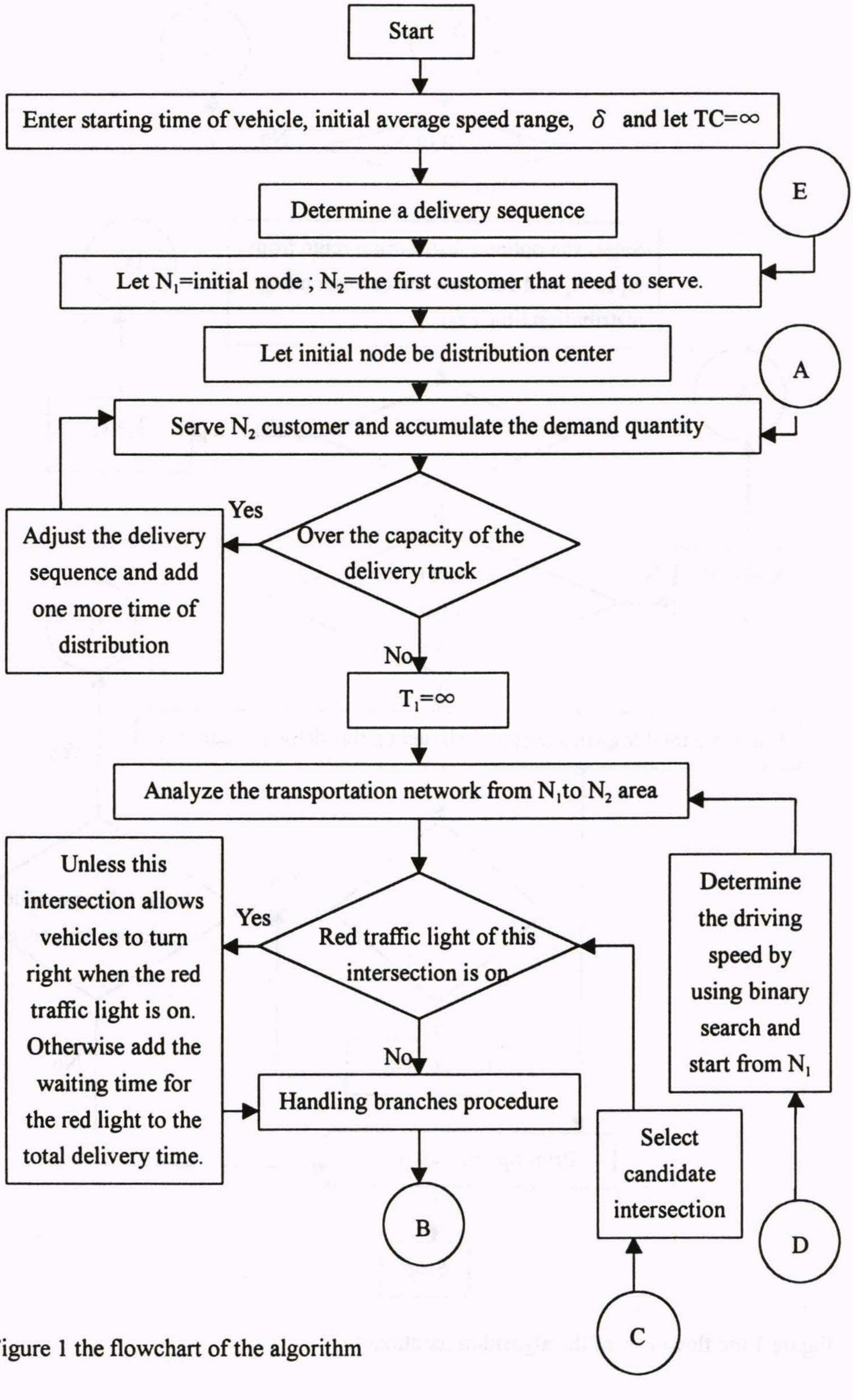


Figure 1 the flowchart of the algorithm

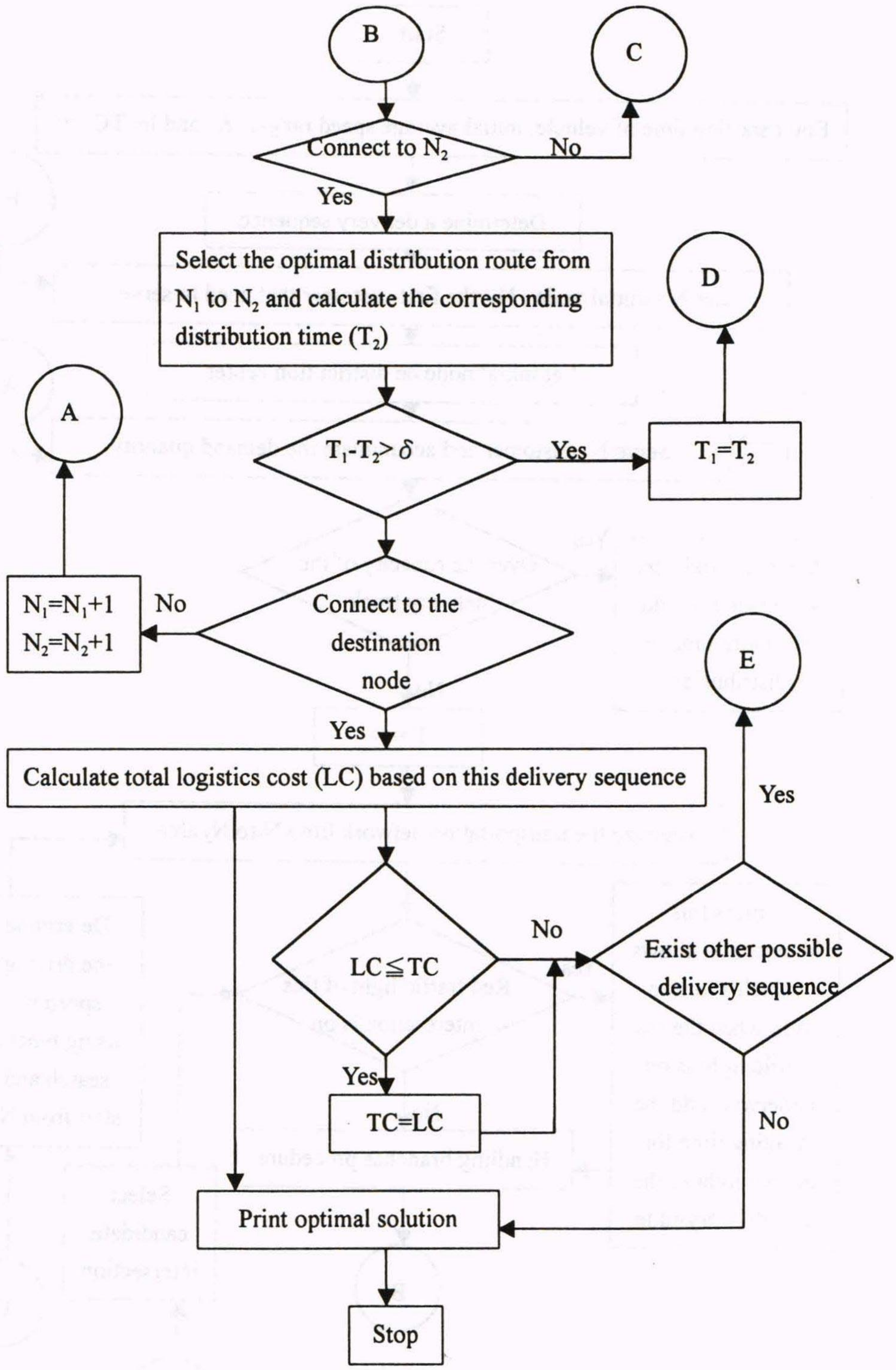


Figure 1 the flowchart of the algorithm (continue) obtained by following sub-steps: (1) When a delivery sequence is known, the distribution center is deemed as the initial node, and then delivery customer nodes and accumulated weight is computed. (2) Where accumulated weight is over the vehicle capacity, the next delivery will be required in order to finish delivery.

Step 5: Analyzing the transportation network: Its major procedures are as follows
(1) Computing the delivery time for each road section under a fixed vehicle speed;
(2) Determining the number of available vehicle routes for each intersection which will serve as a basis for the Step 6.

Step 6: Handling branch procedures
Determining whether a driver can turn right or not with the red light on and solving the branch problem are proceeded according to the following four sub-steps: (1) If the vehicle arrives at the intersection where it can turn right even though the red light is on, such a node can unfold into two branches. The delivery time for each branch includes (i) the total delivery time from the initial node to the intersection with the waiting time for the red light, and (ii) the total delivery time from the initial node to the intersection without the waiting time for the red light. (2) Developing the two branches according to (1). (3) At the same node, the shortest path based on cyclic algorithm should be selected as the major developing branch and the longer paths can serve as potential intersections. (4) If the vehicle still does not arrive at the ending node (N_2), it can continue to select the shortest path among potential intersections to keep unfolding, until arriving at the destination.

Step 7: Applying the binary search
This step focuses on the search of the shortest path between any two customers. Its major procedures can be categorized as follows: (1) Assuming the delivery time is an infinity: (2) Determining the speed within the speed range by means of the binary search: (3) Comparing with the previous delivery time: If the difference of the total delivery time is more than the convergent value, the temporary optimal speed can be found and referred to as "T_1"; then keep looking for the next potential optimal speed by using the binary search; (4) Comparing with the previous delivery time: If the difference of time is no more than the convergent value, both speeds will constitute of the ranges of the optimal speed. Taking the middle value of the optimal speed range as the vehicle driving speed for passing through two nodes, this algorithm calculates the delivery time for any two nodes based on the shortest path through the cyclic algorithm. If the ending node is not one of these two customers, then $N_1=N_1+1$ and $N_2=N_2+1$.

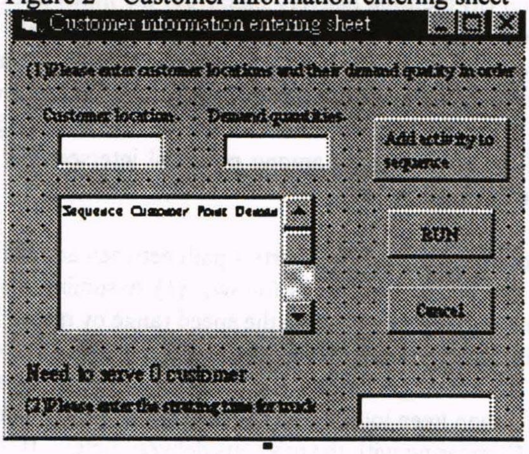
Step 8: Calculating of the logistics cost:
Its major procedures are as follows: (1) After finishing each delivery operation, one should use equation to calculate its logistics cost. The gasoline fees will be determined by the vehicle capacity and the distance between any two nodes. (2) The gasoline fee for a returning trip will be based on those of vacant vehicles. (3) Accumulation of logistics costs for each delivery between two customers will be the total logistics cost of this delivery sequence.

Step 9: Determining the lowest logistics cost among all possible delivery sequences. If the logistics cost under a delivery sequence is the lowest among all possible sequences, one can move forward to the step 10; otherwise, we have to try another delivery sequence and go back to the step 3.

Step 10: Printing the result
Printing the total delivery time, logistics cost of the shortest path between the initial node and ending node, as well as the optimal speed range and the corresponding shortest path between any two consecutive nodes in the optimal delivery sequence.

The important parameter which influences the performance of the algorithm developed by this study is the convergent value (α). If the convergent value (α) is too large, its contribution will not be obvious and the shortest path sought by it will probably be the local best solution instead of the global one. If the convergent value (α) is too small, it is possible that the vehicle speed within the optimal speed range will almost be inflexible. Given these, the user must assign an appropriate convergent value depending on his company's attitude towards the cost control. In the course of developing a computer program, this study develops a user interface (as shown in Figure 2) to facilitate the input of delivery information, i.e. customer information entering sheet. After entering customer's location and demand quantity, then pressing the "add activities to sequence" button, the entered customers information will appear in the sheet item by item. The starting delivery time of the vehicle will be input eventually. With all information is input, pressing the "RUN" button will begin to execute this program.

Figure 2 Customer information entering sheet



4. EXAMPLE

This example takes Taichung city in Taiwan as the delivery area. This transportation network (as shown in Figure 3) includes 100 nodes and at least 170 arcs. The route with heavy traffic load in this network will serve as the major delivery route to connect other paths. The major and minor routes compose of a transportation network. Each node represents the intersection in each road section. The arc data among node indicates the fixed distance between two nodes. The delivery time will be varied according to the driving speed. For example, assuming that the distance from node 44 to node 54 is 1.6 km and the speed is 60 km per hour, the delivery time will be 96 seconds. Traffic signal lights are installed at each intersection and change regularly. The time of changing traffic signal lights is 50 seconds on the major route and 35 seconds on the minor route. The intersections where it is allowed to turn right even when the red light is on include nodes 22, 44, 65, 67, 84, 87 and 96. For the night delivery, the delay resulting from the traffic load would not be taken into consideration due to the low traffic load at night. The network information includes the distance between two nodes, time and direction, etc. Parts of the information are shown in Table 1.

As shown in the Table 1, the distance from the node 3 to node 6 is 1.26 km. with the east-west direction. If the speed is 57.5 km per hour, the time for passing through this road section will be 79 seconds.

This study takes this example as basis for testing the algorithm. In this example, we assume that all the goods that need to be delivered in Taichung area are stocked in the distribution center (node 1). These goods should deliver to five customers on a certain day with information shown in Table 2. The customers' locations are given in Figure 3.

The capacity of a frozen delivery vehicle is 1.5 tons. If the demand quantity is over the truck capacity, the truck has to return to the distribution center (node 1) to proceed with another delivery until finishing the delivery.

This study assumes that the starting distribution time of the first delivery is 00:00:10. Because the minimum and maximum speed limits in the urban area are 40km/hr and 60km/hr in Taiwan, we use these speed limit as the initial speed range and set the acceptable convergent value as 60 second, i.e. $\alpha<=60$. That is, among the optimal speed range the difference of the total delivery time between any two customers can not be over 60 sec. This study uses the binary search to determine the optimal speed in the search process. In fact, the higher the vehicle speed is, the less the total delivery time will be; therefore, the delivery operation can be finished as early as possible. By applying the VBA program to determine the logistics cost, the result is shown as Tables 3 and 4. The output includes the number of distribution times, delivery time, delivery distance, optimal speed, logistics cost and delivery route between the starting node and the ending node.

Table 1. the network information of the partial distribution area in Taichung of Taiwan.

Starting node	Ending node	Direction*	Distance(km)	Moving time(sec)
1	2	south-north	2.08	130
1	3	south-north	1.6	100
2	1	south-north	2.08	130
2	5	east-west	3.16	198
3	1	south-north	1.6	100
3	4	south-north	1.34	84
3	6	east-west	1.26	79
4	3	south-north	1.34	84
4	5	south-north	1.4	88
4	8	east-west	0.6	38
5	2	east-west	3.16	198
5	4	south-north	1.4	88
5	9	east-west	0.26	16
5	10	south-north	1.36	85

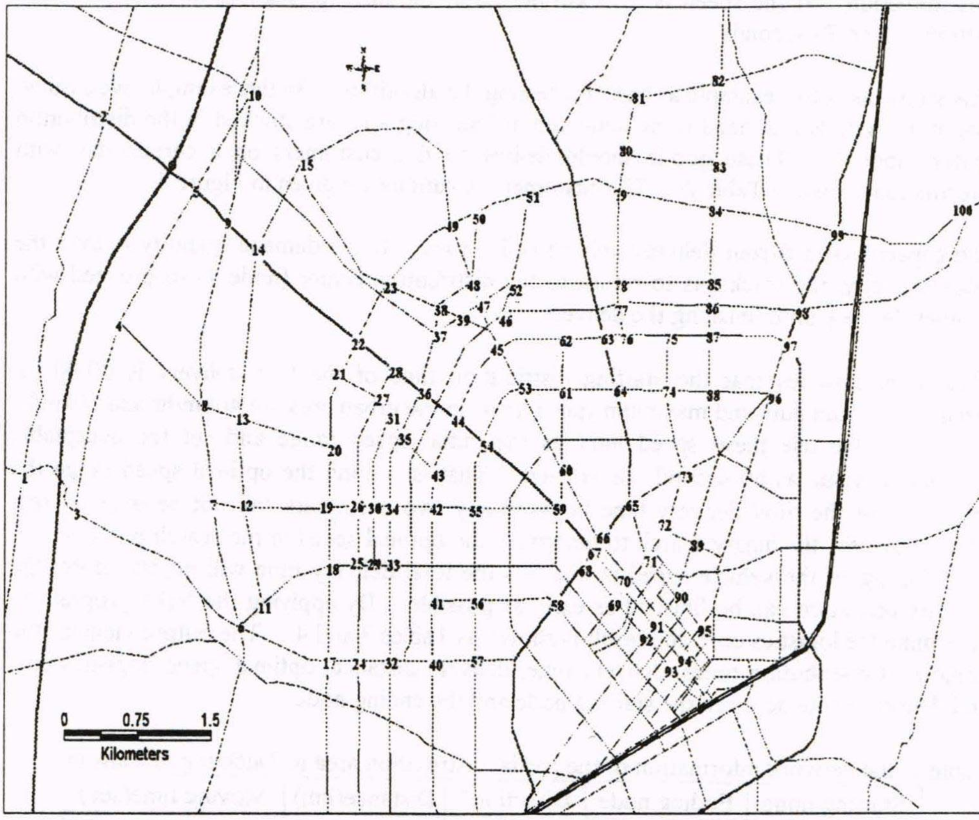


Figure 3 The low temperature distribution network of the example

Table 2 customer data

Customer location(node)	Demand quantity
2	17
48	15
45	30
8	28
100	96
Total demand quantity :	186

Table 3 the optimal solution of the distribution example

Number of distribution times	Starting node	Ending node	Delivery time	Distance (Km)	Optimal speed range (km/hr)	Optimal speed (km/hr)	Weight (10kg)	Logistics cost (dollar)
1	1	8	223	3.54	[55,60]	57.5	28	7.48
1	8	48	296	3.84	[55,60]	57.5	15	7.16
1	48	45	69	0.96	[40,60]	50	30	1.66
1	45	2	418	6.56	[55,60]	57.5	17	9.64
1	2	1	143	2.08	[55,60]	57.5	0	2.75
*1	1	100	891	14.14	[57.5,60]	58.75	96	30.61
		Total	2040	31.12	--	--	--	59.30

* the route for return trip

Table 4 the optimal distribution route of the example

Starting node	Ending node	Distribution route
1	8	1→ 3→ 4→ 8
8	48	8→13→20→21→22→23→38→48
48	45	48→47→39→45
45	2	45→39→38→23→22→14→9→5→2
2	1	2→1
1	100	1→3→6→11→18→25→29→33→41→56→58→68→ 69→70→71→72→73→88→96→97→98→100

As shown in Table 3 and Table 4, the optimal delivery sequence is customer 8, 48, 45, 2, 1 and 100. Also, the vehicle has to conduct two times of deliveries before the whole delivery is completed. The capacity of the delivery vehicle can only burden the accumulated demand quantity to node 2. Therefore, when the first delivery to node 2 is finished, the vehicle only needs to return back to node 1 and conduct a second delivery to complete the delivery operation. The optimal speed as shown in Table 3 is based on the average value of the optimal speed range. For example, if the optimal speed range from node 8 to node 48 is from 55km/hr to 60km/hr, the optimal speed will be its average value, i.e. 57.5km/hr. The corresponding delivery time is 296 seconds and the delivery distance is 3.84km. In addition, the vehicle capacity for driving on this road section is 150kg and the delivery cost is NT$7.16. Its delivery path in sequence as shown in the Table 4 is node 8, 13, 20, 21, 22, 23, 38 and 48. As shown in Table 3, the minimum total logistics cost is NT$59.30. The total delivery time is 2040 seconds and the total distance is 31.12km.

5. CONCLUSION

In the past, the focus of the distribution issue was mostly put on the vehicle routing problem (VRP). The distance between any two nodes will be sought by applying the shortest path algorithm. In addition to one-way, two-way and the number of routes connected with every intersection, we incorporate the traffic signal light factor in our algorithm which is regarded as the time window for vehicles driving in the urban area. Also, the calculation of its logistics cost takes the delivery distance, vehicle capacity and gasoline fees into consideration. The algorithm developed by this study can determine the optimal delivery sequence with the minimum logistics cost, to improve the competitive strength of enterprises.

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