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Order Picking System Simulation Model Considering Picking Method and Picker Route to Improve Warehouse Performance

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***Abstract*— This paper presents a comprehensive study to improve warehouse performance by optimizing the order-picking process. The authors developed a simulation model to analyze the impact of various order-picking methods and tour routes on the order-picking time. The study reveals that the current order-picking system is plagued with high unfinished picklists and prolonged waiting times, negatively impacting warehouse performance. To address these issues, the authors propose 12 improvement scenarios that combine different tour routes, picking methods, and picker numbers. The findings suggest that transitioning to a pick-by-voice picking method is more effective in reducing incomplete picklists than increasing the number of pickers. The most efficient scenario is Scenario 8, which incorporates the mid-point route, pick-by-voice picking method, and two pickers. The paper concludes that the choice of the order-picking method significantly influences warehouse performance, thereby encouraging future research to explore other order-picking methods and delve deeper into the process.**

Keywords*— *simulation, order picking, warehouse

I. Introduction

Warehouses have a significant role in a company's supply chain system, one of which is a liaison between producers and customers [1]. In recent years, warehouses have experienced significant changes in operating policies and technology[2, 3]. According to Boysen, et al. [4], the growing demand for a broader range and greater quantity of stored products poses challenges to warehouse operations and technology policies. This increased demand results from sustained trends, the rise of e-commerce, and customer expectations for quicker delivery times. On the other hand, according to Winkelhaus and Grosse [5], companies must also guarantee high service quality. In facing these developments, companies must ensure high efficiency in all warehouse and space utilization core processes. According to Engels, et al. [6], analyzing and enhancing warehouse design is crucial, given the increasing significance of warehouses within the supply chain. Warehouses are an indispensable element of every supply chain and offer a subject for research exploration [7].

Order picking is the most crucial main activity in a warehouse system so it can be used as the primary illustration of warehouse performance. Within warehouse engineering and management, order picking is a manpower-intensive task, constituting around 55% of the overall operational expenses in a warehouse [4, 7]. Order picking takes products from storage facilities in a warehouse to fulfil customer orders [6, 8]. According to Loske, et al. [9], The predominant system for warehouse operations remains manual order picking, underscoring the indispensable role of human workers in these processes. Careful design and control of the order-picking system are necessary to minimize the processing time while maximizing the use of space, equipment, and labour [10, 11].

Improved warehouse performance by optimizing manual order-picking processes that can be scaled up by zoning, batching, routing, and determining the most appropriate storage locations to ensure efficient order-picking operations [12]. The solution to this decision problem usually aims to reduce unproductive time, such as time spent moving between storage shelves, which often reaches up to 50% of the total order-picking time [13]. According to Chan and Chan [10], several factors influence order-picking activities, including methods of picking goods and routes of picking up goods, size and layout of storage systems, material handling systems, product characteristics, demand trends, turnover rates, and space requirements. It is difficult for researchers to consider all factors simultaneously and consistently, especially as the system under study is susceptible to change. So, one possible method to overcome this problem is by simulation.

Generally, order picking is done manually or traditionally with operators walking along the warehouse aisles and is usually referred to as person-to-goods systems [14-16]. In picking up goods, a picker can obtain information using various methods, for example, pick-by paper, pick-by-voice, pick-by-light, and pick-by-display [17-19]. Each method of picking up goods has its advantages and disadvantages. Apart from that, a picker can also choose routes when picking up goods. In practice, determining routes for picking up goods in the warehouse is completed using heuristics. This is caused by several weaknesses in optimal routing in warehouse practice [14, 20]. For example, optimal routing will be complicated in a frequently changing layout. According to De Koster, et al. [14], Various commonly used routes include S-shape, return, mid-point, and largest gap.

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This research aims to find a combination of methods of picking up goods and routes of picking up goods, as well as the number of pickers that can minimize order picking time in the system under study. Several scenarios will be analyzed through simulations. The results of this research can improve the performance of the warehouse under study by reducing order picking time. This research uses direct observation data in warehouses from related companies.

II. Literature Review

In the last decade, order picking in warehouse processes has become a topic raised in research from various countries. Many of these previous studies used various simulation methods to obtain solutions without disturbing the actual system, which is very sensitive to change. The combination of storage, batching, zoning, and routing planning problems in order-picking operations within warehouses has been explored previously by van Gils, et al. [21]. The authors analyze existing literature, propose hypotheses, and conduct a simulation experiment using a real-life warehouse to evaluate different policies. The findings uncover the inefficiency of specific routing policies combined with First Come, First Serve (FCFS) batching. The research concludes that simultaneous consideration of these planning problems can significantly enhance order-picking performance despite practical constraints such as maintaining order integrity and using complex algorithms for batching and routing planning.

On the other hand, Bottani, et al. [22] developed a structured framework for designing and optimizing order-picking systems (OPS) in warehouses, considering factors such as warehouse layout, picking type, routing, storage allocation policy, and picking strategy. The authors validated the framework using two case studies and a software tool, demonstrating its effectiveness in improving the efficiency of the picking process. The study also develops a simulation model in Microsoft Excel to analyze the picking process, revealing that the optimal configuration depends on storage allocation and item grouping criteria. In this case, the routing policy in order picking is always a factor to consider. Other research by Lee, et al. [23], found that considering travel time and picking delays is crucial for improving order-picking operation performance and proposes further research into other warehouse performance factors.

Wang, et al. [24] in their research found that routing policy significantly impacts order picking travel distance. So, in this research, an iterative algorithm to minimize travel distance was also developed. Algoritma Dynamic Bin Assignment (DBA) was developed and validated through simulation experiments using actual data from an online retailer, showing significant improvement in travel distance. Not only that, in research conducted by Rasmi, et al. [25] Picker Routing is also stated as a subproblem that must be considered in achieving warehouse performance.

Bučková, et al. [26] explore the application of computer simulation and genetic algorithms in optimizing transport distances during warehouse order-picking processes. It outlines the steps involved in order-picking planning and the use of simulation to minimize distances covered by workers or trucks. The authors further explain how simulation software can evaluate various combinations of variables and generate output reports and how genetic algorithms can identify optimal solutions. The article underscores the significance of monitoring and planning order-picking processes and the advantages of using computer simulation to optimize warehouse operations.

The effectiveness and efficiency of order picking cannot be separated from the storage media used, for example, a racking system. Loske, et al. [9] investigate the impact of high-density flow-rack storage systems on order-picking time in a German grocery warehouse, comparing it to a standard pallet rack system and considering worker heterogeneity. The study finds that the flow-rack system increases the order-picking process speed by up to 4.60% but slows down replenishment processes by 38.65% compared to pallet rack storage. In other research conducted by Tappia, et al. [27] found that storage system technology impacts order throughput times and the effect of the picking station input buffer size on order picking performance. The study reveals that shuttle-based storage systems can yield cost savings and lower total throughput time than traditional AS/R-based systems.

In certain companies, automation technology in the order-picking process has been considered to improve warehouse performance. Research on hybrid order picking systems (HOPS) in warehouses, which combines manual and automated operations, has been carried out by several previous studies. Zhang, et al. [1] employ an agent-based simulation model to explore the potential of Human-Operated Picking Systems (HOPSs) in mitigating the workload of human order pickers. The results show that HOPSs can decrease operational costs and human workload compared to manual or fully automated systems. The research suggests that a predefined assignment rule can lower energy expenditure and cost per pick. However, changes in team sizes and assignment rules can affect the system's performance. Winkelhaus, et al. [2] simulation experiments assessed the potential economic benefits of the investigated human-robot collaboration concept. The study concluded that HOPSs have the potential to provide further benefits for companies beyond cost reduction and can help transition to fully autonomous order-picking systems. Future research should focus on different technologies, organizational strategies, and environmental factors to further explore the benefits of HOPSs.

On the other hand, several previous studies have discussed zone picking and batch picking. Ho and Lin [28] successfully designed a zone-picking network to enhance order-picking performance in distribution centres. The study proposes various methods to address these issues and evaluates their performance through computer simulations. The results reveal that the proposed zone-picking network outperforms the sequential zone-picking line, with the best dispatching and order-selection rules identified. The study also discovers that order size and workload significantly influence the system's performance. Yang, et al. [29] discuss the optimization of order batch picking in e-commerce warehouses for different storage systems. It proposes various algorithms, including location selection, routing, and batching, to tackle the optimization problems. The algorithms are evaluated based on solution quality and computation efficiency, providing valuable decision references for warehouse managers.

III. Problem Description

The case study in this research focuses on one of the finished goods storage warehouses in Gresik City, East Java. The products stored in this warehouse are various types of industrial products. Therefore, the warehouse team must respond to customer requests for their industrial needs. Through observations and interviews with warehouse managers, information was obtained that currently, the warehouse uses a person-to-goods systems method with one picker. Currently, the warehouse uses the pick-by-paper method for picking up goods and has used S-shape routes in the picking tour. There was a problem with the time to collect the goods which was quite long. On average, only 30 order picking can be done daily within eight working hours. Management wants to analyze this problem and hopes to find a combination of the number of resources, method of picking up goods, and picking routes that can minimize the completion time for picking orders. Figure 1 shows the process from the arrival of the picklist until the picker completes the order-picking tour. Generally, it starts with the arrival of the pick list, and then assignments will be made to pickers. The picker will bring a sheet of checklist paper and go on a tour to pick up all the items on the picklist. The tour is carried out on an S-shape route. When all the items have been picked up, the picker will go to the staging area to place the items. After the order-picking process, the picker can be given another picklist assignment.

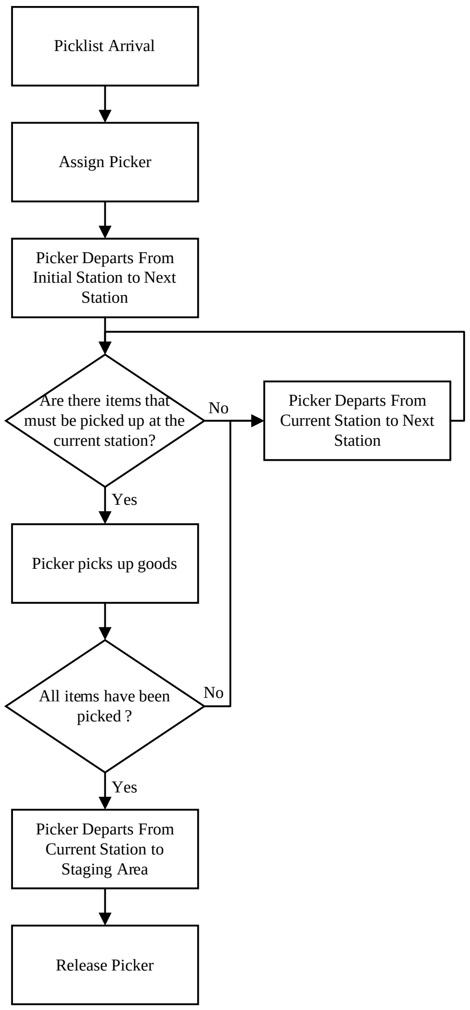

Fig. 1. Order picking process

Based on these problems, this research will develop a discrete event simulation model to describe the warehouse's order-picking system processes. The aim of developing this simulation model is to analyze the impact of various scenarios that consider the number of pickers, order picking methods, and routes.

IV. Model Development

In this research, a simulation model was developed with the help of Arena software. The output that will be analyzed is the average completion time for one picking order and the ability to complete the picklist in one working day. In the initial stage, field observations were carried out to obtain warehouse layout and sample data related to demand in the picklist and the order picking process time. The warehouse has three aisles with six rows of storage shelves. Where the longest row of storage shelves is 20 bays, in detail, the warehouse layout studied can be seen in Figure 2. On the layout, the picker location codes are shown with codes starting from A-S1 to C-S10. In the model developed, location simplification is carried out so that one location includes four storage areas. This is done assuming that at one location, a picker can easily pick up goods from the four surrounding storage areas. The tour routes for each method that have been adapted to the warehouse layout can be seen in Table 1.

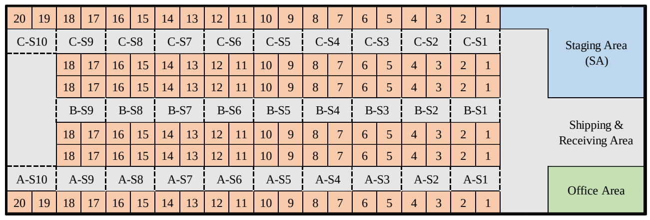

Fig. 2. Warehouse layout

Before the model was developed using Arena software. First, data distribution is carried out with the input analyzer. This distribution fitting is needed as input to the simulation model. This distribution fitting is carried out for data on the time between pick list arrivals, data on the presence or absence of orders at each station along with the order quantity, and data processing time. Table 2 shows the distribution fitting results for data on the presence or absence of orders at each station and the order quantity. In the simulation process, the Picking station will have a value of 0 or 1, indicating whether there are goods to be picked up at that station. Meanwhile, the quantity will have a round value, which indicates the number of items that must be taken at the station, which previously had a value of 1.

TABLE I. Tour Route

Tour Method	Route
S-shape	SA; C-S1; C-S2; C-S3; C-S4; C-S5; C-S6; C-S7; C-S8; C-S9; C-S10; B-S9; B-S8; B-S7; B-S6; B-S5; B-S4; B-S3; B-S2; B-S1; A-S1; A-S2; A-S3; A-S4; A-S5; A-S6; A-S7; A-S8; A-S9; A-S10; SA.
Mid-point	SA; C-S1; C-S2; C-S3; C-S4; C-S5; C-S6; C-S7; C-S8; C-S9; C-S10; B-S9; B-S8; B-S7; B-S6; A-S10; A-S9; A-S8; A-S7; A-S6; A-S5; A-S4; A-S3; A-S2; A-S1; B-S1; B-S2; B-S3; B-S4; B-S5; SA
Return	SA; C-S1; C-S2; C-S3; C-S4; C-S5; C-S6; C-S7; C-S8; C-S9; C-S10; RETURN; B-S1; B-S2; B-S3; B-S4; B-S5; B-S6; B-S7; B-S8; B-S9; RETURN; A-S1; A-S2; A-S3; A-S4; A-S5; A-S6; A-S7; A-S8; A-S9; A-S10; SA.

The simulation model for the existing condition of the order picking system uses several modules, the basic process, including the create, dispose, process, decide, and assign modules. On the other hand, the advance process uses the seize and release module. Apart from that, the advance transfer also uses station and route modules. The simulation model developed is divided into two parts. The first part is the picklist arrival and picking policy model. In another section, there is a tour area model. Visuals of the simulation model developed can be seen in Appendix 1.

TABLE II. DEMAND EXPRESSION

Station	Picking Station	Quantity
AS1	ANINT(TRIA(-0.5, 0.8, 1.5))	ANINT(0.5 + 4 * BETA(1.09, 1.2))
AS2	ANINT(TRIA(-0.5, 0.1, 1.5))	ANINT(0.5 + 4 * BETA(0.849, 0.97))
AS3	ANINT(TRIA(-0.5, 0.9, 1.5))	ANINT(0.5 + 4 * BETA(0.832, 1.02))
AS4	ANINT(-0.5 + 2 * BETA(1.91, 2.14))	ANINT(0.5 + 4 * BETA(0.967, 1.22))
AS5	ANINT(-0.5 + 2 * BETA(1.49, 1.39))	ANINT(0.5 + 4 * BETA(0.732, 0.836))
AS6	ANINT(-0.5 + WEIB(0.873, 1.9))	ANINT(0.5 + 4 * BETA(1.88, 1.73))
AS7	ANINT(TRIA(-0.5, 0.2, 1.5))	ANINT(0.5 + 4 * BETA(1.03, 1.07))
AS8	ANINT(TRIA(-0.5, 0.8, 1.5))	ANINT(0.5 + 4 * BETA(1.25, 1.63))
AS9	ANINT(-0.5 + 2 * BETA(1.91, 2.14))	ANINT(0.5 + 4 * BETA(2.03, 1.57))
AS10	ANINT(-0.5 + WEIB(0.835, 1.9))	ANINT(0.5 + 4 * BETA(1.3, 1.18))
BS1	ANINT(-0.5 + 2 * BETA(1.39, 1.49))	ANINT(0.5 + 4 * BETA(0.741, 0.819))
BS2	ANINT(-0.5 + 2 * BETA(2.14, 1.91))	ANINT(0.5 + 4 * BETA(1.53, 1.26))
BS3	ANINT(-0.5 + 2 * BETA(2.14, 1.91))	ANINT(0.5 + 4 * BETA(1.07, 1.03))
BS4	ANINT(TRIA(-0.5, 0, 1.5))	ANINT(0.5 + 4 * BETA(0.859, 0.949))
BS5	ANINT(-0.5 + 2 * BETA(1.39, 1.49))	ANINT(0.5 + 4 * BETA(0.993, 0.84))
BS6	ANINT(-0.5 + 2 * BETA(1.91, 2.14))	ANINT(0.5 + 4 * BETA(1.15, 1.12))
BS7	ANINT(TRIA(-0.5, 0.5, 1.5))	ANINT(0.5 + 4 * BETA(0.643, 0.965))
BS8	ANINT(TRIA(-0.5, 0.2, 1.5))	ANINT(0.5 + 4 * BETA(1.24, 0.883))
BS9	ANINT(-0.5 + 2 * BETA(1.49, 1.39))	ANINT(0.5 + LOGN(1.74, 1.53))
CS1	ANINT(-0.5 + WEIB(1.38, 3.51))	ANINT(0.5 + 4 * BETA(0.821, 1.07))
CS2	ANINT(-0.5 + 2 * BETA(1.91, 2.14))	ANINT(TRIA(0.5, 3.4, 4.5))
CS3	ANINT(-0.5 + 2 * BETA(2.14, 1.91))	ANINT(0.5 + 4 * BETA(0.751, 0.803))
CS4	ANINT(TRIA(-0.5, 0.5, 1.5))	ANINT(0.5 + 4 * BETA(0.832, 1.02))
CS5	ANINT(-0.5 + 2 * BETA(1.39, 1.49))	ANINT(0.5 + 4 * BETA(0.974, 1.19))
CS6	ANINT(-0.5 + 2 * BETA(1.91, 2.14))	ANINT(0.5 + 4 * BETA(0.959, 1.34))
CS7	ANINT(-0.5 + 2 * BETA(1.91, 2.14))	ANINT(0.5 + 4 * BETA(0.968, 0.968))
CS8	ANINT(TRIA(-0.5, 0.8, 1.5))	ANINT(UNIF(0.5, 4.5))
CS9	ANINT(TRIA(-0.5, 0.9, 1.5))	ANINT(0.5 + 4 * BETA(1.02, 0.927))
CS10	ANINT(-0.5 + 2 * BETA(1.39, 1.49))	ANINT(0.5 + 4 * BETA(1.3, 1.18))

A. *Create Modules*

The simulation model developed describes pick list arrivals as entities entering the system. The create module is used to represent the picklist arrival. The time between arrivals of the picklist obtained from observation data can be expressed in the expression 11 + LOGN(2.82, 2.64) with one picklist for each entity arrival. In detail, it can be seen in Figure 3.

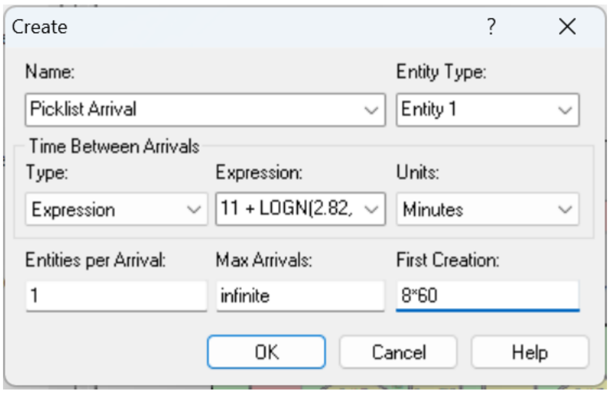

Fig. 3. Create module

B. *Process Modules*

In the case studied, there was a process of searching for and picking goods at the destination. This process requires a specific time related to the method used. The process module describes picking up goods at each destination station. There are resources in the form of floors AS1 to CS10, which symbolize the location currently occupied by the picker. In other words, multiple pickers cannot use a location or picking station. The process module also considers the picking process time using several methods. In this research, two different methods will be used, namely pick by paper and pick by voice, while the expression process time respectively is 13.5 + 7 * BETA (0.919, 0.82) and 6.5 + ERLA (0.642, 4).

C. *Decide Modules*

In the simulation model developed, the decides module determines the next destination concerning the tour route used.

D. *Assign Modules*

The assign module adds attribute data to entities in the form of pick lists. The data is in the form of picking destination stations and quantity orders at each destination station. In detail, it has been explained in Table 2.

E. *Seize and Release Modules*

Seize and release modules are essential to use in this simulation model. The seize module is used when initially assigning a picker. The picker will have a busy status during the order-picking process. When the order-picking process is complete and the picker places the item in the staging area, the entity will pass through the release module, and the picker status will become idle again and can be assigned to another picklist.

F. *Station and Routes*

To accommodate the tour picking process with various routing methods, it is necessary to use station and route modules. The station module in this simulation model describes picking locations in the warehouse layout. Meanwhile, the routes module determines the picker's destination station. That way, the picker will walk according to a predetermined route.

V. RESULT AND DISCUSSION

After the simulation model has been developed and declared valid, numerical experiments are carried out. Numerical experiments were carried out over five working days in one week to describe the conditions of the system under study more comprehensively.

A. *Analysis of the existing conditions*

First, the experiment was carried out with the company's existing conditions. In existing conditions, order picking is carried out using the pick-by-paper method by one picker and the S-shape tour route. The simulation results show a high level of unfinished picklists, with an average of 18 that could not be completed on the same day as they arrived. That way, the picklist must stay overnight and be done the next day. Apart from that, there were also overnight picklists up to a maximum of 26 picklists. This will disrupt warehouse performance, especially order-picking activities the next day. If this happens continuously, it will have a harmful impact in the future. On the other hand, the simulation results also reveal a very long waiting time for a picklist to be worked on, with an average waiting time of 117.6 minutes and up to 341 minutes.

Through the simulation results of existing conditions, it can be concluded that there is a delay in completing order picking from several picklists, which will negatively impact warehouse performance. These delays can occur due to several things, such as a lack of resources or poor speed of the order-picking process.

B. *Improvement Scenarios*

To overcome existing problems, in this research, 12 improvement scenarios were developed. Each improvement scenario is a different combination of tour route, picking method, and number of pickers. In detail, each scenario can be seen in Table 3. Several other tour routes, such as Mid-point and Return, are considered in this improvement scenario. Apart from that, a picking method was also considered, which was felt to have the ability to minimize the order picking process time, namely, pick by voice. By using the pick by voice method, this research also carried out a time study to obtain samples of the picking process time using the pick by voice method. This processing time sample was used in this research. On the other hand, increasing the number of resources or pickers from one person to two people is also considered in the improvement scenario.

TABLE III. LIST OF SCENARIO

Scenario Name	Tour Route	Picking Method	Number of Picker
Scenario 1	S-shape	PBP	1
Scenario 2	S-shape	PBP	2
Scenario 3	S-shape	PBV	1
Scenario 4	S-shape	PBV	2
Scenario 5	Mid-point	PBP	1
Scenario 6	Mid-point	PBP	2
Scenario 7	Mid-point	PBV	1
Scenario 8	Mid-point	PBV	2
Scenario 9	Return	PBP	1
Scenario 10	Return	PBP	2
Scenario 11	Return	PBV	1
Scenario 12	Return	PBV	2

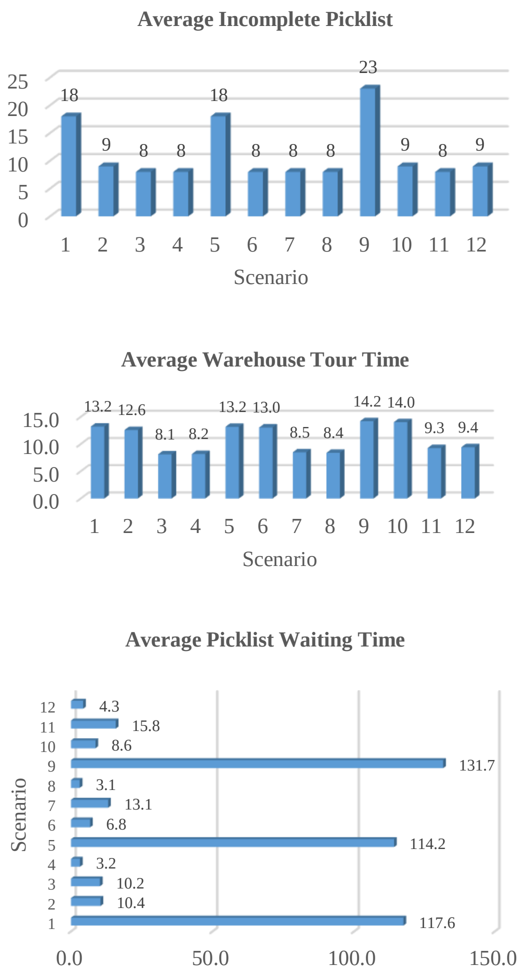

Fig. 4. Experimental Result

Figure 4 shows the warehouse order picking performance from the simulation results of existing conditions and all improvement scenarios with ten replications. The simulation results found that the incomplete picklist value was relatively lower when the picking method was changed to pick by voice compared to simply adding two pickers. In this way, it was also found that by implementing the pick-by-voice method, the company could survive using one picker. The pick-by-voice method also provided the minimum tour time compared to the pick-by-paper method.

The lowest average picklist waiting time, namely 3.1 minutes, occurred using scenario 8. In this scenario, apart from changing the route to mid-point and changing the method to pick by voice, the picker was added to two people. So, it can be stated that scenario 8 is the best scenario that can minimize picklist waiting time and is in line with the average incomplete pickist. Researchers are trying to find another scenario that can be considered, namely scenario 3. This scenario also produces a low average incomplete picklist. Even though scenario 3 produces a higher average picklist waiting time than scenario 8, it is still understandable.

On the other hand, from the route used, it can be concluded that the S-shape and mid-point tour routes are superior to the return route. In more detail, the difference in time between trials of several routes appears less significant. This can happen because the warehouse layout is still in the medium category. From the experiments, it can be concluded that the order-picking method significantly impacts warehouse performance compared to changing the tour route.

VI. CONCLUSION

This research discusses the order picking system simulation model considering the picking method and picker route. The main objective of this research is to improve warehouse performance. In this research, warehouse performance will be seen through the number of picklists not completed in one day, so they had to stay overnight and be done the next day. This is proportional to the time waiting for a picklist that has been received to be processed. On the other hand, performance is also seen from the time it takes to complete one picking order. The simulation model was created and run with Arena software.

Twelve improvement scenarios were developed by combining order picking methods, picking routes, and a number of pickers. The experimental results show scenario eight as the best scenario using the mid-point route, the pick-by-voice picking method, and two pickers. Scenario 8 can produce the lowest average incomplete picklist and warehouse tour time with this combination. The order-picking method can be said to significantly influence warehouse performance. Future researchers can focus on the details of order picking and add several other methods.

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Appendix 1. Simulation Model by Arena Software