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Route Determination Method to Minimize Distribution Cost and Total Time Balance by Using Multi-Objective Genetic Algorithm

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Abstract. The subject of this research is a distribution company engaged in the distribution of eggs to many customers in Bandung. Distribution is carried out every day with 3 types of vehicles which are one way pick up, three ways pick up, and engkel truck. Based on preliminary research, the current route determination method is based on experience so the distance and travel time are thought could be improved. This affects the distribution costs that must be spent to distribute eggs to customers. Distributor also experience workload imbalance of vehicles that be used for the distribution process regarding to the travel time charged to each vehicle.

The proposal in this study is used the metaheuristic method with the multi-objective genetic algorithm concerning to the multi-objective vehicle routing problem. This research is conducted during the fourth week of October 2018 and the chosen method is the proposed route determination method. The results of the comparison between the current system and the proposed system from this study obtained savings in terms of distribution costs of 18.03%, while in terms of total time balance, the distribution time range can be reduced to 95.52% so the workload of the vehicles are more balanced.

Introduction

Distribution is activity of organization that aims to distribute goods or services. This activity is important because it can increase profits by reducing distribution costs. There are several factors that influence the distribution process such as vehicle capacity, customer demand, travel distance, travel time and distribution process time.

The subject in this study is egg Distributor in Bandung who distribute eggs from warehouse to several customers, such as: markets, retails, and industries. Distribution is carried out every day with 3 types of vehicles which are one way pick up, three ways pick up, and engkel truck with different capacity. Distribution is done every day with dynamic demand and customer. Customer demand will be fulfilled on the next day after finish the order and will be distributed at the customer's opening hours. The costs needed in distribution activity include fuel costs, lubricant costs, vehicle service costs, and tire replacement costs, while the time taken is the travel time between two locations, waiting time, and unloading time.

Through observations and interviews that have been made to Distributor, it is known that the current method of route determination is based on experience, so the distance and travel time are thought could be improved. This affects the distribution costs that must be spent to distribute eggs to customers. Distributor also experience workload imbalance of vehicles regarding to the travel time charged to each vehicle. This is indicated by the presence of vehicles that have returned to the warehouse earlier and there are vehicles that must return at the end of working hours. Therefore, this study wants to assist Distributor in making improvements by proposing route determination method to minimize distribution costs and balance vehicle workload that is easy to be implemented by the Distributor.

Vehicle Routing Problem (VRP) is defined as a way to search for an efficient use of vehicles that must travel to visit a number of places to deliver or pick up people or goods. For next the people or goods will be called customer. The term customer shows a stop to take and pick up people or goods. Every customer must be served by only one vehicle. Determination of vehicle-customer pairs is carried out by considering the capacity of the vehicle in a transport to minimize the costs required. Determination of minimal costs is closely related to the minimum distance [1]. There are several types of VRP [2] such as:

1. Capacitated Vehicle Routing Problem (CVRP)
   CVRP is a VRP with consideration about the capacity of vehicle that be used for travel to visit customer. The purpose of CVRP is to minimize the number of vehicles, total travel time, and others with consideration about total demand for each route must not exceed the capacity of the vehicle passing the route.
2. Vehicle Routing Problem With Time Windows (VRPTW)
   VRPTW is a VRP with consideration about time windows or limitation of time period to serve the customer. The period of time usually follow the working hours of producer or customer to make sure all customers could be serve on time in their time windows.
3. Multi-Depot Vehicle Routing Problem (MDVRP)
   MDVRP is a VRP with several depot to serve customer. Each vehicle goes from one depot to serve the customer that have been determined to be served by the depot and returns to the depot. The aim of MDVRP is to minimize the number of vehicles and the total travel time and total demand for goods to be carried out from several depots.
4. Vehicle Routing Problem With Pick Up and Delivery (VRPPD)
   VRPPD is a VRP with regulation that the customer could return the delivered item. In VRPPD, it should be noted that returned items can be put into the delivery vehicle. The aim is to minimize the number of vehicles and the total travel time with the limitation that the vehicle used must have sufficient capacity to deliver goods to customer and return goods to the depot.
5. Split Delivery Vehicle Routing Problem (SDVRP)
   SDVRP is a VRP in which the customer could be serve by more than one vehicle. This usually because of the demand exceed the capacity of vehicle.
6. Stochastic Vehicle Routing Problem (SVRP)
   SVRP is VRP that occurs if the side factors that appear are random. In the SPRV, the problem must be divided into two stages to get a solution. The first solution is determined before the random variable is known and second stage is correction if the value of the random variable is known. The aim is to minimize the number of vehicles and the total travel time to serve customer with random values for each delivery (customer, request, time).

VRP was introduced by Dantzig and Ramser in 1959 by raising the issue of "Truck Dispatching Problem" which models homogeneous vehicles to meet the fuel demand of each gas station with the minimum travel distance [3]. This study was a trigger for many researches about VRP and one of them is generated by Desrochers, Desrosiers, and Solomon in 1992 about VRPTW that serve customer within the time windows by defining the earliest and the latest times of customer will permit the service. In this study, they have developed a new optimization algorithm for its solution using linear programming with set of partitioning formulation of VRPTW and solved by column generation. The linear programming solution achieved an excellent lower bound that is used in a branch-and-bound algorithm to solve the integer set partitioning formulation [4]. The exact algorithms are only efficient for small problem instances but real-life problems are considerably larger in scale (number of customers, depots, vehicles, and variety of constraints). This issue was triggering development of heuristic and metaheuristic algorithm in VRP. In 1994, Gendreau, Hertz, and Laporte have developed a tabu search heuristic for the VRP with capacity and route length restrictions [5]. This study aim some numerical test on a set of benchmark problems and indicate that tabu search out performs the best existing heuristics in VRP. The other metaheuristic algorithm was developed by Zhang, Liu, Duan, and Ren in 2007 [6]. They stated that genetic algorithm is an excellent approach to solving complex problem in optimization with difficult constraints. Because of more complexity problems with several objectives, genetic algorithm have been developed to multi-objective genetic algorithm to solve problems in one iteration.

Multi-Objective Genetic Algorithm (MOGA) is a development of genetic algorithm that contain more than one objective functions to be achieved to solve existing problems. In the real case, objective function to be achieved is not only fixed on one objective, but many objectives of the problem that need to be overcome. In genetic algorithm, the problems to be solved, especially related to vehicle routing problems, can be said to be very good. However, the objective function achieved is only one, whereas if more than one, the data processing must be done again. In MOGA, all objective functions can be achieved with one iteration.

Methodology

This study will provide a proposal of the application of a multi-objective genetic algorithm that will use a mathematical models to determine the decision variable, objectives, and constraints faced by the Distributor. The MOGA used in this paper was taken from the journal of Ombuki, et al (2006) [7] and Sivaramkumar, et al (2018) [8] by making number of modifications to the problems that occurred at the Distributor. The objectives function proposed by Ombuki, et al were to minimize total cost and number of vehicle, but the objective to minimize number of vehicle is not suitable to the problem in this paper because the Distributor has its own. So, this paper used the objective function to minimize total cost by Ombuki, et al and minimize total time balance taken from Sivaramkumar, et al that proposed the objective function of workload balance of vehicle in term of distribution time. The formulation of the multi-objective genetic algorithm models is as follows:

$$X_{rk} = \begin{cases} 1, & \text{if the node of location visited by vehicle.} \\ 0, & \text{if not.} \end{cases} \tag{1}$$

$$\text{Min TC} = \sum_{r=1}^{R} \sum_{k=1}^{K} C_{rk} X_{rk}. \text{ or} \tag{2}$$

$$TC = \sum_{r=1}^{R} \sum_{k=1}^{K} \left\{ \sum_{i=0}^{I} \sum_{j=0}^{J} d_{ijrk} \text{ x } (fr + lr + sr + wr) \right\} X_{rk}. \tag{3}$$

$$\text{Min TTB} = (T_{rk})\text{max} - (T_{rk})\text{min}. \tag{4}$$

$$\sum_{i=1}^{I} \sum_{r=1}^{R} q_{irk} X_{rk} \leq Q. \text{ ; where } k = \{1,\ldots.,K\} \tag{5}$$

$$\sum_{j=1}^{N} X_{0j}^{k} - \sum_{j=1}^{N} X_{j0}^{k} = 0. \text{ ; where } k = \{1,\ldots.,K\} \tag{6}$$

$$\sum_{r=1}^{R} X_{rk} \leq K. \text{ ; where } k = \{1,\ldots.,K\} \tag{7}$$

$$\sum_{k=1}^{K} X_{rk} = 1. \text{ ; where } r = \{1,2,\ldots.,R\} \tag{8}$$

$$\sum_{k=1}^{K} T_{rk} \leq T. ; \ \text{where } r = \{1,2,\ldots.,R\} \tag{9}$$

$$\sum_{k=1}^{k} \sum_{i=1,\, i\neq j}^{N} X_{ij}^{k} = 1. ; \text{where } j = \{1,2,\ldots.,J\} \tag{10}$$

Equation (1) describe about the decision variable to the function by using binery numbers. Number 1 if the node of location visited by charged vehicle and number 0 if not. Equation (2) to (4) are the objective function. Equation (2) and (3) are the objective function of total cost and equation (4) is objective function of total time balance. Equation (5) to (10) are the constraint function which equation (5) describe about the total demand must not exceed the vihecle's capacity. Equation (6) is the constraint for vehicle that left depot must return to depot and the in charged vehicle must not exceed the maximum number of vehicle determined by equation (7). Equation (8) describe about one route must be serve by one vehicle and equation (9) is the constraint for time windows that distribution must be done in allowed time windows. Equation (10) is constraint for node of location must be visited once.

Multi-objective genetic algorithm is strongly recommended to solve VRP problems because it has good efficiency and flexibility, so it is possible to solve problems with multiple objective functions at once with nearly optimal results. This method can be used to solve problems in Distributor to minimize distribution costs and a total time balance. Here are the steps of algorithm process to be applied to the problem in the Distributor.

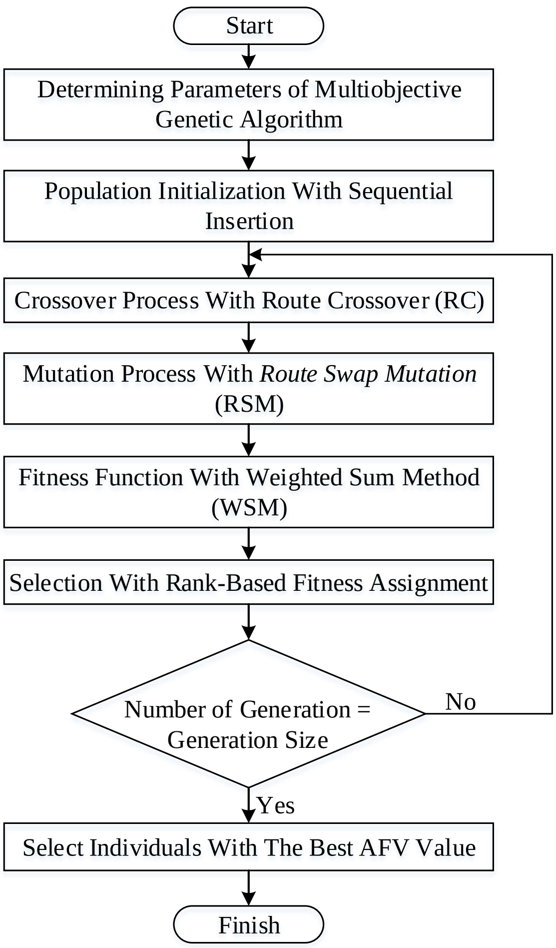

Fig. 1 MOGA Process

1. The first step of MOGA is to determine the parameters. There are some parameters in MOGA refers to research that conducted by Obitko in 1998 [9] such as:
   A. Population Size
   Population size is the number of individual that will be raised in the initialization process and will be proceed to the next process. The greater the size of the population raised, the greater alternative solution will be obtained. A good population size is recommended 20-30 individuals for simple cases, while for complex cases it is recommended that 50-100 individuals.
   B. Crossover Probability
   Crossover probability is used in the crossover process to determine which individuals will be chosen as parents. The greater the probability of a crossover, the greater the likelihood that individuals will be chosen as parents in the crossover process. The recommended crossover probability is 80% - 95%.
   C. Mutation Probability
   Mutation probability is a parameter that determines a chromosome can undergo a mutation process. Genes in existing individuals will be generated random numbers and genes with random numbers smaller than mutation probability will be selected to carry out the mutation process. The recommended size of the mutation probability is 0.5% - 1%.
   D. Generation Size
   Generation size is a parameter that determines when the evolutionary process in the genetic algorithm will stop. The evolutionary process will cease if the evolutionary process has reached a predetermined number of generations at the beginning of the process. The greater the number of generations, the more opportunity for the evolutionary process will continue to grow and get the better solutions.
2. Population Initialization
   In this step, the initial population will be formed according to predetermined algorithm parameters. The more number of individuals formed, the more alternative solutions are formed. The initial population initialization process was carried out using the Sequential Insertion method refers to Joubert, 2006 [10] which was modified according to existing problems and limitations.
3. Crossover Process
   The crossover process is aimed at producing children who are better than the previous parent. The method used for the crossover process is Route Crossover refers to Ombuki et al, 2006 [7]. In the first step, the probability of crossover is determined first. The greater the probability of a crossover being given, the more likely the individual is to initialize the initial population selected to become the parent and produce a new child. Children generated from the crossover process will increase the number of individuals from the previous number of individuals.
4. Mutation Process
   The mutation process is carried out to produce new individuals who are better than before and avoid the local solutions. Gene is allow to follow the mutation process are gene that have random number value smaller or equal to the predetermined mutation probability. The method used in the mutation process is Route Swap Mutation refers to Chand, 2013 [11].
5. Fitness Function
   From a number of individuals formed by the initial population initialization process, the crossover process, and the mutation process, the fitness function value will be calculated for each individual with Weighted Sum Method refers to Ombuki et al, 2006 [7] to identify aggregate fitness value (AFV) that determine the power of solutions.
6. Selection
   The selection process aims to select the best individuals for a number of individuals as many as predetermined population size parameter to proceed to the next generation. The method in this selection uses Rank-Based Fitness Assignment refers to Talby, 2009 [12].
7. Regeneration
   Regeneration is done if the number of generation is equal to the predetermined generation size parameter. This step is used to get better individuals than existing individuals.

Result and Analysis

The egg distribution system applied by Distributor is still done manually. This is known based on the results of the authors observations and interviews with the owner, driver, administration staff, and helper in Distributor. The administration staff will receive a number of orders from a number of customers one day before at the latest of the vehicle departure. This orders will be allocated to three vehicles based on the knowledge and experience of administrative staff by considering the distance of each customer location served on that day and the capacity of each vehicle. If on certain day the customer demand exceeds the vehicle's load capacity, then the request will be diverted to the next day according to FIFO rules. The driver receives assignments from the administrative staff and in distribution activities will be assisted by helper. The driver determines the distribution route to a number of customer locations based on the knowledge and experience of the driver.

The loading process is carried out one day before distribution, so the driver can immediately deliver the order to the customer next day. This distribution activity is carried out on Monday to Saturday at 08.00 a.m until 05.00 p.m, with a one-hour rest period which can be adjusted by driver and helper. All customers can be served at the same working time with Distributor which Monday to Saturday at 08.00 a.m until 05.00 p.m. Distribution activities may not exceed the maximum time of allowed time windows because it cannot be served by customers and there is no overtime system that is subject to overtime fees on these Distributor.

The current system could be improved because decisions are taken based on knowledge and experience which is not necessarily the best decision that raises low distribution costs. In addition, there is an imbalance in the workload of vehicles used for the distribution process related to the distribution time charged to each vehicle. Drivers often complain that there are significant distribution time differences that are considered unfair.

1. Result

Before processing the data using software that has been built with MOGA, this research helps Distributor to determine MOGA parameters to be applied to the problem. Tests were carried out on six days of observation data. The following is a proposal for the parameters to solve the problems faced by Distributor.

A. Population size = 26 individuals
B. Crossover probability = 85%
C. Mutation probability = 1%
D. Generation size = 40 generations

All parameters obtained from the results of parameters testing in this study are dynamic following by the amount of data. The parameters above only apply to the current state of the Distributor with the number of customers ordering per day which ranges from an average of 30 customers per day. If there is a change in the amount of data, it is possible to change the parameters to the proposed system applied in the software. The weight to determine AFV are 70% for distribution cost objective and 30% for total time balance objective.

The metaheuristic method makes it possible to get near optimal results with a shorter time by using multi-objective genetic algorithm. This method is applied using software that runs on a laptop with specifications:

- Operating System: Windows 7 Ultimate 64-bit (6.1, Build 7600)
- Processor: AMD E2-3800 APO with Radeon (TM) HD Graphics (4CPUs), ~ 1.3 GHz
- Memory: 2048MB RAM

The computation time needed to run the algorithm proposed in determining route is an average of 17 seconds with the parameters and number of locations in this study. This will also shorten the process time for determining customer orders to vehicles and routes that will be used as a reference for drivers in distribution activities, because in inputting data, for the current number of Distributor data which is around 30 customers per day, input time is required an average around 5 minutes. The following is a comparison between the current system and the proposed system.

Table 1. Result

Data	Distribution Cost (Rp)		Improvement (%)	*Total Time Balance* (Minutes)		Improvement (%)
	Actual	Proposed		Actual	Proposed	
1	465,253.42	394,197.49	15.27	39.91	0.37	99.08
2	473,058.68	377,073.93	20.29	38.97	2.28	94.14
3	517,635.98	454,329.50	12.23	41.40	2.42	94.15
4	427,396.04	352,945.99	17.42	67.45	0.39	99.42
5	499,743.54	419,913.12	15.97	43.46	4.10	90.57
6	462,116.27	337,263.42	27.02	55.57	2.36	95.75
Total	2,845,203.93	2,335,723.45		286.76	11.92	
Average	474,200.65	389,287.24	18.03	47.79	1.99	95.52

Comparison between the actual and proposed systems obtained savings in terms of distribution costs of Rp 509,480.48/week with an average improvement of 18.03%, while in terms of total time balance, the distribution time range can be reduced to 95.52%, so that the workload of vehicle is more balanced.

2. Analysis

Based on the results of the comparison between the actual system and the proposed system, it is known that extreme conditions occur in terms of distribution costs occurring on data 6 which is equal to 27.02%, while in terms of total time balance occurs on data 1 and data 4, which are 99.08% and 99.42%. In both of these aspects cannot be separated from each other because in MOGA, solutions determination is based on combination of these two objective functions. The possibilities that make these improvements occur in an extreme are the administration staff has not been good at allocating customer orders into each vehicle so that the composition of the customer location contained in the vehicle could be greatly improved. By implementing a proposed system, software could allocate customer orders into each vehicle evenly in terms of distribution time and determine a better distribution route to be applied by the Distributor. The proposed system also obtain savings in term of distribution time to 11.81% and in the term of travel distance to 17.09% because of the allocation of customers to vehicles and route determination that have done by the system.

Based on the results of discussions with Distributor, it was found that for the current proposal there would be weighting the objective functions with a value of 70% for the objective function of distribution costs and 30% for the objective function of total time balance. In this case there is no clear benchmark for the weighting that will be given to each objective function. Therefore, this study trying to analyze the impact of weighting value as a consideration in determining the weight for each objective function. The following is the result several weighting combinations.

Table 2. Objective Functions Weighting Combinations

Weight (%)		Distribution Cost (Rp)		Average Improvement (%)	*Total Time Balance* (Menit)		Average Improvement (%)
Distribution Cost	*Total Time Balance*	Actual	Proposed		Actual	Proposed	
50	50	2,845,203.93	2,723,718.37	4.27	286.76	9.08	96.83
60	40	2,845,203.93	2,601,371.94	8.57	286.76	10.74	96.25
70	30	2,845,203.93	2,335,723.45	18.03	286.76	11.92	95.52
80	20	2,845,203.93	2,301,283.13	19.12	286.76	21.46	92.52
90	10	2,845,203.93	2,252,729.48	20.82	286.76	32.78	88.57

From the table above, it was found that the greater the weight given to the related objective function, the greater the average improvement percentage. Therefore, this weighting result can be taken into consideration by the Distributor in determining the weight of each objective function.

Conclusions

The current method of route determination is based on experience, so the distance and travel time are thought could be improved. This affects the distribution costs that must be spent to distribute eggs to customers. Distributor also experience workload imbalance of vehicles regarding to the travel time charged to each vehicle. This is indicated by the presence of vehicles that have returned to the warehouse earlier and there are vehicles that must return at the end of working hours. The proposed system is metaheuristic method by using multi-objective genetic algorithm.

The benefits that could be obtained by applying this proposal are savings in terms of distribution costs of Rp 509,480.48/week with an average improvement of 18.03%, while in terms of total time balance, the distribution time range can be reduced to 95.52% so that the workload more balanced vehicle. Software designed also could facilitate workers in carrying out their duties and ensure that the results will be close to optimal and shorten the processing time to determine customer orders to vehicles and routes that will be used as a reference for drivers in distribution activities.

The suggestion for the future research are could considering the real time control ability which is possible to help distributor to determine congestion level and situation dynamically that will show the other alternatives of distribution route. The future research also could make a comparison between MOGA and the others metaheuristic method to obtain better solution.

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