A HYBRID GENETIC ALGORITHM IMPLEMENTATION FOR VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

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Abstract: This article is related to approach development in order to determine the most appropriate route for bottled water delivery from warehouse to retail from particular boundaries such as a limit on number of vehicle, vehicle capacity, and time windows to each retailer. A mathematical model of Vehicle Routing Problem with Time Window (VRPTW) is adopted to solve the problem. This article focuses on designing the optimal delivery route with the existing restriction such as vehicle capacity and time window. Hybrid genetic algorithm is used to determine the route shipping companies with the Java programming language. The obtained results show that the implementation of hybrid genetic algorithm is better than the company actual route. Moreover, in this article, the effect of the number of iterations for the computation time, and the influence the number of iterations for the fitness value or violation is also analyzed. This algorithm can be applied for the routing and the result obtained is an optimal solution.

Keywords: VRPTW, hybrid genetics algorithm, fitness.

INTRODUCTION

In the field of distribution of goods or services, considered aspects is how to minimize the cost of distributing goods or services and the distribution of goods destination is reached, one way to minimize costs is by determine the optimal route of vehicle. Transportation cost efficiency will greatly affect the costs of a company. Transportation cost has 66% proportion of the overall logistics costs (Ghiani, et al., 2004). With a large proportion, companies can gain a considerable advantage if successful efficiency the route. However, if something goes wrong in decisions-making the route of travel, it will have an impact on spending high transport costs and increase logistics costs. In addition, delivery delays will lead to consumer dissatisfaction. Issues which aim to create an optimal route, for a group of vehicles, in order to serve a number of customers referred to as Vehicle Routing Problem (VRP). It is estimated that distribution costs account for almost half of the total logistics costs and in some industries, such as in the food and drink business, distribution costs can account for up to 70% of the value added costs of goods (Golden & Wasil, 1987; De Backer & Furnon, 1999). Reports that in 1989, 76.5% of all the transportation of goods was done by vehicles (Halse, 1992), which also underlines the importance of routing and scheduling problems.

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The vehicle routing problem with time windows (VRPTW) is a generalization of the VRP involving the added complexity of allowable delivery times, or time windows. In these problems, the service of a customer, involving pick-up (delivery) of goods or services, can begin within the time window defined by the earliest and the latest times when the customer will permit the start of service. Note that the times at which service begin are the decision variable. This paper treats the hard window case, where if a vehicle arrives at a customer too early, it will wait. In addition, due dates cannot be violated. Time windows arise naturally in problem faced by business organization that works on fixed time schedules. Specific examples of problem with hard time windows include bank deliveries, postal deliveries, industrial refuse collection and school bus routing and scheduling.

In 1960's, Genetic Algorithm, which is known as GA, was firstly developed by Holland and his colleagues at the University of Michigan. The main goal in developing GA is to design the algorithm to explore the phenomenon of nature adaptation mechanism into computer system. The principle of biological evolution for chromosome population movement to other chromosome uses genetic crossover, mutation and inversion. Every single chromosome consists of genes which are symbolized as 0 or 1. The selection of fitter chromosome is allowed to reproduce more offspring than less fit chromosome. The process of crossover exchanges, randomly mutation and reverse inversion are occurred in continuous arraying which follows natural biological recombination (Mitchell, 1998).

In term of the application of hybrid genetic algorithm for the vehicle routing problem with time windows, natural selections such as combining selection, recombination and mutation processes are adapted from the original GA that developed by Holland (1975). The population are derived for better solution, while recombination process are used to next generation in parent selection for producing offspring and finally, mutation has function to avoid local minima. A hybrid genetic algorithm attempts to integrate all the explained process above with the heuristic one. That guarantees a better quality solution in further processes (Berger & Barkaoui, 2003).

METHODS

VRPTW Model

In this article, the problems of vehicle routing from distribution centre to retailers are designed as VRPTW problem, in which the minimum cost of traveling is the objective to determine the optimal routes. In order to obtain the objective, some constraints are applied such as time window and vehicle capacity. The time window or scheduling horizon of the visited retailers is different among them. This article uses VRPTW model to the routing problem and genetic algorithm is used to solve the problem (Kallehauge, 2007). The following mathematic models for VRPTW are formulated as follows:

$$Minimize\ Z = \sum_{k\in V} \sum_{i\in N} \sum_{j\in N} C_{ij} X_{ijk} \quad \text{... (1)}$$

Subject to:

$$\sum_{k\in V} \sum_{j\in N} X_{ijk} = 1 \quad ;\ \forall i \in C \quad \text{... (2)}$$

$$\sum_{i\in C} d_i \sum_{j\in N} X_{ijk} \le q \quad ;\ \forall k \in V \quad \text{... (3)}$$

$$\sum_{j\in N} X_{ojk} = 1 \quad ;\ \forall k \in V \quad \text{... (4)}$$

$$\sum_{i\in N} X_{ihk} - \sum_{j\in N} X_{hjk} = 0 \ ;\ \forall h \in C, \forall k \in V \quad \text{... (5)}$$

$$\sum_{i\in N} X_{I,n+1,K} = 1 \quad ;\ \forall k \in V \quad \text{... (6)}$$

$$S_{ik} + t_{ij} - M_{ij}(1 - X_{ijk}) \leq S_{jk} \;;\; \forall i,j \in N, \forall k \in V \quad \text{... (7)}$$
$$a_i \leq S_{ik} \leq b_i \;;\; \forall i \in N, \forall k \in V \quad \text{... (8)}$$
$$X_{ijk} \in \{0\,,1\} \;;\; \forall i,j \in N, \forall k \in V \quad \text{... (9)}$$

Eq. (1) represents the objective function to obtain minimum total traveling cost; while Eq. (2) is a constraint that ensures each retailer is visited once by vehicle. Eq. (3) indicates that retailers' demands in the same route do not exceed the vehicle capacity, and Eq. (4) and Eq. (6) are the constraints that ensure all vehicles serve in a returned travelling from depot to retailers. Moreover, constraint Eq. (5) and Eq. (7) are used to make sure that each vehicle should serve different retailers after finishing previous retailer, while Eq. (8) states that a vehicle k must serve retailer i in the specified time windows and finally, the constraint Eq. (8) guarantee that all decision variables must be a binary variable.

General of Genetic Algorithms

The Genetic Algorithm (GA), which is initially developed by Holland (1975), has progressed significantly in term of complex problem practices as in De Jong (1975) and Golberg (1989). Further GA application can be found in Mühlenbein and Schlierkamp-Voosen (1993). The recent study using genetic algorithm in a complex problem of VRP has been done by Xiang-yang (2004) and Zhang, et al. (2007). In their study, a NP (Non Polynomial) complex problem in optimization with some difficult constraints was done.

In this article, four major phases such as representation, selection, recombination and mutation are applied. For instance, the first phase or representation step is capturing the basic solution by encoding a chromosome and sequencing genes (Bräysy & Grendrau, 2001; Han & Tabata, 2002).

The phase of reproduction or recombination is used to select "a parent" to produce genes in the next generation. The function of this step is to combine the identical chromosome in potential offspring creation which has a better fitness. In the phase of mutation, a random modification of genes for further exploration of solution space in order to ensure the diversity of genes. The repetition of those phases is done until all old population is replaced by the new one.

Although genetic algorithm characteristics obtain bit-string chromosome, however, in the case of vehicle routing problem (VRP), it is not easily represented by GA behavior. Baker & Ayechew (2003) found that Tabu search and simulated annealing algorithms are superior to solve combinatorial problem like VRP rather than genetic algorithm. The results of their study show that the applications of GA in VRP have not impacted significantly. In other study, Fenghe & Yaping (2010) shows that genetic algorithm is superior to solve vehicle routing problem with time windows (VRPTW) problems and it results a better performance than other algorithms. Other study by Tan, et al. (2001) also indicated that GA system prove superior to other non-polynomial problem algorithms. Thus VRPTW problem discussed in this article use the basic principle of genetic algorithm to solve the routing problem. In this study, Nearest Neighbor Heuristic method is applied to solve the VRPTW problem (Thangiah, et al., 1994).

Establishment of Initial Population

Formation of this population is done by two methods, randomized and heuristic. One of the heuristic methods can be used to solve VRP is Nearest Neighbor

Heuristic method (Joshi & Kaur, 2015). The use of heuristic methods in AG can accelerate time to search for solutions for the initial population will approach the final solution (Ghoseiri & Ghannadpour, 2010). In this article, we proposed to use random and heuristic approaches to solve VRPTW problem.

Fitness

1. Check the amount of each retail demand.
2. Perform calculations vehicle capacity.
3. Provide a penalty value of 1 if total demand exceeds the capacity of the vehicle.
4. Perform simulation calculation of travel time.
5. Provide a penalty value of 1 if the time to less than retail opening hours, and more than retailer's closing hours.
6. Perform calculations total penalty
7. Fitness is the sum of all penalties

Table 1. Fitness Simulation

Route	Demand	Total Demand	Penalty Demand	Arrive	Open Time	Close Time	Distance	Open Penalty	Close Penalty	Total Penalty
B	40	40	0	6:30	7:00	16:00	0:30	1	0	1
A	50	90	0	7:10	7:00	15:00	0:20	0	0	0
D	60	150	0	8:05	7:00	12:00	0:35	0	0	0
G	40	190	0	8:55	7:00	12:00	0:30	0	0	0
X	70	260	1	10:05	7:00	10:00	0:50	0	1	2
W	60	320	1	10:45	7:30	10:00	0:20	0	1	2
Total Fitness										5

Selection of Individuals

At this stage of the selection process will be done, in this process would have been her parent (chromosomes) of chromosomes which have been established and keeping previously. One method is using the Roulette Wheel Selection (RWS), which is the most common selection scheme (Man, et al., 1999). In this method, the parents obtained based on the proportion of the fitness value of the chromosome, meaning that the chromosome with the best fitness value has elected a greater likelihood than other chromosomes. Chromosomes parents elected at the next selection process enter the crossover process to produce offspring chromosomes.

Crossover

However, not all of the chromosomes of parents who elect to experience the crossover process. The chances of a crossover process in the chromosomes of parents in the process of crossover based on a probability-called crossover probability (PC). The method used in this article is Heuristic Crossover (HC), which has a function to perform local search (Jianjun & Jian, 2009). In this method, a two crossing modification is illustrated as follows:

1. Suppose there are three vehicles used, where are: Vehicle 1: X-Z-F-R-K-S; Vehicle 2: A-U-T-D-Y-Q; and Vehicle 3: C-V-W-L-J-P
2. Because of the number of genes were 6, then generated random number between 1 to 6, for example the number that appears is number 4.
3. Find the distance between genes 3 to 4 in vehicle 1 (the distance is 20: F to R) obtained from the distance matrix.

4. Perform the selection of vehicles that will be on the crossover between the vehicle 2 and 3, for example chosen is the second vehicle.
5. Do seeking distance F to the entire retail on the vehicle 2, for example: from F to A: 40; from F to U: 30; from F to T: 20; from F to D: 50; from F to Y: 40; and from F to Q: 10.
6. Change the gene to vehicle 4 one by one, gene vehicle cars 2 has the smallest distance, and should be less than 4. genes car 1. Gene 6 for vehicle 2 has the smallest distance to 6 in the crossover genes, where: Vehicle 1: X-Z-F-Q-K-S; Vehicle 2: A-U-T-D-Y-R; and Vehicle 3: C-V-W-L-J-P
7. Perform repetitions of step 1 to 6 number of chromosomes/vehicle.

Mutation

Not all descendants of crossover mutated. The number of parents who have the mutation will depend on the probability of mutation (Pm) were determined. Parents who do not have mutations will be directly copied into offspring chromosomes. Here is an illustration of the process of gene mutations:

1. Take one gene at random, with the example of chromosome 5 genes therein. Generate a random number of 1 to 5, for example, number 3. It is Vehicle 1: X-Z-F-Q-K-S.
2. Calculate the distance from 2 gene to gene 3, for example distance from retail to retail Z F is 20.
3. Look for a distance of 2 to entire genes other genes on chromosomes, for example: from retail to retail Z X: 30; from retail to retail Z Q: 10; from retail to retail Z K: 15; and from retail to retail Z S: 40.
4. Select one of the genes that have a minimum distance of gene 2 and must be a minimum distance of 2 to gene 3 gene, so that the selected gene 4 with a distance of 2 by 10.
5. Perform between the gene mutations, it is Vehicle 1: X-Z-Q-F-K-S.
6. Perform repetitions step 1 to 5 as number of chromosomes / vehicle.

Establishment a New Population

At this stage it will be formed a new population, population replacement (generational replacement) meant that all the initial chromosomes of one generation is replaced by crossover and mutation of chromosomes results. So it will form a new population, will be repeated before the selection, crossover, and mutation back at the new population.

Repetition Number of Iterations

At this stage, the repetition of the selection phase, evaluation of fitness, crossover, and the formation of a new population to the number of iterations is entered to achieve an optimal value of fitness. So it is expected that the selection that follows the principle of natural selection is, "who is strong (have a better fitness value), he will survive (survive). Chromosomes with a good fitness value certainly have an economical travel route.

Determining the Best Solution

The best solution is chromosomes with the best fitness value. By comparing the value of fitness throughout the chromosome end, it will get the chromosome with the best fitness value.

RESULT AND DISCUSSIONS

In this article, we execute the distance that must be passed by vehicle if we used company's actual route or results route by implementing hybrid genetic algorithm. From that analysis is expected to be visible advantages and disadvantages of each route, especially the results of the used methods. Total trips each vehicle is obtained from the sum of the distance that must be passed from one retailer to another retail up to return to the barn, and then the total journey of each vehicle will be added together to get the value of the total distance that must be taken by all the vehicle on the day.

Table 2. Distance Comparison of Actual Route & Hybrid Genetic Algorithms

Vehicle	Existing Actual Routes		Hybrid Algorithm Route	
	Distance (Hours)	Distance (km)	Distance (Hours)	Distance (km)
1	2,92	125,56	3,2	137,6
2	3,38	145,34	3,9	167,7
3	3,18	136,74	2,3	92,0
Total Distance	9,48	407,64	9,4	397,3

From the total value of the trip can be concluded that the route from results of the implementation of these hybrid genetic algorithm can produce a shorter mileage travel than the company's actual route.

Results of this analysis confirmed the statement of previous research (Astuti, 2012) in a study entitled Application of Hybrid Genetic Algorithm in Vehicle Routing Problem with Time Windows, the authors conclude that "in accordance with the results obtained from the implementation of hybrid genetic algorithm proved to be quite effective in reducing the total distance".

We compared the total cost to be incurred when using the existing actual route, or using route from the results of the implementation of hybrid genetic algorithms which have been calculated previously. Cost components that are used are limited only fuel costs alone, so that the distance be the main reference in determining the fuel costs to be incurred.

Table 3. Total cost comparison of actual route and hybrid genetic algorithm

Vehicle	Company Actual Route	Hybrid Genetic Algorithm
1	IDR. 104.633	IDR. 114.667
2	IDR. 121.117	IDR. 139.750
3	IDR. 113.950	IDR. 76.667
Total	IDR. 339.700	IDR. 331.084

After the sum of all costs incurred for all three vehicles, it can be concluded the results of the implementation of hybrid genetic algorithm is minimum of IDR. 331.084 compared to the actual company are IDR. 339.700. It can be concluded that these were formed by hybrid genetic algorithm has been better than the company's actual service. In this calculation only count up the cost without seeing the total penalty each route.

Results of this analysis confirmed the statement of previous research (Dewi, 2011) in her research titled Application of Genetic Algorithm for Vehicle Routing Problem Solving in PT. MIF, the author concludes that the percentage of savings that can be obtained if the calculation results of this optimization method is applied is 7.88 per cent.

This article also executed analysis and compared total fitness or violations that occur when using company actual route, or using route from the implementation of hybrid genetic algorithms results which have been calculated previously. Increasing the minimum fitness value describe these vehicles are getting better too. Penalty component is divided into 3 penalties, penalty demand which means excessive vehicle load, open penalty which means the vehicle came before retail open or up ahead of time windows retail, and the close penalty which means that vehicle came after retail close or late from time windows retail.

Table 4. Fitness value comparison of actual route & hybrid genetic algorithm

Item	Existing Actual Route	Hybrid Genetic Algorithm
Penalty demand	1	0
Penalty (opening)	3	0
Penalty (closing)	0	0
Total Penalty	4	0

It can be viewed on the company's actual route there is have one penalty demand which means there is a vehicle with a excessive vehicle load than the maximum capacity, and there are 3 open penalty which means there are three occurrences vehicle came before retail open or up ahead of time windows retail, so that the retailer cannot park the vehicle that will deliver the product to the retailer, so the vehicle will have to wait or come back later. Such activity became one of the shipping activity that is not necessary, because it can waste time and increase vehicle mileage. On the results route of the implementation of hybrid genetic algorithm is no penalty or violation committed the entire vehicle, which means the entire vehicle up in each retailer in the time windows of each retailer and whole vehicle carries a charge within the limits of its capacity.

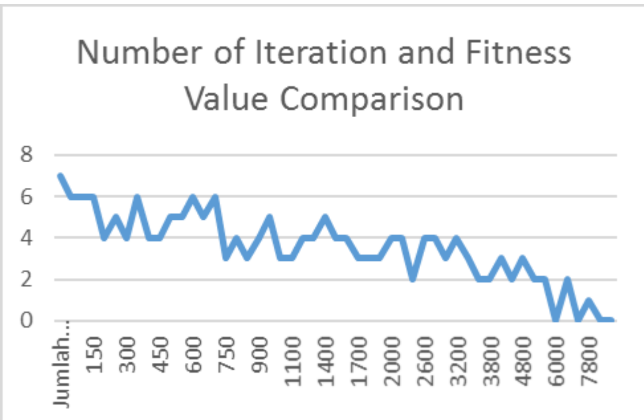

Figure 1. Number of iteration and fitness value comparison

In this article, the execution analysis of the influence of the number of iterations of the route fitness value has been done. A fitness value is determined from the number of offenses committed by vehicles on the route. In general fitness value will be directly proportional to the number of iterations, as more and more repetitions performed, it is expected to be the better route, but did not rule on the number of iterations higher fitness values will actually be greater than the value of fitness in the previous iteration fewer the number of iteration.

The results of this study conclude that initial solution formed has a fitness value of 281.1551, after the selection, crossover, and mutation as many as 1,000 iterations obtained a final solution to the fitness value 191.8136 .

CONCLUSIONS

Based on the results of research on Hybrid Genetic Algorithm Implementation Issues In Vehicle Routing Problem With Time Windows, the results of the case study can be concluded that Hybrid Genetic Algorithms can be applied in determining the distribution route of bottled drinking water (drinking water), because of the resulting better when compared with the actual service companies both in the costs to be incurred by the company, as well as satisfaction of customer service received.

These derived from the calculation hybrid genetic algorithm compared with actual service companies in various aspects, including vehicle mileage, vehicle hours until back at the warehouse, the total cost of transportation, and the total penalties / violations committed by vehicles. It can be concluded from all aspects of the company's actual that has a number of violations over the proposed route. Offenses committed at the time of distribution of goods can lead to loss of value, which include the losses due to increased transportation costs, losses due to lost sales because it could not meet customer demand, the losses due to service are considered to be unsatisfactory for the customer, thus decreasing customer loyalty and therefore contributes to the number of requests were declined.

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