Application of an Open Source Spreadsheet Solver in Single Depot Routing Problem

Taufik Roni Sahroni[1], Leo Adi Anggoro[2], Satria Ismail[3], Aerna[4]

[1,2,3,4]*Industrial Engineering Department,*
BINUS Graduate Program – Master of Industrial Engineering,
Bina Nusantara University, Jakarta 11480, Indonesia
[1]taufik@binus.edu;

[2]leo.anggoro@binus.ac.id;

[3]satria.ismail@binus.ac.id;

[4]aerna@binus.ac.id

***Abstract*— The VRP has been broadly developed with additional feature such as deliveries, selective pickups and time windows. This paper presents the application of an open source spreadsheet solver in single depot routing problem. This study focuses on Fast Moving Consumer Goods (FMCG) Company as a case study. The objective of this research is to minimize the distance travel. This research begins by collecting data from a respective FMCG Company. A FMCG company based in Jakarta, Indonesia provides drinking water packaged in gallon. This FMCG Company have two distributions characteristic. Head office distribution was used in this case study due to highest internally rejected by company such as un-routed order, no visit, not enough time to visit and transportation issue. Based on computational results, overall solutions to delivered 214 gallons to 26 customers having total distance travelled 56.76 km, total driving time 2 hour and 49 minutes, total driver working time 7 hours and 57 minutes. Total savings of distances travelled between current route and the proposed solutions using open source spreadsheet solver is 7.25 km. As a result, an open source spreadsheet solver can be implemented in FMCG Company for single depot routing problem.**

Keywords*—*Vehicle routing problem; Spreadsheet solver; Fast Moving Consumer Goods (FMCG), driving time limit;

1. Introduction

Vehicle Routing Problem (VRP) first proposed more than sixty years ago by Dantzig and Ramser [1] then improved by Clarke and Wright using savings algorithm [2]. The VRP has been broadly developed with additional feature such as deliveries, selective pickups time windows [3]. The VRP is a NP-hard type [4], [5] and formulated under characteristic of the customers, order characteristics and type of vehicles [6]. The VRP plays a major role in area of supply chain management [7] especially in transported of physical goods and services. The VRP is used methods to minimize the cost and duration of transportations through determine the optimal distribution route of products from depot to consumers. The Vehicle Routing Problem (VRP) also has high potential in green logistics by saving environmental costs such as noise, pollution and fuel consumption [8]. But due to complexity to solving a VRP and associated solution algorithms including it large several of constraints, recent development of VRP algorithms are developed in C++ [8], [10], and [11].

There is a need of VRP solver based on Microsoft Excel since it was the common software for quantitative analysis throughout the world, in both scholars and practitioners [12]. Thus, Fast Moving Consumer Goods (FMCG) Company possibly can make positive changes in terms of minimizing the logistic costs with creating optimal routing. The VRP spreadsheet solver should be simple in terms of user interface, flexibility, and accessibility to overcome the problems. The VRP spreadsheet solver also have to generate optimal routes and fulfilling all constrains that have been set.

Recently, Erdogan introduced a VRP solver using Microsoft Excel for solving Vehicle Routing Problem [13], [14]. An open source spreadsheet solver is used a unified formulation [13] that

comprises broad variants of VRP. It also presented two case studies of routing problem in healthcare and tourism sectors. Based on the literature reviews cited, this paper motivates the authors to use Open Source Spreadsheet Solver to solve single depot vehicle routing problem in FMCG Company based in Jakarta, Indonesia. The objective of this paper is to minimize the distance travel from the perspective of simple and friendly user interface.

2. Literature Review

The field of Vehicle Routing Problem is mature, and many approaches variants have been developed in recent years. A survey has been classified VRP applied methods variants into four categories such as heuristic approaches, meta-heuristics, exact methods and hybrid methods [15]. Categories of VRP applied methods variants are shown in Figure 1.

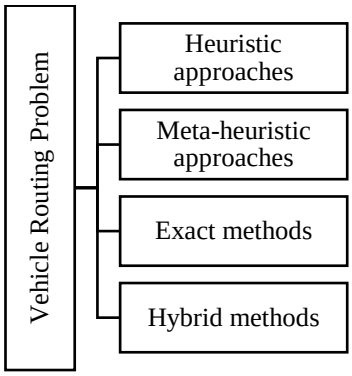

Figure 1. Vehicle Routing Problem Applied Methods Variants

Some heuristic approaches to solve a VRP are as follows: Gendreau, *et al* [16] optimized the planned routes real-time using neighborhood search; Nagata, *et al* [17] using ejection pool, powerful insertion and guided local search to suggest a route minimization; Pang [18] presented an adaptive parallel scheme for route construction and Belfiore, *et al* [22] propose a scatter search approach.

Many meta-heuristic algorithms are developed in the last decade, the most successful being the Adaptive Large Neighborhood Search [19], Iterated Local Search [20], and Genetic Algorithms [21]. Some of meta-heuristic are as follows: Garcia-Najera, et al [23] proposed to solve multi-objective problem using multi-objective evolutionary algorithm. Yu, *et al* [24] proposes optimization using an improved ant colony. Balseiro, *et al* [25] presents an Ant Colony System algorithm hybridized of an Ant Colony System algorithm.

The variants of exact methods are as follows: Azi, *et al* [26] introduced a branch-and-price approach. Gutiérrez-Jarpa, *et al* [3] proposed VRP with Deliveries, Selective Pickups and Time Windows solving using a branch-and-price algorithm. Oesterle, *et al* [27] proposed VRP with Mixed Linehaul and Backhaul Customers, Heterogeneous Fleet, Time Window and Manufacturing Capacity using exact methods. VRP solving with combination of two methods or more are called as hybrid methods such as sweep algorithm plus ant colony system to solve classical VRP [28].

In addition of applied methods variants, VRP also have variants in terms of problem physical characteristics. A brief list of VRP variants in terms of problem physical characteristics are as follows: number of depots [2], [9]; time window type [3], [17], [18], [22] - [27]; number of vehicles [2], [26]; capacity consideration [4], [10], [29]; and travel time [30]. Categories of VRP physical characteristic variants are shown in Figure 2.

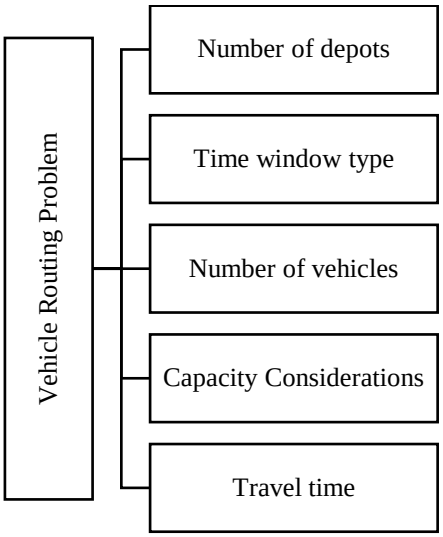

Figure 2. Vehicle Routing Problem Physical Characteristics Variants

3. Methodology

The main method for this research is using the application of an Open Source Spreadsheet Solver that focused in certain elements which is measured to decrease the distanced travelled by setting up the optimal route although this solver is used a unified formulation that comprise large variants of the VRP [13]. Structure of the open source spreadsheets solver are shown in Figure 3.

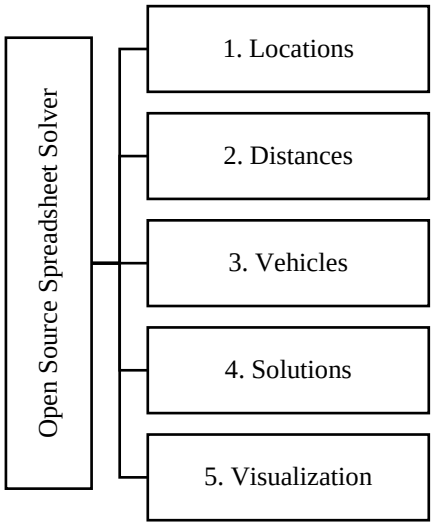

Figure 3. Structure of Open Source Spreadsheet Solver

This research begins by collecting data from a respective FMCG Company. A FMCG company based in Jakarta, Indonesia provides drinking water packaged in gallon. This FMCG Company have two distributions characteristic. These two distributions characteristics are head office distribution and modern distribution center. In December 2017, 2.90% or 1001 delivery orders are rejected for internal reason from total 34469 delivery orders. Company policy to internally reject a delivery orders are as follows: un-routed order; no visit; not enough time to visit; transportation issue; sales quota restriction; and unclear address. Total delivery order rejected because of un-routed order, no visit, not enough time to visit and transportation issue are 88,61% or 887 delivery orders from 1001 delivery orders rejected for internal reason. This issue mostly happens in head office distribution. This paper proposed to use Open Source Spreadsheet Solver to minimize distance travelled with a test case from head office distribution with 26 customers with total delivered order 214 gallons. The current route of this test case has distance travelled 64 km with two trips.

As the problem of internally rejected are also because of not enough time to visit, we set up this visits as time window specified and all delivery order scheduled on a given day must be visited. The service time per customers are simply adjusted to quantity number of gallon delivered order. In one up to six gallons delivered, service time needed is 11 minutes and increase one minute in addition of one up to six more gallons. This study is considered to set identical vehicles as operational parameters with capacity 140 gallons for each vehicle. Each driver has a driving time limit of 8 hours as per the general regulations about driving, and a working time limit of 9 hours including the lunch break. All trucks eventually go back to the depots using the exact same route traversed in the reverse direction.

Various parameters of this single depot routing problem are filled in solver console worksheet. The number of depots with one and number of customers with 26 were used in this study. In order to achieve the shortest distance, the constraint of average vehicle speed to fifty kilometers and route type were determined. Next, the number of vehicles type was set to one and every vehicle must return to depot. In addition, time window was set to hard type and no backhauls. CPU time limit to run the solver was set to 60 seconds. A screenshot of the worksheet is presented in Figure 4.

Sequence	Parameter	Value
0.Optional - GIS License	Bing Maps Key	AvJ2YUt24JHXR_6pnqKTxw8myp3M1
1.Locations	Number of depots	1
	Number of customers	26
2.Distances	Distance / duration computation	Bing Maps driving distances (km)
	Bing Maps route type	Shortest
	Average vehicle speed	50
3.Vehicles	Number of vehicle types	1
4.Solution	Vehicles must return to the depot?	Yes
	Time window type	Hard
	Backhauls?	No
5.Optional - Visualization	Visualization background	Bing Maps
	Location labels	Location IDs
6.Solver	Warm start?	No
	Show progress on the status bar?	Yes
	CPU time limit (seconds)	60

Figure 4. VRP Solver Console Worksheet

The next step is set up the locations worksheet and filled in the details about information location and service time. Latitude and longitude are used to ensure the accurate customer locations. Time windows starts at 07:00 and ends at 16:00. Every customer is set to must be visited, and service time is adjusted with number of gallons to be delivered. A screenshot of locations worksheet is presented in Figure 5.

Location ID	Name	Latitude (y)	Longitude (x)	Time window start	Time window end	Must be visited?	Service time	Pickup amount	Delivery amount
0	Depot	-6.18880	106.91110	07:00	16:00	Starting location	0:00	0	0
1	Customer 1	-6.23169	106.82734	07:00	16:00	Must be visited	0:11	4	4
2	Customer 2	-6.22767	106.83348	07:00	16:00	Must be visited	0:11	5	5
3	Customer 3	-6.22422	106.84256	07:00	16:00	Must be visited	0:11	4	4
4	Customer 4	-6.23045	106.82562	07:00	16:00	Must be visited	0:11	3	3
5	Customer 5	-6.23250	106.82920	07:00	16:00	Must be visited	0:12	8	8
6	Customer 6	-6.22422	106.84256	07:00	16:00	Must be visited	0:18	43	43
7	Customer 7	-6.22787	106.83315	07:00	16:00	Must be visited	0:11	1	1
8	Customer 8	-6.22396	106.84286	07:00	16:00	Must be visited	0:17	42	42
9	Customer 9	-6.23169	106.82735	07:00	16:00	Must be visited	0:10	0	0
10	Customer 10	-6.22787	106.83315	07:00	16:00	Must be visited	0:10	0	0
11	Customer 11	-6.23045	106.82562	07:00	16:00	Must be visited	0:11	1	1
12	Customer 12	-6.22750	106.83377	07:00	16:00	Must be visited	0:12	7	7
13	Customer 13	-6.23045	106.82562	07:00	16:00	Must be visited	0:11	1	1
14	Customer 14	-6.22444	106.84229	07:00	16:00	Must be visited	0:14	24	24
15	Customer 15	-6.23071	106.82736	07:00	16:00	Must be visited	0:11	5	5
16	Customer 16	-6.23119	106.82741	07:00	16:00	Must be visited	0:13	15	15
17	Customer 17	-6.22767	106.83348	07:00	16:00	Must be visited	0:12	9	9
18	Customer 18	-6.23078	106.82742	07:00	16:00	Must be visited	0:11	4	4
19	Customer 19	-6.23045	106.82562	07:00	16:00	Must be visited	0:11	4	4
20	Customer 20	-6.23112	106.82719	07:00	16:00	Must be visited	0:12	12	12
21	Customer 21	-6.22767	106.83348	07:00	16:00	Must be visited	0:11	2	2
22	Customer 22	-6.23067	106.82714	07:00	16:00	Must be visited	0:11	1	1
23	Customer 23	-6.23200	106.82900	07:00	16:00	Must be visited	0:12	9	9
24	Customer 24	-6.22785	106.83347	07:00	16:00	Must be visited	0:11	1	1
25	Customer 25	-6.22767	106.83355	07:00	16:00	Must be visited	0:11	2	2
26	Customer 26	-6.23063	106.82745	07:00	16:00	Must be visited	0:12	7	7

Figure 5. Locations Worksheet

After the solver console and locations worksheet filled, set up distances worksheet was determined. In distances worksheet, the distance and duration automatically populate to get shortest route. This worksheet populates all the distances and travel durations between every two points that are specified in the Locations worksheet. A screenshot of sample locations worksheet is presented in Figure 6 and detail distances for every point is presented in Figure 7.

From	To	Distance	Duration
Depot	Depot	0.00	0:00
Depot	Customer 1	13.54	0:38
Depot	Customer 2	12.43	0:39
Depot	Customer 3	10.83	0:31
Depot	Customer 4	13.39	0:37
Depot	Customer 5	13.43	0:35
Depot	Customer 6	10.83	0:31

Figure 6. Detail Distances Worksheet

	Depot	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26
Depot		13.60	13.84	10.68	13.86	13.33	10.68	13.62	10.83	13.60	13.62	13.86	13.82	13.86	10.70	13.61	13.68	13.84	13.62	13.86	13.70	13.84	13.63	13.37	13.71	13.83	13.60
C1	13.54		2.49	3.67	1.02	0.75	3.67	2.27	3.82	0.00	2.27	1.02	2.47	1.02	3.72	0.42	0.16	2.49	0.42	1.02	0.10	2.49	0.44	0.58	2.35	2.48	0.41
C2	12.43	3.35		2.42	3.62	3.08	2.42	3.06	2.58	3.35	3.06	3.62	0.25	3.62	2.48	3.36	3.42	0.00	3.36	3.62	3.45	0.00	3.37	3.12	0.07	0.20	3.35
C3	10.83	3.31	3.55		3.57	3.04	0.00	3.33	0.15	3.31	3.33	3.57	3.53	3.57	0.05	3.32	3.38	3.55	3.32	3.57	3.41	3.55	3.33	3.08	3.42	3.54	3.31
C4	13.39	0.79	2.52	3.52		0.78	3.52	2.30	3.67	0.79	2.30	0.00	2.50	0.00	3.57	0.64	0.71	2.52	0.64	0.00	0.89	2.52	0.66	0.61	2.39	2.51	0.63
C5	13.43	0.29	2.14	3.55	0.54		3.55	1.93	3.71	0.29	1.93	0.54	2.12	0.54	3.61	0.71	0.44	2.14	0.71	0.54	0.38	2.14	0.72	0.24	2.01	2.14	0.69
C6	10.83	3.31	3.55	0.00	3.57	3.04		3.33	0.15	3.31	3.33	3.57	3.53	3.57	0.05	3.32	3.38	3.55	3.32	3.57	3.41	3.55	3.33	3.08	3.42	3.54	3.31
C7	12.41	1.30	1.20	3.35	1.56	1.03	3.35		3.50	1.30	0.00	1.56	1.18	1.56	3.40	1.31	1.37	1.20	1.31	1.56	1.40	1.20	1.32	1.07	1.07	1.19	1.30
C8	11.10	3.50	3.74	0.27	3.76	3.23	0.27	3.52		3.50	3.52	3.76	3.72	3.76	0.33	3.51	3.58	3.74	3.52	3.76	3.60	3.74	3.53	3.27	3.61	3.73	3.50
C9	13.54	0.00	2.49	3.67	1.02	0.75	3.67	2.27	3.82		2.27	1.02	2.47	1.02	3.72	0.42	0.16	2.49	0.42	1.02	0.10	2.49	0.44	0.58	2.35	2.48	0.41
C10	12.41	1.30	1.20	3.35	1.56	1.03	3.35	0.00	3.50	1.30		1.56	1.18	1.56	3.40	1.31	1.37	1.20	1.31	1.56	1.40	1.20	1.32	1.07	1.07	1.19	1.30
C11	13.39	0.79	2.52	3.52	0.00	0.78	3.52	2.30	3.67	0.79	2.30		2.50	0.00	3.57	0.64	0.71	2.52	0.64	0.00	0.89	2.52	0.66	0.61	2.39	2.51	0.63
C12	12.41	3.33	3.26	2.41	3.60	3.06	2.41	3.04	2.56	3.33	3.04	3.60		3.60	2.46	3.34	3.41	3.26	3.34	3.60	3.43	3.26	3.36	3.10	3.12	3.25	3.33
C13	13.39	0.79	2.52	3.52	0.00	0.78	3.52	2.30	3.67	0.79	2.30	0.00	2.50		3.57	0.64	0.71	2.52	0.64	0.00	0.89	2.52	0.66	0.61	2.39	2.51	0.63
C14	10.77	3.26	3.49	1.47	3.51	2.98	1.47	3.28	1.62	3.26	3.28	3.51	3.47	3.51		3.27	3.33	3.49	3.27	3.51	3.36	3.49	3.28	3.02	3.36	3.49	3.25
C15	13.44	0.25	2.39	3.57	0.92	0.66	3.57	2.17	3.73	0.25	2.17	0.92	2.37	0.92	3.63		0.06	2.39	0.00	0.92	0.35	2.39	0.01	0.49	2.26	2.38	0.31
C16	13.38	0.19	2.33	3.51	0.86	0.59	3.51	2.11	3.66	0.19	2.11	0.86	2.31	0.86	3.56	0.26		2.33	0.26	0.86	0.29	2.33	0.28	0.42	2.20	2.32	0.25
C17	12.43	3.35	0.00	2.42	3.62	3.08	2.42	3.06	2.58	3.35	3.06	3.62	0.25	3.62	2.48	3.36	3.42		3.36	3.62	3.45	0.00	3.37	3.12	0.07	0.20	3.35
C18	13.44	0.25	2.39	3.57	0.92	0.65	3.57	2.17	3.72	0.25	2.17	0.92	2.37	0.92	3.63	0.33	0.06	2.39		0.92	0.35	2.39	0.01	0.48	2.26	2.38	0.31
C19	13.39	0.79	2.52	3.52	0.00	0.78	3.52	2.30	3.67	0.79	2.30	0.00	2.50	0.00	3.57	0.64	0.71	2.52	0.64		0.89	2.52	0.66	0.61	2.39	2.51	0.63
C20	13.44	0.25	2.39	3.57	0.92	0.65	3.57	2.17	3.72	0.25	2.17	0.92	2.37	0.92	3.62	0.32	0.06	2.39	0.32	0.92		2.39	0.34	0.48	2.25	2.38	0.31
C21	12.43	3.35	0.00	2.42	3.62	3.08	2.42	3.06	2.58	3.35	3.06	3.62	0.25	3.62	2.48	3.36	3.42	0.00	3.36	3.62	3.45		3.37	3.12	0.07	0.20	3.35
C22	13.43	0.24	2.38	3.56	0.91	0.64	3.56	2.16	3.71	0.24	2.16	0.91	2.36	0.91	3.61	0.31	0.05	2.38	0.31	0.91	0.34	2.38		0.47	2.25	2.37	0.30
C23	13.19	0.46	1.91	3.31	0.71	0.17	3.31	1.69	3.47	0.46	1.69	0.71	1.88	0.71	3.37	0.24	0.31	1.91	0.24	0.71	0.55	1.91	0.26		1.77	1.90	0.23
C24	12.56	3.48	0.13	2.56	3.75	3.21	2.56	3.19	2.71	3.48	3.19	3.75	0.39	3.75	2.61	3.49	3.56	0.13	3.49	3.75	3.58	0.13	3.51	3.25		0.13	3.48
C25	12.43	3.36	0.01	2.43	3.63	3.08	2.43	3.06	2.58	3.36	3.06	3.63	0.26	3.63	2.49	3.37	3.43	0.01	3.37	3.63	3.45	0.01	3.38	3.12	0.08		3.35
C26	13.46	0.27	2.41	3.59	0.94	0.67	3.59	2.19	3.74	0.27	2.19	0.94	2.38	0.94	3.64	0.01	0.08	2.41	0.01	0.94	0.36	2.41	0.03	0.50	2.27	2.40	

Figure 7. Detail Distances Worksheet

The vehicle data including starting point, driving time limit, and the distance limit of the vehicle capacity are filled in vehicles worksheet. The fixed cost per trip and costs per unit distance are set to zero. This study also set the number of vehicles with two vehicles because the total delivered order is exceeded the capacity of vehicle. A screenshot of the vehicles worksheet is shown in Figure 8.

Starting depot	Vehicle type	Capacity	Fixed cost per trip	Cost per unit distance	Distance limit	Work start time	Driving time limit	Working time limit	Return depot	Number of vehicles
Depot	T1	140	0.00	0.00	200.00	07:00	8:00	9:00	Depot	2

Figure 8. Vehicles worksheet

4. Results

Before continuing to the solver process, a brief of the specification of computer was used to generate the solutions such as Intel i3 CPU running at 3.3 GHz with 4 GB of RAM. All applications are closed except the open source spreadsheet solver.

The solution algorithms of VRP Spreadsheet Solver started with a feasibility check and searches reasons for infeasibility. The search involves customer's data and all constrains that has been set up. If any of the issues are found, the user is alerted with a message, and given a choice to stop or proceed. If the user decides to proceed, the resulting solution will certainly be infeasible but may still be useful. In this trial, the result shows no infeasible alert message. Thus, the solutions generate are feasible and satisfying all the constrains. Proposed route are generate in solutions worksheet including the list of stops for each trip depot to customer to depot, distance travelled, driving time, working time, and maximal load of trucks.

Since the total delivered order is exceeded the truck capacity there will be two solutions generated by spreadsheet solver. Screenshots of solutions worksheet is presented in Figure 9 and Figure 10.

Vehicle:	V1	Stops:	13		
Stop count	Location name	Distance travelled	Driving time	Working time	Lo
0	Depot	0.00	0:00	0:00	1
1	Customer 12	12.41	0:38	0:50	1
2	Customer 21	12.66	0:39	1:02	1
3	Customer 17	12.66	0:39	1:14	1
4	Customer 2	12.66	0:39	1:25	1
5	Customer 25	12.67	0:39	1:36	1
6	Customer 24	12.80	0:39	1:47	1
7	Customer 10	13.86	0:42	2:00	1
8	Customer 7	13.86	0:42	2:11	1
9	Customer 14	17.14	0:50	2:33	1
10	Customer 6	17.19	0:50	2:51	1
11	Customer 8	17.46	0:51	3:09	1
12	Customer 3	17.61	0:52	3:21	1
13	Depot	28.29	1:23	3:52	1

Figure 9. Solutions worksheet of 1st trip

Vehicle:	V2	Stops:	15		
Stop count	Location name	Distance travelled	Driving time	Working time	Load
0	Depot	0.00	0:00	0:00	74
1	Customer 19	13.39	0:37	0:48	74
2	Customer 13	13.39	0:37	0:59	74
3	Customer 11	13.39	0:37	1:10	74
4	Customer 4	13.39	0:37	1:21	74
5	Customer 20	14.31	0:41	1:37	74
6	Customer 9	14.41	0:41	1:47	74
7	Customer 1	14.41	0:41	1:58	74
8	Customer 16	14.59	0:42	2:12	74
9	Customer 22	14.64	0:42	2:23	74
10	Customer 18	14.65	0:42	2:34	74
11	Customer 15	14.65	0:42	2:45	74
12	Customer 26	14.67	0:42	2:57	74
13	Customer 23	14.90	0:43	3:10	74
14	Customer 5	15.13	0:44	3:23	74
15	Depot	28.46	1:26	4:05	74

Figure 10. Solutions worksheet of 2nd trip

Based on computational results, solutions to delivered 214 gallons to 26 customers in Single Depot Routing Problem using Open Source Spreadsheet Solver are as follows:

a) First trip has optimal route with 13 stops, maximal load 140; distance travelled 28.29 km; driving time 1 hours and 23 minutes; and working time 3 hours and 52 minutes.
b) Second trip has optimal route with 15 stops, maximal load 74 gallons; distance travelled 28.46 km; driving time 1 hours and 26 minutes; and working time 4 hours and 5 minutes.

Overall solution of this routing problem are 56.76 km total distances travelled; 2 hour and 49 minutes total driving time; 7 hours and 57 minutes total driving working time. These solutions satisfy all constrains that has been set. Total savings of distances travelled between current route and propose solutions using open source spreadsheet solver is 11.32% (7.25 km) and shown in Figure 11.

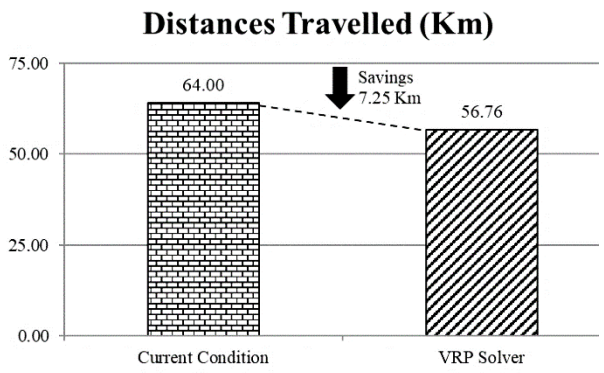

Figure 11. Distances Travelled

5. Conclusions

This research proposed to solve single depot routing problem using open source spreadsheet solver and shows the spreadsheet solver was able to generate optimal route to minimize the distances travelled and satisfying all constraints that have been set. The current condition using the existing methods in the company have distances travelled 64.00 km to deliver 214 gallons to 26 customers. By using open source spreadsheet solver eventually distances travelled are 56.76 km and saving 11.32 % (7.25 km).

It is agreed that VRP Spreadsheet Solver has high potential tool to be implemented due to its simplicity, flexibility, accurate estimation and accessibility. For further work, VRP Spreadsheet Solver need to automatically calculate the number of trip and vehicle needed if delivered order exceeded the capacity of vehicle.

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