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Optimization of Multi Objective Vehicle Routing Problem with Time Windows using Total Time Balance

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Abstract: ***Vehicle Routing Problem time window (VRPW) used in supply chain management in the physical delivery of goods and services, and the determination of all routes for a fleet of vehicles, starting and ending at a depot and serving customers with known demands by increasing the efficiency and profitability of transportation systems. The main objective of this study is to refutes a multi-objective vehicle routing problem with time windows by minimization of the number of vehicles, the total distance traveled and rout balance not sufficient instead of using 'total time balance'. To test the performance of the objective it considers GA with the fitness Aggregation approach comparing with the related literature based on Solomon's benchmark instance standard data. The time makespan produced by FAGA and the time makespan mentioned in related literature is compared. From the result, fitness Aggregation approach with genetic algorizim (FAGA) provides better result including the real-time window as compared to previous work .***

Keywords: ***Vehicle Routing Problem time window, optimization, transportation,makespan, fitness Aggregation, 'total time balance'***

I. INTRODUCTION

Transportation of raw materials, finished products, and human beings is a vital task in day to day life and a huge amount of money is expended for it in the present scenario. The vehicle routing problem (VRP) is a complex optimization issue in the field of operations research. The VRP may be defined as the process of finding routes for delivery vehicles which are started from a central department to deliver a group of consumers with known positions and known order quantity for a certain commodity. The capacitated vehicle routing problem (CVRP) is a type of VRP. The conditions for CVRP are each vehicle should strictly depart and arrive at the central department, each consumer should exactly treat by one vehicle and the summation of all consumers' required quantity in all routes must not go beyond the vehicle capacity [1]. In the real case, particularly in transportation and distribution, the CVRP is multi-objective. The most common objectives in CVRP are minimizing the total distance traveled by all vehicles, the number of vehicles used, driver remuneration, route balance and maximizing customer satisfaction, profit [2].

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Though a lot of research has used single objective optimization to resolve this CVRP problem, it has infrequently considered in the multi-objective optimization due to the following reason. In single-objective optimization, fitness function evaluation for all solutions is quite easy, but at the time of handling with multi objectives, it turns into a challenging task [3].

VRP was first presented by Dantzig and Ramser [4], Prins [5] implemented a genetic algorithm to solve CVRP and compared the results with tabu search. Their algorithm outperformed most of the published tabu search heuristics on the fourteen classical Christofieds instances. Ai and Kachitvichyanukul [6] constructed a model for CVRP to minimize the distance traveled by the vehicles and used particle swarm technique to solve the problem. The computational result showed that the method was better than other methods for solving CVRP.

Mazzeo and Loiseau [7] considered minimization of cost in CVRP and reported that the performance of the ant colony algorithm was better than simulated annealing and tabu search. Lee et al.

[8] considered minimization of total traveling cost as objective function and proposed enhanced ant colony optimization (EACO) to resolve the CVRP. The algorithm was found to be better than the original ant colony system. Szeto et al [9] introduced an artificial bee colony algorithm for the CVRP. The method produced solutions better than all other heuristics. Lin et al. [10] employed a hybrid approach between simulated annealing and tabu search to solve CVRP. The algorithm found the best solutions for eight out of fourteen benchmark problems. Nazif and Lee [11] minimized traveling costs for CVRP by using a genetic algorithm with an optimized crossover operator. The outcomes displayed that the suggested algorithm was superior by the nature of the solutions produced. Jozefowiez et al. [12] developed a model for bi-objective CVRP, where minimization of the total length and route balance are the two objective functions and considered multi-objective genetic algorithm (MOGA) with target aiming Pareto search to solve the problem. The results showed that the method was quite effective as compared to other heuristics. Jozefowiez et al. [13] proposed a bi-objective CVRP in which the total length of routes, as well as the route balance, was minimized. The elitist diversification method was integrated into the multi-objective evolutionary algorithm (MOEA) to improve the results. In this paper, a different fitness assignment approach and specialized crossover are incorporated into the genetic algorithm for solving the multi-objective CVRP.

II. MATHEMATICAL MODELS

2.1. MODEL FOR MINIMIZATION OF NUMBER OF VEHICLES (K) AND THE TOTAL DISTANCE TRAVELLED BY ALL VEHICLES (D)

Eq.2 indicates that the sum of the distance travelled by each vehicle, and the Euclidean distance between two customers, the distance and the time taken shown below in Eq.3.

$$Min\ D = \sum_{j=1}^{K} d_j \quad \dots \dots 1$$

$$d_j = \sum_{i=0}^{N_j} d_{(i,i+1),j} \quad \forall_{j=1,2,\dots,K} \dots \dots 2$$

Where

$$d_{(i,i+1),j} = t_{(i,i+1).j} = [(x_i - x_{i+1})^2 + (y_i + y_{i+1})^2]^{1/2} \quad \forall_j = 1,2,\dots,K \dots \dots 3$$

$$Min\ K \dots \dots 4$$

I. Vehicle Capacity Constraint

All the customers demand in a route equal or less than the vehicle capacity (C) is shown below:

$$\sum_{i=1}^{N_i} q_{(i,j)} \le C \quad \forall_j\ 1,2,\dots,K \dots \dots 5$$

II. In Time Window Constraint

The time widows constraint described by eq.6.

$$e_{i,j} \le (a_{i,j} + w_{i,j}) \le l_{(i,j)} \quad \forall_j = 1,2,\dots,K \dots \dots 6$$

Where , ($w_{(i,j)}$) is the waiting of time, vehicle arrival of time ($a_{(i,j)}$), customer ready of time ($e_{(i,j)}$), due of time ($L_{(i,j)}$) the orders are strictly rejected by the customers when the vehicle reaches the customer beyond the due of time ($L_{(i,j)}$) which is shown below in Eq.7.

$$w_{(i,j)} = \{0 \quad if\ e_{(i,j)} \le a_{(i,j)} \le l_{(i,j)}\ e_{(i,j)} - a_{(i,j)} \quad if\ a_{(i,j)}\ is\ less\ than\ e_{(i,j)} \dots \dots 7$$

Where ($a_{(i,j)}$) is the arrival of time of the vehicle

For particular customer the arrival time of vehicle in a specific route is shown in Eq. (8).

$$a_{(i,j)} = a_{(i-1,j)} + w_{(i-1,j)} + s_{(i-1,j)} + t_{(i-1,i),j} \dots \dots 8$$

Where: ($a_{(i-1,j)}$) is the sum of arrival of time

($w_{(i-1)}$) is waiting of time

($s_{(i-1,j)}$) is service of time

($t(i-1, i), j$) is travel of time between the two successive customer

Iii. Mathematical Model Maximum Of Route Time Constraint

The inequality constraint for route time constraint is shown as:

$$\sum_{i=0}^{N_j} [t_{(i,i+1),j} + w_{i,j} + s_{(i,j)}] \le L_0 \quad \forall_j = 1,2,\dots,K \dots \dots 9$$

Where, (L_0) is maximum allowed route time

2.2. MATHEMATICAL MODEL ROUTE BALANCE (RB)

The multi objective optimization, mathematical model by the total balance of time is the sum of vehicle travel time, waiting of time and service of time with the general VRPTW. The mathematical model for the formula of route balance (RB) is shown in Eq.(10).

In Eq. (11) and (12) respectively shows the mathematical model of $(d)_{max}$ and $(d)_{min}$.

$$Min\ RB = (d)_{max} - (d)_{min} \dots \dots 10$$

Where maximum of distance travelled ($(d)_{max}$), minimum of distance travelled ($(d)_{min}$)

$$d_{max} = Max[(d)_j] \quad \forall_j = 1,2,\dots,K \dots \dots 11$$

$$d_{min} = Min[(d)_j] \quad \forall_j = 1,2,\dots,K \dots \dots 12$$

In general, the complete mathematical model for Multi objective optimization by taking general VRPTW objectives along with the route balance can be presented as follows:

$$Min\ D = \sum_{j=1}^{K} d_j$$

$$Min\ K$$

$$Min\ RB = (d)_{max} - (d)_{min}$$

Subject to

$$\sum_{i=1}^{N_i} q_{(i,j)} \le C \quad \forall_j = 1,2,\dots,K$$

$$e_{i,j} \le (a_{i,j} + w_{i,j}) \le l_{(i,j)} \quad \forall_j = 1,2,\dots,K$$

$$\sum_{i=0}^{N_j} [t_{(i,i+1),j} + w_{i,j} + s_{(i,j)}] \le L_0 \quad \forall_j = 1,2,\dots,K$$

I. Balance of Total Time

The Multi-objective optimization of a mathematical model by taking the individual vehicle by calculating the total time of balance (TTB) is equal to the difference of maximum of total time ((TT) max) and the minimum of total time in the route Eq (13) . The total time in the route $(TT)_i$ is equal to the total travel of time , total service of time and the total waiting of time in the route as shown in Eq. (16).

$$Min\ TTB = (TT)_{max} - (TT)_{min} \dots \dots 13$$

Where

$$(TT)_{max} = Max[(TT)_J] \quad \forall_j = 1,2,\dots,K \dots \dots 14$$

$$(TT)_{Min} = min[(TT)_j] \quad \forall_j = 1,2,\dots,K \dots \dots 15$$

$$(TT)_j = \sum_{i=0}^{N_j} [t_{(i,i+1),j} + w_{(i,j)} + S_{(i,j)}] \ \forall_j = 1,2,\dots,K. 16$$

Therefore, The Multi objective optimization of mathematical model by indicating the total time balance along with general VRPTW objectives can be shown as follows:

$$Min\ D = \sum_{j=1}^{K} d_j$$

$$Min\ K$$

$$Min\ TTB = (tt)_{max} - (tt)_{min}$$

Subject to

$$\sum_{i=1}^{N_i} q_{(i,j)} \leq C \qquad \forall_j = 1,2,\ldots\ldots\ldots\ldots\ldots, K$$

$$e_{i,j} \leq (a_{i,j} + w_{i,j}) \leq l_{(i,j)} \qquad \forall_j = 1,2,\ldots\ldots\ldots\ldots, K$$

$$\sum_{i=0}^{N_j} [t_{(i,i+1),j} + w_{i,j} + s_{(i,j)}] \leq L_0 \qquad \forall_j = 1,2,\ldots, K$$

III. METHODOLOGY

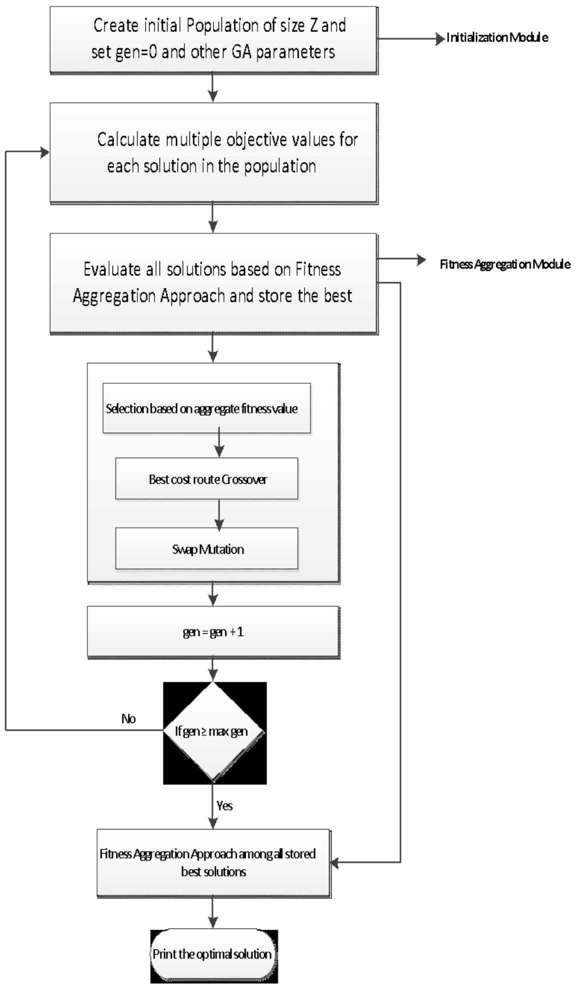


Figure 1. Genetic Algorithm Flow chart for FAGA

IV. COMPUTATIONAL RESULTS

In the VRPTW the best known standard is Solomon's benchmark instances and this standard used for the tests in the following conditions (14). The demands of each customer, capacity of the vehicle, windows time, and service times for different test conditions are shown below.

A. Multi objective optimization of a general VRPTW objective (i.e. the total distance traveled minimization by all vehicles and all vehicles used).

B. Multi objective optimization by taking the route balance along with general VRPTW objectives.

C. Multi objective optimization by taking the total time of balance by considering the sum of vehicle travel of time, waiting of time and service of time along with general VRPTW objectives.

The number of customers and the geographical locations of customers like 25, 50 and 100 are different. The individual vehicles results of time taken indicated in the tables 1, 2 and 3 and maximum of time taken for the three conditions. From the result of three conditions, the maximum of time taken value compared in figure 2. It compares makespan values among the three conditions. From tables 1,2 and 3, and from Fig. 2, it can be observed that in some of the problems, the algorithm produced a high maximum of time taken value in conditions B on a general multi objective VRPTW by considering route balance.

Relatively, it is not happening in conditions A, which considers the overall multi objective VRPTW without any balancing objectives. This is because route balance is adequate for VRP and, additional in a VRP, there are no time elements excluding the travel time required to cross the distance. Thus, if route balance is minimized in a VRP, the longest distance between the vehicles is automatically minimized. By minimizing the maximum time taken (Makespan), the longest time taken to cross the distance is proportionately minimized. However, if route balance is considered and minimized in a VRPTW, the travel time required to cross the distance may become balanced. Incidentally, there is still a high chance of imbalance in the waiting time and service time taken for vehicles

Table 1 By using the FAGA the total distance travelled by all vehicles, the total number of vehicles and the time taken by individual vehicles produced

Problem instance	Makespan.	Problem instance	Makespan.	Problem instance	Makespan.
C101.25.	1049.5	C101.50	1201	C101.100	1225.3
C105.25	1049.5	C105.50	1196.2	C105.100	1218.6
C106.25	1049.5	C106.50	1075.2	C106.100	1199
C108.25	1123.2	C108.50	1134.8	C108.100	1154.7
R102.25	228.21	R102.50	219.87	R102.100	229.09
R106.25	222.5	R106.50	219.64	R106.100	228.87
R107.25	217.03	R107.50	226.45	R107.100	228.89
R111.25	223	R111.50	227.46	R111.100	228.98
RC102.25	226.16	RC102.50	232.18	RC102.100	235.41
RC104.25	233.57	RC104.50	234.4	RC104.100	239.06
RC105.25	236.5	RC105.50	236.5	RC105.100	238.85
RC107.25	209.26	RC107.50	235.82	RC107.100	239.28

because a VRPTW has more time elements. As a result, in a VRPTW, regardless of the route balance is minimized, the longest time taken may or may not be minimized. This is because the time taken by the individual vehicle is the sum of time the vehicle travelled, waiting time and service time. Such a result may produce a high value of makespan (maximum of time taken) because makespan (maximum of time taken) is the maximum of all individual vehicles' time taken. For example, in Fig. 2 and in problems C106.50, C106.100, C101.25, R107.25, R102.50, RC102.25, RC104.25, R111.100, RC102.50, R107.50, RC102.100 and RC104.50, the algorithm produces high makespan (maximum of time taken) values in case B as compared to case A. Even though the route balance is minimized by maintaining the general VRPTW objectives, the makespan (maximum of time taken) cannot be

Table 2. Multi-objective optimization by considering route balance along with general VRPTW objectives Time taken by individual vehicles and makespan (maximum of time taken) produced by the FAGA

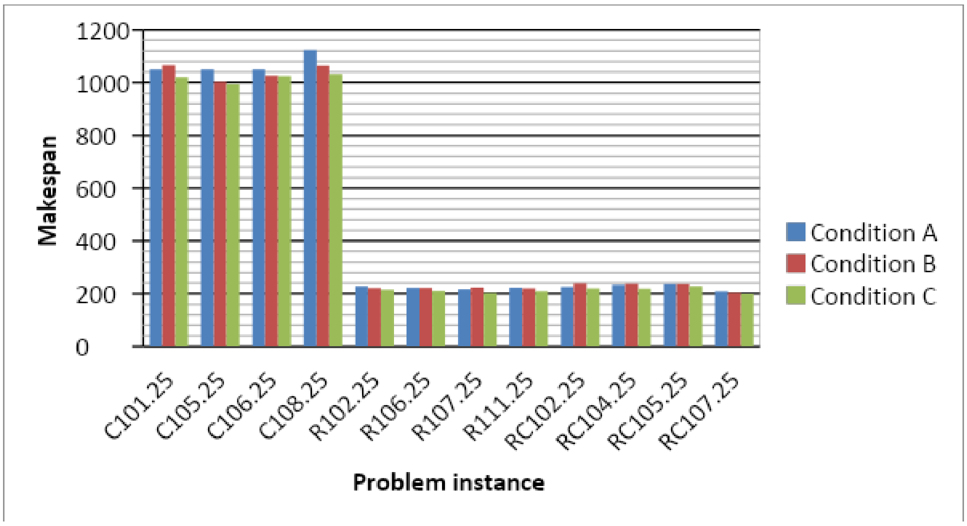
Problem instance	Makespan.	Problem instance	Makespan.	Problem instance	Makespan.
C101.25.	1066.1	C101.50	1201	C101.100	1201
C105.25	1002.7	C105.50	1184.2	C105.100	1194.7
C106.25	1025.9	C106.50	1225.1	C106.100	1213
C108.25	1065.2	C108.50	1094.8	C108.100	1142.3
R102.25	221.54	R102.50	221.54	R102.100	228.26
R106.25	222.21	R106.50	217.03	R106.100	226.45
R107.25	224	R107.50	229.89	R107.100	228.72
R111.25	220.61	R111.50	224.89	R111.100	229.54
RC102.25	238.7	RC102.50	234.99	RC102.100	239.05
RC104.25	237.41	RC104.50	238.86	RC104.100	238.38
RC105.25	236.5	RC105.50	233.94	RC105.100	237.9
RC107.25	203.76	RC107.50	235.82	RC107.100	236.03

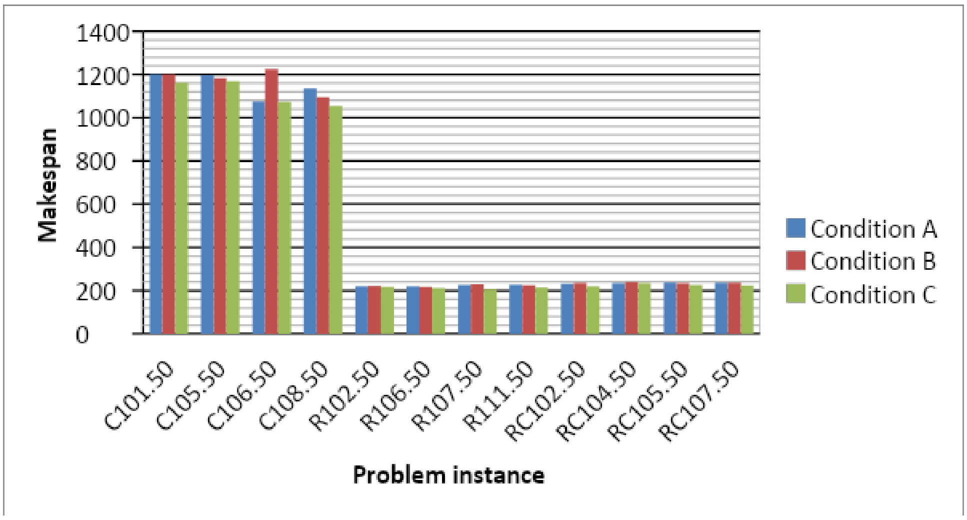
minimized by the algorithm. Yet, if the total tim e balance (i.e. the balance of the sum of travel time, waiting time and service time) is considered, instead of route balance on a multi-objective VRPTW, it is possible to balance the workload and minimize the makespan simultaneously, which is explained by Table 3 and Fig. 2. From Tables 1 and 3 and from Fig. 2, it is observed that for all the problems the present algorithm is able to produce the lowest value for makespan (maximum of time taken). It happens when the total time balance is considered along with general VRPTW objectives, i.e. Multi-objective optimization by considering the total time balance (the balance of the sum of vehicle travel time, waiting time and service time) along with general VRPTW objectives. The comparison of multi objective optimization for general VRPTW objectives (i.e. Minimization of the total distance travelled by all vehicles and the total number of vehicles used). The time taken by an individual vehicle is the sum of

Table 3.The balance of the sum of vehicle travel time, waiting time and service time along with general VRPTWobjectives Time taken by individual vehicles and makespan produced by the FAGA

Problem instance	Makespan.	Problem instance	Makespan.	Problem instance	Makespan.
C101.25.	1020.7	C101.50	1162	C101.100	1165.6
C105.25	994.2	C105.50	1169	C105.100	1169
C106.25	1024.2	C106.50	1073.2	C106.100	1088.8
C108.25	1032.6	C108.50	1053.9	C108.100	1056.5
R102.25	215.54	R102.50	217.43	R102.100	220.91
R106.25	210.72	R106.50	211.54	R106.100	222.74
R107.25	202.54	R107.50	205.98	R107.100	227.33
R111.25	209.72	R111.50	213.99	R111.100	223.02
RC102.25	220.44	RC102.50	219.67	RC102.100	234.24
RC104.25	219.5	RC104.50	234.4	RC104.100	237.47
RC105.25	228.25	RC105.50	226.28	RC105.100	236.5
RC107.25	199.79	RC107.50	224.05	RC107.100	235.28

vehicle travel time, waiting time and service time. Hence, if the total time balance is minimized (the balance of the sum of vehicle travel time, waiting time and service time), then the longest time taken among vehicles is automatically minimized, which, in turn, produces the lowest makespan(maximum of time taken) value for all the problems. Similarly, it is observed from Tables 3 and 4 that for all problems, the present algorithm is able to produce the lowest value for makespan(maximum of time taken) for case of considering the total time balance along with general VRPTW objectives as compared with case of considering route balance along with general VRPTW objectives. From the above analysis, it is concluded that, by considering the total time balance instead of route balance on VRPTW, it is possible to balance the workload in terms of time and minimize the makespan simultaneously.





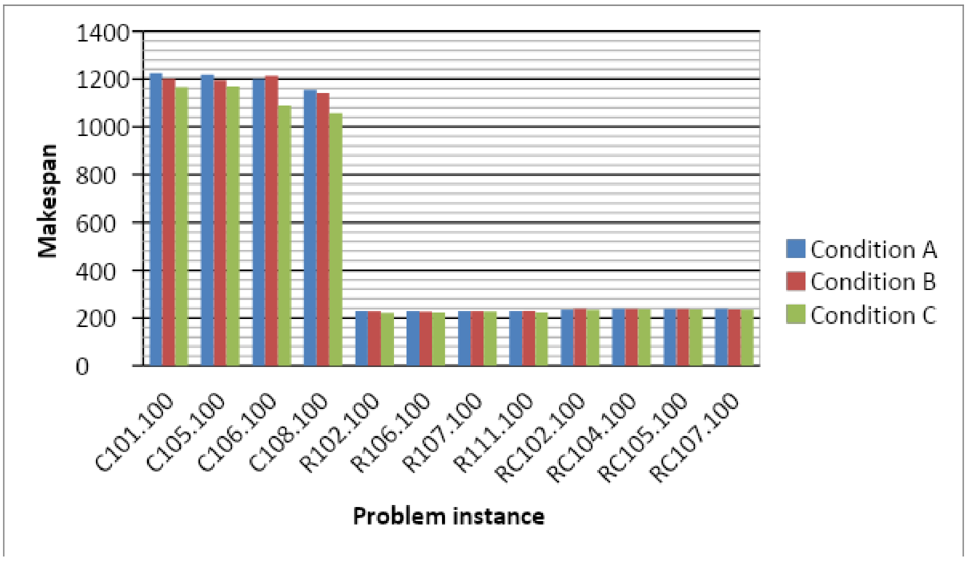


Fig. 2. Comparison of maximum of time taken (Makespan) for condition A, B and C

V. COMPARISON OF MAKESPANBETWEEN PUBLISHED WORKS OF CONDITION A , CONDITION B AND RESULTS PRODUCED BY THE FAGA FOR CONDITION C

Table 4 shows the time taken by individual vehicles and makespan from some of the published works of condition A (a general multi-objective VRPTW). Table 5 shows a comparison of the makespan values between published works of condition A (a general multi objective VRPTW) and results produced by the FAGA for condition C which considers the total time balance on a general multi objective VRPTW. In Tables 4 and 5, the total distance travelled is represented by D and the total number of vehicles used is represented by K. It is observed from Table 5 that even though both D and K are high for condition C compared to publish works of condition A, it is possible in condition C to complete the entire distribution process in less time, i.e. with less makespan value as compared to published works of case A for all problems. Logically, the total time taken should be minimized if the distance travelled by the vehicle is minimized. This is all right for VRP because in VRP there are no time elements. However, in VRPTW with more time elements, the total time taken may be or may not be minimized when the distance travelled by the vehicle is minimized. It is to be noted that the total time taken is the sum of vehicle run time, waiting time and service time. This may be shown in Fig.3. Figure 3 shows the for C101.25 for both published results of condition A and results produced by FAGA for condition C. From Fig.3, it is observed that though D is less for condition A as compared to condition C , it could not produce better makespan.

Even though the distance travelled for vehicle 1(V1) in condition A is less, i.e. 59.45 (sum of values highlighted in green), the vehicle 1(V1) serves 11 customers and hence its service time is high 990, sum of values highlighted in yellow). This, quite automatically, increases its total time taken 1049.5. Similarly, though the distance travelled by vehicle 3 in case A is very small, i.e. 36.44 (sum of values highlighted in green), this vehicle spends 440.76 as waiting time, increasing its total time taken 1017.2. In case of vehicle 2(V2) in condition A, the total time taken is 815.9. From these illustrations, it is observed that the makespan is the maximum of total time of all vehicles and in condition A it is 1049.5 is maximum among 1049.5, 815.9 and 1017.2. In contrast, in condition C, though the D is high as compared to condition A, it could produce better makespan value.

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The number of serving customers is reduced from 11 to 10 for vehicle 1 in case C. Therefore, its service time is reduced from 990 to 900, thereby reducing its total time taken from 1049.5 to 959.4. Similarly, the number of served customers is increased for vehicle 2(V2) in condition C from 8 to 9, which in turn increases its total time taken from 815.9 to 1020.7. Makespan, the maximum of all vehicles total time for condition A 1020.7 is maximum among 959.4, 1020.7 and 1017.2 . From the above discussion, it is observed that if companies want to implement just in time principles in their distribution of item, then they should be prepared to expense some of their general objectives (total distance travelled D and total number of vehicles K used) and they must consider a general multi objective VRPTW along with the total time balance instead of considering a general multi-objective VRPTW alone or a general multi objective VRPTW with route balance.

Table 4.Time taken by individual vehicles and makespan from some of the published works of case A (a general multi-objective VRPTW, i.e. minimization of 'total distance' and 'total number of vehicles')

Problem instance	D	K	Maximum of time taken (Makespan)	Reference
R106.100	1252.03	12	229.21	R [17]
C101.100	828.94	10	1234.8	R [15]
C105.100	828.94	10	1234.8	R [15]
R102.100	1486.12	17	229.09	R[16]
C108.100	828.94	10	1234.8	R[15]
C106.100	828.94	10	1234.8	R [15]
RC105.100	1633.72	13	237.58	R [17]
C101.25	191.81	3	1049.5	R [18]

Table 5. Comparison between condition A and results produced by the FAGA for condition C with published works of maximum of time taken.

Published results of case A (i.e. a general multi-objective VRPTW)				Results produced by FAGA for case C (i.e. Considering 'total time balance' on a general multi objective VRPTW)			
Problem instance	D	K	Maximum of time taken (Makespan)	D	K	Maximum of time taken (Makespan)	Reference
C101.25	191.81	3	1049.5	198.6	3	1020.7	R [18]
C101.100	828.94	10	1234.8	1268.7	11	1165.6	R [15]
C105.100	828.94	10	1234.8	1299.4	11	1169	R [15]
C106.100	828.94	10	1234.8	1480.9	11	1088.8	R [15]
C108.100	828.94	10	1234.8	1303.8	11	1056.5	R [15]
R102.100	1486.12	17	229.09	1855.3	18	220.91	R [16]
R106.100	1252.03	12	229.21	1685.2	14	222.74	R[17]
RC105.100	1633.72	13	237.59	1981.8	16	236.5	R [17]

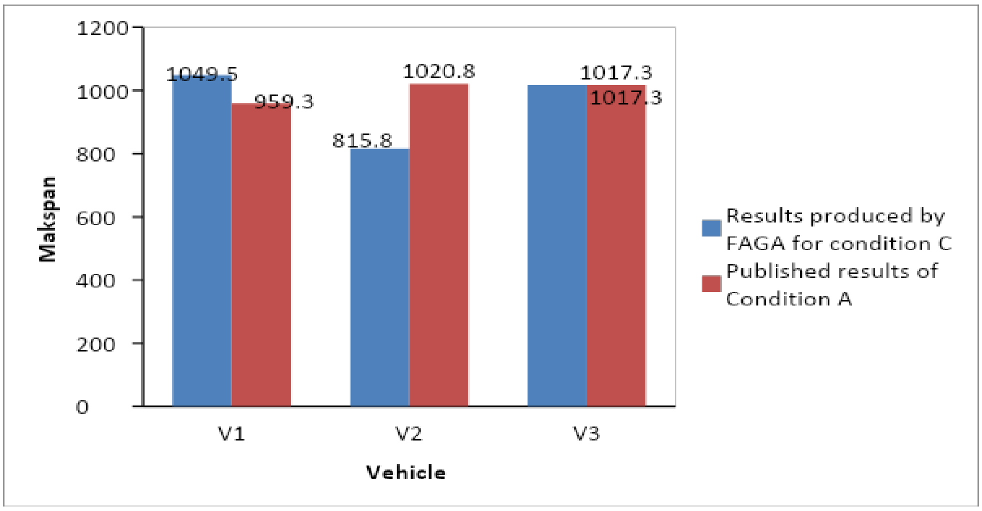

Fig.3 C101.25 for condition A (published) and condition C (produced by FAGA)

VI. CONCLUSIONS

The vehicle distance travelled and the time taken calculated by using the recommended algorithm in the three conditions are tabulated and compared. From the condition A and condition B comparative analysis observed that out of thirty six problems of conditions B, twelve problems results high makespan compared to condition A while minimizing route balance. In the same way comparing the results between condition A and condition C, it is noticed the condition C produces the minimized makespan among all the problems, the result compared to other condition.

Also, the results produced by the proposed algorithm for condition C are compared with the literature results of condition A. These comparisons indicated the importance of considering the total time balance over route balance on multiobjective VRPTW problems. It is also promising to balance of the workload in terms of time and minimize the makespan at similarly. From the analysis of these overall results shows, using 'total time balance' is better instead of route balance on a multiobjective VRPTW problem. For this reason, future research work may be possible by developing some advanced algorithms for achieving a hundred present balance of total time by the lowest possible makespan values.

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