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by Hayati Asih

TRAVELING SALESMAN PROBLEM WITH PRIORITIZATION FOR PERISHABLE PRODUCTS IN YOGYAKARTA, INDONESIA

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ABSTRACT: The Traveling Salesman Problem (TSP) is challenging, especially when multiple nodes have varied opening hours and the product is perishable. Due to some nodes' inconsistent store opening times, truck drivers frequently reroute on those same networks. This study proposes the TSP model to resolve the distribution problem based on a case study of a bakery distributor's small and medium enterprises (SMEs) in Yogyakarta, Indonesia. This study proposed the TSP model to solve two conditions: the classical and the weighted TSP model. A classical TSP model was for unprioritized nodes, and the weighted TSP model was for the distribution problem, considering the prioritized nodes due to the opening hours of nodes or depots starting in the early morning or afternoon. Therefore, this model aims to minimize the distance travelled by finding the optimum sequence delivery nodes on tour for classical and weighted TSP. To achieve the objective, some experiments using genetic algorithms were employed. Based on the result of experimenting with the proposed model using GA, the total distance-saving improvements for the classical and weighted TSP models were about 46.68% and 45.74%, respectively. The proposed model can help a driver truck decide the product's sequence delivery nodes.

KEYWORDS: *Travelling Salesman Problem; Route; Genetic Algorithm; Weighted Travelling Salesman Problem*

1.0 INTRODUCTION

Travelling Salesman Problem (TSP) is a challenging problem in Operational Research [1]. Generally, this problem assumes a finite number of nodes, each node is visited only once with each node visited only once, and the distance or the cost to travel between each city is known [2]. The main goal is to find the shortest route with a list of specific destinations (nodes) to the distance travelled or the transportation cost can be minimized.

Perishable products will lose a significant value if stored, and the economic value decreases when late delivery [3]. Some products included as perishable products are fresh fruits and vegetables, flowers, food, and other products with a short lifespan, such as blood, drugs, and concrete [4]. The efficiency in distributing these products is required and challenging. Some previous studies have discussed perishable product distribution problems, such as bakery products [5], newspaper [3], etc. One way is to optimize the delivery route to minimize the distance, reducing distribution costs and increasing company profit.

In the real industry, some weights are required to be considered in TSP [6] based on the preferences of the company. The additional weights on the nodes will complicate the problem compared to the classical TSP. To meet customer orders, perishable products should not be delivered too long after production [4]. As a result, the solution to this problem is interesting. The cost of transportation is also decreased for tours with a lower overall distance covered.

The weight or prioritization of TSP has been discussed in previous studies. Ginting et al. [7] proposed item delivery simulation using Dijkstra Algorithm to find the shortest route for the salesman by considering some priorities. It is in line with previous research [8] that also examined the weight of the nodes during a tour by developing the approximation algorithm and randomized search heuristics.

TSP is fundamental in combinatorial optimization and canonical NP-hard problems [9]. Previous studies have investigated TSP by employing some methods. Xing et al. [10] compared Monte Carlo tree search and deep search neural networks in solving TSP. Another study [11] developed an ant colony optimization method and a self-adaptive discrete particle swarm optimization technique for TSP to attain the smallest sum of distance. Later, a study solved a case study using Anchorage, Alaska's transportation network, to explore the travelling salesman problem in intelligent transportation systems [12]. The goal is to find the route with the lowest cost.

Furthermore, integer linear programming and the branch-and-cut algorithm were developed to solve Steiner TSP [13]. Huang et al. [14] proposed multi-solutions TSP using a niching memetic algorithm. Karaboga and Gorkemli [15] developed a combinatorial artificial bee colony algorithm to solve TSP. In addition, a genetic algorithm (GA) with a modified crossover operator was proposed to find the best routes within 5 to 50 cities [16].

Additionally, employing GA and comparing crossover operators could decrease the route path by altering three variables: the number of cities, the number of generations, and the population size [17]. From those methods, GA is proved more efficient in solving optimization [18]. It is also supported by Vandana et al. [19] who compared GA and dynamic programming, branch and bound, and greedy algorithms to solve TSP. Not only TSP but GA was also successfully implemented in various applications, such as inventory problems [14, 15, 18, 21] , forecasting error [22], scheduling [23], and distribution problem [24].

This study aims to minimize the total distance travelled by taking into account some weights of the nodes classified as stores. The primary contribution of this study is the GA solution proposed for finding the best route while considering the weight of each store. The experiment using GA is run by changing a few of the parameters to discover those optimum values. These parameters included the population size, the probability of crossovers, and the probability of mutations. It investigated the impact of changing those operators on finding the most effective solutions. For managerial insights, the research results can solve the distribution problem for perishable products with minimum travelled distance. This can also assist drivers in determining which stores should be visited based on their priority.

The remainder of this paper is structured as follows. The following section uses a mixed integer programming model to describe the issue in more detail. Section 3.0 describes results and discussion. Finally, Section 4.0 elaborates conclusion and future research.

2.0 PROPOSED MODEL

2.1 Problem description

This research develops the TSP model based on a real case study of a bakery distributor's small and medium-sized enterprise (SME) in Yogyakarta, Indonesia for the distribution of perishable products. Initially, the bakery is regarded as the origin of products (pool) that are prepared for shipment to some stores. The problem with product delivery is that a truck driver frequently reroutes on the same nodes since some nodes have inconsistent store opening times. For instance, some stores are possibly opened in the early morning or afternoon. As a result, unsynchronized delivery nodes make a truck driver do redundant tasks to deliver the product while the product is perishable. Furthermore, this problem can affect to the long-distance travel and directly increase the transportation costs. To solve these problems, some nodes require the weight in a route. The weight in this case study refers to the nodes that should be prioritized based on the store opening time. Therefore, this paper develops the TSP model with priority nodes based on the weight given. The objective of this model is to minimize the distance travelled by determining the optimal sequence delivery nodes in one route. In short, the specification of the proposed model in which representing the case of being studied are defined as follows:

i. There is a single truck in which distributing a single product into 17 nodes.
ii. Each store is visited only once.
iii. The distance to travel between each store is known.
iv. The weight proposed in this model is based on the store opening time.

2.2 Mathematical model

The mathematical model of classical TSP problem could be formulated as follows:

$$Z(X) = \sum_{i=1}^{n} D(X_i, X_{i+1}) + D(X_n, X_1) \qquad (1)$$

where, n is the total number of stores, X_1 is considered as the bakery distributor (initial pool). While, X_{i+1} is the store number in position $i + 1$, and $D(X_i, X_{j+1})$ is the distance from X_i to X_{i+1} and $D(X_n, X_1) =$ the distance from the last stores to the initial pool .The objective in Eq. (1) is minimizing the total distance of a complete tour by optimizing the sequence of delivery stores. Based on Eq. (1), the weighted (w) TSP model is subsequently developed, which modifies the conventional TSP model by taking prioritized nodes into account:

$$Z(X) = \sum_{i=1}^{n} Dw_i(X_i, X_{i+1}) + Dw_n(X_n, X_1) \quad (2)$$

In practice, these nodes are likely bakeries, schools, supermarkets, and small shops. Because of the products distributed is bread, which is mostly eaten in the morning (high demand and open early morning), so that certain nodes like schools are the most priority ones. Then, the supermarkets are the last node that is distributed, because they are open in the afternoon so that there is no need to re-route. Figure 1 presents the scheme of the proposed TSP model for the bakery distributor's SME system.

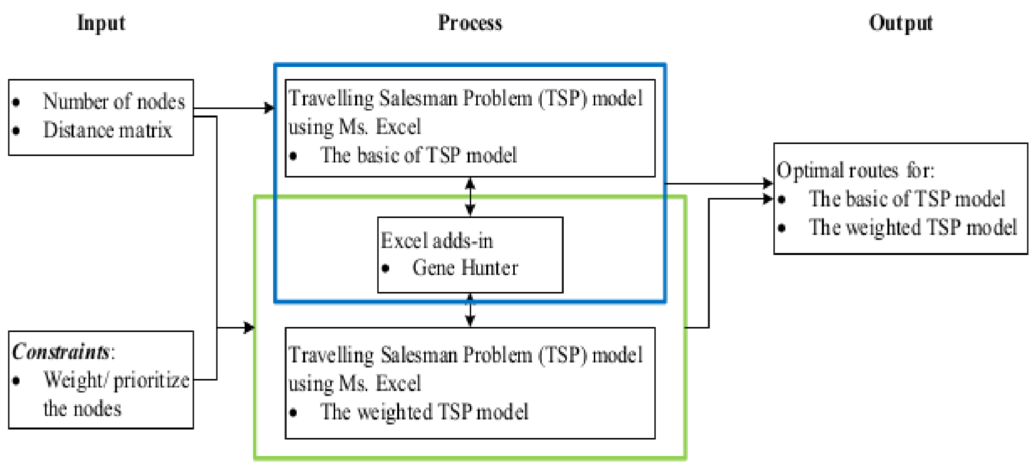


Figure 1: The scheme of the proposed TSP model for the bakery distributor's SME system.

Based on Figure 1, there are input, process, and output. The inputs are the distance matrix and the number of nodes with the constraint given is the weight/ prioritize the nodes. The mathematical model either classical or weighted TSP problem is coded in Microsoft Excel software. This software is compatible because industrial practitioners commonly use this software whose general purpose that can easily solve distribution problems without learning new modeling or programming language, or buy expensive and specific tools, or hire a specialist to do so. In contrast, previous researches employed modeling language (i.e. MATLAB, GAMS, AMPL), or programming language (i.e. Delphi, Java, C), or commercial solvers such as CPLEX which makes the proposed solution difficult to be applied on the real industry. Moreover, to find the near or optimum solution of the TSP model, then the GA based GeneHunter software is used. Therefore, both Microsoft Excel and GeneHunter are employed to conduct experiments to find the best routes with minimum distance for both the classical and weighted TSP model. A detailed discussion of the optimization process using a GA is presented in the next sub-section.

2.3 GA method

As mentioned earlier, the GA method is employed to solve the problem of classical and weighted TSP. The main objective is to minimize the total distance travelled and thereby reduce transportation costs. To start the GA method, the following initial information is required:

i. Population size (N): Sets of the chromosome are kept in each generation.
ii. Crossover rate (Pc): The probability of crossover in the GA method.
iii. Mutation rate (Pm): The probability of mutation in the GA method.

Generally, the steps in the GA method are as follows:

i. Initialization
An initial value of population (N) is generated randomly. In this case, the population consists of several chromosomes that refer to the sequence delivery nodes of a tour (which is gen in GA) as shown in Figure 2. Meanwhile, the population size (N) is determined based on the modeler for each experiment.

X_1	X_2	X_3	…	…	X_{n-1}	X_n

Figure 2: Example of chromosome

ii. Evaluating fitness function
Since GA is categorized as an optimization problem, then a fitness function that is referred to as the objective function needs to be calculated to evaluate the chromosome or solutions in the population. Therefore, the expression of a fitness function is equal to that of TSP model.
iii. Selecting the chromosome
This stage is the selection phase which how the GA chooses the parents for the next generation. It chooses N chromosomes among the parents and the offspring with the best fitness value. There is some selection method, such as roulette wheel, tournament, ranking, and elitist. In this study, the elitist method is used to select the best chromosome.

iv. Performing crossover

This phase is an important part of GA in which two parent chromosomes are paired to create offspring. This research is conducted by selecting randomly a pair of chromosomes from the generation with probability Pc. In this research, the probability of crossover is set into several values to experiment such as 0.95, 0.9, 0.85, 0.8, 0.75, and 0.7. The crossover process has some different types of crossover operators are one-point, two-point, multiple-points, and uniform. This study employs a one-point crossover to generate new offspring. Figure 3 presents a graphical representation of the crossover operations based on the TSP problem. First, a random crossover point is chosen, then split the parents at that point(s), finally, the offsprings are created by exchanging the tails.

v. Performing mutation

The mutation process is required to do as it maintains genetic diversity from one generation of a population so that it ensures a border search space to be searched by GA. By having appropriate mutation probability, the premature convergence can be avoided [25]. The probability of mutation in the experiment uses 0.01, 0.02, 0.025, 0.3, 0.4, and 0.5. Figure 4 illustrates the mutation process.

vi. Termination of the GA process

The last step of GA is to stop the searching process after a solution that is near or optimum has met the user's expectation. This research decides to stop the process of GA after 300 generations. Moreover, the best chromosome with minimum fitness is selected as the near or optimum solution for each experiment.

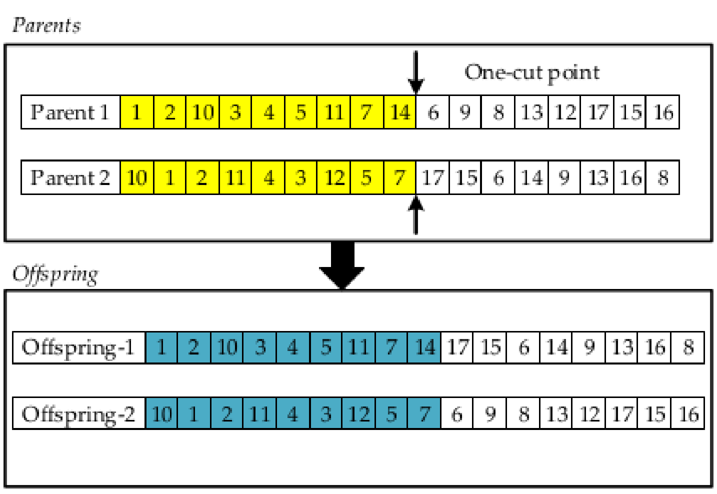


Figure 3: The one-cut point crossover

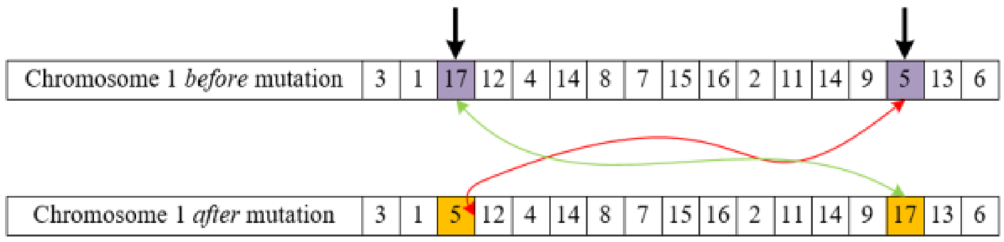


Figure 4: The mutation process

3.0 RESULTS AND DISCUSSION

This section elaborates on the experimental results of the proposed model by evaluating its performances. The data, such as the distance matrix among nodes collected from a real case study, was collected. After that, those data and Eq. (1) are employed to develop the classical and weighted TSP model through GA.

Table 3 presents the experimental results of the classical TSP model and the weighted TSP model. It shows three different experiments (i.e. experiment 1, 2, and 3 for the classical TSP model has the same fitness value even though there are differences in crossover probability, mutation probability, and population size. The different values of GA parameters have experimented with the effect of the performance. In this table, "CPUt" denotes the CPU time of solving the problem in seconds and "Fitness" denotes the fitness value in kilometers.

Table 3: Experimental results: the classical TSP and the weighted TSP

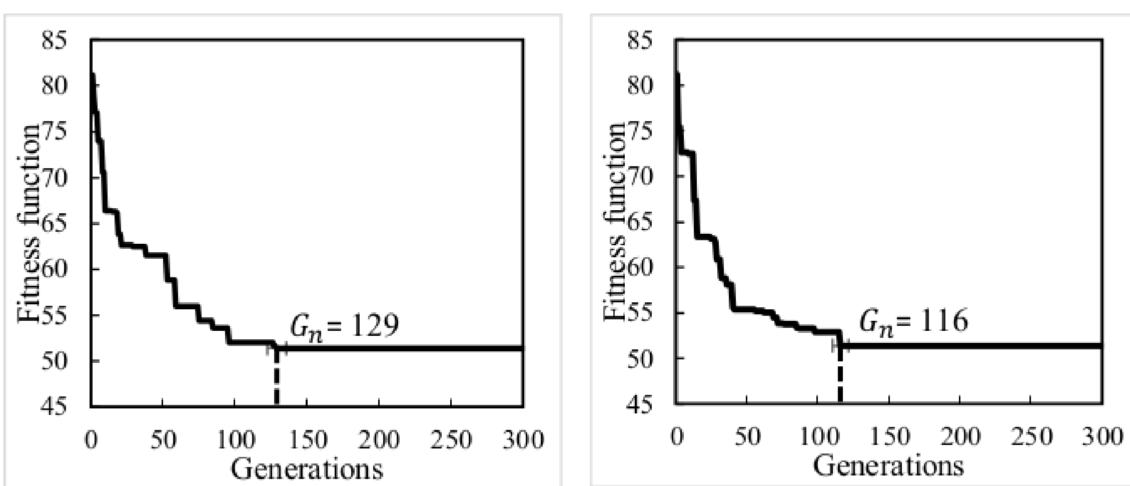
Model	No. of Experiment	Crossover	Mutation	Pop	Fitness	CPUt
The classical TSP model	1	0.95	0.04	80	51.4	20
	2	0.9	0.01	100	51.4	25
	3	0.85	0.03	120	51.4	29
	4	0.8	0.05	140	54.6	32
	5	0.75	0.025	160	53.9	38
	6	0.7	0.02	180	52.2	43
The weighted TSP model	1	0.95	0.04	80	58.8	22
	2	0.9	0.01	100	55.9	28
	3	0.85	0.03	120	52.3	32
	4	0.8	0.05	140	55.5	35
	5	0.75	0.025	160	57.7	40
	6	0.7	0.02	180	59.6	45

For the classical TSP model, the best fitness value is 51.4. It means the total distance traveled in a tour is 51.4 kilometers. Figures 5 shows the trend of fitness value optimization in the classical TSP of the parameter-tuned GA for different crossover probability, mutation probability, and population size. On the other hand, the fitness value optimization for the weighted TSP model is presented in Figure 6.

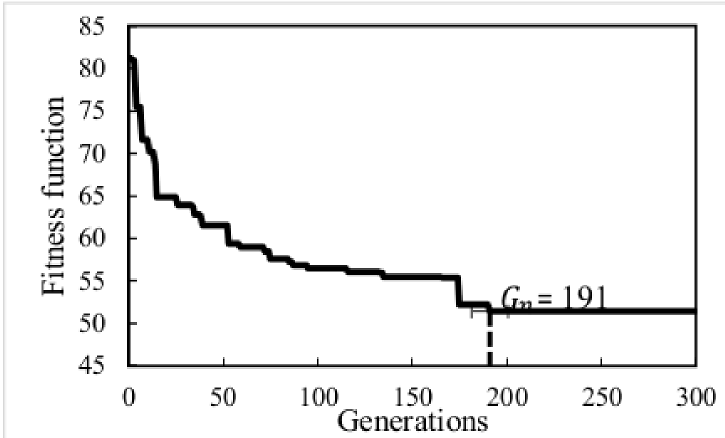
To examine the percentage of fitness value reduction (total distance traveled in a tour) obtained by the implementation of the parameter-tuned GA above as follows.

$$Improvement\ (\%) = \frac{TD_{after} - TD_{before}}{TD_{before}} x100 \quad (3)$$

TD_{before} denotes the total distance of the current system without optimization. TD_{after} denotes near-optimal total distance traveled of the parameter-tuned GA. According to the obtained results, there are improvements in total distance saving for the classical TSP model and the weighted TSP model, i.e. 46.68% and 45.74%, respectively. The weighted TSP model has smaller improvement than the classical one as it considers some contraints to minimize the travel distance while considering some prioritizations due to the high demand and the opened nodes or stores in the early morning or afternoon.



(a) (b)



(c)

Figure 5: The trend of fitness value optimization: The classical TSP model for (a) experiment 1, (b) experiment 2, and (c) experiment 3

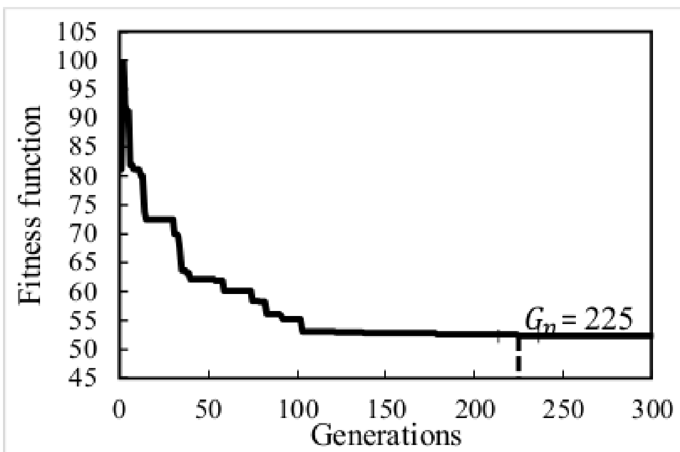


Figure 6: The trend of fitness value optimization: The weighted TSP model for experiment 3

Even though the weighted TSP model has smaller improvement and has higher CPU time (see Table 2) than the classical one, the weighted TSP model is more applicable for bakery distributor's SME in Yogyakarta, Indonesia as this model considers the prioritization of particular nodes to find the optimal sequence of delivery nodes in a tour.

When each store is assigned a priority value that must be met before any others, GA is able to identify the route with the greatest priority value. However, a longer distance is affected by this. Of course, it will affect shipping costs as well. However, the GA solution is still a viable option. This is so that the model can identify the shortest distance while also finding the best route based on a high priority value. Some earlier literature, like da Silva et al [6] and Bossek et al [8] provide additional support for these findings.

4.0 CONCLUSION

In this paper, the TSP model was developed for distribution perishable product under the case study of several nodes or depots in Yogyakarta. The proposed TSP model consists of the classical and weighted TSP model. Specifically, the weighted TSP model is developed by considering the nodes that should be prioritized due to the high demand and the opened nodes or depots in the early morning or afternoon. Hence, the objective of both models is to minimize the distance traveled by finding optimum sequence delivery nodes on a tour. To find near or optimum solution, then GA is employed. Based on the result of experimenting with the proposed model by using GA, then there are improvements on total distance saving for the classical TSP model and the weighted TSP model about 46.68% and 45.74, respectively. It shows that the proposed model can be useful to help a driver truck in deciding the sequence delivery nodes of the product under two conditions, namely un-prioritized and prioritized nodes based on the demand and the opened nodes in a certain time. For future research, this model can be extended into several considerations include, the model can be developed by considering uncertainty in the time of delivery, and the other solution approaches can be applied to solve the model problem, therefore, a comparison among algorithm become interesting topics in term of model performance.

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