TRUCK QUEUING ANALYSIS AT LANDFILL SITES IN A WASTE COLLECTION VEHICLE ROUTING PROBLEM

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ABSTRACT. This paper presents an analysis of a truck queuing problem at landfill sites due to a static rest time of truck drivers in a waste collection vehicle routing problem. The analysis is based on a solution of two datasets from a benchmark waste collection problem using the nearest greedy heuristic algorithm. In this problem, all drivers need to have a one-hour rest break during their collection. The rest break can start from 11.00 a.m. to 12.00 p.m. However, based on the solution from a previous study, all drivers have their rest break almost at the same time. Consequently, all drivers travelled to landfill sites to unload waste approximately at the same time. Based on the truck queuing analysis presented in this paper, there is a long queue at landfill site 3 (ten trucks arrived between 2.52 p.m. to 2.53 p.m.) for dataset 1; whereas for dataset 2, 13 trucks arrived at landfill site 1 between 4.10 p.m. to 4.55 p.m. Thus, it may be concluded that the static rest time period of truck drivers can cause truck queuing at landfill sites. Long queues at landfill sites will increase the service time at landfill sites as well as affect the drivers' arrival time at customers. This paper suggests that future works need to consider a dynamic rest time period in solution techniques to overcome the truck queuing problem at landfill sites for solving the waste collection vehicle routing problem.

Keywords: landfill queuing, waste collection, heuristic, rest time window, vehicle routing problem.

INTRODUCTION

Vehicle routing problems (VRP) have been discussed extensively in previous studies since 1959 by George Dantzig and John Ramser. The main objective of VRP is to construct vehicle routes for drivers with two main objectives: to minimize the total distance travelled and to minimize the number of vehicles used. One of the most important VRP real-life applications that attract researchers' attention is a waste collection problem. Generally, researches in this area aim to help the waste management team in reducing operational costs as low as possible, and at the same time, they could provide good services to communities.

There are three main components in a waste collection VRP: depot, landfill sites, and customers. Basically in this problem, all drivers start their collections from a single depot. Next, wastes are collected from customers. When the waste trucks are almost full, they will travel to a landfill site to unload the collected waste. Then, they will continue the collection for other customers. The process is repeated until all customers have been served and they will return to the depot with empty trucks.

The waste collection VRP becomes complicated when many real-life constraints have been considered in solving this problem. For example, the drivers need to meet time windows of the customers/landfill sites/depot when completing the collections; the drivers need to have a rest break during their collection, more than one landfill site are available, thus the drivers need to unload the waste at suitable landfill sites that will not increase the total distance travelled when completing the collection.

In this paper, the authors focused on a benchmark waste collection problem that has been introduced by Kim et al. (2006). In this problem, all drivers need to have an hour rest break that may start from 11.00 a.m. to 12.00 p.m. In line with a solution from a previous study using the nearest greedy heuristic algorithm, Benjamin (2011) showed that all drivers have almost the same rest break time. Based on the solution, the arrival time of each driver at the landfill sites is presented in this paper. The result of the arrival time is analyzed in order to investigate the effect of having the same rest break time on truck queuing at the landfill sites.

LITERATURE REVIEW

This section discusses the previous studies that not only solve waste collection problems, but also any VRP application that considered drivers' rest break. Coelho et al. (2015) solved VRP in the furniture and electronics industries at a Quebec-based company. The drivers start their shift between 7.00 a.m. and 8.30 a.m. and must return to the depot before 6.00 p.m. In order to avoid the morning traffic, the first customers will be served as late as possible in the morning session, whereas the last customers will be served as early as possible to ensure the collection is finished within the time frame. An hour lunch hour break is required by all drivers, which is between 11.00 a.m. to 1.30 p.m.

Rochat and Semet (1994) solved a real-life VRP in a Swiss company producing pet food and flour. They considered two drivers' breaks by day: a 30-minute break in the morning and a 60-minute break at lunch time. The drivers can start the morning break from 7.30 a.m. to 10.00 a.m., whereas for the lunch break, they can start from 11.45 a.m. to 1.00 p.m.

Goel and Gruhn (2006) described the regulations for drivers' working hours in the European Union. They considered that the maximum daily driving hour is nine hours with a break not less than forty-five minutes after a driving period of four hours and thirty minutes. However, the total weekly driving hours must not exceed 56 hours.

A case study at a medium-size Danish waste collection company was conducted by Buhrkal, Larsen, and Ropke (2012). The drivers start their daily routine as early as 4.00 a.m. to 6.00 a.m. The maximum working hour length is nine hours. They are required to take a lunch break after a maximum of four hours and thirty minutes of working. The lunch break allowed is 45 minutes. However, they are able to split the lunch break into two breaks: 15 minutes and 30 minutes each. No specific lunch locations are required. They assumed that the lunch breaks are taken anywhere between two stops at three different points; directly after servicing customer A, travelling between customer A to customer B, and directly before servicing customer B. Therefore, no additional travel cost is required for the lunch breaks. They believed that the flexibility of the lunch period could save the travelling time and costs, and ensure the task is completed within the time frame.

Markov, Varone, and Bierlaire (2014, 2015) made a study on a recyclable waste collection company in Geneva, Switzerland. They restricted the drivers' working hours to a maximum duration of eight hours with a one-hour rest break after four hours of continuous work. Similarly, a one-hour break is also required by waste collection drivers in Kim et al. (2006), Ombuki-Berman (2007), Benjamin and Beasley (2010, 2013), and Islam and Rahman (2012) in solving a benchmark waste collection problem by Kim et al. (2006).

METHODOLOGY

In this analysis, a solution for a waste collection benchmark problem using the nearest greedy heuristic algorithm presented in Benjamin (2011) is referred. The solution from this heuristic is compared well with the solution from Kim et al. (2006) in terms of the total distance travelled as well as the total number of trucks used. The benchmark problem consists of ten datasets. However, only two datasets are considered in this paper. The characteristics of both datasets (i.e. the number of customers and landfill sites) and the solutions from Benjamin (2011) and Kim et al. (2006) are compared in Table 1. The last column in Table 1 gives the percentage improvement in distance when compared to the result of Kim et al. (2006), namely 100(distance from Kim et al. (2006) – distance from Benjamin (2011))/distance from Kim et al. (2006). The positive number indicates that the solutions from Benjamin (2011) for both datasets are better than Kim et al.'s (2006). With respect to the number of trucks, Benjamin (2011) used one less truck than Kim et al. (2006) for dataset 2.

Table 1. Characteristics and Solutions of Datasets

Dataset	Number of customers	Number of landfill sites	Total number of trucks used		Total distance (mile)		% improvement in distance over Kim et al. (2006)
			Benjamin (2011)	Kim et al. (2006)	Benjamin (2011)	Kim et al. (2006)	
1	2092	7	16	16	1823.6	1833.8	0.56
2	1927	4	16	17	1346.1	1395.3	3.53

Other characteristics of both datasets that have been considered in this problem are the unlimited number of waste trucks with a capacity of 462 tonnes per truck, the maximum of 2000 tonnes of collected waste per day, the maximum of 500 customers served per day, and the drivers' rest time window of [11:00, 12:00].

In this analysis, the authors re-examined the nearest greedy heuristic algorithm presented in Benjamin (2011) in order to capture the rest time of all drivers and the arrival time at the landfill sites. Both times are needed in order to investigate the existing truck queuing problem in both datasets due to a static rest time window.

RESULTS AND DISCUSSION

Tables 2 and 3 present the rest time of the truck drivers for datasets 1 and 2, respectively, which start from 11.00 a.m. to 12.00 p.m. Table 2 shows that drivers 3, 7, and 15 have the earliest break, which is at 11.00 a.m., whereas driver 16 starts the rest break at the latest time at 11.18 a.m. Table 3 shows that all drivers start their rest time from 11.00 a.m. to 11.10 a.m. Overall, it can be concluded that all drivers for both datasets have a rest break at almost the same time of each other.

Table 2. Drivers' Rest Time for Dataset 1

Driver	1	2	3	4	5	6	7	8
Rest Time	11:06	11:02	11:00	11:01	11:02	11:01	11:00	11:01
Driver	9	10	11	12	13	14	15	16
Rest Time	11:04	11:16	11:01	11:03	11:05	11:02	11:00	11:18

Table 3. Drivers' Rest Time for Dataset 2

Driver	1	2	3	4	5	6	7	8
Rest Time	11:03	11:05	11:01	11:05	11:01	11:06	11:05	11:00
Driver	9	10	11	12	13	14	15	16
Rest Time	11:01	11:05	11:01	11:10	11:03	11:00	11:04	

Here, for reasons of space, this paper presents the number of trips and the arrival time of drivers to the landfill sites for dataset 1 only (as shown in Table 4). From the table, it can be seen that the majority of drivers travelled three times (3 trips) to the landfill sites in order to unload collected waste from the customers, except for drivers 12, 14, and 16. Drivers 12 and 14 travelled only two times to the landfill sites, whereas driver 16 travelled only once to the landfill site. The first trip of driver 14 to landfill site 6 is at 8.11 a.m. Then, for the second trip, he travelled to landfill site 7 at 2.23 p.m. before he returned to the depot. In order to analyze truck queuing at the seven landfill sites, the authors summarized information in Table 4 into Table 5.

Table 4. Drivers' Trips to Landfill Sites for Dataset 1

Trip	Driver 1		Driver 2		Driver 3		Driver 4	
	Time	Landfill	Time	Landfill	Time	Landfill	Time	Landfill
1	8:15	3	7:40	3	7:32	3	8:03	3
2	12:55	3	12:55	3	12:39	3	12:48	3
3	14:53	3	14:52	3	14:53	3	14:53	3
	Driver 5		Driver 6		Driver 7		Driver 8	
	Time	Landfill	Time	Landfill	Time	Landfill	Time	Landfill
1	8:07	3	7:54	6	7:21	6	7:45	5
2	13:11	3	12:12	6	12:18	6	10:50	5
3	14:52	3	14:36	6	14:52	3	14:52	3
	Driver 9		Driver 10		Driver 11		Driver 12	
	Time	Landfill	Time	Landfill	Time	Landfill	Time	Landfill
1	7:52	7	7:40	6	7:54	1	7:51	7
2	12:37	7	11:16	3	12:54	3	14:14	7
3	14:35	7	14:53	3	14:52	3		
	Driver 13		Driver 14		Driver 15		Driver 16	
	Time	Landfill	Time	Landfill	Time	Landfill	Time	Landfill
1	8:07	1	8:11	6	9:36	2	11:18	7
2	13:00	1	14:23	7	13:03	2		
3	14:52	3			13:51	2		

Table 5 clearly shows a list of drivers for dataset 1 who travelled to the same landfill sites and the time they arrived at the landfills. The information for dataset 2 is presented in Table 6. Table 5 shows that only two drivers (drivers 11 and 13) travelled to landfill site 1. Driver 11 arrived at 7.54 a.m., whereas driver 13 arrived at 8.07 a.m. for the first trip and arrived at 1.00 p.m. for the second trip. Only driver 15 travelled to landfill 2.

Ten drivers travelled to landfill 3. There is no truck queuing in the morning at landfill 3. However, in the afternoon, there are three trucks (drivers 1, 2, and 11) in the queue between 12.54 p.m. to 12.55 p.m. Again, there is a long queue in the evening at landfill 3 between 2.52 p.m. to 2.53 p.m.

No drivers have travelled to landfill 4 to unload waste and there is also no truck queuing at landfills 5 and 6. At landfill 7, there are only two trucks in the queue between 7.51 a.m. and 7.52 a.m.

Table 5. Drivers' Arrival Time at Landfill Sites for Dataset 1

Landfill site	**D11**	**D13**								
1	7:54	8:07								
1		13:00								
	D15									
2	9:36									
2	13:03									
2	13:51									
	D1	**D2**	**D3**	**D4**	**D5**	**D7**	**D8**	**D10**	**D11**	**D13**
3	8:15	7:40	7:32	8:03	8:07					
3	**12:55**	**12:55**	12:39	12:48	13:11			11:16	**12:54**	
3	**14:53**	**14:52**	**14:53**	**14:53**	**14:52**	**14:52**	**14:52**	**14:53**	**14:52**	**14:52**
	D8									
5	7:45									
5	10:50									
	D6	**D7**	**D10**	**D14**						
6	7:54	7:21	7:40	8:11						
6	12:12	12:18								
6	14:36									
	D9	**D12**	**D14**	**D16**						
7	**7:52**	**7:51**								
7	12:37			11:18						
7	14:35	14:14	14:23							

Table 6 shows the same information as in Table 5, but in a different table format. Each row in Table 6 shows the arrival time of the 16 drivers at three landfill sites. From Table 6, it can be seen that most drivers unloaded waste at landfill site 1. Thus, there are two long queues in the morning and in the evening. In the morning, five drivers (drivers 7, 12, 13, 14, and 15) arrived between 9.59 a.m. to 10.21 a.m., whereas 13 drivers arrived between 4.10 p.m. to 4.55 p.m. For landfill site 2, it has only one queue in the evening. Three drivers arrived between 4.50 p.m. to 4.57 p.m. Meanwhile, for landfill site 3, only one driver arrived at 5.55 a.m.

Table 6. Drivers' Arrival Time at Landfill Sites for Dataset 2

	Landfill site 1		**Landfill site 2**		**Landfill site 3**
D1		**16:55**		12:20	

D2	9:14	**16:54**			
D3		15:25	8:56	**16:57**	
D4	9:37	**16:55**			
D5	12:46	**16:52**			
D6	10:56			**16:54**	
D7	**10:18**	**16:47**			
D8		**16:36**	9:27		
D9	8:50	**16:26**			
D10	13:06	**16:55**			
D11	8:59	**16:10**		**16:50**	
D12	**10:02**	**16:43**			
D13	**10:21**	**16:54**			
D14	**10:07**	**16:50**			
D15	**9:59**	**16:46**			
D16	6:42				5:55

CONCLUSION

Based on the arrival times of the drivers to the landfill sites, it can be concluded that a static drivers' rest time window will cause truck queuing at landfill sites. Long queues at landfill sites will increase the service time at the landfill sites as well as the drivers' arrival time at the customers' location. This paper suggests that future works need to consider a dynamic rest time window in the solution techniques to overcome the truck queuing problem at landfill sites for solving waste collection VRP.

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