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Research Article

An Integrated Optimization Model of Product Mix, Assortment Packing, and Distribution in A Fashion Footwear Company

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ABSTRACT

Recognizing the paramount importance of operational effectiveness and resource management in supply chain management (SCM) of the fashion industry, this study addresses a specific challenge faced by a prominent Indonesian fashion footwear company. The inefficiency is due to repetitive sorting and packaging processes during product distribution, which significantly impact optimal production mixes and product distribution from the distribution center to the point of sale. A crucial aspect is also the optimization of the delivery route. To address these challenges and minimize the total cost of ownership, the study proposes an integrated optimization model. This model simultaneously determines the optimal production quantity, assortment packaging and distribution channels, taking into account decision variables related to distribution in configuration boxes, overload and underload products, as well as production numbers that respond to store-specific demand fluctuations. A notable contribution of this research is the integration of product mix decisions into the assortment packaging and distribution model, which represents a novel approach. The optimal solution determined using the LINGO 18.0 software highlights the significant influence of product penalty costs and product demand parameters on the objective function, while shipping costs have no noticeable influence. By emphasizing the integration of product mix decisions into the optimization framework, this research contributes significantly to improving the understanding and practical application of efficient supply chain management in the fashion industry.

Keywords: product-mix decision, assortment packing problem, distribution routes, fashion SCM

INTRODUCTION

The fashion industry, which has played a significant role in Indonesia's economic growth, has shown positive progress in the second quarter of 2022, with a growth rate of 1.64 percent, despite the obstacles posed by the Covid-19 pandemic in previous years [1]. The Ministry of Industry recognizes the importance of the fashion sector and has strategically included it in the Making Indonesia 4.0 program, emphasizing the need for collective support to further improve and sustain this growth [2].

Within the fashion industry, supply chain management (SCM), is a vital function that involves a complex web of interconnected organizations collaborating to effectively plan the acquisition and distribution of goods [4]. To deliver goods and services on time and within budget, it entails coordinating stakeholders like manufacturers, distributors, retailers, suppliers, and customers [5]. SCM is also a concept that pertains to the distribution patterns of products, including logistics, production schedules, and distribution activities [6]. The fashion industry still faces SCM challenges, such as inefficient operations and suboptimal resource utilization, despite positive industry outcomes. Problems such as excess truck capacity and high logistics costs, which are more than twice the GDP of developing nations, continue to exist [7]. In order to overcome these obstacles, a significant shift toward an integrated decision-making model is required. This model seeks to lower overall operating costs and increase operational efficiency, providing a complete answer for optimizing supply chain management (SCM) activities in the fashion industry.

The problem of assortment packaging is a particular challenge in fashion SCM. Sorting and packing, which are crucial for the distribution process from manufacturers to retailers, are the focus of this challenge. Retailers face inefficiencies when they have to incur additional costs to repackage products to meet the needs of specific stores, even though manufacturers find traditional solid packaging methods that place one type of product in each box to be efficient [8]. In this situation, using assortment packing becomes a better option. By guaranteeing timely arrival of products before the sales season and allowing a more balanced distribution to all stores, this strategy improves the efficiency of the entire sales process. However, the use of assortment packaging presents particular difficulties, particularly when it comes to balancing the quantity of products distributed with store demand. In situations where there is a large discrepancy between the quantity of product distributed and the quantity demanded, this balance is important to prevent over- or under-utilization [9]. When it comes to supply chain management (SCM) in the fashion industry, it is crucial to optimize the packaging and distribution of configuration boxes. This involves finding the ideal balance and reducing inconsistencies, which will ultimately improve supply chain efficiency.

In the supply chain, a factory plays crucial roles, determining optimal production quantity, packaging processes, and the number of products for distribution, as well as the distribution route. The limited resources in the production process should be used efficiently which have become one of the industrial development strategies [10]. According to [11], the product mix problem is a problem related to production planning to find the amount of each product to be produced. The goal of optimizing product mix problems is to maximize company profits and use resources efficiently while keeping customer orders in mind [4]. However, the product mix is one of the most important decisions made in a production system due to the capacity constraints in which it will constrain the company to meet demand for all product [12].

The synergy of production and distribution functions holds significant potential to optimize supply chain performance. A widely used strategy to address distribution routing challenges involves the application of vehicle routing problem (VRP) models. VRP is described as an integer programming and combinatorial optimization problem [13] and serves as a valuable tool in planning and decision-making processes, illustrated by models for minimizing the distance traveled [14]. Introduced by Danzig and Ramser in 1959, VRP aims at route optimization and vehicle capacity problems, relying on graph theory to establish connections between points and lines [15][16]. Essentially, VRP is a method that determines the most efficient distribution channel and minimizes costs, from a central depot to geographically dispersed customers [17]. Several VRP variants are commonly used, including Capacitated VRP, VRP with Time Windows (VRPTW), and Multiple Depot VRP (MDVRP). In this study, due to specific capacity constraints for vehicles involved in the product distribution process, a capacitated VRP model (CVRP) is chosen, where each vehicle starts and ends its route at the distribution center (DC) [18].

The model in this study is developed based on the research of Wang et al. [7], which discusses the development of an optimization model for the assortment packing process and the application of collaborative shipping on fashion products. Specifically, Wang et al. [7] focus solely on assortment packing and collaborative delivery from the distribution center (DC) to retail stores. In this study, the model is enhanced by integrating the product mix problem proposed by Butrat & Supsomboon [11] and incorporating the distribution routing model developed by Lalang et al. [13]. Consequently, the integrated model simultaneously addresses the product mix, assortment packaging, and distribution routing problems. Formulated a level above linear programming, the model is expressed in quadratic form with integer variables [19, 20]. A Proximal Interior-Point Quadratic Programming (PIQP) solver toolkit is utilized in the model formulation process. Following the linearization of the Mixed Integer Non-Linear Programming (MINLP) model, a Mixed Integer Linear Programming (MILP) model is formulated with the primary objective of minimizing total costs, including over/underload and transportation costs.

METHODS

System Description

XYZ Co., a leading retail company, has more than 2,000 retail stores across Indonesia and has a diverse portfolio of over 100 brands. Led by XYZ co. is the ABC brand, which is the focus of this research and specifically targets the

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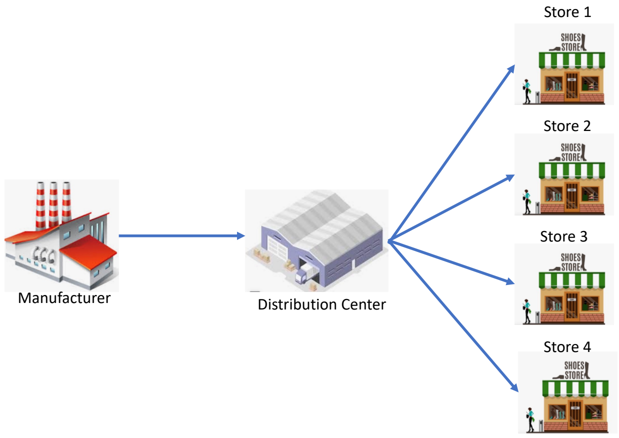

Figure 1. The distribution process flow of XYZ

four new retail stores in Jakarta and Banten region. Given their new status, these stores require special attention to ensure optimal service delivery to customers. For the product distribution process, ABC uses a single distribution center (DC) to facilitate the shipping of products from the manufacturer to its retail stores. The distribution process flow of PT XYZ is visually shown in Figure 1.

The number of products distributed to each retail store is determined by the merchandise team independently and based on expert opinions. In the discovery process, the merchandise team reviews past product sales data in each store, which can also be viewed through sales. Sell Through is a scoring matrix in the form of a percentage of sales of a product sold by retailers after it has been shipped from suppliers to individual stores [21]. In the next step, the merchandiser team analyzes the product sales data in more detail in terms of the model category and also the size of the product in each store. Based on the analysis results, the merchandiser team determines the number of future product demand. The final data is used as key considerations during the purchasing process and as reference data for the product allocation process. The process of determining product demand is shown in Figure 2.

ABC offers eighteen sandal products with different models, colors and sizes. October 2021 product allocation data and product demand data from each retail location are assumed to be consistent. The observations show that each product weighs approximately the same - one kilogram. We therefore assume that each product weighs 1 kg in order to simplify the problem. At the beginning of the supply chain, XYZ acts as a manufacturer by producing the product, providing the configuration box and handling the packaging. According to [22], four work stations are required to produce a sandal, each of which completes its own manufacturing process. The cutting, sewing, assembly and finishing processes (also called quality control or QC) are completed by workstation 1 to 4, respectively. After passing through these four work stations, the products go through a process of sorting and packaging into five different types of boxes with different configurations. The total amount of configuration boxes that DC sends to each retail location is equal to the number of configuration boxes sent to DC from the manufacturer. The transport vehicle is a box typed- pickup van with a payload of 1000 kg. There is only one carrier for the shipping process and the rental fee per day is IDR. 600,000. The vehicle begins distributing products from the distribution center to each retail location. Once each configuration box is delivered to each store, the vehicle returns to the DC point.

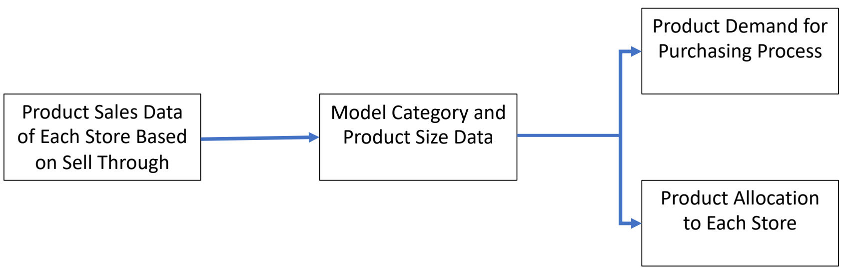

Figure 2. The Stages of The Process of Determining Product Demand

Model Development

Notation

i : The set of all products (1, 2, …, 18);
s : The set of all retail stores (1, 2, …, 5), where 1 represents the DC;
b : The set of all configuration boxes (1, 2, …, 5);
j : The set of all work stations (1, 2, …, 4);
l, m, n : Nodes index, where $l, m, n \in S$;

Parameters

d_{is} : Demand of product i at retail store s (unit);
c_{mn} : Shipping cost from point m to point n (IDR);
M_b : Maximum number of configuration box b (type);
w : Maximum capacity of the vehicle (unit);
g_i : Weight of product i (kg);
c_i : Production cost of product i (IDR);
F : The rental cost of a vehicle per day (IDR);
e_{ib} : Numbers of product i which can be packed into configuration box b (unit);
a_{ij} : Processing time of product i at work station j (mins.);
r : Available labor time resources (mins.);

Decision variables

t_{bs} : The number of configuration box b distributed to retail store s (type);
o_{is} : The number of overloads of product i at store s (unit);
u_{is} : The number of underloads of product i at store s (unit);
n_b : The number of configuration box b delivered to DC (type);
P_i : The production quantity of product i (unit);
X_{mn} : $\begin{cases} 1 & \text{if} \quad \text{vehicle delivers product from node } m \text{ to node } n \\ 0 & \text{otherwise} \end{cases}$

Assumption

The assumptions used in the preparation of this research are:

1. The real data for product allocation is the same as the product demand data for each store;
2. Shipping costs use the data in the research of [7] (see Appendix A.2);
3. The product value and its overload and underload penalty costs are equal with production cost;
4. The cost of shipping point m to point n is not the same as point n to point m;
5. The manufacturer is willing to provide and package products into 5 different types of configuration boxes;
6. Only one vehicle with a capacity of 1000 kgs is available;
7. The cost of renting a vehicle per day is IDR 600,000;
8. The working time of the workers in the factory is 480 minutes per day or 2880 minutes a week;
9. The time resources available at XYZ to fulfill demand are 25,000 minutes or 52 days;
10. The driver's rental fee is included in the cost of renting a vehicle for 1 day;
11. Each configuration box must be fully filled before being sent to each store.

Model Formulation

Objective Function

$$\text{Min } TPC = \sum_{i \in I} \sum_{s \in S} c_i (u_{is} + o_{is}) \quad (1)$$

$$\text{Min } TPS = \sum_{m \in DCS} \sum_{n \in S} (c_{mn} X_{mn}) \quad (2)$$

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s.t.:

$$\sum_{b\in B} e_{ib}t_{bs} - o_{is} + u_{is} = d_{is}, i \in \mathrm{I}, s \in S \quad (3)$$

$$o_{is}u_{is} = 0, i \in I, s \in S \quad (4)$$

$$\sum_{b\in B}\sum_{s\in S} t_{bs} \leq \sum_{b\in B} M_b \quad (5)$$

$$\sum_{b\in B} t_{bs} \geq 1, s \in S \quad (6)$$

$$\sum_{s\in S}\sum_{b\in B} e_{ib}t_{bs} \leq p_i,\ i \in I \quad (7)$$

$$\sum_{s\in S}\sum_{i\in I}\sum_{b\in B} e_{ib}t_{bs}g_i \leq w \quad (8)$$

$$\sum_{b\in B} e_{ib}n_b \geq \sum_{s\in S} d_{is},\quad i \in I \quad (9)$$

$$n_b = \sum_{s\in S} t_{bs}, b \in B \quad (10)$$

$$\sum_{n\in S} x_{1n} = 1 \quad (11)$$

$$\sum_{m\in S} x_{m1} = 1 \quad (12)$$

$$\sum_{m\in L\cup S} x_{mn} = 1,\ m \neq n,\ n \neq 1 \quad (13)$$

$$\sum_{m\in L\cup S} x_{mn} = 1,\ m \neq n,\ n \neq 1 \quad (14)$$

$$x_{mn} = 0,\ m = n \quad (15)$$

$$\sum_{m\in L\cup S} x_{ml} - \sum_{n\in L\cup S} x_{ln} = 0,\quad m \neq l, l \neq n, l \in S \quad (16)$$

$$\sum_{i=1}^{n} a_{ij}P_i \leq r, j \in J \quad (17)$$

$$t_{bs}, o_{is}, \mathrm{u_{is}}, N_b, P_i \geq 0 \text{ and integer} \quad (18)$$

$$x_{mn} \in \{0,1\} \quad (19)$$

The objective function of the model in this research is selected based on the result of interview with the decision maker of the company. They concerned with minimization of a total cost which comprises of two cost components i.e., the penalty cost of underload and overload (PC) and the shipping cost (SC). Equation (1) represents the penalty cost of underload and overload experienced any stores due to mismatch between demand of store and shipping quantity received from DC. Equation (2) is the cost incurred by the manufacturer whenever the product delivery is initiated from DC to each store.

The model constraints are explained as follows. Equation (3) is the demand constraint to ensure there is no uncounted demand, meaning that the total demand equals to sum of the number of products delivered to a certain store and underload product minus the overload product. The delivered product to any store is calculated in terms of the number of box and its capacity. Equation (4) denotes that the number of overload and underload product are mutually exclusive, which mean that those events cannot occur in the same time. Equation (5) describes the box capacity constraint to ensure the selected number of configuration box cannot exceed the maximum number of configuration box. Equation (6) restricts the demand at each store is not allowed to be completely unfulfilled. Equation (7) ensures the number of products sent to the retail stores cannot exceed the production capacity. Equation (8) limits the number of products which can be loaded and carried by the transportation vehicle. Equation (9) ensures the number of products received by DC at least equal to the number of product demand at each retail store. Equation (10) indicates the number of configuration boxes sent to the DC must be equal to the total number of configuration boxes sent to each store. Equations (11) and (12) ensures the shipping process from DC to each store started and ended at the DC. Equation (13) and (14) imposes a condition that each retail store can only be visited exactly once, where L and S denotes the set of products and stores. Equation (15) ensure there is no vehicle traveling from and to the same store at a time. Equation (16) describes that if the vehicle visits one retail store, it will leave the retail store and continue to visit the other retail stores. Equation (7) limits the number of products quantities which should not exceed the labor capacity. Finally, equation (18) and (19) presents non-negativity constraint and binary constraint, respectively.

Case Implementation

The data used in the case study were taken from XYZ Co. and shown in Appendix A1-A5. Appendix A1 shows product demand at each store, product weight, and product penalty cost. Appendix A2 shows the shipping costs from store m to store n. Appendix A3 shows the available number of configuration boxes. Appendix A4 shows the configuration of the box and processing time at each work station. Appendix A5 shows the time resource capacity of workers. The carrier capacity and its rental price were cited from [23] and [24] with the values as stated in the assumption sub-section.

Based on the result, the number of stores that experience overload is greater than the one that experience underload. Both underload and overload are caused by the difference between the product demand and the product received by the stores. In average, the percentage of the total overload across all stores only 12%, while for the underload it is only 2%. This phenomenon was happened due to the high production capacity of the manufacturer which makes the shipped product greater than the demand of each store. The optimal route of the carrier is DC → Store 1 → Store 2 → Store 4 → Store 3 → DC. The route gives the least cost among other alternative routes. For the optimal results of configuration box distribution and the respective routes are shown in Table 1.

RESUTS AND DISCUSSION

A Sensitivity analysis is a model development stage that is carried out to determine changes in the objective value due to the changing parameters and to determine the change interval limit so that the solution remains optimal [25]. In this study, sensitivity analysis was carried out by varying the values of certain important parameters of the model. The important parameters are the ones that have high possibility to change due to some environmental circumstances and expected to be highly sensitive to the model. The sensitivity analysis is performed to determine the model behavior so the company can anticipate any consequences and make the right decisions. In this research, the analysis is performed to three parameters. First, demand at each store (d_{is}) which has the possibility to change due to changes in trend each period. Form the company data, we change the demand data by -1, -6, +1, and +2 of the original values. The demand scenario represents the minimum and maximum number of the demand in the demand data. Second, the shipping costs (c_{mn}) which may change due to an increase in fuel price. The shipping cost

Table 1. Route and Distribution of Configuration Boxes

Location	Box configurations in vehicle	Arrival location	Box configurations dropped off upon arrival	Box configurations in vehicle after arrival
DC	Box Conf. 1:3 Box Conf. 2:6 Box Conf. 3:1 Box Conf.4:1 Box Conf 5:1	Store 1	Box Conf. 1:1 Box Conf. 2:1 Box Conf 5:1	Box Conf. 1:2 Box Conf. 2:5 Box Conf. 3:1 Box Conf.4:1
Store 1	Box Conf. 1:2 Box Conf. 2:5 Box Conf. 3:1 Box Conf.4:1	Store 2	Box Conf. 1:1 Box Conf. 2:2 Box Conf.4:1	Box Conf. 1:1 Box Conf. 2:3 Box Conf. 3:1
Store 2	Box Conf. 1:1 Box Conf. 2:3 Box Conf. 3:1	Store 4	Box Conf. 2:2 Box Conf. 3:1	Box Conf. 1:1 Box Conf. 2:1
Store 4	Box Conf. 1:1 Box Conf. 2:1	Store 3	Box Conf. 1:1 Box Conf. 2:1	-
Store 3	-	DC	-	

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Table 2 The Effect of Product Demand on The Objective Function

Change of Demand	Objective Function (IDR)	Change of Percentage (%)				
		Obj. Function	Overload	Underload	Production	Config.Box
-6	367,586,000	-22.05%	-21.00%	-13.00%	-34.00%	-33.00%
-2	479,997,000	1.78%	-2.00%	75.00%	-12.00%	-11.00%
0	471,580,000	0.00%	0.00%	0.00%	0.00%	0.00%
+1	546,165,000	15.82%	10.00%	106.00%	10.00%	6.00%
+2	556,130,000	17.93%	12.00%	150.00%	11.00%	11.00%

Table 3 The Effect of Shipping Cost on Objective Function

Change of Shipping Cost	Objective Function (IDR)	Change of Percentage (%)				
		Obj. Function	Overload	Underload	Production	Config.Box
-15%	457,751,000	-2.93%	-54.00%	0.00%	-32.00%	-33.00%
-5%	503,545,000	6.78%	-54.00%	0.00%	-32.00%	-33.00%
0%	471,580,000	0.00%	0.00%	0.00%	0.00%	0.00%
+5%	450,759,000	-4.41%	-54.00%	0.00%	-32.00%	-33.00%
+15%	446,425,600	-5.33%	-54.00%	0.00%	-32.00%	-33.00%

was changed by -5%, -15%, +5% and +15% of the original values. Third, product penalty costs (c_i) which may change due to the inflations with the change of -10%, -20%, +10%, and +10% of the original values.

The results of the sensitivity analysis of product demand on the objective function are shown in Table 2. From the table we can see that slightly decrease of product demand will have significant effect on the objective function. A decrease of the demand by 2 units will raise the cost by 1.78%, while the decrease of the demand by 6 units will decrease the total cost by 22.05%. Conversely, when the demand increases by 1 and 2 units, then the objective function will increase by 10.00% and 12.00% respectively. The effect of product demand on the decision variables are also shown in the table. From the table, the effect of the demand in line with the result on the objective function. The most significant effect can be found in underload product, in which the small increase of the demand will greatly increase the underload product. We conclude that the product demand sensitive to the objective function and all decision variables.

Table 3 shows the effects of changing the shipping cost on the objective function and decision variables. From the table we can see that the shipping cost has an insignificant effect on the objective function. An interesting result emerge from the sensitivity analysis in which the increase of shipping cost decreases the total cost by about 5%. From the results on the decision variables, we can understand the decrease of total cost. The increase of shipping cost will decrease all decision variables except the underload product. Hence, the shipping cost has significant effects on all decision variables except the underload product. Even the increase or decrease of shipping cost has no effect on the underload product.

Table 4 The Effect of Penalty Cost on The Objective Function and Decision Variables

Change of Demand	Objective Function (IDR)	Change of Percentage (%)				
		Obj. Function	Overload	Underload	Production	Config.Box
-20%	393,540,800	-16.55%	3.57%	37.50%	0.43%	0.00%
-10%	443,451,400	-5.96%	4.46%	25.00%	0.22%	0.00%
0	471,580,000	0.00%	0.00%	0.00%	0.00%	0.00%
+10%	501,224,400	6.29%	-2.68%	12.50%	-0.36%	0.00%
+20%	574,269,800	21.78%	1.79%	12.50%	9.29%	0.00%

The effects of penalty cost on the objective function and decision variables are shown in Table 4. The objective function linearly changes when the penalty cost changed. The increase percentage of penalty cost follows by almost the same increase percentage of the objective function. The decrease of penalty cost follows the same pattern. For the decision variables, the penalty cost has the most significant impact on underload product, and relatively has insignificant impact to the other decision variables. We can also see from the table that increasing number of underload product prohibits more configuration box shipment which make the demand cannot fully fulfilled.

CONCLUSION

We developed an integrated model with the aim at determining the optimal number of productions, assortment packing, and product distribution routes. The objective function of the model was to minimizing the total cost consisting of shipping costs and penalty costs for overload and underload products at the store. Based on the results of sensitivity analysis, the objective function is sensitive to the changes of two parameters, namely the demand and penalty cost. While for the decision variables, all of the decision variables are sensitive to the changes of the demand. Overload product also sensitive to the changes of shipping cost, while underload product is sensitive to the penalty cost. Several points should be given for further research. This study considers only one manufacturer, one DC, and several stores. This can be further developed by expanding the system to include multi manufacturers, multi-DC and multi store. In addition, other considerations for further development include the inclusions of uncertainty in several parameters and sustainability in manufacturing and transportations.

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CONFLICT OF INTEREST

This research has been conducted with the utmost integrity and adheres to ethical standards. The author declares no conflicts of interest that could potentially influence the interpretation or presentation of the research findings.

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Appendix

A.1. Demand data and product penalty cost

Product	Product Demand				Weight (kg)	Product Penalty Cost (IDR)
	1	**2**	**3**	**4**		
1	16	20	16	8	1	2,099,000
2	12	20	12	8	1	2,099,000
3	12	12	8	4	1	2,099,000
4	12	24	16	8	1	2,099,000
5	16	24	16	12	1	2,099,000
6	12	24	20	12	1	2,099,000
7	12	20	12	12	1	2,099,000
8	12	16	8	8	1	2,099,000
9	12	16	12	4	1	2,099,000
10	12	20	12	8	1	2,099,000
11	12	16	12	4	1	2,099,000
12	8	12	16	4	1	2,099,000
13	12	12	12	4	1	1,599,000
14	12	12	8	8	1	1,599,000
15	8	12	12	4	1	1,599,000
16	16	20	16	8	1	1,599,000
17	8	12	8	4	1	1,599,000
18	8	12	8	4	1	1,599,000

A.2. Unit shipping costs (IDR)

	Nodes n					
		DC	**Store 1**	**Store 2**	**Store 3**	**Store 4**
Nodes m	**DC**	0	30,000	43,000	37,000	39,000
	Store 1	50,000	0	31,000	32,000	48,000
	Store 2	45,000	36,000	0	42,000	40,000
	Store 3	37,000	33,000	36,000	0	49,000
	Store 4	42,000	34,000	41,000	38,000	0

A.3. The number of configuration box

Configuration Box	Number of Corresponding Boxes
1	5
2	10
3	3
4	2
5	3

A.4. Box configuration and processing time at each work station

Product	Configuration Box					Work Station			
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**
1	4	6	5	4	7	9	2	8	1
2	5	6	3	5	4	9	2	8	1
3	2	4	3	5	7	9	2	8	1
4	3	7	2	5	2	9	2	8	1

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A.4. (Cont.)

Product	Configuration Box					Work Station			
	1	2	3	4	5	1	2	3	4
5	6	6	5	6	4	9	2	8	1
6	5	7	6	3	2	9	2	8	1
7	5	6	2	2	3	9	2	8	1
8	7	3	4	4	2	9	2	8	1
9	3	4	4	2	5	9	2	8	1
10	6	5	5	7	2	9	2	8	1
11	2	5	3	5	5	5	1	4	1
12	4	3	3	4	3	5	1	4	1
13	3	4	6	6	7	5	1	4	1
14	6	2	4	3	4	5	1	4	1
15	2	4	4	3	5	5	1	4	1
16	5	6	6	5	6	5	1	4	1
17	3	3	4	3	2	5	1	4	1

A.4. Available capacity of workers

No	Work Hour	Unit
1	15	Day
2	7200	Minute

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