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Intelligent Warehouse Picking Improvement Model for e-Logistics Warehouse Using Single Picker Routing Problem and Wave Picking

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***Abstract*— The development and use of technological innovations have changed people's behavior from an industrial society to an information society. It can be seen in the increase in people's consumption patterns from trading through physical stores (offline) to trading through electronic systems, often referred to as e-commerce. Logistics services are distribution actors in the downstream line which are tasked with delivering products from the fulfillment center from e-commerce to the end customer. The uncertainty of the number of requests is the biggest challenge for logistics service players. The growth of e-commerce has also led to an increase in sales volume in e-commerce which has given rise to a new generation of warehouses that are specifically tailored to the special needs of online retailers who directly serve the demands of end-customers in the business-to-consumer (B2C) segment. Traditional warehousing systems cannot handle orders with the characteristics of many transactions but smaller sizes. In addition, warehouses that handle e-commerce are also required to have a fast process in the warehouse because shipments must be made on the same day. In this study, the author aims to perform calculations to find the optimal order picking time in the warehouse, so orders in e-commerce can be processed faster by comparing the picking process time using ordinary Single Picker Routing Problem (SPRP) and combined with the concept of wave picking using Genetic Algorithm (GA). Based on a theoretical study in this paper, the combination between SPRP and wave picking can reduce 42.28% picking time.**

***Keywords*— E-commerce; intelligent warehouse; order picking; wave picking; Single Picker Routing Problem (SPRP); logistic.**

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I. INTRODUCTION

The development and use of technological innovations have changed people's behavior from an industrial society to an information society. These changes can be seen in the increase in people's consumption patterns, from trading through physical stores (offline) to trading through electronic systems, often referred to as e-commerce [1]. The data shows that the number of daily online transactions increased from 3.1 million to 4.8 million. The value of the E-commerce market in Indonesia is expected to grow in the range of USD $55 - $65 billion by 2022 [2].

E-commerce has brought new challenges, as well as opportunities in logistics management. Logistics services are distribution actors in the downstream line which are tasked with delivering products from the fulfillment center from e-commerce to the end customer. Logistics services are required to be able to fulfill requests from consumers in accordance with the service level agreement (SLA). The uncertainty of the number of requests is the biggest challenge for logistics service players [1]. Logistics plays a very important role in increasing the effectiveness and efficiency of the flow of materials and information to meet consumer needs. Thus, logistics performance is also important in e-commerce [3]. The impact of the current growth of e-commerce has resulted in a rapid increase in orders, which has put retailers under pressure to manage stock and provide efficient delivery in terms of speed, price, service, and quality [4]. The growth of e-commerce has also led to an increase in sales volume in e-commerce which has given rise to a new generation of warehouses that are specifically tailored to the special needs of online retailers who directly serve the demands of end-customers in the business-to-consumer (B2C) segment. Traditional warehousing systems will not be able to handle orders that have the characteristics of many transactions but with a smaller size. In addition, warehouses that handle e-commerce are also required to have a fast process in the warehouse because shipments must be made on the same day.

Several types of order picking are suitable for e-commerce business processes in warehouses based on strategies and policies, including batch picking, wave picking, and cart picking [5], [6]. In this study, the author aims to perform calculations to find the optimal order picking time so that orders in e-commerce can be processed faster by comparing the picking process time using the Single picker routing problem (SPRP) and Single picker routing problem (SPRP) with the concept of wave picking using Genetic Algorithm (GA).

II. Materials and Method

A. *E-commerce*

E-commerce is defined as a commercial transaction in the form of the process of buying, selling, or trading data, goods, or services through or using digital technology to meet consumer demand by streamlining ordering and shipping costs [7], [8], [9]. E-commerce is classified into six types of models [10], namely: (1) Business-to-Consumer (B2C), (2) Business-to-Business (B2B), (3) Consumer-to-Consumer (C2C), (4) Mobile e-commerce (m-commerce), (5) Social e-commerce, (6) Local e-commerce. This research will discuss the fulfillment of consumer demand in B2C e-Commerce. In the demand fulfillment process, B2C e-commerce has characteristics consisting of (1) customer characteristics, (2) demand characteristics, and (3) implications of customer and demand characteristics [11]. Demand criteria for B2C e-commerce are the high number of order transactions, but the transaction size tends to be smaller. It can even be one customer, one product per order. Another characteristic of demand is that sometimes customer demand is seasonal and demand fluctuations. The wide customer segment that makes it difficult to deliver products as quickly as possible.

B. *Logistics*

The logistics concept consists of logistics operations and logistics coordination. Logistics operations are about the management of moving and storing the company's materials and finished products [12], [13]. Logistics operations can be divided into three categories: physical distribution management, material management, and inventory transfer within the company [14].

Figure 1 describes the general operations and activities involved in logistics. The figure also explains the differences in activities and operations for local zones and overseas zones. These logistics operations and activities start from actors in the shipping department (Shippers) to end at the destination point (customers). Material (product) or information transactions occur in these operations and activities. The figure describes the main activities in logistics, including transportation, processing, storage, consolidation, packaging, labeling, kitting, assembly, and custom [15].

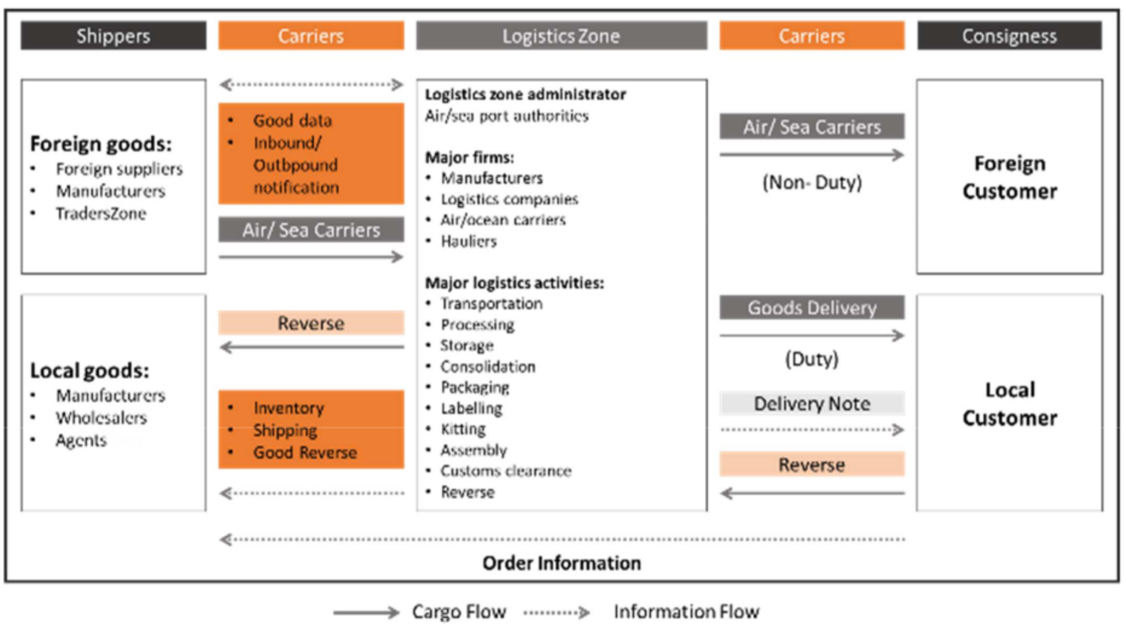

Fig. 1 Main operations and logistics activities [15]

C. *The Relationship between e-commerce and Logistics*

The dynamic development of e-commerce forces companies to develop from various sides, especially the use of logistics in distributing products from retailers or e-commerce companies to consumers [16], [17]. In e-commerce, there are four forms of logistics organization, which show the scope of the processes that can be carried out, namely: (1) Insourcing logistics, (2) Dropshipping [18], [2]. (3) Fulfillment service [19]. (4) One-stop e-commerce [18]. Integration is needed to build links between e-commerce and logistics activities to meet customer demands, especially for

B2C e-commerce. The relationship between e-commerce and logistics activities can also be seen in Figure 2, which shows the usefulness of logistics in the e-commerce function. Logistics services are useful for e-commerce as a logistics process management manager (flow of goods or information), storage, inventory availability, and transportation of goods to consumers following the previous discussion of logistics operations and activities. However, the use of these logistics must also meet the character that exists in e-commerce. Under the discussion of this paper, the storage (warehouse) must-have criteria in the form of (1) product range, (2) operational speed in the warehouse, (3) attractive price offers for storing products in the warehouse [20].

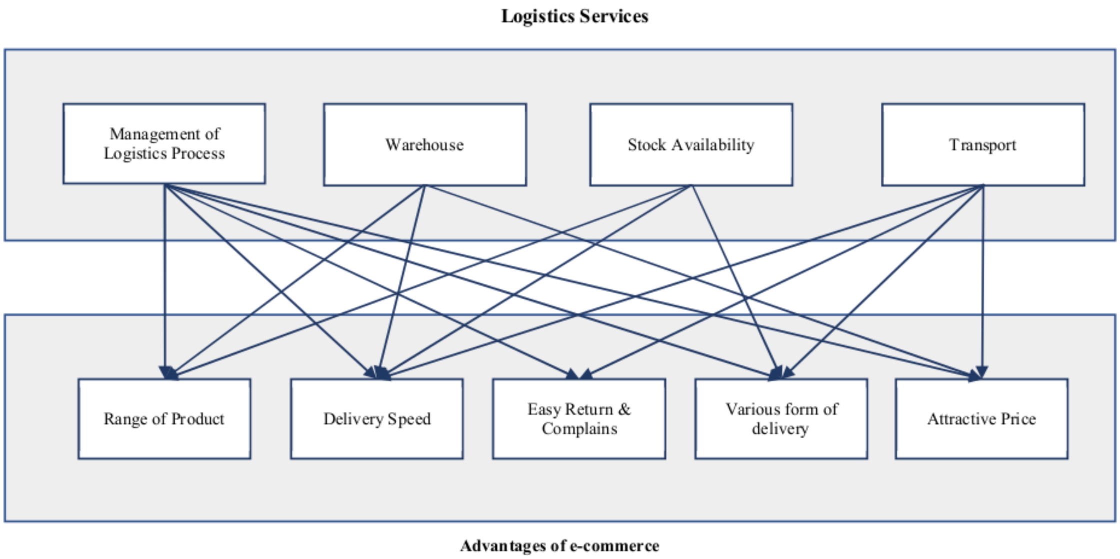

Fig. 2 The Relationship of E-Commerce and Logistics [20]

This product range consists of quite complex criteria because this product range can be based on the availability of space used as storage media and the diversity of product types. This diversity of product types is since online stores will offer more types of products than online stores. Product diversity is important because it significantly affects logistics problems [21]. Operational speed in the warehouse is one of the challenges that e-commerce warehouses have in handling and delivering online orders with many transactions and small order sizes. This causes the optimal policy for traditional manual warehouses may not be suitable for e-commerce warehouses [22]. So, we need effective activities in handling e-commerce warehouses, so that product handling in e-commerce warehouses becomes faster and more precise. Further explanation will be provided in the next sub-chapter regarding the e-commerce warehouse. In addition to the optimal operating speed in the warehouse, the warehouse must consider the logistics costs in the warehouse. However, this study will not discuss logistics costs or warehouse costs.

D. Warehouse e-commerce

The warehouse is a facility to store goods as a buffer for requests so that requests can be fulfilled. In addition, the warehouse also functions as a point of delivery of goods where all goods are received and shipped effectively and efficiently [23], [24]. In general, the activities and processes in the warehouse that function to increase the value of the functions and benefits of the warehouse consist of: (1) Receiving, (2) Put away, (3) Order Picking, (4) Packaging, (5) Sortation, (6) Unitizing and Shipping [25]. Meanwhile, the processes and activities in e-fulfillment consist of (1) slotting (storage), (2) picking, (3) sorting, (4) packaging (5) delivery processes [11]. In conventional warehouses still use the traditional warehouse arrangement, namely, the picker takes the product to the SKU storage rack successively according to the requested order. Traditional warehouse arrangements are considered less productive, as the picker moves from one shelf to another and returns to each order's product collection point [26]. Even this traditional warehouse arrangement is not suitable if applied to warehouses that handle e-commerce sales. This is due to the increasing volume of e-commerce sales, so it is necessary to create a new generation of warehouses specifically tailored to e-commerce companies' needs to handle end customer requests directly, which can be called the B2C segment [26], [24]. The warehouse requirements used to handle the B2C segment are as follows: (1) Small order, (2) Large assortment, (3) Tight schedule, (4) Varying workloads [26].

E. Methodological Design

To conduct this research, we use some methodological approaches to prove whether modeling in B2B warehouses can be applied to B2C warehouses: (A) Single Routing Problem, (B) Scheduling; (C) Wave picking, (D) Batch Order Picking, and (E) Solving with Genetic Algorithm (GA).

1) Single Picker Routing Problem: Single picker routing problem (SPRP) is the application of the shortest routing method in the warehouse to retrieve products ordered by customers and stored in certain storage locations in the warehouse [27], [28], [29], [30]. The purpose of the Single picker routing problem (SPRP) is to determine the path with the least cost that starts and ends at the same point when collecting all the stock-keeping units (SKUs) contained in the pick list from the storage locations in the warehouse. The single picker routing problem uses a calculation basis on the Traveling Salesman Problem method by considering several additional criteria [27] such as (1) Number of pickers (also can be set as a parameter); (2) Warehouse racking specifications; (3) Distance matrix between slots; (4) Warehouse Layouts.

Before determining the route for picking the product using the Single Picker Routing Problem, it is recommended to repair the warehouse slotting first so that the product is stored in the right location in the warehouse. Slotting process, using the fastest picking (dropping) time comparison calculation. This process is carried out after determining the number of items stored on the shelves for each SKU's. The calculation of the comparison of picking (dropping) time is used to speed up the dropping process in picking activities.

Four variables are used to calculate the picking (dropping) time: horizontal travel time, vertical travel time, picking time for each level, and double handling time. The horizontal travel time is obtained from calculating the distance by the rectilinear method from the location where the material handling equipment is stored, divided by the horizontal travel speed of the material handling equipment. Vertical travel time is obtained from calculating the vertical distance for each level, divided by the lifting speed of material handling specifications. The picking time of each level is obtained from the observation of cycle time, then added with an adjustment factor and an allowance factor (standard time).

2) Scheduling: Scheduling is used to carry out the process of assigning a resource to carry out the process to achieve a certain goal [31], [32]. Single Picker Routing Problem is closely related to scheduling, especially to scheduling resources for picking. The scheduling model used in Single Picker Routing Problem is job shop scheduling. Job shop scheduling is characterized by the organization of similar equipment by function. As jobs flow from one workstation to another, different types of operations are performed in each workstation or department [31], and the work may follow a similar or different path of operation. Job shop scheduling can be implemented in many research fields, such as production scheduling, railway scheduling, project management, etc.

3) Wave Picking: We also consider the wave picking method to conduct this research. Wave picking is a pick-up system usually used if the same destination point (such as departure at a certain time with a certain operator) is sent simultaneously to several warehouse areas [33]. Basically, there are two criteria for order batching: proximity to pick-up locations and time window. Proximity determination minimizes travel time, while time window stacking optimizes due date performance. Wave picking is a method of picking of several orders carried out simultaneously in one Wave. The order picker picks up one batch, and all order pickers start simultaneously. Wave picking is applied when multiple order pickers simultaneously handle a larger set of orders and the response time for the complete set is important [34].

4) Batch Order Picking: Order batching is a method of grouping a set of orders into several subsets, each of which can be retrieved in a single picking tour [35], [36]. The order batching problem is an NP-hard problem [37]. We use the model Single Picker Routing Problem [27] and Integrated Order Batching [37]. Integrated Order Batching is a mathematical model for solving order picking problems in the warehouse. The developed model aims to minimize the delay in picking time which is fatal to the distribution chain. The model setting for Integrated Order Batching:

Sets	
B	: Set of all feasible batches, B = {1,...,m}
O	: Set CO, O = {1,…,n}
L	: Set storage location, L = {1,…,g}
K	: Set the batch scheduling position, K = {1,…,m }
Index	
b	: batch index, b ∈ B
o	: CO index, o ∈ O
i,j	: storage location indicator, i, j ∈ L
k	: batch index, k ∈ K
Parameter	
C	: capacity of pick-up basket
wo	: capacity utility of demand (customer order)
dij	: time between locations i and j
S	: subset of storage locations binary indicator that states whether ordered items are retrieved from storage location *i* (s_{io} = 1) or not (s_{io} = 0)
eo	: due date (maximum picking time allowed)
G	: large (positive) number
Decision Variable	
Xbo	: binary decision equal to 1 if and only if order *o* is scheduled in batch *b*
Ybij	: binary decision equal to 1 if and only if location *i* is visited just before location *j* in batch *b*
Zbi	: binary decision equal to 1 if and only if location *i* is visited in batch *b*
Zbj	: binary decision equal to 1 if and only if location *j* is visited in batch *b*
Ubk	: binary decision equal to 1 if and only if batch *b* is scheduled at position *k*
Vok	: binary decision equal to 1 if and only if order *o* is scheduled on a batch that is at position *k*
Mk	: completion time of the batch at position *k*
Tok	: time delay of order o if placed in batch in position *k*

Mathematical model is adopted from previous research [37]:

Objective function

Minimize

$$\sum_{o \in O}\sum_{k \in K} T\,ok \qquad (1)$$

Model constrains

$$\sum_{i \in L, j \neq i} Ybij = Zbi \qquad \forall b \in B, i, \in L \qquad (2)$$

$$\sum_{i \in S, j \in L \setminus S} Ybij \geq Zbi \qquad \forall b \in B, S \subset \qquad (3)$$

$$\sum_{b \in B} Zbi \leq \sum_{O \in 0} Sio \qquad \forall i \in L \tag{4}$$

$$\sum_{b \in B} Xbo = 1 \qquad \forall o \in O \tag{5}$$

$$\Sigma_{o \in 0} Wo \ \times Xbo \leq C \qquad \forall b \in B \tag{6}$$

$$\sum_{b \in B} Ubk \leq 1 \qquad \forall k \in K \tag{7}$$

$$Mk - 1 + \sum_{b \in B} \left(Ubk \sum_{i \neq j \in L} (dij\ Ybij) \right) \leq Mk \qquad \forall k \in K \backslash \{1\} \tag{8}$$

$$\sum_{b \in B} \left(Ubk \sum_{i \neq j \in L} (dij \ \times \ Ybij) \right) \leq Mk \qquad \forall k = 1 \tag{9}$$

$$Mk - Tok \leq eo + G(1 - Vok) \quad \forall o \in O, K \in k \tag{10}$$

$$Xbo = \sum_{k \in K} Ubk\ Vok \quad \forall b \in B, o \in O \tag{11}$$

$$Xbo, Ybij, Zbi, Ubk, Vok, \in \{0,1\} \ \forall b \in B, i \in L, o \in O, k \in K \tag{12}$$

$$Mk, Tok \geq 0 \ \forall o \in O, k \in K \tag{13}$$

5) Solving Algorithm: Due to the complexity of the model, we use Genetic Algorithm (GA) to run order picking batching. We also tested this model to execute large number of customer order which come from e-commerce platforms. We use 20% of mutation rate and 80% of crossover rate. Figure 3 shows the steps of problem-solving using GA.

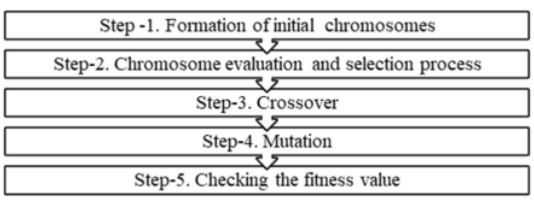

Fig. 3 The steps of problem-solving using GA [38]

Step -1. The initial chromosomal formation is used as input data from the genetic algorithm [38]. Chromosomes were obtained by random generator technique. The random generator technique will generate a random number using a certain technique that is used as the initial chromosome. A random generator will sort the existing orders as the initial chromosome. Once obtained, the orders will be scheduled into batches based on the order created. Determination of orders in each batch is limited to the maximum capacity of the pick-up basket per batch. After the orders that have that order are entered into the batch, the route of each batch will be solved by the Travel Salesman Problem (TSP). In TSP, sales start from the starting point and must return to that starting point. During the journey, the salesperson may only visit each city or location once. Each of these batches will have a completion time [39].

Step-2. After the chromosomes are formed, an evaluation will be carried out on the fitness values on each chromosome [38]. The evaluation stage will carry out the process of eliminating chromosomes that have a lower fitness value. Chromosomes with higher fitness have a higher chance of survival, so they will not be eliminated. This stage aims to obtain good parents. Based on the theory, good parents will produce a good child. The fitness value in this study is the time delay of the order when it is in a certain batch. Each batch that is formed has a completion time, and the batch has a completion position for that batch. Orders that enter a certain batch will be seen whether the order is delayed.

Step-3. The crossover process requires two chromosomes to be used as parents [38]. This process is useful for obtaining offspring that allow for better fitness values. The crossover process in this study uses a two-point crossover, which means that the two parents will exchange information that has been separated at two-point randomly obtained.

Step-4. Mutation process is done by swapping individuals on chromosomes [38]. The mutation process in this study was carried out by swap-based mutation, which means swapping two individuals in the chromosome randomly. This process will produce a new chromosome which is expected to have a better fitness value.

Step-5. The fitness value to get a solution to this problem is the total time delay in the order [38]. Each chromosome will be checked against its fitness value. The chromosome which has the lowest delay time value will be determined as the best population, which will be declared as the result of the calculation.

6) Modeling Framework: Based on this modeling framework, it shows the operational activities in Warehouse X. Starting from inbound activity to outbound activity. The inbound activity begins with the process of receiving goods, checking goods, labeling, and other inbound activities carried out in the goods receiving area. Storage activities consist of put way activities, and picking activities carried out in the storage area. Meanwhile, outbound activities consist of moving goods from the storage area to the staging area, checking for outgoing goods, and outbound docking and shipping. Activity details can be seen in Figure 4. Parameters used include existing warehouse layout, the time between picking locations, working hours, customer order data, order index, batch index, number of batches, picking capacity, and order weight.

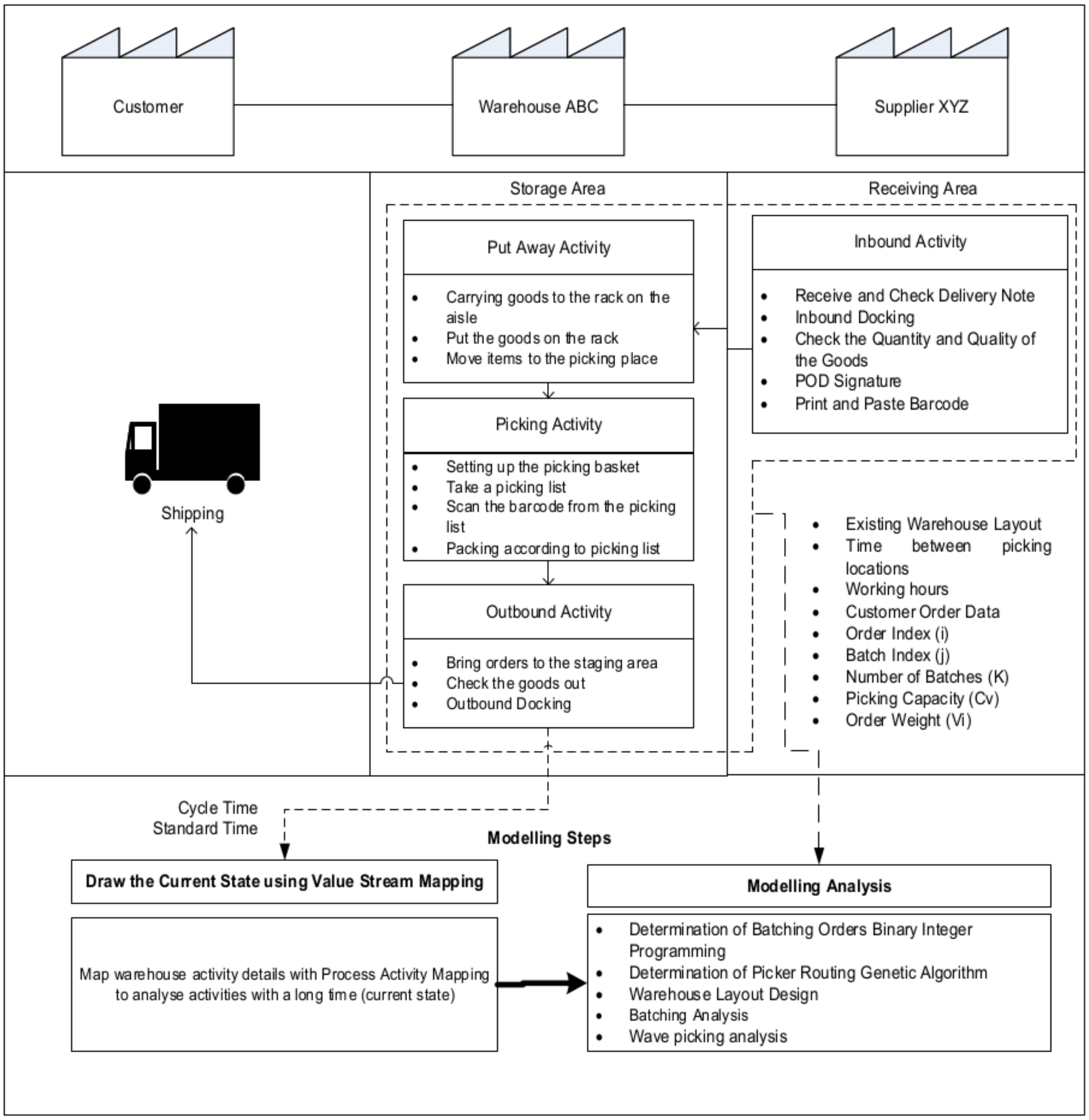

Fig. 4 Modelling Framework

III. Results and Discussion

The modeling step has been described in Figure 4. This modeling step contains the stages of analysis carried out in this study. The steps taken include (1) Value Stream Mapping (VSM) and (2) Modelling Analysis.

A. *Value Stream Mapping (VSM)*

Value Stream Mapping (VSM) is to describe a map of the current state by analyzing the flow of material in its current condition, which will provide information about activities that add and do not add value in the warehouse [40], [41]. VSM describes the details of each warehouse activity by classifying these activities into several categories, operation, transportation, storage, inspection, and delay activities, using the current method SPRP. Based on the improvements that have been made to several activities, the total lead time in the warehouse is 401.28 seconds for processing one pallet. From the lead time, there is a value-added time of 312.81 seconds, or around 77.593%. A more detailed explanation can be seen in Figure 5.

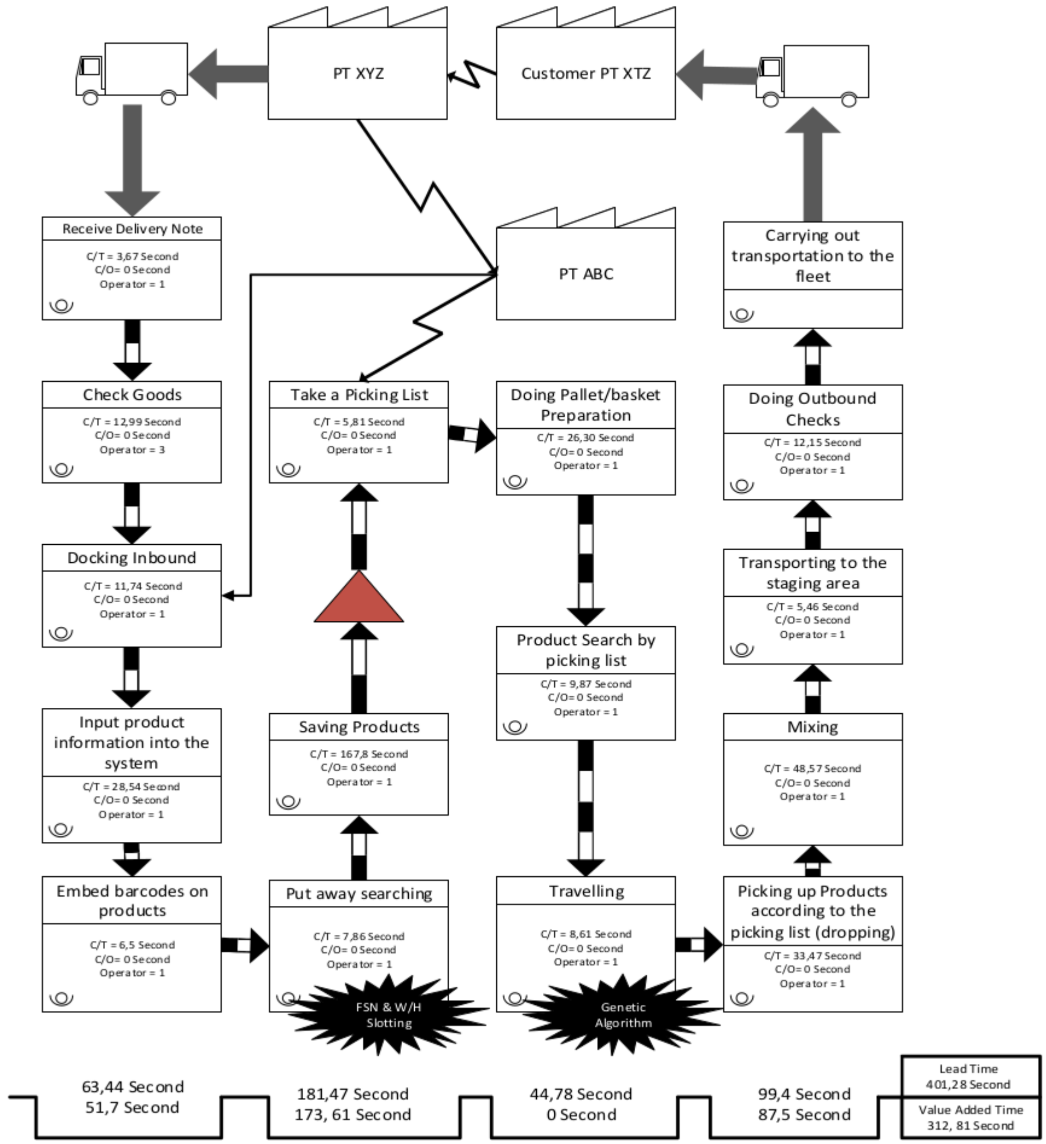

Fig. 5 Value Stream Mapping (VSM) using SPRP Model

B. Modeling Analysis

After conducting VSM analysis by mapping warehouse activities, the next step is to analyze the model based on the previously designed model to compare the results of solving GA on the picking process using the SPRP model and merging the SPRP model with the Wave Picking concept. The previous model that was designed was then solved using GA. The analysis is carried out by analyzing the number of picking times for each batch order. The fulfillment of each batch of orders is very important because every batch of orders has a schedule for fulfillment. One batch order can consist of different SKUs and quantities.

Figure 6 shows the results of the calculation analysis using GA for picking activities using the SPRP model for each batch order. When viewed from the analyzed VSM, it shows that this model considers product allocation and slotting. In picking, there is a decision making to take products in each batch, such as the order in which the products are taken according to the picking list. If the analysis is done using solving GA, the average picking time is 149 minutes.

The importance of applying the SPRP and wave picking models is to perform slotting and allocation in the warehouse. After doing optimization in the warehouse, then apply the model for the concept of wave picking, where the product releases slowly according to the waves. It is known that the average picking value for setting orders is 86 minutes, see Figure 7.

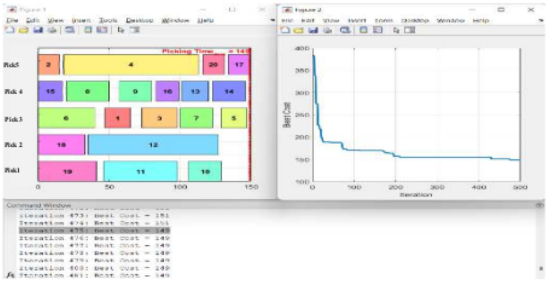

Fig. 6 Analysis Result using SPRP Model

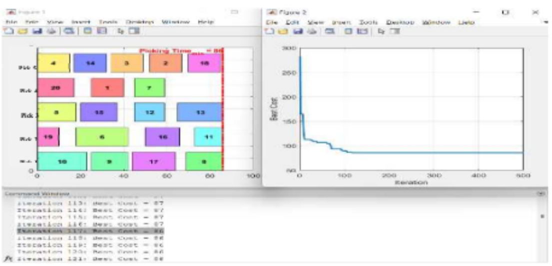

Fig. 7 Analysis Result using SPRP and Wave Picking

IV. CONCLUSION

E-commerce can be processed faster by comparing the picking process time using the Single picker routing problem (SPRP). The concepts Based on this modeling framework show the operational activities in Warehouse X. Starting from inbound activity to outbound activity. The inbound activity begins with the process of receiving goods, checking goods, labeling, and other inbound activities carried out in the goods receiving area. Storage activities consist of put way activities, and picking activities carried out in the storage area. Meanwhile, outbound activities consist of moving goods from the storage area to the staging area, checking for outgoing goods, and outbound docking and shipping. Activity details can be seen in Figure 4.

Parameters used include existing warehouse layout, the time between picking locations, working hours, customer order data, order index, batch index, number of batches, picking capacity, and order weight. Genetic Algorithm (GA) calculation results show: (1) The calculation results of the average picking time for each batch using the Single picker routing problem (SPRP) model with GA is 149 minutes. (2) The calculation results of the average picking time for each batch using the Single picker routing problem (SPRP) model with the concept of wave picking and solving with GA, which is 86 minutes (decreased by 42.28%). From the results of this calculation, it can be concluded that for optimal order picking time in e-commerce warehouses, we can use the Single picker routing problem (SPRP) model for the traveling process in the warehouse and then use the concept of wave picking.

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