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Procedia Computer Science 17 (2013) 96 – 103
Procedia Computer Science

Information Technology and Quantitative Management (ITQM2013)

A Systematic Approach to Order Fulfillment of On-demand Delivery Service for Bento Industry

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Abstract

This paper proposes a three-stage approach to solve the order fulfillment problem of on-demand delivery service with large quantities of orders for bento (boxed meal) industry. At the first stage, a geographic information system (GIS) is used to locate the delivery destinations designated by customers. Then the k-means algorithm is utilized to cluster customer orders based on locations and according to the number of delivery vehicles. At the final stage, a genetic algorithm (GA) is employed to minimize the total travel distance of deliveries. Experimental results show that the proposed approach is highly feasible and very potential in dealing with the present order fulfillment problem. In addition, the influences of increasing the number of clusters on the profit and the service level are discussed.

Selection and peer-review under responsibility of the organizers of the 2013 International Conference on Information Technology and Quantitative Management

Keywords: On-demand delivery service, culstering, genetic algorithm, GIS, k-means, Bento

1. Introduction

In an on-demand delivery service (ODDS) model [1-2], deliveries are made fairly quickly after orders are received. In order to provide greater value to the customer, more and more bento (boxed meal) stores implement ODDS and deliver lunch or dinner boxes to customers within very short periods of time, usually one hour. In such a model, lots of customers request bento during peak hours such as at noon or at evening. To make significant profits, the stores need to expedite deliveries and reduce order fulfillment costs, which require to deal with batch orders rather than a single one and to deliver meal boxes with a shortest route. When the number of customer orders becomes large and the required customer service level is high, fulfillment of orders grows to be a complex problem.

To ensure a high customer service level, which is generally defined as the ratio of the number of customer orders satisfying customer needs to the total number of customer orders, the store manager needs to decide a service distance or a service region within which ODDS will be conducted. A schematic diagram of the service

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doi:10.1016/j.procs.2013.05.014

region is illustrated in Fig. 1, where r is the service distance and the destinations to be delivered is marked by black points. Inside the service region, delivery destinations are diversely located at different positions. It is not easy to fulfill orders efficiently without a systematic approach, especially when the distance r is long and the number of customer orders is large. Hence, there is a need to present an effective approach that can find solutions quickly to satisfy the requirements of ODDS.

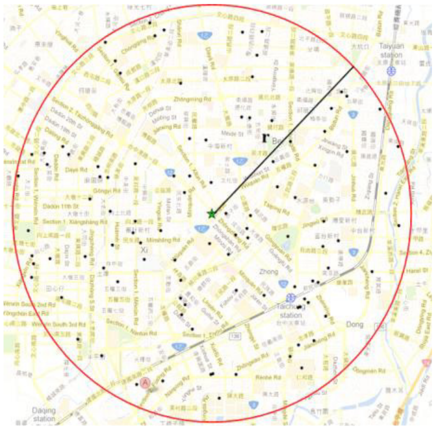


Fig. 1. A schematic diagram of the on-demand delivery service region.

2. The Problem

The present order fulfillment problem is illustrated in Fig. 2 and it can be briefly described as follows. A bento store receives a lot of customer orders from different channels such as telephones, the Internet, and mobile phones in a specific period of time. The total number of the orders received during the period is s. Since the destinations of two different customer orders may be the same, the actual number of destinations which needs to deliver is N, where $N \leqq s$. For the store, there are k delivery vehicles (generally the motorcycles) which are used to deliver meal boxes. The bento store manager hopes to aggregate customer orders, find out the positions of delivery destinations, divide destinations into k clusters, and for each cluster deliver meal boxes to all destinations with the shortest travel distance. In addition, the store manager needs to decide the value of k and to evaluate the benefits of increasing delivery vehicles.

To minimize the travel distance, the optimization problem can be described mathematically as:

$$\text{Minimize } Z = \sum_{i=0}^{N} \sum_{j=0}^{N} d_{ij} x_{ij} \tag{1}$$

s.t.:

$$\sum_{i=0}^{N} \sum_{j=0}^{N} x_{ij} = N + 1, \qquad i \neq j, \qquad i = 0,1, \ldots N;\ j = 0,1, \ldots N \tag{2}$$

$$\sum_{j=0}^{N} x_{ij} \leq 1, \qquad i = 0,1, \ldots N; \tag{3}$$

$$\sum_{i=0}^{N} x_{ij} \leq 1, \qquad j = 0,1, \dots N; \tag{4}$$

$$x_{ij} \in \{0,1\}, \qquad i = 0,1, \dots N;\ j = 0,1, \dots N \tag{5}$$

Equation (1) requires the total travel distance to be as short as possible, where both $i = 0$ and $j = 0$ stand for the origin (the location of the store). Equation (2) requires that the number of total paths traveled is equal to $N + 1$. Equations (3) and (4) requires each path between destination i and destination j travels at most one time. The value of decision variable x_{ij} should be either 1 or 0, as indicated in Eq. (5). Note that the distance d_{ij} is known. It is the actual distance between two destinations. Note that the waiting time during delivery should also be considered if a high service level is required.

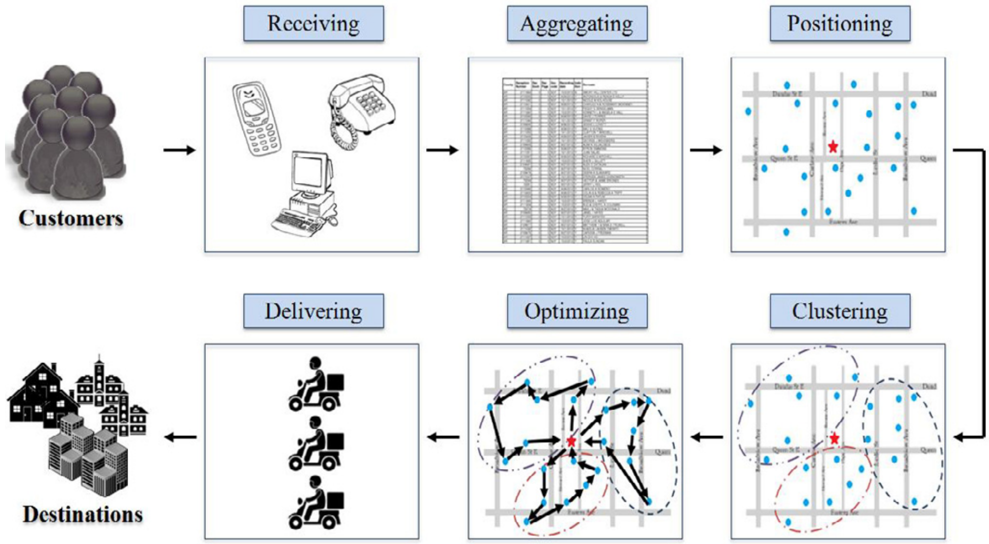


Fig. 2. A schematic diagram of the order fulfillment problem.

When the number of customer orders becomes large, the shortest travel distance problem turns out to be complex. The present problem is a travelling salesman problem (TSP) [3-6], which is NP-hard. Consequently, heuristic approximate algorithms might be more appropriate than exact ones. Amid the most effective heuristic algorithms, GA [7-16] is one of the most popular approximate algorithms to solve the TSP problem. Previous studies have demonstrated that GA is very effective to solve such problems [7, 14]. Therefore, in this paper GA is employed to find solutions.

3. The Approach

To solve the problem mentioned above, a three-stage approach is proposed. At stage 1, a geographic information system (GIS) [17-20] is used to locate the delivery destinations designated by customers. The coordinates of destinations are found at this stage. Then a clustering algorithm [21-22] is utilized to cluster customer orders based on their locations. The algorithm we used in this paper is k-means [21]. The value of k

can be set according to the need of the store manager. An easy way to set this value is to let k be equal to the number of delivery vehicles. At stage 3, a GA is employed to minimize the total travel distance of deliveries. Since the number of clusters is equal to k, the GA program should be performed k times. The proposed approach is illustrated in Fig. 3. To facilitate the deliveries, both a visualized chart showing the travel route and a table showing the related information of customers are generated.

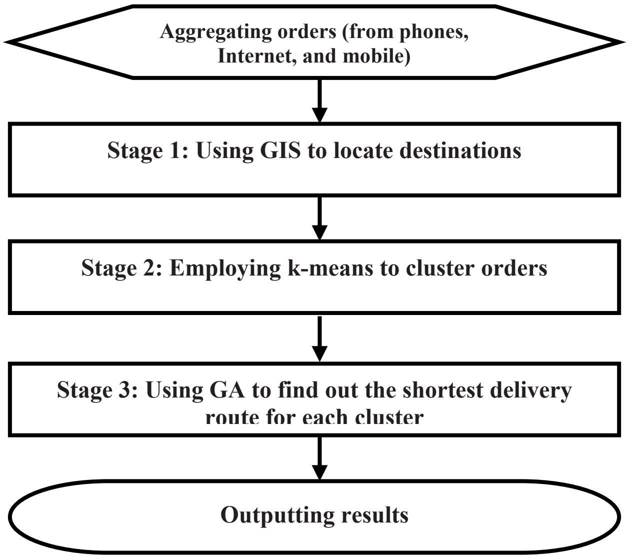


Fig. 3. The framework of the proposed approach.

The encoding of GA is illustrated in Fig. 4. The number of genes is equal to n, i.e., the number of destinations at a cluster ($n \leqq N$, $n = N$ if $k = 1$). Note that the number of destinations at each cluster may be different. The location of gene stands for the priority of destinations. For example, the first destination to be delivered is destination No. 39, the second destination to be delivered is destination No. 2, and the like.

Priority	1	2	3	4	…	n
Destination	39	2	25	17	…	40

Fig. 4. The representation of a chromosome.

4. Results and Discussion

To find the shortest travel route, a GA program was developed. The GA program was built up using VB.NET 2008, as illustrated in Fig. 5. The program was run on a PC with an AMD Athlon (tm) 2.6 GHz 64 processor and a 512 RAM. Each case was run with 30 trials to test the stability of the program. In 30 trials, we designate the average value of the optimal fitness at each trial as *AVG*, the lowest fitness value as *MIN*, and the coefficient of variation as C_v.

To evaluate the performance of the GA program, experiments with different numbers of destinations were done. The population size was set to be 30, generation number = 3000, mutation rate = 0.005, and crossover rate = 0.8. The numbers of destinations at a cluster were set be 10, 20, 30 and 40, respectively. All the values of

C_v at different numbers of destinations are low, indicating that the GA program is quite stable (Table 1). In addition, the difference between *AVG* and *MIN* is small, showing that the program can easily obtain solutions that are very close to the optimal solutions.

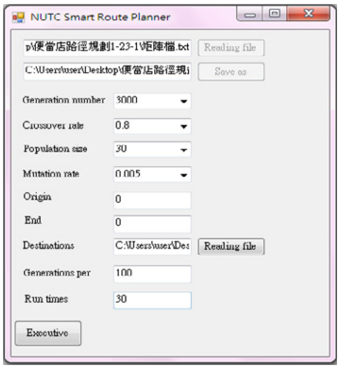
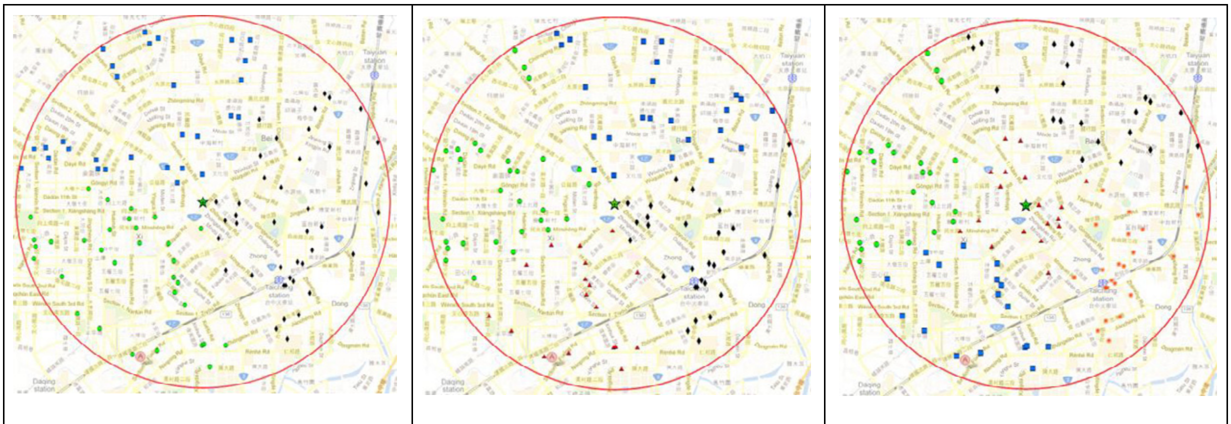


Fig. 5. The interface of the GA program.

Table 1. The test results of GA with different numbers of destinations in 30 trials.

Number of destinations, *n*	*AVG*	*MIN*	C_v
10	13582	13341	0.0208
20	21015	20314	0.0138
30	23941	23159	0.0215
40	29808	29130	0.0218

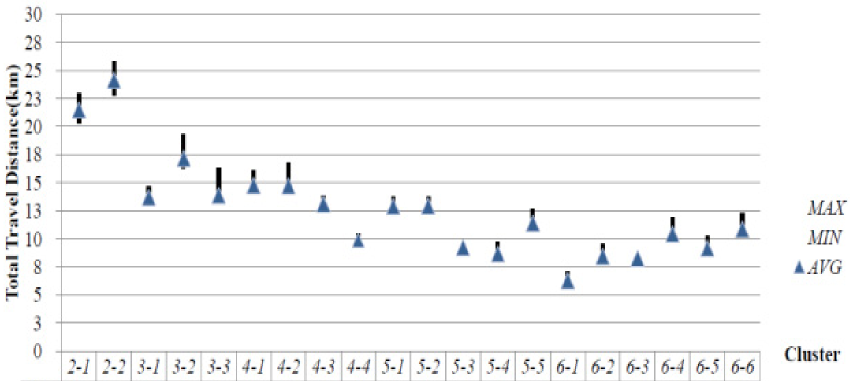
The clustering results with different *k* values are shown in Fig. 6. When *k* increases, the number of destinations at each cluster decreases. A very important issue for the store manager is: What is the best *k* value? Does the total travel distance decrease as *k* increases? What are the benefits of increasing or decreasing delivery vehicles?



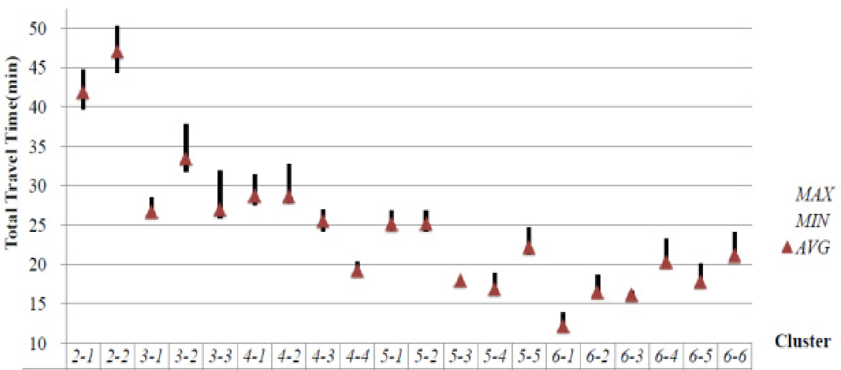
k = 3 *k* = 4 *k* = 5

Fig. 6. The results of clustering with different *k* values.

To address the abovementioned questions, experiments were performed with k = 2, 3, 4, 5, and 6, respectively. The results are shown in Fig. 7, where “2-1” stands for the number of clusters k = 2 and the cluster is the first one, “2-2” the number of clusters k = 2 and the cluster is the second one, and the like. Since the GA program was run 30 times for each case and the initial population was generated randomly, the result for each time may be different. An effective representation of the results is shown in this figure, from which the possible difference between two runs can be easily observed. In addition, when k increases, the average value of the total travel time at each cluster decreases, implying that an increase in the number of delivery vehicles can shorten the total travel time and thus favorably ensure a higher service level. However, increasing the number of vehicles means an increase of costs, negatively influencing the profits. Hence, there should be a tradeoff between the profit and the service level.



	2-1	2-2	3-1	3-2	3-3	4-1	4-2	4-3	4-4	5-1	5-2	5-3	5-4	5-5	6-1	6-2	6-3	6-4	6-5	6-6
MAX	23	26	15	19	16	16	17	14	10	14	14	9	10	13	7	10	9	12	10	12
MIN	20	23	13	16	13	14	14	12	10	12	12	9	8	11	6	9	9	11	9	11
AVG	21	24	14	17	14	15	15	13	10	13	13	9	9	11	6	8	8	10	9	11



	2-1	2-2	3-1	3-2	3-3	4-1	4-2	4-3	4-4	5-1	5-2	5-3	5-4	5-5	6-1	6-2	6-3	6-4	6-5	6-6
MAX	45	50	29	38	32	31	33	27	20	27	27	18	19	25	14	19	17	23	20	24
MIN	40	44	26	32	26	28	28	24	19	24	24	18	16	21	12	17	17	21	18	21
AVG	42	47	27	33	27	29	29	26	19	25	25	18	17	22	12	16	16	20	18	21

Fig. 7. The results of clustering with different k values.

To facilitate deliveries of bento to customers, a visualized chart which shows the delivery route and a table which indicates the related information of customers are generated (Figs. 8 and 9). In the chart the priority and the number of destinations are clearly illustrated, as we can see from Fig. 9.

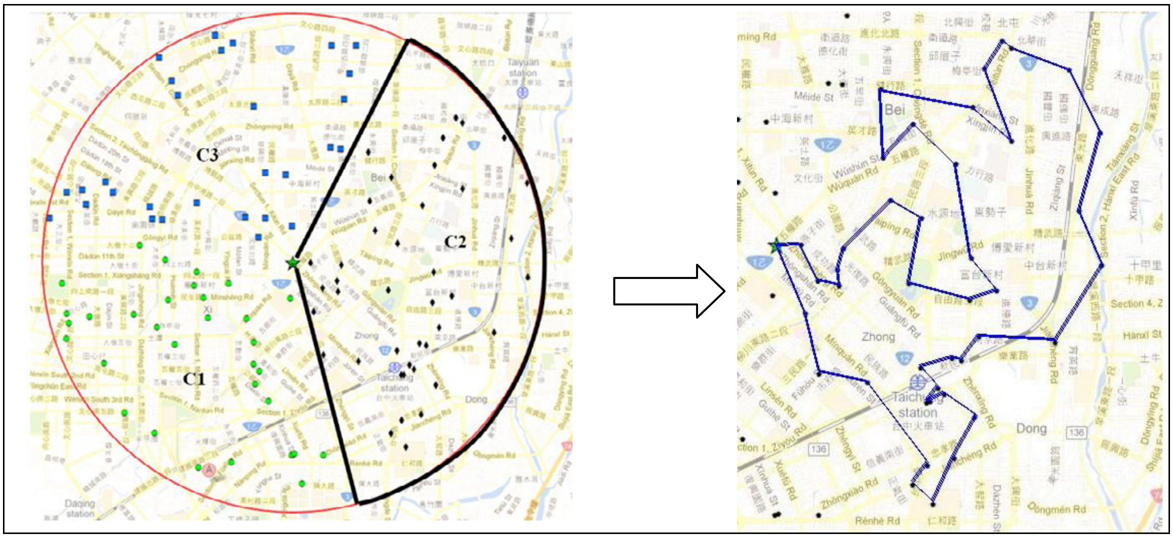


Fig. 8. A visualized delivery route is output after optimization.

Priority	Destination No.	Address	Contact person	Phone No.
1	0	No.118_ Guangfu Rd._ Central Dist._ Taichung City 393	Chiu	04-22583658
2	102	No.180_ Minquan Rd._ West Dist._ Taichung City 403	Ma	0914231456
3	99	No.99-1_ Minquan Rd._ West Dist._ Taichung City 403	Huang	04-22271236
4	93	No.45_ Jianzhong St._ East Dist._ Taichung City 401	Lin	04-22271236
5	97	No.26_ Minzu Rd._ Central Dist._ Taichung City 400	Ma	0958589632
6	96	No.258_ Zhongxiao Rd._ East Dist._ Taichung City 401	Li	0914231456
7	81	No.305_ Sec. 4_ Fuxing Rd._ East Dist._ Taichung City 401	Ma	04-22581258
8	60	No.39_ Zhenfu Rd._ Taiping Dist._ Taichung City 411	Lin	04-22242665
9	47	No.483_ Jinhua Rd._ North Dist._ Taichung City 404	Chiu	04-22581258
10	63	No.72_ Nanjing Rd._ East Dist._ Taichung City 401	Li	04-25128888
11	78	No.14_ Ln. 220_ Sec. 4_ Fuxing Rd._ East Dist._ Taichung City 401	Wu	0958589632
12	88	No.182_ Dazhi Rd._ East Dist._ Taichung City 401	Li	04-22271236
13	82	No.4_ Ln. 236_ Sec. 4_ Fuxing Rd._ East Dist._ Taichung City 401	Chang	0962236589
14	67	No.222_ Jianguo Rd._ Central Dist._ Taichung City 400	Chang	0959111222
15	68	No.135_ Luchuan W. St._ Central Dist._ Taichung City 400	Chiu	04-22271236
16	62	No.46-2_ Hanxi St._ East Dist._ Taichung City 401	Li	04-22246666
17	43	No.1_ Ln. 80_ Sec. 1_ Chongde Rd._ North Dist._ Taichung City 404	Lin	04-25122145
18	44	No.30_ Sec. 2_ Shuangshi Rd._ North Dist._ Taichung City 404	Chen	0958589632
19	36	No.126_ Sec. 2_ Zhonghua Rd._ North Dist._ Taichung City 404	Chang	0958654123
20	24	No.328_ Jingwu Rd._ East Dist._ Taichung City 401	Lin	04-22271236

Fig. 9. A table which indicates the related information of customers is generated after optimization.

5. Conclusions

In this paper, a systematic three-stage approach has been proposed to solve the ODDS problem with a large number of orders for bento stores. A geographic information system (GIS) is employed at the first stage to locate the delivery destinations designated by customers. Then k-means is utilized to cluster customer orders based on locations of destinations and according to the number of delivery vehicles. At the final stage, a genetic algorithm (GA) is used to optimize the delivery travel route which has the shortest travel distance. Experimental results show that the proposed approach is promising in dealing with the on-demand service problem of bento. In addition, as the number of clusters increases, the total travel distance also increases, negatively increasing transportation costs and thus reducing the profit. However, the average travel time to delivery bento for a cluster is decreased, favorably ensuring a higher service level.

The proposed approach is promising to deal with other similar problems which need to locate destinations, cluster similar orders and optimize a travel route. Further investigations are recommended to use the proposed approach to solve other similar optimization problems such as same-day delivery.

Acknowledgements

The authors wish to express their appreciation to Yu-Pei Chou for her help during the course of writing this paper. This work was supported by the National Science Council under grant number 101-2221-E-025-013.

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