Model for Job Order Allocation to Suppliers Considering Transportation and Manufacturing Costs

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Abstract. In the manufacturing industry, there is a tendency that will continue to strengthen in the future is how to produce in a network. This development is causing one foreign electronics companies in Indonesia changes the way its produce the products. The increasingly fierce competition in the electronics market makes the company made further changes where plants owned by the company only do the final assembly of the product while all components, sub-assemblies, and main-assemblies made in the company's network. The condition raises the issue to determine the allocation of job order both components, sub-assemblies and major assemblies to generate a production plan to meet demand at the lowest cost. The model developed here is a type of mixed integer programming models. The objective function is to minimize the costs of production, assembly, and transportation in all stages of making the components, assembly of sub-assemblies, the assembly of the main-assembly, and final product assembly. Numerical exercise on one product of the company, that is DVD player, shows that the priority decision on allocation of job order will be on the plants that have the lowest cost, the available capacity, and the minimum number of order simultaneously.

Keywords: production network, multi-plant, supply chain, job allocation, mixed integer programming

1. INTRODUCTION

In the manufacturing industry, there is a tendency that will continue to strengthen in the future is how to produce in a network. The competitive environment in the manufacturing industry today demand the fulfillment of the required value by customers who increasingly difficult to meet if a manufacturing company performs all the activities of design, fabrication, assembly, and distribution alone. Establishment of a network of cooperation with other manufacturing companies can produce better performance and fit for the challenges of the current competition for a manufacturing company can obtain economical production costs as well as the resources and competencies that are superior through this collaboration (Wiendhl & Lutz, 2002).

This development is causing a foreign electronics companies in Indonesia make changes to how production performed. During this time, the company has factories that make products fully but then to transfer the manufacture of some sub-assemblies to several suppliers through a long-term contract. The increasingly fierce competition in the electronics market makes the company initiated further changes where plants owned by the company only do the final assembly of the product. All components, sub-assemblies, and major assemblies handed over to other companies that become suppliers, because of this arrangement of production in a network, the company's production costs becomes cheaper.

These changes lead to new problems, namely how to plan production involving production facilities outside the company. The supplier company in cooperation networks is located in various places that have the ability to make different components, sub-assemblies, or main-assemblies. Similarly, the cost of production and assembly in every company is different although the suppliers produce the same components, sub-assemblies, and main-assembly. In addition, differences in geographic location of the suppliers raises varied transport costs. The condition raises the issue to determine the allocation of job order both components, sub-assemblies and major assemblies to generate a production plan to meet demand at the lowest cost.

Research conducted by Tseng et al (2007), generating a model to resolve the issue of determination of assembly sequence and its place for assembly of sub-assembly, main-assembly, and final assembly of a product in the manufacturing collaboration system environment. The model decides the assembly sequence and location of the factory where the assembly performed so in order to obtain the lowest assembly costs for the product. Thus, this model is not yet a production plan but more on planning the assembly process that determines the best assembly sequence that take advantage of the assembly at several different locations. The lowest assembly cost, which also includes the cost of transportation between the locations of the assembly, is the performance criteria used for determine the assembly sequence and location.

Tseng et al (2008) continued the research by considering the phases of fabrication of components that may affect the assembly process. On a collaboration system manufacturing, fabrication of components made in factories that work which has the ability of different manufacturing process that can produce different tolerances. Different process capability that affects components tolerance will affect the assembly process at a later stage. Therefore, Tseng et al developed a model of two stages where the first stage is the determination of the location of fabrication of components to obtain the best tolerance according to the design of products that followed by the second stage of the model to determine the location of the assembly. Again, the model is in assembly plan stage with different to the model developed in this research that belongs to operation stage.

Cheng et al (2009) conducted a study on problems similar to the ones in this study. The study determined the allocation of order execution on multiple suppliers by considering the balance loading on each supplier. Similar research was also conducted by Xiang et al (2012), where the allocation considering the balance of load on each supplier.

In this study, which involves the manufacture of electronic products DVD player, the company's suppliers doing the assembly process in addition of a processing before the assembly process performed. The network consists of four levels. On the first level is the finished product fabricator who holds the brand products. Thus, there is only one final product assembly plant. The second level is a supplier company assembling the main assembly. The main assembly of the product DVD is composed of several types. Similarly, the plant at this level consists of several factories with capacity for assembling of different types of major assemblies. At the next level, there are several sub-assembly supplier factories. Sub-assemblies that can be created in any supplier also vary. On the fourth level or the last, is the supplier who prepared the components for delivery to the company's suppliers in level three.

2. MODEL DEVELOPMENT

On this model, each supplier plant that is at the level of 2, 3, and 4 has a production capacity that is different and has different production capabilities demonstrated by the difference in the cost and time of production or assembly. Order allocation to each supplier at levels 2, 3, and 4, limits by the minimum number of orders for the respective supplier. Thus, the allocation to each supplier and orders placed are multiples of this minimum order.

Product demand occurs in the final product assembly plant or at the network level 1. Demand is deterministic and allocation of work done for one event order. Transportations conducted simultaneously by assuming the vehicle is always available. Calculation of transport deemed to include both the departure and the return of origin and destination. In this model, there is only one type of product.

The objective function of the model developed is minimizing the total cost of production of the product. Total cost of production here consists of the cost of manufacturing, subassembly plant costs, the cost of a main-assembly plant and the costs of final assembly plant. Activities performed on the real conditions in the network is in addition to the existing assembly and processing activities, there is also a quality inspection activities and the use of material handling that should be considered. The input variable in this study is the demand of production and product structure. The decision variables in this study are the number of orders for each of the components, sub-assemblies, and main-assemblies along with the location where the order allocated. For a final product assembly because there is only one location then it is not consider as a decision variable.

Supplier plants on the fourth level providing components notated e (where e = 1, 2, .. E) shows supplier factories in fourth level that the 1st, 2nd, until all E. By the same token supplier factories in third level denoted by f ($f = 1, 2, \ldots,$ F) ; supplier factory in level two is denoted by g ($g = 1, 2, \ldots,$ G). The final product assembled in one final product plant denoted by h.

At each plant at all levels, except at the first level (component makers), there are activities of set up, processing, assembly, quality inspection, and material handling. At the first level factory all those activities are performed unless the activities of the assembly. Each of these activities has a different time on each plant. To carry out these activities incurred costs that become parameters in this model as follows:

At the component plant *e*:

P_{ae} = cost of processing component a in the plant component e per unit time, where $a = 1, 2, \ldots, A$).

S_{ae} = cost of set up component a in the plant component e per unit time.

C_{ae} = cost of quality inspection of component a in the plant

component e per unit time.
M_{ae} = cost of material handling components a in the plant component e.

At sub-assembly plant *f*:

P_{bf} = cost of processing sub-assemblies b at the sub-assemblies plant f per unit time, where $b = 1, 2, \ldots, B$)
A_{bf} = assembly cost of sub-assemblies b at the sub-assemblies plant f per unit time of assembly
S_{bf} = cost of set up sub-assemblies b at the sub-assemblies plant f per unit time
C_{bf} = costs of quality inspection of sub-assemblies b in the sub-assemblies plant f per unit time
M_{bf} = cost of material handling sub-assemblies b in the sub-assemblies plant f.

At main-assembly plant *g*:

P_{cg} = main-assembly c processing cost at the main-assembly plant g per unit time, where $c = 1, 2, \ldots, C$)
A_{cg} = main-assembly c assembly costs at the main-assembly plant g per unit time
S_{cg} = main-assemblies c set up cost on the main-assembly plant g per unit time
C_{cg} = main-assembly c quality inspection cost in the main-assembly plant g per unit time
M_{cg} = main-assemblies c i material handling cost at the main-assembly plant g.

At the end product plant *h*:

P_{fah} = final product fa processing cost at the end product plant h per unit time, where $fa = 1$)
A_{fah} = cost of final product assembly at the end product plant h per unit time
S_{fah} = cost of the final product set up at the end product plant h per unit time
C_{fah} = cost of the final product quality inspection up at the end product plant h per unit time
M_{fah} = cost of material handling products in the factory fa final end product h.

For setup activities, assembly, processing, and quality inspections at each factory are denoted as follows:
tp_{ae} = processing time of component a in component plant e
tc_{ae} = quality inspection time of component a in component plant e
ts_{ae} = set up time of component a in component plant e
tp_{bf} = processing time of sub-assemblies b in sub-assemblies plant f
ta_{bf} = assembly time of sub-assemblies b in sub-assemblies plant f
tc_{bf} = quality inspection time of sub-assemblies b in sub-assemblies plant f
ts_{bf} = set up time of sub-assemblies b in sub-assemblies plant f
tp_{cg} = processing time of main-assemblies c in main-assemblies plant g
ta_{cg} = assembly time of main-assemblies c in main-assemblies plant g
tc_{cg} = quality inspection time of main-assemblies c in sub-assemblies plant g
tc_{cg} = set up time of main-assemblies c in main-assemblies plant g
tp_{fah} = processing time of final product fa in final product plant h
ta_{fah} = assembly time of final product fa in final product plant h
tc_{fah} = quality inspection time of final product fa in final product plant fa
ts_{fah} = set up time of final product fa in final product plant h

In every plant there is a maximum capacity and minimum order quantity allowed. At the components plant, sub-assemblies and main-assemblies plants, the maximum capacity are denoted as KAP_e, KAP_f , and KAP_g . While the minimum order amount on components plant, sub-assemblies and main-assemblies' plants are respectively MP_e , MP_f , and MP_g .

For transportation activities between the plants at every level, use the following notations:
HS = fuel price per liter
J_{ef} = distance component plant e to sub-assemblies plant f
J_{fg} = distance sub-assemblies plant f to main-assemblies plant g
J_{gh} = distance main-assemblies plant g to final product plant h
T_e = ratio of fuel usage for transportation from component plant e (liter per kilometer)
T_f = ratio of fuel usage for transportation from sub-assemblies plant f (liter per kilometer)
T_g = ratio of fuel usage for transportation from main-assemblies plant g (liter per kilometer)

Product has an assembly structure and the notation fir this respects are as follows:
IK_{ab} = number of components a needs to form sub-assembly b corresponding to product structure
ISU_{bc} = number of sub-assemblies b needs to establish the main-assembly c corresponding to product structure
ISE_{cd} = number of main-assemblies c needs to establish the final product d corresponding to product structure

The model developed here is a type of mixed integer programming models. The objective function is to minimize the costs of production, assembly, and transportation in all stages of making the components, assembly of sub- assemblies, the assembly of the main-assembly, and final product assembly. On the other hand, the decisions are made up of three groups of decisions. The first group is the decision on determination of place at component plant e for component a, the amount of components allocated, and determination of transportation destination of the components to meet the needs of sub-assembly plant f. The second is the determination of the place for assembly of sub-assemblies b at the sub-assemblies plant f, the amount of sub-assemblies allocated, and determination of transportation destination of the sub-assemblies to meet the needs of main-assembly plant *g*. The third is the determination on the location of the main-assembly *c* assembling at main assembly plant *g*, the amount of allocation, and determination of transportation destination of the main-assemblies to meet the needs of final-product plant *h*. These decisions stated as follows:

$$V_{aef} = \begin{cases} 1, & if\ component\ a\ produce\ in\ plant\ e\ for\ meeting\ demand\ of\ plant\ f \\ 0, & else \end{cases}$$

$$Vs_{bfg} = \begin{cases} 1, & if\ sub\ assembly\ b\ produced\ in\ plant\ f\ for\ meeting\ demand\ of\ plant\ g \\ 0, & else \end{cases}$$

$$Vse_{cgh} = \begin{cases} 1, & if\ main\ assembly\ c\ produce\ in\ plant\ g\ for\ meeting\ demand\ of\ plant\ h \\ 0, & else \end{cases}$$

$$X_{aef} = number\ of componen\ a\ order\ in\ plant\ e\ for\ meeting\ demand\ of\ plant\ f$$

$$X_{bfg} = number\ of sub\ assembly\ b\ order\ in\ plant\ f\ for\ meeting\ demand\ of\ plant\ g$$

$$X_{cgh} = number\ of main\ assembly\ c\ order\ in\ plant\ g\ for\ meeting\ demand\ of\ plant\ h$$

$$Y_{aef} = \begin{cases} 1, & if\ component\ a\ have\ similar\ origin\ from\ plant\ e\ and\ destination\ to\ plant\ f \\ 0, & else \end{cases}$$

$$Z_{bfg} = \begin{cases} 1, & if sub\ assembly\ b\ have\ similar\ origin\ from\ plant\ f\ and\ destination\ to\ plant\ g \\ 0, & else \end{cases}$$

$$W_{cgh} = \begin{cases} 1, & if\ main\ assy\ g\ have\ similar\ origin\ from\ plant\ g\ and\ destination\ to\ plant\ h \\ 0, & else \end{cases}$$

The objective function is the minimization of the costs incurred in all stages of product manufacturing is the cost at the manufacturing stage (O_m), costs at stage of subassembly (O_{su}), costs at the stage of the main assembly (O_{se}), and the cost of the final stages of assembly (O_{fa}).

Costs at the manufacturing stage derived from all the activities set up, process, quality inspection, material handling performed by components plant in accordance with a request from the sub-assembly plant *f* plus the cost of transporting the components from plant *e* to plant *f*. The formula for it is:

$$O_m = \sum_{a=1}^{A}\sum_{e=1}^{E}\sum_{f=1}^{F} S_{ae} \times ts_{ae} \times V_{aef} + \sum_{a=1}^{A}\sum_{e=1}^{E}\sum_{f=1}^{F}(P_{ae} \times tp_{ae} + C_{ae} \times tc_{ae} + M_{ae}) \times X_{aef} + \sum_{a=1}^{A}\sum_{e=1}^{E}\sum_{f=1}^{F} T_e \times 2j_{ef} \times Y_{aef} \times HS \quad (1)$$

Costs at the stage of sub-assembly are all expenses incurred on plant *f* selected to meet the demand of the main assembly of plant *g*. Costs incurred for the activities set up, processing, assembling, quality inspection, and material handling. The formulation of these costs is:

$$O_{su} = \sum_{b=1}^{B}\sum_{f=1}^{F}\sum_{g=1}^{G} S_{bf} \times ts_{bf} \times V_{bfg} + \sum_{b=1}^{B}\sum_{f=1}^{F}\sum_{g=1}^{G}(P_{bf} \times tp_{bf} + A_{bf} \times ta_{bf} + C_{bf} \times tc_{bf} + M_{bf}) \times X_{bfg} + \sum_{b=1}^{B}\sum_{f=1}^{F}\sum_{g=1}^{G} T_f \times 2j_{fg} \times Z_{bfg} \times HS \quad (2)$$

The cost of the main assembly stages are all costs incurred in the main assembly plant *g* selected to meet the demand for the end product of final product assembly plant *h*. The costs are:

$$O_{se} = \sum_{c=1}^{C}\sum_{g=1}^{G}\sum_{h=1}^{H} S_{cgh} \times ts_{cg} \times Vse_{cgh} + \sum_{c=1}^{C}\sum_{g=1}^{G}\sum_{h=1}^{H}(P_{cg} \times tp_{cg} + A_{cg} \times ta_{cg} + C_{cg} \times tc_{cg} + M_{cg}) \times X_{cgh} + \sum_{c=1}^{C}\sum_{g=1}^{G}\sum_{h=1}^{H} T_g \times 2j_{gh} \times W_{cgh} \times HS \quad (3)$$

For the final product assembly, it is performed only at one final product plant *h*, so the cost is as follows:

$$O_{fa} = (S_{fah} \times ts_{fah}) + (A_{fah} \times ta_{fah} + C_{fah} \times tc_{fah} + M_{fah}) \times X_{fah} \quad (4)$$

Constraints on this model are as follows:
Constraints belong to transportation are aimed at ensuring that transportation will only be done from one plant to another plant if there is a demand on the plant and constraint needed to ensure that there is only once delivery of goods (component or assembly) from origin plant to destination plant. This applies to the plant at all levels. The constraints are as follows:

$$X_{aef} \geq Y_{aef} \qquad \forall a \in A, \forall e \in E, \forall f \in F \quad (5)$$

$$\sum_{a=1}^{A} Y_{aef} = 1 \qquad Y_{aef} \in 0{,}1\ \forall f \in F, \forall e \in E \quad (6)$$

$$X_{bfg} \geq Z_{bfg} \qquad \forall b \in B, \forall f \in F, \forall g \in G \quad (7)$$

$$\sum_{b=1}^{B} Z_{bfg} = 1 \qquad Z_{bfg} \in 0{,}1\ \forall g \in G, \forall f \in F \quad (8)$$

$$X_{cgh} \geq W_{cgh} \qquad \forall c \in C, \forall g \in G, \forall h \in H \quad (9)$$

$$\sum_{c=1}^{C} W_{cgh} = 1 \qquad W_{cgh} \in 0{,}1\ \forall h \in H, \forall g \in G \quad (10)$$

Constraints on availability of plant capacity:

$$\sum_{a=1}^{A}\sum_{f=1}^{F} X_{aef} \leq KAP_e \qquad \forall e \in E \quad (11)$$

$\sum_{b=1}^{B}\sum_{g=1}^{G} X_{bfg} \le KAP_f \qquad \forall f \in F \qquad (12)$

$\sum_{c=1}^{C}\sum_{h=1}^{H} X_{cgh} \le KAP_g \qquad \forall g \in G \qquad (13)$

Constraints on set up to ensure that if at the factory job is allocated, then there will be set up and set up process appears only once for all similar order the same at the plant.

$X_{aef} \ge V_{aef} \qquad \forall a \in A, \forall e \in E, \forall f \in F$ (14)

$\sum_{f=1}^{F} V_{aef} = 1 \qquad V_{aef} \in 0,1 \qquad \forall e \in E, \forall a \in A$ (15)

$X_{bfg} \ge Vs_{bfg} \qquad \forall b \in B, \forall f \in F, \forall g \in G$ (16)

$\sum_{g=1}^{G} Vs_{bfg} = 1 \qquad Vs_{bfg} \in 0,1 \qquad \forall f \in F, \forall b \in B$ (17)

$X_{cgh} \ge Vse_{cgh} \qquad \forall c \in C, \forall g \in G, \forall h \in H$ (18)

$\sum_{h=1}^{H} Vse_{cgh} = 1 \qquad Vse_{cgh} \in 0,1 \qquad \forall g \in G, \forall c \in C$(19)

Constraints on minimum order quantities on each supplier's plant are as follows:

$\sum_{f=1}^{F} X_{aef} \ge MP_e \qquad \forall e \in E, \forall a \in A$ (20)

$\sum_{g=1}^{G} X_{bfg} \ge MP_f \qquad \forall f \in F, \forall b \in B$ (21)

$\sum_{h=1}^{H} X_{cgh} \ge MP_g \qquad \forall g \in G, \forall c \in C$ (22)

Constraints for representing fulfillment of demand on each item (component or assembly) must be in accordance with the product structure are interconnected. These constraints must be adapted to the structure of the product in the problem. In the test model of a product that used as an example is a DVD player with a product structure that depicted in Figure 1. It states that the number of order of one type of goods (component or assembly) on all plant components or assemblies plant in the upper level equal to the number of overall demand.

Last constraints are non-negative constraints as follows:

$X_{aef} > 0 \qquad \forall a \in A, \forall e \in E, \forall f \in F$ (23)

$X_{bcg} > 0 \qquad \forall b \in B, \forall f \in F, \forall g \in G$ (24)

$X_{cgh} > 0 \qquad \forall c \in C, \forall g \in G, \forall h \in H$ (25)

3. NUMERICAL EXERCISE

The model tested on a DVD player product made by the company. Production networks involved consists of four plant supplier at manufacturing stages, three plant suppliers at sub-assembly stages, three main-assembly suppliers plant at main-assembly stage, and the final assembly plant that also acts as a holder of the brand. Product DVD player has a structure as shown in Figure 1.

From Figure 1 it can be seen that the product DVD player has two parts main-assembly (C1 and C2), 12 parts sub-assembly (B1 , B2 , B3 , B4 , B5 , B6 , B7 , B8 , B9 , B10 , B11 , B12) as many as 16 pcs, and 21 components with a total of 24 pcs . The final demand on these products amounted to 100 units. The capacity of each plant described in Table 1 and the location of factories in the network described in Table 2.

With all the parameters are known, the solution generates from the allocation model developed is depicted in Figure 2.

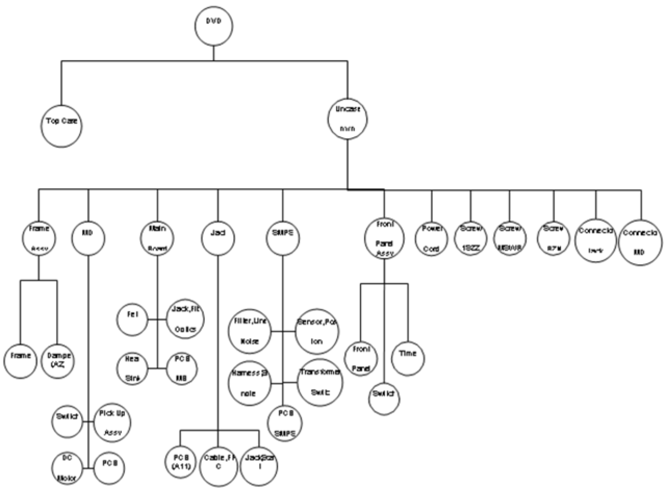


Figure 1: Product assembly structure

Table 1: Plants' Capacity

Plant	Capacity (unit)
Plant (e1)	475
Plant (e2)	750

Plant (e3)	175
Plant (e4)	1000
Plant (f1)	175
Plant (f2)	450
Plant (f3)	975
Plant (g1)	50
Plant (g2)	80
Plant (g3)	70
Plant (h)	475

4. DISCUSSIONS

Solution provided by the model on DVD case, shows that the decision of allocation of job order prioritized on the plants that has the lowest cost, the available capacity, and the minimum number of order simultaneously. Therefore, if the number of demand is equal to the amount of capacity in one of the plant with the lowest cost, then one of that plant will only meet the demand.

Experiments in the form of a sensitivity analysis conducted to see the behavior of the model as well as to verify the model. The sensitivity analysis conducted by three experiments by varying the cost of manufacturing of the components frame at supplier in component plant stage, varying supplier capacity plant at sub-assembly stage, and varying assembly time at main-assembly of uncase DVD at the main assembly stage.

Table 2: Distance data from plant to plant in the network.

From to	e1	e2	e3	e4	f1	f2	f3	g1	g2	g3	h
e1	-	-	-	-	16	18	15	-	-	-	-
e2	-	-	-	-	17	15	14	-	-	-	-
e3	-	-	-	-	15	16	17	-	-	-	-
e4	-	-	-	-	18	16	18	-	-	-	-
f1	16	18	15	16	-	-	-	0	14	11	-
f2	17	15	14	17	-	-	-	10	0	12	-
f3	15	16	17	15	-	-	-	15	14	0	-
g1	-	-	-	-	0	14	11	-	-	-	10
g2	-	-	-	-	10	0	12	-	-	-	14
g3	-	-	-	-	15	14	0	-	-	-	12
h	-	-	-	-	-	-	-	10	14	12	-

The distance in kilometers; *e* = a supplier of components, f = supplier of sub- assemblies, g = main assembly suppliers, h = assembler of the final product.

Figure 2: Allocation Results

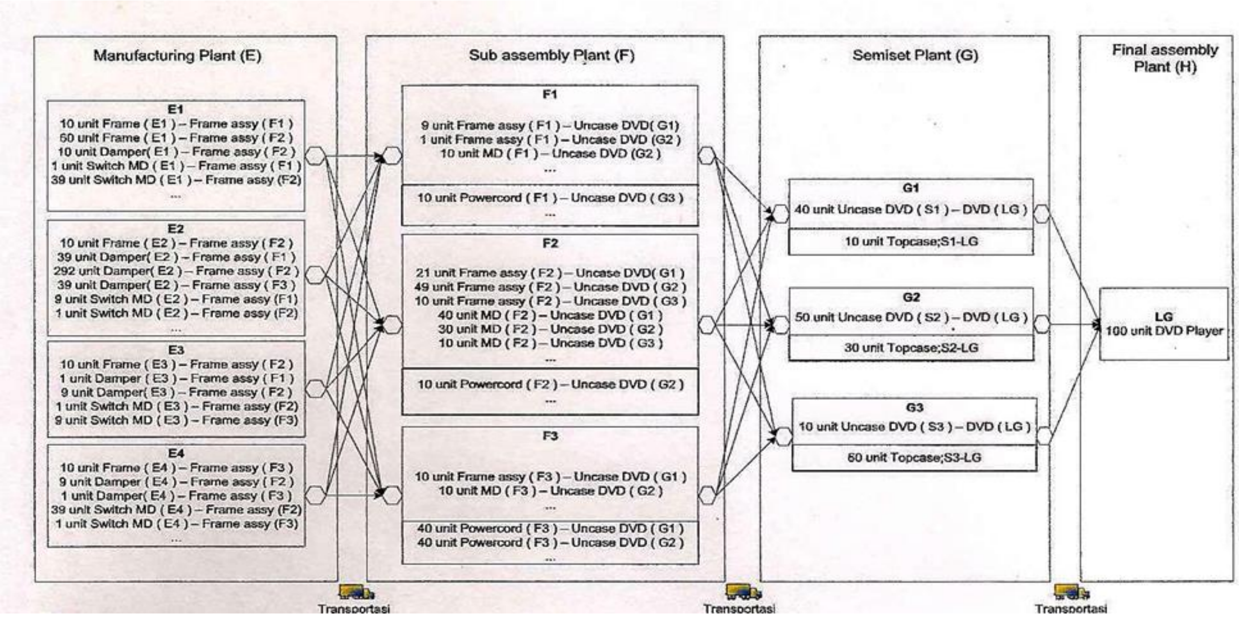
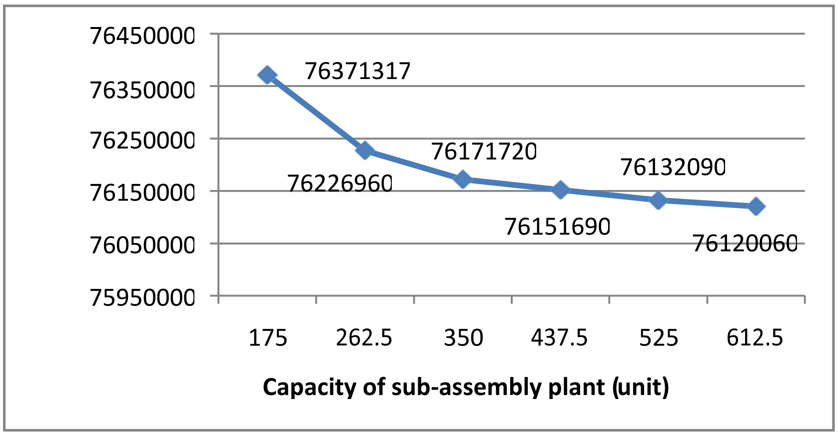


Figure 3: Effects of capacity increment on Sub-Assembly Plant to total cost



Changes in cost is done by adding the cost of manufacturing the components of the frame at component plant suppliers gradually by 50 % , 100 % , 150 % , 200 % and 250 %. Increased cost on suppliers' component plant would mean that the supplier is less efficient. Thus, sensitivity analysis performed here is to examine the effect of suppliers' efficiency in the decision of allocation. The increment of the cost on manufacturing of the components frame at the supplier plant will result in a change of the result of a job order allocation and increase the total cost of production. Changes solution results occurred only at the incremental cost of manufacturing by 50%. As for the addition of over 50%, although it affects the increase in production costs but does not change the job allocation of the order.

Capacity variation performed by adding a sub-assembly plant capacity gradually by 50 %, 100 %, 150 %, 200 %, and 250 %. Additional capacity of sub-assembly plant means the sub-assembly plant suppliers make a long-term investment to become more competitive by increasing the production capacity of the plant. Main objective of this sensitivity analysis is to examine the effect of suppliers' capacity expansion to the job allocation decision. Figure 3 described the effect of capacity changes. Additional production capacity at sub-assembly plant supplier will result in changes combination of number and location of the order, which then lowers the total cost of production. However, at a certain point the capacity addition does not affect the reduction in total costs as the final product demand remains.

The last sensitivity analysis performed for examining the effects of assembly time in main-assembly plant to allocation decision. Changes in assembly time mean changes in assembly efficiency of the main-assembly plant. In this case the assembly time of DVD gradually increased by 50 %, 100 %, 150 %, and 200 % and 250 %. The results obtained with the addition of time will lead to changes in the combination of the number and location of the order, which then increases the total cost of production. However, changes only occurred when additional assembly time by 50%. As for the increment of over 50%, although it increased the total production costs but does not change the combination of the number and location of the order.

5. CONCLUSIONS

Model developed has successfully solved the problem faced by an electronics company that works in a production network. This model applied for various forms of the production network.

The behavior of the model indicates that the job allocated to plants that have a combination of lowest costs, large capacity, and large minimum order. The more efficient the plants within networks the more possibility job will be allocated to the plants. If the final demand remains and the network plants' efficiency reduced, the total cost will increased but at a certain rate of inefficiency the cost will not significantly increased.

Further development expected to do is to consider production planning within a longer period so that aspect of balancing the allocation of orders will be taken into consideration.

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