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Container Loading Problem in Multiple Heterogeneous Large Object Placement Problem to Minimize Delivery Delays

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***Abstract*— Timely delivery of goods is the main target of a third-party logistics engaged in transportation. The problem that is often discussed in previous research to minimize delivery delays is by optimizing the route so that it minimizes total travel time. In this study, we found variables that contribute to delays that occur in a shipment, namely, loading time and unloading of goods to a fleet. This variable has the second largest processing time contribution after travel time. This study discusses the optimal way of stacking goods in a fleet so that it will minimize loading and unloading time. We adapted the Container Loading Problem theory to solve this problem. The result of this study is that the loading and unloading process can be reduced by 19%.**

Keywords—transportation, container loading problem, operation research, supply chain management

I. INTRODUCTION

Transportation is one of the most important components in the industrial world. Without transportation, an industry will lose one of the much needed activities, namely the distribution of goods. According to Ref. [1], transportation is the transfer of goods or passengers from one place to the desired destination. This makes transportation planning and distribution a component that needs to be considered by the industry.

Based on research conducted by Ref. [2], it became one of the cornerstones that made researchers want to develop previous research. PT. XYZ is a combination of some of the largest companies in Indonesia and international investment groups. The company which was established in 1993 and obtained the ISO 9001, 2008 certificate aims and is committed to introducing world-class export, import and logistics service companies to meet solutions and customer satisfaction. PT. XYZ provides services in the form of transportation and distribution of raw materials from distribution centers to customer locations located in the Greater Jakarta area.

Problems faced by PT. XYZ is a delay in shipping activities. Based on the results of observations in Fig. 1., it shows that what affects the delivery time of goods is the travel time, loading, unloading, checking and administration. From the fourth time of the process, which has a large contribution is the travel time of (39%), the unloading time is (30%) and the loading time is (25%). So it can be concluded that the travel time is the main factor causing delays in delivery. Previous researchers [2] have minimized travel time by determining transportation routes.

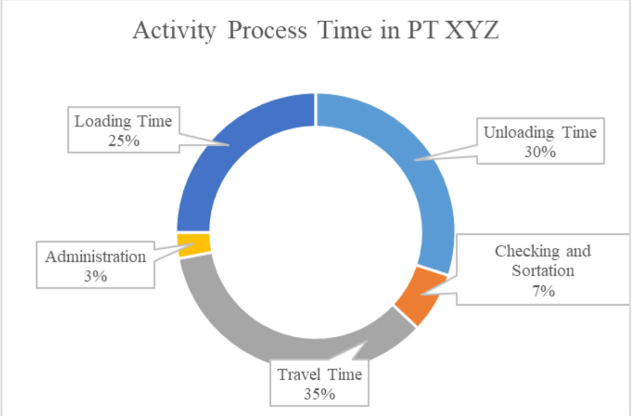

Fig. 1. Activity Process Time in PT XYZ

The initial identification of the problem at unloading time is by comparing the unloading cycle time with the standard time owned by PT. XYZ. The difference between the unloading cycle time and the standard time can be seen in Figure 2. The data is obtained from previous researchers' data [2].

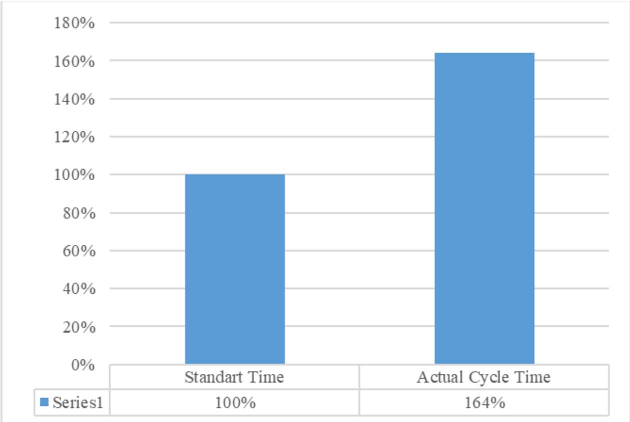

Fig. 2.Comparison of Unloading Cycle Time and Standard Time PT. XYZ

The initial identification of the problem at unloading time is by comparing the unloading cycle time with the standard time owned by PT. XYZ. The difference between the unloading cycle time and the standard time can be seen in Figure 2. The data is obtained from previous researchers' data [2].

After the author conducts further assessments, in the process of sending, the depot does the arrangement of the box into the truck container irregularly. For the depot, the process aims to minimize loading time. Whereas the impact of carrying out irregular arrangement of goods is when the loading and unloading process is often the unloading operator must reduce and re-enter items that are not supposed to be removed from the container. This makes the unloading time longer because the preparation of the item does not apply LIFO (Last In First Out).

In this study, we will improve the process of loading goods into vehicles at the initial shipping depot. The concept of the Loading Problem Container will be adapted to carry out the stacking process in the fleet. The product will be arranged according to the order in which the goods are delivered, so there is no double handling process. This process will minimize the high unloading time of the goods, so as to minimize delays in the delivery of goods. To improve the loading problem in this study, we developed a Container Loading Problem by using no parameters, namely, length, width and height of the container box. In addition, we also discuss the heterogeneous size of the container box that will be inserted into the container.

II. Literature Review

A. Container Loading Problem

Container Loading Problem (CLP) according to [3] is a problem of orthogonal placement of a square-shaped cardboard subset into a fixed dimension container which is also square. In addition to reducing shipping costs, optimal cargo filling can increase the stability of the cargo in the container. Depending on the purpose function and its constraints, there are several types of CLP including:

a. Packing strip. In this type of problem, the container has a fixed width and height that is not fixed in length. The purpose of this problem is to arrange all the boxes into containers in such a way that the required length of the container is minimal. Strip packing problems can be found in a multi-drop situation, which is a situation that requires the separation of shipment items into groups according to the destination location of each item.
b. Knapsack loading. In this type of problem, each cardboard is related to the profit that will be obtained. The purpose of this problem is to arrange each cardboard in a container so that the container profit is maximal. If the profit of a cardboard is determined based on its volume, this problem is the same as minimizing the remaining space of a container.
c. Bin-packing. In this type of problem, all containers have a fixed dimension and all boxes must be placed in a number of containers in such a way that the minimum number of containers needed.
d. Multi-container loading. This type is similar to the bin-packing problem. But in this type the dimensions of containers can vary. The purpose of this problem is to choose a container subset so that the minimum shipping costs are obtained.

Reference [4] investigated a three-dimensional single container loading problem, which aims to pack a given set of unequal-size rectangular boxes into a single container such that the length of the occupied space in the container is minimized. Motivated by the practical logistics instances in literature, the problem under study is formulated as a zero-one mixed integer linear programming model. Due to the NP-hardness of the studied problem, a simple but effective loading placement heuristic is proposed for solving large-size instances. The experimental results demonstrate that the developed heuristic is capable of solving the instances with more than two hundred boxes and more efficient than the state-of-the-art mixed integer linear program and existing heuristic methods.

According to [5] there are several other constraints that can be added to the problems above, namely the limited rotation of the cardboard, the type of product in the cardboard and there are provisions regarding the maximum number of cardboard stacks. In addition, according to [5] additional support for cardboard also needs to be considered because a cardboard cannot be placed on a cardboard box where the other side of the cardboard is floating.

Reference [6] addressed container loading problem with multiple constraints that occur at many manufacturing sites, such as furniture factories, appliances factories, and kitchenware factories. These factories receive daily orders with expiration dates, and each order consists of one or more items. On a particular day, certain orders expire, and the expiring orders must be handled (shipped) prior to the non-expiring ones. All of the items in an order must be placed in one container, and the volume of the container should be maximally utilized. A heuristic algorithm is proposed to standardize the packing of (order) items into a container.

Reference [7] proposed a multi-population biased random-key genetic algorithm (BRKGA), with a new fitness function that takes static stability and load balance into account. Extensive computational experiments were performed with different variants of the proposed approach. Also solutions taken from the literature were evaluated in terms of load balance. The computational results show that it is possible to obtain stable and load balanced solutions without compromising the performance in terms of container volume utilization, and demonstrate also the advantage in incorporating load balance in the packing generation algorithm.

Reference [8] developed a two-phase algorithm to solve the problem. In phase one, we estimate the most promising region of the solution space based on performance statistics of the sub-problem solver. In phase two, we find a feasible solution in the promising region by solving a series of 3D orthogonal packing problems. A unique feature of our approach is that we try to estimate the average capability of the sub-routine algorithm for the single container loading problem in phase one and take it into account in the overall planning.

B. Container Loading Problem Optimization

Container Loading Problem Optimization is divided into two types, namely minimizing the input value and maximizing the output value. The type of problem minimizes input values including:

a. Single Stock-size Cutting Stock problem (SSSCSP) The problem in arranging a heterogeneous (weak) cargo set into an identical container with the minimum number of containers used.
b. Multiple Stock-size Cutting Problem (MSSCSP) Problems in packaging heterogeneous (weak) cargo into

heterogeneous containers (weak) so that the use of containers can be minimized.

c. Residual Cutting Stock Problem (RCSP)
Problems in the preparation of heterogeneous (weak) cargo into heterogeneous (strong) containers so that the use of containers can be minimized.

d. Single Bin-Size Bin Packing Problem (SBSBPP)
Problems in packaging heterogeneous (strong) cargo into identical containers so that container use can be minimized.

e. Multiple Bin-Size Bin Packing Problem (MBSBPP)
The problem in arranging a heterogeneous (strong) cargo set into a heterogeneous (weak) container so that the use of containers can be minimized.

f. Residual Bin Packing (RBPP)
Problems in packaging a heterogeneous (strong) cargo set into a heterogeneous (strong) container so that container usage can be minimized.

g. Open Dimension Problem (ODP)
Problems packing a set of cargo into a container with one or more variable dimensions so that the volume of the container can be minimized.

As for the type of problem maximizing the output value are as follows:

a. Identical Item Packing Problem (IIPP)
Problems in loading a container with small objects that are identical to the maximum amount of cargo.

b. Single Large Object Placement Problem (SLOPP)
The problem in loading a heterogeneous (weak) cargo into one container so as to maximize the amount of cargo loaded.

c. Multiple Identical Large Object Placement Problems (MILOPP)
The problem in loading a heterogeneous (weak) cargo into identical containers so as to maximize the amount of cargo loaded.

d. Multiple Heterogeneous Large Object Placement Problems (MHLOPP)
Problems in loading a heterogeneous (strong) cargo into heterogeneous containers (weak or strong) so as to maximize the amount of cargo loaded.

e. Single Knapsack Problem (SKP)
Problems in loading a heterogeneous (strong) cargo into one container so as to maximize the amount of cargo loaded.

f. Multiple Identical Knapsack Problem (MIKP)
The problem in loading a heterogeneous (strong) cargo into identical containers so as to maximize the amount of cargo loaded.

g. Multiple Heterogeneous Knapsack Problem (MHKP)
The problem is that it contains a heterogeneous (strong) cargo into a heterogeneous container (strong) so that it can maximize the amount of cargo loaded.

III. Research Method

Based on the description of the problems in Section 1, it can be seen that there is the problem of the length of time for unloading goods from the container. This is because the goods in the container are not arranged according to the order of delivery. So that the unloading operator when picking up the goods for the first customer must unload the items that prevent him because the goods are not based on LIFO (Last In First Out).

This study begins with the initial data collection, namely the box dimension data for each variant, type of product, number of shipments (demand), type of fleet, order of delivery which is the initial solution obtained from previous research [2]. Initial data consisting of box dimension data, product type, number of shipments (demand), fleet dimensions and shipping order are needed to determine the preparation of goods in containers. Then the data is used as input in making mathematical models that are in accordance with the problems that consist of the objective function and the existing constraints.

After that, optimization of the preparation of goods using genetic algorithms is carried out. The results obtained from the genetic algorithm are visualization of the order of the preparation of goods in an optimal 3D form by considering the product type, delivery order, stack orientation, stack stability, and the weight of each product.

After obtaining visualization of the preparation of the goods, the calculation of the loading and unloading time will be carried out on the results of the preparation of the goods. Calculation of loading and unloading time is carried out to determine the difference between the initial loading and unloading time before the preparation of the goods after the preparation of the goods. The research method of this study can be seen in Figure 3.

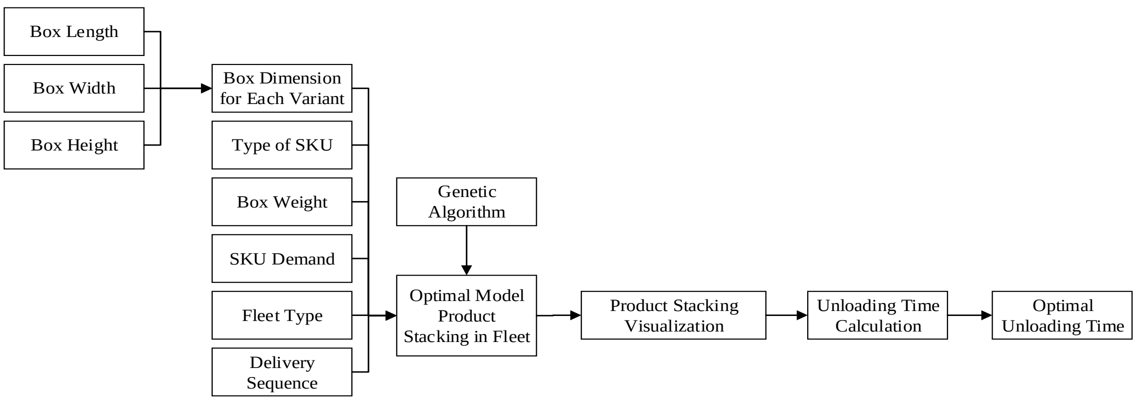

Fig. 3.Research Method

IV. Mathematical Model

Problems in the initial conditions are formulated into mathematical models [9] with the objective function of minimizing unused space in containers by arranging the goods based on the shipping sequence obtained from previous research which will have an impact on loading time. The mathematical model is as follows:

Index:

i	Box/container which will be stack in vehicle container
j	Vehicle container
C	Variables that show the box i [i = 1, ..., C]
D	Variables that indicate vehicle j [j = 1, ..., D]

Parameter:

nn	Number of boxes transported
nm	Number of vehicles available
M	Big number (Big-M) for logical model
m	Small number for logical model
as	The supporting areas considered in the model can be assumed to be 0 and 1. Value 0 which means providing 0% of the supporting area, and a value of 1 which means providing 100% of the supporting area.
O_i	Box delivery order i. Boxes that have a low value will be sent first time and the box that has a large value will be sent the last time.
p_i, q_i, r_i	Length, width and height of the box i.
L_j, W_j, H_j	Length, width and height of vehicle compartment j.

Decision Variable:

x_i, y_i, z_i	Coordinates that indicate position of box i.
lx_i, ly_i, lz_i	Variables that indicate the length of the box i are parallel to the X, Y or Z axis.
wx_i, wy_i, wz_i	Variables that indicate the width of the box i are parallel to the X, Y or Z axis.
hx_i, hy_i, hz_i	Variables that indicate the height of the box i are parallel to the X, Y or Z axis.
s_{ij}	A binary variable that shows the box i is placed on a vehicle j. Value 1, if box i is placed in vehicle j, if the opposite will be 0.
n_j	Binary variables that indicate vehicle j are used. Value 1, if vehicle j is used, if the opposite will be 0.
δ_{ijk}	Binary variables that show the box i and box k are placed on the vehicle j. Value 0, if box i and box k are placed on vehicle j. Value 0 if otherwise.

$$\text{Min } \theta = \sum_{j \epsilon D} L_j\, W_j\, H_j\, n_j - \sum_{i \epsilon C} p_i\, q_i\, r_j\, s_{ij}$$

The objective function explains that the purpose of this research is to minimize the empty space of the container by compiling the goods based on the shipping location which will affect the loading time.

Constrain:

$$x_i + p_i lx_i + q_i(lz_i - wy_i + hz_i) + r_i(1 - lx_i - lz_i + wy_i - hz_i) - \delta_{ikj}M \le x_k + (1 - a_{ik})M \quad \forall i,k \in C : i \neq k \quad (1)$$

$$x_k + p_k lx_k + q_k(lz_k - wy_k + hz_k) + r_k(1 - lx_k - lz_k + wy_k - hz_k) - \delta_{ikj}M \le x_i + (1 - b_{ik})M \quad \forall i,k \in C : i \neq k \quad (2)$$

$$y_i + q_i wy_i + p_i(1 - lx_i - lz_i) + r_i(lx_i + lz_i - wy_i) - \delta_{ikj}M \le y_k + (1 - c_{ik})M \quad \forall i,k \in C : i \neq k \quad (3)$$

$$y_k + q_k wy_k + p_k(1 - lx_k - lz_k) + r_k(lx_k + lz_k - wy_k) - \delta_{ikj}M \le y_i + (1 - d_{ik})M \quad \forall i,k \in C : i \neq k \quad (4)$$

$$z_i + r_i hz_i + q_i(1 - lz_i - hz_i) + p_i lz_i - \delta_{ikj}M \le z_k + (1 - e_{ik})M \quad \forall i,k \in C : i \neq k \quad (5)$$

$$z_k + r_k hz_k + q_k(1 - lz_k - hz_k) + p_k lz_k - \delta_{ikj}M \le z_i + (1 - f_{ik})M \quad \forall i,k \in C : i \neq k \quad (6)$$

Constrain variable (1) - (6) ensures that the two boxes in the same vehicle do not overlap with box k in all positions (top, bottom, front, back, right and left).

$$a_{ik} + b_{ik} + c_{ik} + d_{ik} + e_{ik} + f_{ik} \ge 1 - \delta_{ikj} \quad \forall i,k \in C : i \neq k; j \epsilon D \quad (7)$$

$$\sum_{j \epsilon D} S_{ij} = 1 \quad \forall i \in C \quad (8)$$

$$\sum_{i \epsilon C} S_{ij} \le M n_j \quad \forall j \in D \quad (9)$$

The limiting variable (7) ensures that two boxes in the same vehicle have at least one position. The limiting variable (8) ensures that each box is placed in only one vehicle. The limiting variable (9) ensures that the box placed into the vehicle, the vehicle is used.

$$x_i + p_i lx_i + q_i(lz_i - wy_i + hz_i) + r_i(1 - lx_i - lz_i + wy_i - hz_i) \le L_j + (1 - S_{ij})M \quad \forall i \in C, j \in D \quad (10)$$

$$y_i + q_i wy_i + p_i(1 - lx_i - lz_i) + r_i(lx_i + lz_i - wy_i) \le W_j + (1 - S_{ij})M \quad \forall i \in C, j \in D \quad (11)$$

$$z_i + r_i hz_i + q_i(1 - lz_i - hz_i) + p_i lz_i \le H_j + (1 - S_{ij})M \quad \forall i \in C, j \in D \quad (12)$$

The limiting variable (10) (12) ensures that all boxes included in the vehicle do not exceed the dimensions of the vehicle compartment.

$$lx_i + ly_i + lz_i = 1 \quad \forall i \in C \quad (13)$$

$$wx_i + wy_i + wz_i = 1 \quad \forall i \in C \quad (14)$$

$$hx_i + hy_i + hz_i = 1 \quad \forall i \in C \quad (15)$$

$$lx_i + wx_i + hx_i = 1 \quad \forall i \in C \quad (16)$$

$$ly_i + wy_i + hy_i = 1 \quad \forall i \in C \quad (17)$$

$$lz_i + wz_i + hz_i = 1 \quad \forall i \in C \quad (18)$$

The limiting variable (13) (18) ensures that the dimensions of each box (length, width, height) must be parallel to one side of the vehicle compartment.

$$2 - s_{ij} - s_{kj} \ge m\delta_{ikj} \quad \forall i,k \in C, j \epsilon D \quad (19)$$

$$2 - s_{ij} - s_{kj} \le M\delta_{ikj} \quad \forall i,k \in C, j \epsilon D \quad (20)$$

The limiting variable (19) (20) defines the variable assumed to be 0 if the box i and box k are in the vehicle j. Value 1 if otherwise.

$$x_i, y_i, z_i \ge 0 \quad \forall i \in C \quad (21)$$

$$lx_i\,, ly_i\,, lz_i, wx_i\,, wy_i\,, wz_i, hx_i\,, hy_i\,, hz_i, n_i \epsilon \{0,1\} \qquad \forall i \in C \quad \text{...(22)}$$

$$s_{ij}\ \epsilon \{0,1\} \qquad \forall i \in C, j \in D \quad \text{...(23)}$$

$$a_{ik}, b_{ik}, c_{ik}, d_{ik}, e_{ik}, f_{ik}\ \in \{0,1\} \qquad \forall i,k \in C \quad \text{...(24)}$$

$$\delta_{ikj} \in \{0,1\} \qquad \forall i,k \in C\ , j \epsilon D \quad \text{...(25)}$$

$$lx_i + ly_i\ +\ lz_i\ + wx_i\ +\ wy_i\ +\ wz_i + hx_i\ +\ hy_i + hz_i = 3 \qquad \forall i \in C \quad \text{...(26)}$$

$$a_{ik} = b_{ki} \qquad \forall i,k \in C : i \neq k \quad \text{...(27)}$$

$$c_{ik} = d_{ki} \qquad \forall i,k \in C : i \neq k \quad \text{...(28)}$$

$$e_{ik} = f_{ki} \qquad \forall i,k \in C : i \neq k \quad \text{...(29)}$$

The limiting variable (21) ensures that the coordinates of each box must equal 0 or more than 0. The limiting variable (22) - (25) defines a binary variable in the model. The limiting variable (26) ensures that each side of the box in each box is parallel to the side of the vehicle compartment. Limiting variables (27) - (29) ensure the position of each box. If the box is to the left of the box k, then the box k is to the right of the box i.

V. Result

Validation of algorithms that have been designed aims to check whether or not genetic algorithms are designed to produce a good solution. The quality of this solution can be seen from the fulfillment of the container loading problem (CLP) model. Some things that can be used as validation are as follows:

1. The fleet compartment used is quite maximal
   This validation can be seen from whether the container used is already maximal or not. This can be seen from the tests that have been carried out showing that all items shipped as many as 150 boxes can enter the container.
2. The box has been arranged according to the order of delivery
   The visualization of the resulting 3D object can be seen in Figure 4. From the visualization shows that the preparation of the goods is based on the order of delivery. The items to be removed especially indicated by the cyan color. Then the items that are derived in the second delivery sequence are indicated by the magenta color, while the items that have the final destination are shown in yellow.
3. There are no boxes that come out of the compartment
   In the 3D object visualization image above shows that there is no cardboard that comes out of the compartment. Even with mathematical calculations, the coordinates of the entire cardboard point are in the compartment as evidenced by the results of the coordinate point.
4. There is no box that is irregular
   That each coordinate point of each box is interconnected or it can be said that there are no boxes that intersect with other boxes. The final coordinate point of the first box will be the second box coordinate point.

After calculation, the calculation shows that the loading and unloading time after the preparation of goods has decreased by 19%. The decrease in time occurs because the goods are arranged according to the order of delivery so that operators can easily and quickly reduce goods without moving other items first. This proves that the preparation of goods in the fleet compartment based on the shipping order affects the loading and unloading process by showing that the resulting time is smaller than the initial time before the preparation is carried out.

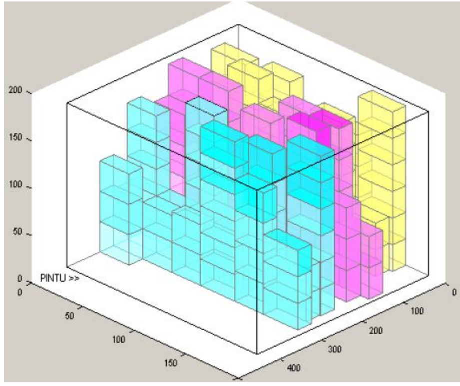

Fig. 4.Container Loading Problem Visualization

VI. Conclusion

This genetic algorithm research produces solution solutions that have limitations. Determination of the rules for the preparation of goods by considering the types of items in the genetic algorithm results in an empty space in the middle of the stack. This situation causes cardboard to move places during the trip. In addition, there are several other possibilities such as cardboard colliding with other cardboard boxes and cardboard can also fall from above. On the other hand, with the empty space in the middle of the stack, more and more free space will be wasted causing less optimal.

The algorithm in this study has the advantage of the feasibility of a good algorithm. Visualization of the image that has been seen can show that this is one of the advantages of the algorithm that has been compiled. In the preparation of the goods that have been carried out there is no floating cardboard. For further research, the authors suggest considering new variables, namely dynamic stacking. This variable serves to overcome if there is a change in the product delivery order caused by changes in the shipping route.

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