Minimizing the handling time in VRP with pickup-and-delivery and time windows

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Abstract. Improving services through goods pickups and deliveries to expand the market is currently being carried out by many companies. This effort needs another step of optimization to avoid losses due to additional resources, such as time, which must be held by the company. In the case of simultaneous goods pickups and deliveries using a vehicle with single transport access, the policy of arranging goods in the vehicle can affect the length of time for service. Single transport access causes goods that want to be unloaded obstructed by the other goods, thus requires additional time for handling. In this paper, the problem of a vehicle's route and handling time in picking and delivering goods with time windows is modeled as the Traveling Salesman Problem. The objective function of this problem is to minimize the total travel time and handling time during the picking and delivering goods. The model is implemented in the case of bicycle pickup and delivery services involving 15 bicycle shops. The capacity of the vehicle is 15 units of bicycle. In this case, a solution consisting the pickup and delivery route and optimal goods order is obtained with an objective function value of 334 minutes.

1. Introduction

Today, many companies are increasing their services through goods pickups and deliveries service to expand the market. Companies that can provide shuttle services have added value in the eyes of customers because it can facilitate the buying and selling process. However, the provision of this shuttle service certainly requires additional costs such as transportation costs and time that must be sacrificed by the company. To avoid losses, efforts are needed to minimize the costs incurred. The effort that can be done is to determine the right route and or the optimal policy for the achievement of service efficiency during the process of shuttle goods taking place.

Minimizing costs in the process of picking up goods in mathematics can be modeled as a Vehicle Routing Problem (VRP) problem. VRP is the determination of distribution route of goods by vehicles that depart from the depot to a number of customers who are geographically dispersed to minimize travel costs where all the given constraints are met [1]. Research related to VRP and its development have also been proposed, such as "An Improved Differential Evolution Algorithm for Vehicle Routing Problems with Simultaneous Pickups and Deliveries and Time Windows" by Mingyong and Erbao [2]. In this paper, it is researched the process of picking up goods simultaneously with time constraints so that the shuttle of goods can be done at the same time with a minimum cost and in accordance with the customer's time window. If the shuttle is done using only one vehicle, then this problem can be categorized as a Traveling Salesman Problem with Pickup and Delivery (TSPPD). Previous researchers, Battarra et al.
[3], in the article titled "The Traveling Salesman Problem with Pickups, Deliveries, and Handling Costs" discussed the development of the TSPPD problem by considering various policies for the optimal preparation of goods in vehicles so that the process of picking up goods can also be carried out with handling costs minimum.

Research examining the arrangement of goods in shuttle vehicles such as those conducted by Batarra et al. [3] has not been studied much by researchers. In fact, in the case of a shuttle of goods carried out at the same time, it is important to consider when the vehicle used has single transport access. That is, there is only one way to lower and raise goods to and from the vehicle. This condition makes it possible for items to be unloaded from vehicles obstructed by other items so that additional handling is required. The application of policies and improper route selection can cause additional time which is relatively long for handling or even not meeting the time windows constraints of each customer. According to Melany et al. [4], in the process of creating and delivering product elements to customers, effective design and implementation are required. A poorly designed process will disrupt customers because it will cause delays, bureaucracy, and ineffective service delivery.

This scientific paper discusses the problem of vehicle routes and handling times in the process of picking up goods by one vehicle with single haul access that is modeled as a TSPPD problem. Considering that the customer's schedule and policy for preparing goods are important to consider, the model is developed into TSPPD with Handling costs and Time windows (TSPPDH-TW). The completion of this model produces a solution in finding optimal routes and policies so that the shuttle process can be carried out at a minimum cost and in accordance with the customer's schedule. In this case, the cost is uninformed as the total time that must be sacrificed by the company to process the delivery of goods to all customers. The minimum total time required is obtained by minimizing the mileage and additional handling time required during service.

2. Traveling Salesman Problem (TSP)

TSP is the most well-known problem in discrete optimization. For example, it is given the set of \( n \) cities and \( c_{ij} \) as the cost of travel from city \( i \) to city \( j \) for all \( i, j \). The objective function of the problem is to determine the minimum total travel cost to visit each city exactly once and return to the starting point. TSP is said to be symmetric if \( c_{ij} = c_{ji} \) for all \( i, j \), others are asymmetric. The cost of \( c_{ij} \) satisfies the equation of the triangle if \( c_{ij} \leq c_{ik} + c_{kj} \) for every \( i, j, k \) [5].

Simplification of the notation can be done by supposing \( G = (V, E) \) as a complete undirected graph with \( n \) vertices of \( V \) (\( |V| = n \)) and \( (i, j) \) members of \( E \) are edges (undirected) between \( i \) and \( j \), \( \forall i, j \in V \). In this case, \( V = \{1, \ldots, n\} \) represents the city to be visited with the origin depot represented by \( i = 1 \) while \( i = n + 1 \) as the destination depot [6]. The following is a TSP model formulation in the form of ILP according to Winston [7].

Sets:
\( V \) = set of cities that will be visited including the city of origin,
\( E \) = set of sides or routes from city \( i \) to city \( j \), \( \forall i, j \in V, i \neq j \).

Indices:
\( i, j = 2, 3, \ldots, |V| \) the indices for cities, with \( i = 1 \) denotes for the city of origin (depot).

Parameter:
\( c_{ij} \) = the travel cost from city \( i \) to city \( j \).

Decision variable:
\( x_{ij} = \begin{cases} 1, & \text{if route } (i, j) \text{ is selected as solution} \\ 0, & \text{others.} \end{cases} \)
Objective function:

\[ \text{minimum } Z = \sum_{(i,j) \in E} c_{ij} x_{ij} \]

that is minimizing the total cost of travel to visit each city exactly once.

Constraints:

1. Each city is only visited exactly once.
   \[ \sum_{i \in V} x_{ij} = 1, \forall j \in V. \]
   \[ \sum_{j \in V} x_{ij} = 1, \forall i \in V. \]

2. No subtour is formed on the route, so there is only one tour route in the cycle.
   \[ u_i - u_j + nx_{ij} \leq n - 1, \forall i, j \in V, u_j \geq 0. \]

3. Guarantee that \( x_{ij} \) is a binary variable.
   \[ x_{ij} \in \{0,1\}, \forall (i,j) \in E. \]

TSP has several variations, including TSP with Time Windows (TSP-TW), TSP with Pickups and Deliveries (TSPPD), and TSP with Pickups, Deliveries, and Handling Costs (TSPPD-H). TSP-TW is a development of TSP which a set of city defines as a set of customer. Each customer has a service time (the time when the customer must get service) and a time window that shows the deadline for starting and ending the service. Each customer must be visited before the end of the service deadline so that any tour that visits the customer after that time limit is not feasible. If the vehicle arrives before the deadline for commencement of service, it will result in a waiting time [8]. TSPPD is a variation of TSP with the customer set divided into three sub-sets, namely P, D, and PD. Every customer \( i \in D \) has a request for delivery of goods defined as \( d_i \), every customer \( i \in P \) has a request for pickup of goods defined as \( p_i \), and every customer \( i \in PD \) has a request for both. The three sub-sets of customers provide the same income, namely \( r_i \). The vehicle starts from the depot and have a capacity of \( Q \) with \( Q \geq \sum_{i \in V} d_i \). TSPPD aims to find routes that start and end at the depot, serve all requests for pickup and delivery of goods, and minimize the total costs obtained from the total travel costs minus the income generated from the collection of goods picked up [9]. Meanwhile, TSPPD-H is a development of TSPPD that considers the position of placing goods in a vehicle that affects the cost (time) required to load and unload (handle) goods in a vehicle at the customer's location, in this case, referred to as handling costs [3]. In the TSPPD-H, the vehicle is represented as a single stack in which the commodities can be loaded and unloaded only from the rear. Under the assumption that the goods have one dimension comparable to the truck width, this vehicle condition allows that the delivery operations are obstructed by pickup commodities. The objective of TSPPD-H is to determine a Hamiltonian tour in which the commodities on the vehicle are possibly rearranged at the customer locations so that minimize the sum of additional handling and routing costs [10].

3. Mathematical Model

The problem of vehicle routes and handling time in the process of picking up goods with time windows is defined as the problem of determining the route and policy of arranging goods in the vehicle appropriately to minimize the total travel time required for visiting all customers and additional handling time required at each customer location. Each customer has a request for delivery of some goods (later called the goods of type I) or pick-up some goods (later called the goods of type II), and possibly for both. The process of simultaneous pickup and delivery must be done within the time windows of each customer. Customers can only be visited exactly once by vehicle. During the pickup
and delivery process, the number of both types of goods in the vehicle must not exceed the vehicle capacity.

The pickup and delivery process is undertaken by using a vehicle with a capacity of \( Q \) units. All units can be arranged in order of position 1, 2, 3, \( \ldots \), \( Q \) with position 1 representing the rearmost position while the order of position \( Q \) represents the foremost position. An item with a smaller serial number will be handled (unloaded) earlier than that with a larger number. In Cherkesly et al. [11], it is called the last-in-first-out (LIFO) loading. LIFO loading means that when a pickup node is visited, its corresponding item is loaded on top of a linear stack, and an item can only be delivered if it is on top of the stack. In this paper, handling time is the length of time required to unload and load some goods (types I and II) for a position \( k \). Meanwhile, the additional time for handling is the length of time required to unload some goods (types I and II) which obstructed the goods of type I when it will be unloaded from a certain position \( k \) or the goods of type II when it will be loaded to the other position \( k \) in the vehicle.

The following is problem formulation of vehicle routes and handling time in the form of TSPPDH-TW. The problem is modeled by combining the concepts of TSP-TW and TSPPDH models. Some of the assumptions used for model simplification are:

1. The number of vehicles used in the goods pick-up process is 1 and the vehicle only has one access to load or unload the goods.
2. The route for picking and delivering goods is always started from and ended at the depot.
3. The distance between customers is symmetric, meaning that the distance from customer \( i \) to customer \( j \) is the same as the distance from customer \( j \) to customer \( i \).
4. Each customer is visited exactly once by the vehicle.
5. The vehicle has a limited carrying capacity.
6. The total number of goods to be delivered to all customers and the total goods taken from all customers is known and the amount does not exceed the vehicle capacity.

### 3.1 Notations

**Sets:**
- \( V \) = the set of customer that will be visited including the depot,
- \( V_c \) = the set of customer that will be visited,
- \( E \) = the set of side or route from customer \( i \) to customer \( j \), \( \forall i, j \in V, i \neq j \).

**Indices:**
- \( i, j = 1, 2, 3, \ldots, |V| \) is the index for the depot (\( i = 1 \)) and customers,
- \( i, j = 2, 3, 4, \ldots, |V_c| \) is the index for the customers,
- \( k = 1, 2, 3, \ldots, Q \) the index for the position of the goods in the vehicle.

**Parameters:**
- \( c_{ij} \) = the travel time from customer location \( i \) to customer location \( j \),
- \( a_i \) = the number of goods type I or goods that must be sent to customer \( i \),
- \( \beta_i \) = the number of goods type II or goods that must be taken from customer \( i \),
- \( Q \) = vehicle capacity,
- \( h_a \) = the time it takes to unload each type I item from the vehicle,
- \( h_b \) = the time required to load each type II item into the vehicle,
- \( l_i \) = the earliest time service to customer \( i \) can be done,
- \( u_i \) = the latest time for customer service \( i \) may be done.

**Decision variables:**
- \( x_{ij} = \begin{cases} 1, & \text{if side } (i,j) \text{ is the selected route} \\ 0, & \text{others.} \end{cases} \)
\[ a_{ij}^k = \begin{cases} 1, & \text{if position } k \text{ is occupied by goods of type I when the vehicle passes through the route } (i, j) \\ 0, & \text{others} \end{cases} \]

\[ b_{ij}^k = \begin{cases} 1, & \text{if position } k \text{ is occupied by goods of type II when the vehicle passes through the route } (i, j) \\ 0, & \text{others} \end{cases} \]

\[ r_i^k = \begin{cases} 1, & \text{when the vehicle is at the customer } i \text{'s location} \\ 0, & \text{others} \end{cases} \]

\[ v_i^k = \text{length of handling time for position } k \text{ at customer } i \text{ location}, \]

\[ s_i = \text{the time when the service of customer } i \text{ is started.} \]

3.2 Objective Function

The objective function of this problem is to minimize the total time of travel and handling required to transport goods to all customers, written mathematically as follows.

\[
\min Z = \sum_{(i,j) \in E, t \neq j} c_{ij} x_{ij} + 2 \left[ \sum_{t \in V_c, k \in Q} v_i^k - \sum_{t \in V_c} h_i \alpha_t \right]
\]

(1)

with \( \sum_{t \in V_c} h_i \alpha_t \) is formulated to obtain precisely the additional handling time required. This formulation is carried out based on the consideration that for each customer \( t \), the time required to unload the number of goods type I or load the number of goods type II belonging to customer \( t \) is not calculated as additional handling time at customer \( t \)'s location because that time requirement is unavoidable in the process of picking and delivering goods.

3.3 Constains

The following constraints must be met.

\[
\sum_{j \in V, j \neq i} x_{ij} = 1, \quad i \in V. \tag{2}
\]

\[
\sum_{i \in V, j \neq i} x_{ij} = 1, \quad j \in V. \tag{3}
\]

\[
\sum_{j \in V} \sum_{k=1}^{Q} (a_{ij}^k - a_{ij}^k) = \alpha_t, \quad i \in V. \tag{4}
\]

\[
\sum_{j \in V} \sum_{k=1}^{Q} (b_{ij}^k - b_{ij}^k) = \beta_t, \quad i \in V. \tag{5}
\]

\[
r_i^k \leq r_i^{k-1}, \quad i \in V_c, k \in \{2, \ldots, Q\}. \tag{6}
\]

\[
a_{ij}^k + b_{ij}^k \leq x_{ij}, \quad (i, j) \in E, k \in \{1, \ldots, Q\}. \tag{7}
\]

\[
a_{ij}^{k-1} + b_{ij}^{k-1} \leq a_{ij}^k + b_{ij}^k, \quad (i, j) \in E, k \in \{1, \ldots, Q\}. \tag{8}
\]

\[
\sum_{j \in V, j \neq i} a_{ij}^k - \sum_{j \in V, j \neq i} a_{ij}^k \leq r_i^k, \quad i \in V_c, k \in \{1, \ldots, Q\}. \tag{9}
\]

\[
\sum_{j \in V, j \neq i} a_{ij}^k - \sum_{j \in V, j \neq i} a_{ij}^k \leq r_i^k, \quad i \in V_c, k \in \{1, \ldots, Q\}. \tag{10}
\]

\[
\sum_{j \in V, j \neq i} b_{ij}^k - \sum_{j \in V, j \neq i} b_{ij}^k \leq r_i^k, \quad i \in V_c, k \in \{1, \ldots, Q\}. \tag{11}
\]
\[\sum_{j \in V, j \neq i} b_{ji}^k - \sum_{j \in V, j \neq i} b_{ij}^k \leq r_i^k, i \in V_c, k \in \{1, \ldots, Q\}. \tag{12}\]

\[v_i^k = \sum_{j \in V, j \neq i} (h_a a_i^k + h_b b_{ij}^k) r_i^k, i \in V_c, i \neq j, k \in \{1, \ldots, Q\}. \tag{13}\]

\[l_i \leq s_j, i \in V_c. \tag{14}\]

\[s_i + \sum_{k=1}^{Q} v_i^k \leq u_i, i \in V_c. \tag{15}\]

\[s_i \geq l_i, i \in V_c. \tag{16}\]

\[s_i + 2 \sum_{k=1}^{Q} v_i^k + h_b \beta_i - h_a \alpha_i + c_{ij} - M(1 - x_{ij}) \leq s_j, i \in V_c, j \in V_c, i \neq j. \tag{17}\]

\[u_i \geq 1 + (|V| - 2)x_{1i}, \forall i \in V, i > 1. \tag{18}\]

\[u_j \geq |V| - 1 - (|V| - 2)x_{ij}, \forall j \in V, j > 1. \tag{19}\]

\[u_j \geq u_i + x_{ij} - (|V| - 2)(1 - x_{ij}) + (|V| - 3)x_{ji}, \forall i, j \in V, j \neq 1. \tag{20}\]

\[x_{ij}, a_{ij}, b_{ij} \in \{0, 1\}, k \in \{1, \ldots, Q\}. \tag{21}\]

\[r_i^k \in \{0, 1\}, i \in V_c, k \in \{1, \ldots, Q\}. \tag{22}\]

\[v_i^k \geq 0, i \in V_c, k \in \{1, \ldots, Q\}. \tag{23}\]

\[s_i \geq 0, i \in V_c, k \in \{1, \ldots, Q\}. \tag{24}\]

Constraint (2) states that each customer is only visited exactly once. Constraint (3) ensures that the deviation of the total goods to be delivered and picked up by the vehicle between before and after a customer i is visited must be equal to the number of requests for delivery of goods by the customer i. Constraint (4) and (5) guarantee that the deviation of the total goods delivered and picked up by the vehicle after and before the customer i is visited must be equal to the number of requests for picking the goods by the customer i. Constraint (6) guarantees that at each customer location i, the goods in position k will not be involved in the handling process if the goods at position k - 1 are not involved in the handling process. Constraint (7) shows that each k position can only be occupied by one unit type of goods. Constraint (8) indicates that if position k - 1 is filled, position k must also be filled. Constraints (9) - (12) ensure that if there is no handling process at customer i’s location that involves goods in position k, the goods will occupy the same position as before the pick-up and delivery process at customer i’s location was carried out. Constraint (13) is a constraint for variable v_i^k to estimate the length of time for handling at customer i. This constraint also shows the assumption that the length of time for handling each unit of goods is not affected by its position in the vehicle. Constraints (14) - (16) indicate that the beginning of time for service to the customer i must be within the time window of the customer. This constraint is formulated with the assumption that services are said to have been completed at least after the goods to be sent to customer i have been unloaded from the vehicle. Constraint (17), if side (i,j) is the selected route, the beginning of time for service to the customer j must be greater than the total service time and travel time from i to j, with \[2 \sum_{k=1}^{Q} v_i^k + h_b \beta_i - h_a \alpha_i \] states the length of service time, whether it requires a customer or not, includes the process of loading type II goods belonging to customer i into the vehicle and unloading type I goods belonging to customer i from the vehicle. Constraints (18) - (20) are the sub tour elimination constraints that guarantee the connectedness of the solutions. Finally, constraints (21) - (24) are constraints of binary and nonnegative variables.

4. An Illustrative Example
The implementation of the model is carried out in the case of bicycle pick-up and delivery by a company that offers bicycle repair services as well as buying and selling new bicycles with pick-up and delivery service. Pick-up and delivery are carried out by a vehicle where all bicycle units are arranged in each position. The capacity of each vehicle is 15 bicycles so that the bicycles are arranged with the serial number position 1, 2, 3, ..., 15. In this case, the new bicycles or bicycles that have been repaired called as type I goods which want to be sent. Whereas, the type II goods or the goods to be taken are damaged
bicycles that want to be repaired. The data used for the implementation of the model is data from 15 bicycle shops around Bogor (1 as a depot and 14 as a customer). Travel time between shops is obtained through Google maps. The collected data are presented in Tables 1 and 2 below.

### Table 1. List of bike shops in Bogor

| Customer-\(i\) | Name of shop                        | Location                                      |
|----------------|-------------------------------------|-----------------------------------------------|
| 1              | Semeru Bike Shop                    | Dr. Sumeru St. No. 13, Central Bogor          |
| 2              | Toko Sepeda Focus                   | Merdeka St. No. 53, Central Bogor             |
| 3              | Rodalink Bogor                      | Siliwangi St. No. 72, Lawang Gintung          |
| 4              | Infinite Bike                       | Dramaga St. No. 3, Margajaya                  |
| 5              | Toko Sepeda Koto Jambak             | Pemda St. No. 12, Cibinong                    |
| 6              | Toko Sepeda Family                  | Cibuluh St. No. 293, North Bogor              |
| 7              | Bike Colony Terasutra Bogor         | Pajajaran St. No. 121, Baranangsiang         |
| 8              | Central Sepeda                      | Suryakencana St. No. 82, Gudang              |
| 9              | United Bike                         | Suryakencana St. No. 166, Gudang             |
| 10             | Toko Harapan Kencana                | Suryakencana St. No. 94, Gudang              |
| 11             | Bogor Mountain Biking               | Tangkuban Prahu St. No. 3, Babakan            |
| 12             | Bengkel Sepeda Berkah               | Dramaga St., Sindangbarang                    |
| 13             | Toko Sepeda Oeyand                  | Pemda Cibinong Karadenan, Cibinong            |
| 14             | Toko dan Bengkel Sepeda Kiki        | Kp. Kencana St. No. 9-68, Jaya               |
| 15             | Sinar Harapan Bogor                 | Suryakencana St. No. 68, Gudang              |

### Table 2. The travel time for each shop to each other in minutes

| \(i\) | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1     | 0  | 3  | 19 | 25 | 29 | 21 | 18 | 16 | 17 | 16 | 9  | 15 | 28 | 27 | 16 |
| 2     | 3  | 0  | 17 | 23 | 29 | 22 | 15 | 14 | 14 | 14 | 7  | 14 | 28 | 28 | 13 |
| 3     | 19 | 17 | 0  | 37 | 34 | 26 | 3  | 14 | 14 | 14 | 18 | 28 | 34 | 34 | 13 |
| 4     | 25 | 23 | 37 | 0  | 30 | 22 | 33 | 36 | 36 | 36 | 30 | 7  | 33 | 29 | 35 |
| 5     | 29 | 29 | 34 | 30 | 0  | 15 | 34 | 31 | 31 | 25 | 31 | 1  | 19 | 30 |
| 6     | 21 | 22 | 26 | 22 | 15 | 0  | 26 | 24 | 24 | 24 | 17 | 23 | 14 | 26 | 22 |
| 7     | 18 | 15 | 3  | 33 | 34 | 26 | 0  | 10 | 11 | 11 | 15 | 30 | 34 | 35 | 8  |
| 8     | 16 | 14 | 14 | 36 | 31 | 24 | 10 | 0  | 1  | 1  | 14 | 27 | 37 | 38 | 17 |
| 9     | 17 | 14 | 14 | 36 | 31 | 24 | 11 | 1  | 0  | 1  | 14 | 26 | 37 | 38 | 17 |
| 10    | 16 | 14 | 14 | 36 | 31 | 24 | 11 | 1  | 1  | 0  | 13 | 26 | 36 | 38 | 17 |
| 11    | 9  | 7  | 18 | 30 | 25 | 17 | 15 | 14 | 14 | 13 | 0  | 27 | 27 | 29 | 8  |
| 12    | 15 | 14 | 28 | 7  | 31 | 23 | 30 | 27 | 26 | 26 | 27 | 0  | 31 | 23 | 24 |
| 13    | 28 | 28 | 34 | 33 | 1  | 14 | 34 | 37 | 37 | 36 | 27 | 31 | 0  | 21 | 26 |
| 14    | 27 | 28 | 34 | 29 | 19 | 26 | 35 | 38 | 38 | 38 | 38 | 29 | 23 | 21 | 0  |
| 15    | 16 | 13 | 13 | 35 | 30 | 22 | 8  | 17 | 17 | 17 | 8  | 24 | 26 | 31 | 0  |

In this case, \(i=1\) is a depot, in other words, the bicycle pick-up and delivery process starts and ends at the Semeru Bike Shop. The hypothetical data related to the number of requests for delivery and pickup of bicycles and time windows of each store are presented in Table 3.
Before the pick-up and delivery process is carried out, it is assumed that the company already knows the demand for bicycle delivery and pickup from each shop. This is necessary so that the bicycles can be arranged according to the visiting costumers' order before the vehicle leaves the depot. It is also assumed that the time required to load and unload each bicycle is the same, whether the bicycle is damaged or new. In this case, we use $h_a = h_b = 1$ in minutes. In summary, the solutions obtained are presented in Table 4.

| Customer (i) | Name of shop          | Number of new bicycles (unit) | Number of damaged bicycles (unit) | Time Windows   |
|--------------|-----------------------|------------------------------|----------------------------------|----------------|
| 1            | Semeru Bike Shop      | -                            | -                                | 06.00-22.00    |
| (depot)      |                       |                              |                                  |                |
| 2            | Sepeda Focus          | 2                            | 2                                | 06.00-10.00    |
| 3            | Rodalink Bogor        | 1                            | 2                                | 11.00-15.00    |
| 4            | Infinite Bike         | 1                            | 2                                | 08.00-10.00    |
| 5            | Koto Jambak           | 2                            | 0                                | 07.00-12.00    |
| 6            | Sepeda Family         | 1                            | 2                                | 12.00-16.00    |
| 7            | Bike Colony           | 1                            | 0                                | 09.00-14.00    |
| 8            | Central Sepeda        | 3                            | 0                                | 13.00-16.00    |
| 9            | United Bike           | 0                            | 1                                | 16.00-17.00    |
| 10           | Harapan Kencana       | 1                            | 2                                | 08.00-09.00    |
| 11           | Mountain Biking       | 0                            | 1                                | 16.00-20.00    |
| 12           | Sepeda Berkah         | 1                            | 1                                | 13.00-17.00    |
| 13           | Sepeda Oeyand         | 1                            | 0                                | 08.00-12.00    |
| 14           | Sepeda Kiki Jaya      | 0                            | 1                                | 12.00-14.00    |
| 15           | Sinar Harapan         | 1                            | 1                                | 19.00-22.00    |
Based on Table 4, in this case, the vehicle route for bicycle pick-up and delivery starts from Semeru Bike Shop as a depot, then to Focus Bike Shop (customer 2) as the first customer visited, then ends at Bogor Mountain Biking (customer 11) before finally returning to Semeru Bike Shop. It can be seen that the time window constraints for all bicycle shops are met with the first service being carried out at the Focus Bike Shop at 06.00. This means that the vehicle must depart from Semeru Bike Shop at the latest 05.57 so that the service can start on time because the travel time from Semeru Bike Shop to Focus Bike Shop is about 3 minutes. It is assumed that the initial time windows of the depot are the earliest time the vehicle can perform service. Then, look at customer 9 that is the United Bike Shop. Service starts at 17.00 which is the latest time that United Bike Stores can be served. In this case, the service can still be carried out because United Bike does not have demand for the delivery of new bicycles but only has the demand for pickup a damaged bicycle. This is because it is assumed that the process of loading each damaged bicycle does not require a customer at the location and this applies to all customers.

| Customer (i) | Route  | Travel Time (minute) | The Beginning of Time Service | Length of Service (minute) | Time Windows       |
|--------------|--------|----------------------|-------------------------------|-----------------------------|--------------------|
| 2            | 1-2    | 3                    | 06.00                         | 6                           | 06.00-10.00        |
| 13           | 2-13   | 28                   | 08.00                         | 1                           | 08.00-12.00        |
| 5            | 13-5   | 1                    | 08.02                         | 8                           | 07.00-12.00        |
| 10           | 5-10   | 31                   | 08.41                         | 3                           | 08.00-09.00        |
| 4            | 10-4   | 36                   | 09.48                         | 1                           | 08.00-10.00        |
| 14           | 4-14   | 29                   | 12.00                         | 1                           | 12.00-14.00        |
| 12           | 14-12  | 23                   | 13.00                         | 6                           | 13.00-17.00        |
| 7            | 12-7   | 30                   | 13.59                         | 1                           | 09.00-14.00        |
| 3            | 7-3    | 3                    | 14.20                         | 29                          | 11.00-15.00        |
| 8            | 3-8    | 14                   | 15.31                         | 3                           | 13.00-16.00        |
| 6            | 8-6    | 24                   | 15.58                         | 5                           | 12.00-16.00        |
| 9            | 6-9    | 24                   | 17.00                         | 1                           | 16.00-17.00        |
| 15           | 9-15   | 17                   | 19.00                         | 4                           | 19.00-22.00        |
| 11           | 15-11  | 8                    | 19.30                         | 1                           | 16.00-20.00        |
| 1            | 11-1   | 9                    | -                             | -                           | 06.00-22.00        |

Table 4. The solution of the study case
Table 5. Overview of policy solutions for the arrangement of goods (bicycles)

| Customer | Route   | Position in the vehicle | Demand |
|----------|---------|-------------------------|--------|
| 2        | 1-2     |                         |        |
| 13       | 2-13    |                         |        |
| 5        | 13-5    |                         |        |
| 10       | 5-10    |                         |        |
| 4        | 10-4    |                         |        |
| 14       | 4-14    |                         |        |
| 12       | 14-12   |                         |        |
| 7        | 12-7    |                         |        |
| 3        | 7-3     |                         |        |
Table 5 provides a detailed description of the policies for arranging bicycles in vehicles. It is known that the Focus Bike Shop (customer 2) has requested 2 new bicycle deliveries and 2 damaged bicycle pickup units. This means that the company needs to load 2 damaged bicycles to the vehicle and unload 2 new bicycles from the vehicle at the Focus Bike Shop location. Considering that all the bikes in the vehicle have been arranged according to the order of the intended customer, the 2 new bicycles requested by Focus Bike Shop will be in the rear position so that they can be easily unloaded. The next policy of arranging the items so that the next service can be carried out efficiently is to arrange 2 damaged bicycles belonging to the Focus Bike Shop in positions 2 and 3. Whereas, position 1 filled by a new bicycle requested by Oeyand Bike Shop (customer 13) as the next customer who will be visited. As a result, implementation of this policy requires an additional 2 minutes of handling time, which is 1 minute to unload 1 unit of the bicycle that does not belonging to the requested by Focus Bike Shop and 1 minute to raise it back to the vehicle. However, no additional handling time is required when servicing the Oeyand Bike Shop whose bicycle has been placed in the rear so that it can be immediately unloaded.
In contrast to the service at the Koto Jambak Bike Shop (customer 5), unloading 2 new bicycles of this shop was obstructed by 2 damaged bicycles belonging to the Oeyand Bike Shop, thus require additional handling. This handling consists of unloading that 2 damaged bicycles so that the 2 new bicycles requested by the Koto Jambak Bike Shop could be unloaded. Then, it is also necessary to unload 1 new bicycle unit requested by Toko Harapan Kencana (customer 10) which is in position 4. It’s because of the 2 damaged bicycles belonging to the Oeyand Bike Shop will be placed in positions 5 and 6. As a result, 1 new bicycle unit requested by Toko Harapan Kencana will be in the rearmost position (in this condition in position 4). Thus, when the vehicle arrives at the location of the Harapan Kencana Shop, the company can immediately drop it off so that no additional handling is needed at this location. This principle continues until service is carried out to all shops.

However, let see when the vehicle arrives at Rodalink Bogor (customer 3). The longest additional handling time is at this location. The optimal policy recommended for service efficiency to the next customer is to arrange all new bicycle units in the rear position. The additional handling time required is 26 minutes. This time is needed to unload 8 damaged bicycles and 5 new bicycles that are left in the vehicle after 1 new bicycle belonging to Rodalink Bogor is unloaded. Then, the 8 damaged bicycles and 2 damaged bicycles belonging to Rodalink Bogor are rearranged in the front position (position 6 to position 16). Meanwhile, 5 new bicycle units that were previously unloaded are arranged in five rear positions (position 1 to position 5). Applying this policy at the Rodalink Bogor location generates efficient service at the other shops, Central Bicycles to Bogor Mountain Biking. The optimal results obtained indicate that the bicycle pick-up and delivery process for all shops requires total travel time and additional handling time of 334 minutes.

5. Conclusion

Vehicle route problems and handling time of pickup and delivery with time windows using one vehicle that has single access can be modeled as the Integer Linear Programming (ILP). The problem modeling as TSPPDH-TW can be implemented in companies which pick up two different types of goods. As an example, it’s implemented in the company which pick up damaged bicycles (which want to be repaired) and delivery of new bikes (including damaged bikes that have been repaired). The solution of the model provides route recommendations and optimal item arrangement policies in the vehicle to minimize travel time and additional handling time required during service. In this case, the minimum total travel time and additional handling time for 15 customers is 334 minutes.

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