ICEB 2005 Proceedings

International Conference on Electronic Business (ICEB)

Winter 12-5-2005

Multi-Plant Assembly Planning Model in Collaborative Manufacturing and Commerce Systems

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Abstract: With emerging e-business models in a global supply chain, the components or parts of a product may be distributed and produced at various plants in a collaborative way for the purpose of expanding capacity and reducing costs. For an assembled product, the assembly operations for assembling the product may be performed at different assembly plants at various geographical locations. In the collaborative commerce environment, it is required to develop a multi-plant assembly planning model for organizing and distributing the assembly operations to the suitable plants for completing the final product. In this research, a multi-plant assembly planning model for generating and evaluating the multi-plant assembly sequences is presented. A graph-based model is developed to model and generate the assembly sequences. The feasible assembly sequences are analyzed and evaluated based on several cost objectives. The multi-plant assembly planning model is formulated with an aim of minimizing the total of assembly costs and multi-plant costs. As a result, the optimized multi-plant assembly sequences can be obtained and each of the assembly operations is assigned to the suitable plant with a minimized cost. Example parts are tested and discussed.

Keywords: Collaborative commerce; SCM; Collaborative manufacturing; Assembly planning; Multi-plant.

I. Introduction

The main purpose of assembly planning is to organize a proper assembly sequence with which the components can be grouped or fixed together to construct a final product. A component is a basic part where no assembly operation occurs. A subassembly is a group of assembled components built for certain functional or manufacturing purposes, but a subassembly is not a final product. An assembly is a final product in which all the components are assembled. An assembly sequence is an ordered assembly operations for grouping and fixing the components and subassemblies to create the final product.

In the related research for assembly planning, it can be summarized that assembly planning can be performed in three stages: (1) assembly modeling and representation, (2) assembly sequence generation, and (3) assembly analysis and evaluation. A recent review can be found in Abdullah *et al.* (2003) in which the research into software and other tools

Proceedings of the Fifth International Conference on Electronic Business, Hong Kong, December 5-9, 2005, pp. 851 - 855.

to support the closely related methodologies of assembly system selection, design for assembly, and assembly planning is reviewed. The previous research in assembly planning can be classified into three categories based on different approaches and purposes. The first category uses rules or knowledge bases to perform generation of different assembly sequences such as developed in Baldwin *et al*. [1], Tonshoff [12], Ye and Urzi [14], and Swaminathan and Barber [11]. The second category presents automatic generation of feasible assembly sequences using graph representation forms. Various graph-based representation schemes are presented in Homem de Mello and Sanderson [7], Santochi and Dini [10], and Lin and Chang [9], and Choi *et al.* [5]. The third category focuses on assembly analysis and evaluation for searching the better or the optimal assembly sequence. The research in this class includes Homem de Mello and Sanderson [7], Ben-Arieh and Kramer [3], Laperriere and ElMaraghy [8], , Gottipolu and Ghosh [6], Zha *et al.* [15] , Zhao and Masood [16], Tseng and Liou [13], and Chen *et al*. [4].

In a typical assembly planning scheme, the assembly sequences for producing a product are designed and arranged to be performed in a single plant. The available assembly operations and assembly workstations are restricted in a single plant. Also, the assembly costs associated with the assembly operations are constrained in a specific plant location.

In a multi-plant collaborative commerce model, a product can be designed and manufactured at different plants at multiple locations. Due to the increasing product complexity and increasing production scale, a multi-plant manufacturing scheme is usually adopted to reduce production costs, enhance product variety, and to expand production capacity. For an assembly product, the multi-plant system may be composed of several manufacturing plants and multiple assembly plants located at different geographical locations. It is important to find the best place to manufacture each component, the best place to assemble the components and subassemblies, and the best place to assemble the final product. Therefore, it is required to develop a multi-plant assembly planning model to integrate the cross-plant resources and costs.

In this research, a multi-plant assembly planning model is presented. In this multi-plant model, the components and subassemblies are distributed and assembled at different plants. In a multi-plant assembly sequence, each plant is assigned and arranged to perform a portion of the assembly operations to complete the product. At the final step, the components and subassemblies are gathered and assembled to build the final product at the final plant.

A graph-based model is developed to formulate the multi-plant assembly sequences. The assembly sequences are analyzed and evaluated based on assembly operation costs and multi-plant costs. The following model Assembly Sequence Tree (AST) describing the relationship between components and subassemblies of a product is introduced. The graph-based tree representation model is developed to generate and represent the feasible assembly sequences. With the feasible assembly sequences as input, a linear programming model is formulated to evaluate all the feasible assembly sequences. The objective attempts to find the optimized multi-plant assembly sequences with the lowest cost. As a result, the multi-plant assembly sequences can be evaluated and the assembly operations are assigned to the most suitable plants.

II. Graph-Based Model for Eprese-Nting Assembly Sequences

In this research, a graph-based model is developed for representing the components and the assembly operations. The graph-based model is used as input for generating the feasible sequences. The feasible sequences are then evaluated in the next section.

A graph-based tree called Assembly Sequence Tree (AST) is developed to represent the feasible assembly sequences. A directed graph G = (E, P) is used to represent an AST where E is the set of component nodes and P denotes the set of linking arcs between nodes. A linking arc from node i to node j is represented by an operation arc in P and is denoted as pk. An operation arc represents the assembly operation required to assemble the two component nodes. The precedence is represented by the directed linking arc from node i to node j. Each graph contains a single source node and a destination node and the graph is called a feasible assembly sequence. A feasible sequence can be generated by traversing the component nodes through the operation arcs.

Using the subassembly information of a product as input, a feasible assembly sequence can be generated and represented as an AST. A search can be performed starting from the base component node to traverse all the component nodes until all the nodes are visited and all the assembly operations are executed. By traversing the nodes and arcs in a systematic way, all the feasible assembly sequences can be generated. As an illustrative example, the component and subassembly information of an example product is shown in Figure 1, the generated AST is shown in Figure 2.

III. Formulation of Multi-Plant Assembly Planning Model

Since the feasible assembly sequences may be combinatorial, the focus of the research is on developing a new model for finding the optimized multi-plant assembly sequence with a minimized cost. To formulate the problem under investigation, the following notations are used.

E_G : set of subassemblies,

F : set of manufacturing plants,

Y : set of assembly plants,

E : set of components,

B : set of feasible assembly sequences,

X : set of assembly operations,

$As_{[E_R]bx}$: assembly operation time,

$Num_{[E_R]efy}$: number of components needs to be transported from a manufacturing plant to an assembly plant,

C : manufacturing cost for components,

$Co_{[E_R]y}$: assembly operation cost for a subassembly group,

$Cr_{[E_R]dfy}$:transportation cost for component from a manufacturing plant to an assembly plant,

$Ct_{[E_R]y}$: transportation cost for transportation to the next assembly operation,

Cp_y : assembly operation cost at an assembly plant,

$Q_{[E_R]b}$: decision variable of feasible assembly sequence in E_g and $Q_{[E_R]b} \in (0,1)$,

$E_{[E_R]efy}$: decision variable representing component e of E_g transported from f to y in E_g ,

$H_{[E_R]y}$: decision variable representing E_g assembled at the assembly plant y .

The problem formulation is as follows.

1. Assembly costs:

$$Co_{[E_R]y} = \min \sum_{b=1}^{B} \sum_{x=1}^{X} (As_{[E_R]bx} \times Cp_y) \times Q_{[E_R]b}$$

$$s.t. \sum_{b=1}^{B} Q_{[E_R]b} = 1 \tag{1}$$

The objective function attempts to minimize the total cost of assembly operations.

2. Multi-plant assembly costs:

$$\min \sum_{E_R=1}^{E_G} \sum_{y=1}^{Y} Co_{[E_R]y} \times H_{[E_R]y} +$$

$$\sum_{E_R=1}^{E_G}\sum_{e=1}^{E}\sum_{f=1}^{F}\sum_{y=1}^{Y} Cr_{[E_R]efy} \times Num_{[E_R]efy} \times E_{[E_R]efy} + \sum_{E_g=1}^{E_G}\sum_{y=1}^{Y} Ct_{[E_g]y} \times H_{[E_g]y} \quad (2)$$

$$s.t. \sum_{f=1}^{F}\sum_{y=1}^{Y} E_{[E_R]efy} = 1$$

$$\sum_{y=1}^{Y} H_{[E_g]y} = 1$$

The cost objective is the total of the total assembly operation cost, the transportation cost from a manufacturing plant to an assembly plant, and the transportation cost for delivering a subassembly from one assembly plant to the next assembly plant. The constrain ensures that each component in a subassembly can be transported only one time from one plant to the next plan and each subassembly is assigned only one time to the plant with the lowest cost. With the above formulation, the optimized output of the model including the assembly sequence, the assembly time, the assembly cost, and the assembly plant location can be obtained.

IV. Test Result and Discussion

In this section, a wireless mobile phone is used as an example product to show the models and the tested results. The optimized solution of the linear programming problem is obtained using the Lingo software.

The part definitions and the product information are given as input. A description of the components of the product is shown in Table 1. It is assumed that for the purpose of reducing cost and expanding capacity, the seven manufacturing plants and three assembly plants need to be considered. There are fifteen components in the product given as {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15}. There are seven manufacturing plants {F1, F2, F3, F4, F5, F6, F7} as shown in Table 1. There are three assembly plants {Y1, Y2, Y3} as shown in Table 2. Figure 2 illustrates the component and subassembly structure of the product. The AST list is shown in Figure 3. The three assembly plants and the assembly operation cost for each assembly plant is listed in Table 2. The transportation cost for transporting a component from a manufacturing plant to an assembly plant is shown in Table 3. The transportation cost for transporting a component from an assembly plant to the next assembly plant is shown in Table 4. The subassembly information is described in Table 5. With the formulation, the feasible sequences are evaluated based on cost objectives.

The optimized result of the multi-plant assembly sequence with the lowest cost is shown in Table 6. It shows that the E1 subassembly is assembled at plant Y1 and the assembly sequence is from component 1, 2, to 3. The E2 subassembly is assembled at plant Y3 and the assembly sequence is from component 4 to 5. The E3 subassembly is assembled at plant Y2 and the assembly sequence is from component 8, 7, to 6. The E5 subassembly is assembled at plant Y1 and the assembly sequence is from subassembly E1, E2, and E3, to component 9, 10, 11, and then to subassembly E4, and finally to component 14 and 15. This sequence shown in Table 7 represents the optimized multi-plant assembly sequence with the lowest cost.

Based on the formulation, the sum of two main cost factors, assembly operation cost and multi-plant transportation cost, is minimized. It is observed that, in a multi-plant environment, if the assembly operation cost of a plant is too high, then the assembly operation will not be assigned to the plant. Also, if the assembly operation cost of a plant is low enough to cover the transportation cost, then the assembly operation can be assigned to that plant. This is a practical situation in the collaborative manufacturing environment in the current global supply chain in which the manufacturing and assembly operations are distributed with justified transportation costs to the plants with low operation costs.

Since this modeling and solution method is performed with a combinatorial programming approach, a larger size of problem might lead to a complex calculation process. At this stage of the research, a model with a systematic method is provided, but the complexity problem is not further explored.

.V. Conclusion

With the developing collaborative commerce and e-business models in a global logistic supply chain, a product can be designed and manufactured at different plants at multiple locations. In a multi-plant assembly sequence, the assembly operations can be performed at various assembly plants at various geographical locations. In this paper, the problem of multi-plant assembly planning is identified. A graph-based representation model is developed for representing the multi-plant assembly sequences. A mathematical programming model is formulated to evaluate all the feasible multi-plant assembly sequences. The formulated model is aimed at minimizing the total cost of assembly cost and multi-plant cost. The results present an optimized multi-plant assembly sequence in which all the components, subassemblies, and product are manufactured and assembled at the most suitable plants with the lowest cost. It can be concluded that the proposed multi-plant assembly planning model is an effective approach to solve the multi-plant assembly planning problem. Further research should be concerned with the additional cost functions such as activities generated due to the different plants located at different countries and other cost issues.

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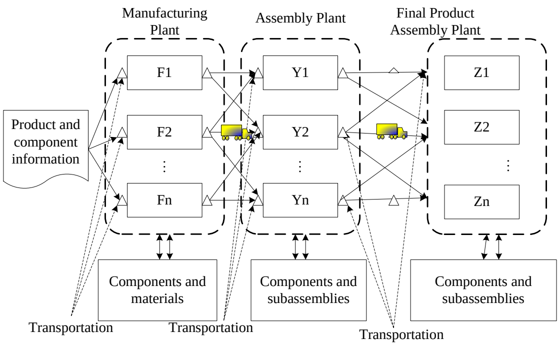

Figure 1. Illustration of a multi-plant manufacturing and multi-plant as sembly scheme.

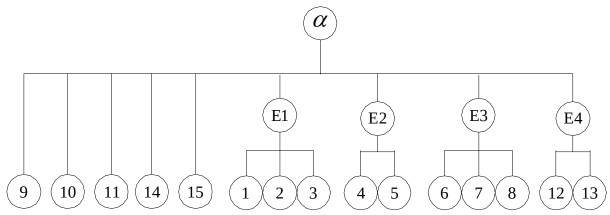

Figure 2. The components and subassemblies of the example product.

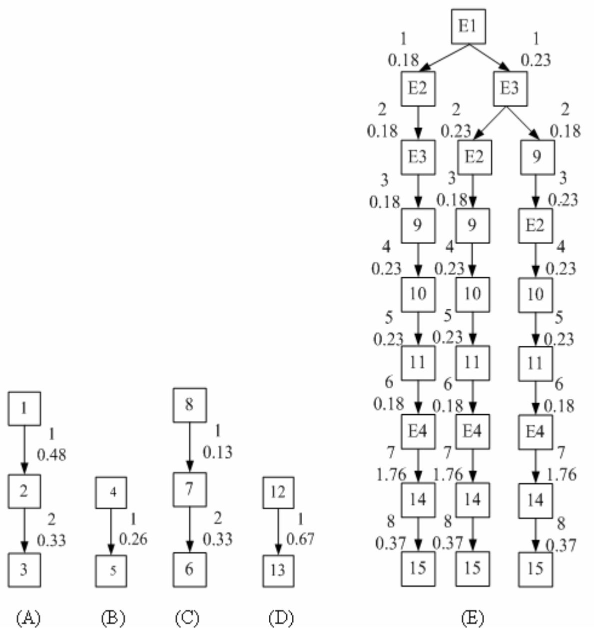

Figure 3. The AST of the example product

Table 1. The components of the example product.

Component	Description	Manufacturing plant
1	Upper case	F1
2	Keypad	F2
3	Frame	F1
4	Earphone rubber	F3
5	Earphone	F4
6	Panel upper cas e	F5
7	Display panel	F6
8	Backlight modul e	F6
9	Keypad conduct or	F5
10	Printed circuit b oard	F7
11	I/O Connector	F4
12	Shielding	F5
13	SIM card cover	F5
14	Screw	negligible
15	Back case	F1

Table 2. The assembly operation cost.

Assembly plant	Y1	Y2	Y3
Assembly operation cost	1.8	2	0.25

Table 3. The transportation cost for transporting a component from a manufacturing plant to an assembly plant.

Component	Assembly plant Y1	Assembly plant Y2	Assembly plant Y3
1	15	20	50
2	20	10	55
3	20	40	60
4	30	40	8
5	60	45	15
6	40	20	5
7	60	25	80
8	30	10	60
9	40	15	10
10	60	40	30
11	60	45	15
12	50	30	10
13	30	15	6
15	15	25	50

Table 4. The transportation cost for transporting a component from an assembly plant to the next assembly plant.

Assembly plant	Y1	Y2	Y3
Y1		100	150
Y2	100		80
Y3	150	80	

Table 5. The subassembly information.

Subassembly	Components in the subassembly
E1	1、2、3
E2	4、5
E3	6、7、8
E4	12、13
E5	E1、 E2、 E3、 E4、9、10、11、14、15

Table 6. The optimized multi-plant assembly sequence with the lowest cost

Subassembly	Assembly plant	Assembly sequence	Cost
E1	Y1	$1 \to 2 \to 3$	56.258
E2	Y3	$4 \to 5$	23.065
E3	Y2	$8 \to 7 \to 6$	55.62
E4	Y3	$12 \to 13$	16.168
E5	Y1	E1 $\to$ E2 $\to$ E3 $\to$ 9 $\to$ 10 $\to$ 11 $\to$ E4 $\to$ 14 $\to$ 15	548.358
Cost=699.649			