Allocation of Manufacturers through Internet-based Collaboration for Distributed Process Planning

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Abstract

The pursuit of lower cost, shorter time-to-market, and better quality has led to a shift toward global production in today's competitive business environment. This shift, however, forces manufacturing enterprises to have separate design houses and manufacturing facilities. In general, design houses are located in the same regions as customers to enable them to respond to the rapidly changing demands of customers. By contrast, manufacturing facilities can be placed in regions in which production costs are lower. However, this physical and logical separation between designers and manufacturers (or between upstream manufacturers and downstream manufacturers) raises various integration issues. The present paper addresses two of these issues: the framework for representing the data necessary to communicate requirements and objectives of the designer, and the methodology for utilizing such data to optimize the business objectives related to production cost and quality. The proposed representation, collaboration framework, and methodology will enable design houses and manufacturing facilities to realize the benefits of global production and to accommodate the management of loosely integrated supply chains.

Keywords: Collaborative manufacturing, Process planning, Distributed manufacturing, Supply Chain Integration

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1. Introduction

In the pursuit of higher customer satisfaction and lower production costs, enterprises are increasingly adopting a global production strategy in which trading partners work together in a distributed manner in space, time and organizations (Perrin & Gordart, 2004). For such a strategy to succeed, the trading partners must be able to send and receive collaboration messages in order to collaboratively design and manufacture products. The recent advent of information exchange frameworks makes this type of communication feasible. Two representative information exchange frameworks that have proved effective are the web-based e-business standards ebXML (http://www.ebxml.org) and Web Services (http://www.w3.org/2002/ws). They provide the basis for assuring interoperability in establishing electronic business-to-business relationships among companies. Such collaborations may occur in every function of a company, for example, procurement, sales, design, engineering, and manufacturing. The present paper focuses on the design and engineering aspects of business-to-business collaboration.

A designer in one region may want to produce a product using manufacturers located in other parts of the globe. In this situation, the designer needs to form supply chain partners for his or her product by sending requests for quotes (RFQs) to manufacturers, who then send quotes in response. This procedure entails the discovery and allocation of manufacturers in performing distributed process planning for efficient and effective manufacturing of the designed product.

However, the physical and logical separation between designers and manufacturers may raise various integration issues. In a dynamic relationship environment, the designer must first be able to generate a universal process plan without considering the capabilities and capacities of specific manufacturers. Second, the manufacturers may not know the precise needs of designers beforehand. Third, a proper chain among multiple manufacturers and multiple designers must be established in terms of resource allocation and delivery requirements. Integration between designers and manufacturers thus becomes an issue requiring attention. Careful process planning for this strategy can make the value chain more competitive in terms of cost, time, and quality.

The objective of the present paper is to explore the problems associated with distributed process planning via collaboration between a designer and manufacturers located in different regions, and to propose solutions to those problems. The detailed objectives are to present 1) the representation and evolution of the designer's plan data that facilitates the integration between a designer and manufacturers, and 2) an approach to optimally allocate the manufacturers to the universal process plan through collaborative bidding.

The following assumptions are made to simplify the modeling and analysis:

1) The scope is limited to discrete parts.
2) Each of the designers and manufacturers is an independent corporation or organization. That is, we do not consider cases where designers and manufacturers have a strategic association or a business relationship.
3) Only a single designer negotiates with multiple manufacturers.

The paper is organized as follows: Chapter 2 presents past work. Chapter 3 provides the proposed process-planning framework in the distributed environment. Chapter 4 describes the universal process plan and briefly discusses issues related to finding manufacturers in cyber space. Chapter 5 proposes a methodology for generating the RFQs used to determine which manufacturers are the most economical. Chapter 6 presents a procedure for selecting the best manufacturer. Conclusions are provided in Chapter 7. It is noted that Chapters 4, 5, and 6 include case studies for ease of understanding.

2. Related Work

In process planning research, much effort has been devoted to the problem of how a single company, without collaborating with other companies, can carry out all the activities associated with the design, planning, and manufacturing of a part. Process planning provides the essential instructions necessary for realizing the designed product and service from the raw material and resource (Cho, 1993). The process plan contains the information contents to evaluate manufacturability, manufacturing cost, and product completion time (Wysk, *et al.*, 1995). It may be represented either in a classical table form or as an AND/OR directed graph. The primary purpose of a process plan is to assist the manufacturing system in monitoring the progress of an order, decision making, and executing the scheduled tasks required to fill the orders (Cho and Wysk, 1995).

Nowadays, new ways of working, new forms of organizations, and new business models are emerging, such as virtual enterprises, integrated supply chains, and value networks (Jayaweera, *et al.*, 2001). As the manufacturing industry gradually moves towards a borderless business environment, a new model for enterprise cooperation and collaboration is required to meet the imminent challenge posed by an increasingly competitive marketplace (Lau *et al*., 2000). This environment should enable manufacturers to be better equipped, with capabilities to cope with demands such as a faster response to market changes, a shortened lead time of production, improved quality and speed, as well as the ability to deliver quality products to global customers, and improved communications and transportation systems (Lan *et al*., 2003). Unfortunately, conventional process planning is not suitable for the distributed manufacturing environment. Rapid progress in information technology has seen engineering functions such as design, planning, and manufacturing begin to be distributed and collaborative.

Processes requiring distributed and collaborative process planning have two distinguishing features (Weigand *et al*., 1998). Firstly, the resources needed for the process cannot be managed centrally as they reside in different organizations. For example, if a company uses resources of another company, it cannot know the capacity and capability of the resources. Secondly, the organizations involved in the process have a certain degree of autonomy, that is, no central authority has control over all the cooperating organizations. These features have seen the emergence of distributed manufacturing environments as a new area of process planning research.

Process planning within a distributed environment has been studied in various disciplines. For example, multi-agent planning is used to generate distributed plans. Coordination between agents is controlled by a global plan specifying all actions and interactions between agents (Ulieru *et al*., 2000). Given that several different manufacturers may use the same process plan, the designer must be able to generate a universal process plan for unknown target resources. To that end, the concept of a resource independent process plan has been proposed (Kulvatunyou, 2001; Kulvatunyou *et al*., 2003).

3. Overview and Framework

The procedure used to find the manufacturers and allocate them to the resource-independent process plans via collaboration is illustrated in Figure 1. The product designer generates a resource-independent process plan for a particular product; in this plan, manufacturers are not yet assigned to each operation. The names of manufacturers suitable for each operation in the plan are obtained from a public registry that gives information on the manufacturing capabilities and capacities of manufacturers. It is noted that if no suitable manufacturer can be found for a particular operation, the designer may modify the specifications of the operation (e.g., shape and tolerance of the product). After identifying suitable manufacturers, the product designer then enters into negotiations with each of these manufacturers in regard to manufacturing and handling costs. In the negotiation process, the designer issues RFQs for the operations, and the manufacturers reply with quotes. The manufacturers are then evaluated by analyzing the quotes. Finally, a distributed process plan (DPP) is finalized by allocating each operation to the chosen manufacturer.

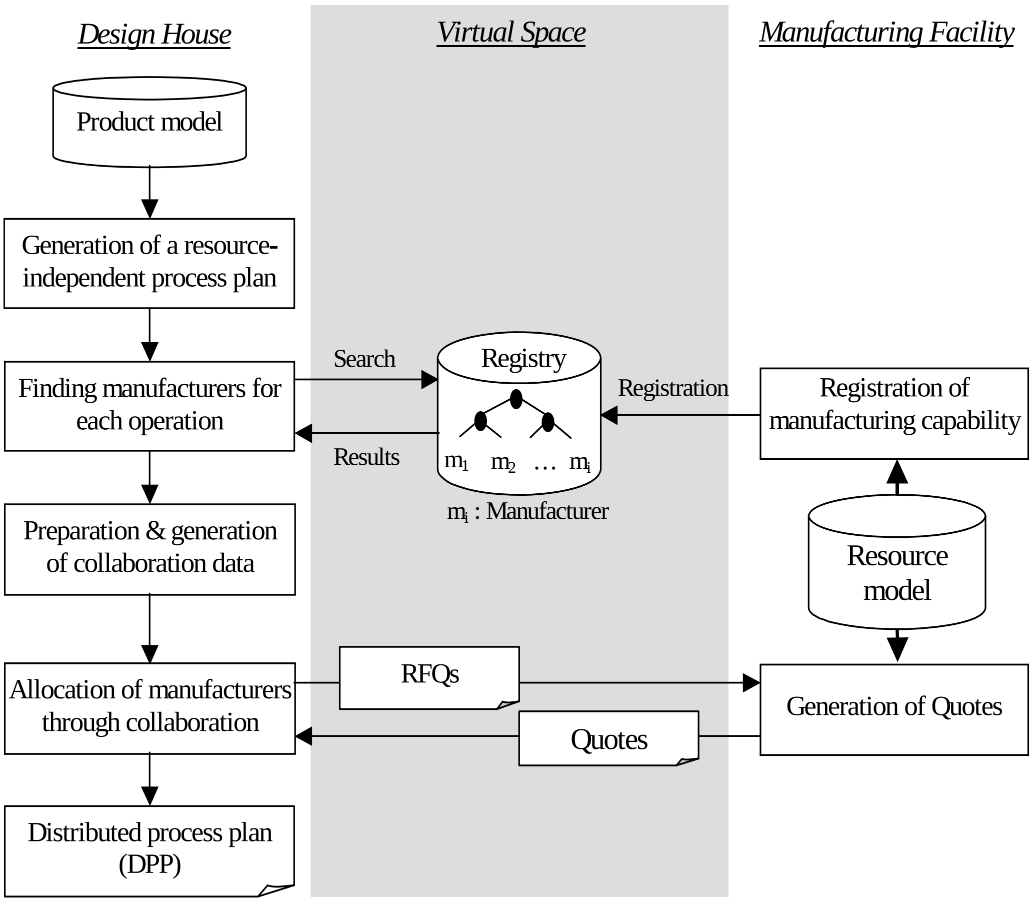


Figure 1: Procedure for allocating manufacturers to process plans

Several requirements have been identified for implementing the proposed procedure.

1) The product designer must be able to generate a resource-independent process plan.
2) The product designer must be able to provide sufficient information for the manufacturer to prepare the manufacturing cost for a bid.
3) The product designer must be able to evaluate all the manufacturers' quotes efficiently and effectively to finalize the DPP.
4) The manufacturers must be able to reply with the quotes for the RFQ.
5) The manufacturers must register their manufacturing capacities and capabilities with the appropriate public registry.

4. Preparation of Collaboration

4.1. Generation of a Resource-Independent Process Plan

In the distributed manufacturing environment, the product designer generates a universal process plan because no information about the specific resources of manufacturers is available. This initial plan, referred to as a resource independent process plan (RIPP), only indicates the implicit works necessary to produce the product. The RIPP consists of two levels: an upper level comprised of operations and their precedence relationships, and a lower level comprised of processes and their precedence relationships within each operation.

A process is defined as an activity that changes the state of the product. Different states of a product may be reflected by its shape, location, quality, etc. Hence, the state of a product can be changed by various processes, such as machining, inspection, and transportation. A machining process is related to a removal feature (e.g., hole, slot, or pocket) for discrete parts. For example, if a product can be produced by eliminating three (3) removal features (e.g., two holes and one pocket) from the raw material, the designer can define the three (3) corresponding processes ("First hole making process", "Second hole making process", and "Pocket making process"). The implicit steps within each of these processes can be identified to produce each feature (e.g., drill and ream or drill and bore for a hole).

Removal features may have tolerance dependencies. Removal features with high positional repeatability requirements must be manufactured without refixturing; in other words, they must all be manufactured at the same setups in a manufacturing facility. Such requirements necessitate that the relevant processes be bound to an operation; that is, all of the processes contained within an operation must be performed at the same manufacturing facility with the same setup. For example, if the two hole-making processes have a positional tolerance dependency, they are bound to a single operation. Therefore, the allocation of manufacturers to the RIPP must be performed at the operation level.

The operations defined at the upper level of the RIPP are connected to one another via nonlinear precedence relationships using an AND/OR directed graph. An operation consists of several processes, which may also have nonlinear precedence relationships to one another. Hence, an RIPP is a two-level graph: an operation level graph (OLG) at the upper level and a process level graph (PLG) within each operation. Each node in the OLG describes the operation type, equipment requirements, and work-holding requirements. Each node in the PLG contains process capability requirements such as type of process, accuracy, and associated geometric entities.

4.2. Finding Manufacturers

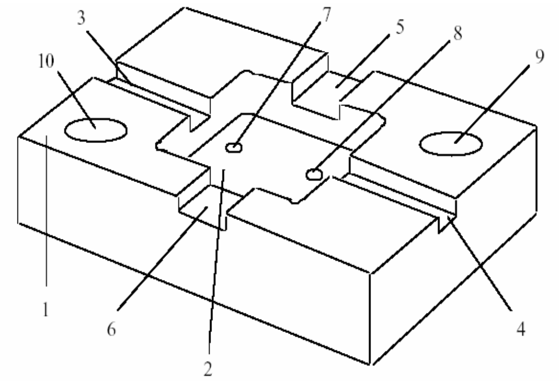
For a designer to be able to find a manufacturer suitable for a particular process, the manufacturer must have its manufacturing profile (e.g., capabilities, capacities, constraints, locations) registered on an appropriate public registry. Several public registry protocols are available, including Universal Description, Discovery and Integration (UDDI) (www.uddi.org), and ebXML Registry (www.oasis-open.org/committees/regrep). The registry specifications provide various interfaces for storage, classification, and retrieval of business information. However, these registries use the same generic information structure for all industries. For our approach, a manufacturing specific registry is required; such a registry has been researched by Kulvatunyou *et al*. (2003). In this paper, we assume that an appropriate registry is readily available.

Once an RIPP is ready for a particular product, the designer allocates manufacturers to each operation defined in the RIPP. Since designers do not have their own manufacturing facilities, they must search a public registry to find manufacturers whose profiles match the requirements specified in the operations and processes. Each operation in the RIPP then becomes associated with the manufacturers identified. The updated process plan is called a manufacturer-dependent process plan (MDPP). Each operation node in the MDPP has several alternative manufacturers assigned. A manufacturer may be assigned to more than one operation. If no suitable manufacturer is found for one or more processes, the designer may regenerate the RIPP.

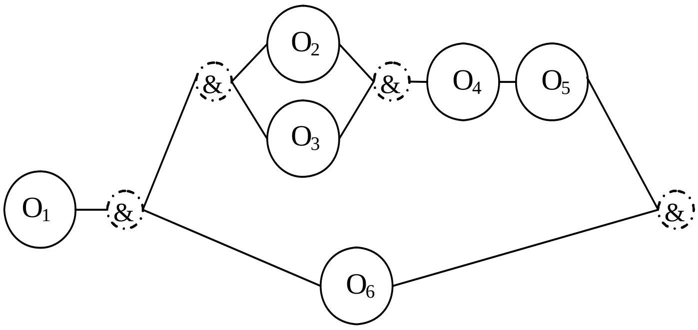
It is noted that the full details of how to register manufacturers and how to retrieve manufacturers from a registry are beyond the scope of this paper.

4.3. Case Study

A prototype product and its corresponding RIPP are illustrated in Figure 2. The product is manufactured by removing various features, such as holes, slots, and pockets, from the raw material. The precedence relationships between the removing features are represented in the process level graphs. It is noted that '3 & 4' implies that the combined feature comprised of features 3 and 4 is manufactured with a single cut, and similarly for '5 & 6'. The designer then binds several processes into an operation by considering setups, tolerance dependencies, which results in an operation level graph.



a) Product sketch and identified features



b) Operation level graph

Operation	Features
O_1	1
O_2	3 & 4
O_3	5 & 6
O_4	2
O_5	7 & 8
O_6	9 & 10

c) Operation vs. Feature

Figure 2: Exemplary product and its resource independent process plan

Assuming that a set of manufacturers (e.g., M_A, M_B, M_C, M_D, M_E, M_X, M_Y, and M_Z) are registered on a public registry, the designer can find the set of valid manufacturers for each operation in the RIPP. Without loss of generality, it is assumed that relevant manufacturers are discovered for each operation and its related MDPP is illustrated in Figure 3. Some operations have multiple manufacturers attached, implying they are alternatives.

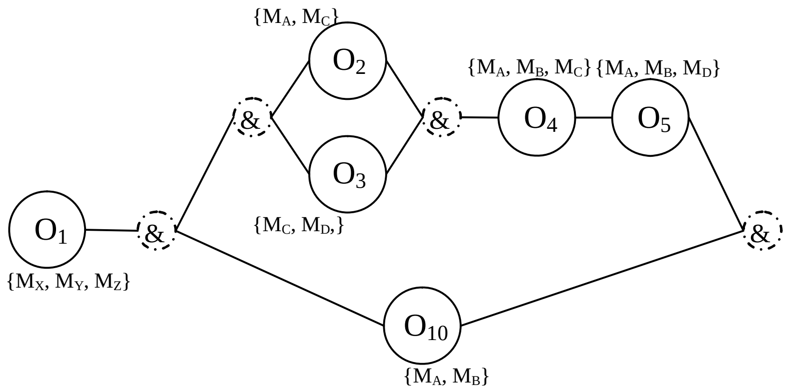


Figure 3: MDPP transformed from the RIPP in Figure 2

5. Generation of Collaboration Data

5.1. Requirements for Efficient Collaboration

As stated above, the exchange of RFQs and quotes through an information exchange framework is required in order to choose an appropriate manufacturer for each operation and then determine the sequence of the operations. The selection of manufacturers is important because an incorrect decision may result in unnecessary transportation costs and unacceptable product quality. However, the generation of RFQs and the evaluation of the resulting quotes directly based on the MDPP have two associated problems.

First, a large number of communications would be required to check whether a single manufacturer can be assigned multiple operations. To obtain this information, the manufacturer would need to process multiple RFQs. Second, excessive computing costs would be incurred because too many alternatives exist both in choosing the best manufacturer and in determining the best operation sequence. In practice, this computing burden would make the system unworkable.

To resolve the aforementioned problems, the process plan graph is transformed and organized. Each operation node assigned with multiple manufacturers is replicated for each manufacturer such that it is attached to only one manufacturer. Then, nodes that can be produced by a single manufacturer are grouped together, resulting in a manufacturer-oriented process plan (MOPP).

5.2. Transformation of a Process Plan Graph for Efficient Collaboration

The preparation of collaboration data involves the transformation of the MDPP into the MOPP. It can be viewed as an information-generation stage that provides the instructions necessary for effective negotiation between the designer and the manufacturers. The collaboration data are generated according to the following steps:

1) Pruning: Eliminate from the MDPP operation nodes that are deemed uneconomical or manufacturers that are not available.
2) Expansion: Expand the operation nodes with the manufacturer alternatives by using OR-junctions such that each operation node contains only a single valid manufacturer.
3) Grouping: Group the operation nodes that can be produced by the same manufacturer.
4) Generating & Refining: Generate the MOPP without any AND-junctions and eliminate needless sequences in the MOPP.

In the pruning step, the objective is to eliminate unavailable or uneconomical manufacturers from the MDPP. If any manufacturer changed its profile and therefore cannot perform the assigned operation, it is removed to reduce the problem complexity.

In the expansion step, each operation node is expanded into several operation nodes, each with only a single manufacturer attached. This implies that an operation node containing multiple manufacturer alternatives is duplicated as many times as there are manufacturer alternatives. The duplicated nodes are joined together with an OR-junction.

In the grouping step, a transportation cost-saving heuristic is applied. Operations that can be performed by the same manufacturer without violating the precedence constraints are grouped together to reduce transportation and handling costs.

In the generation and refining step, all AND-junctions in the graph are transformed into OR-junctions. This procedure gives a MOPP that consists only of operation, group, and OR-junction nodes. The operation and group nodes are performed by a single manufacturing facility. However, this MOPP needs to be refined further because it contains many alternatives, and hence will incur an excessive communication load for collaboration. To achieve this, the designer can eliminate alternatives that can confidently be assumed to be needlessness, even though the exact cost has not been evaluated. For example, the designer can roughly evaluate the transportation cost from the geographical information on the manufacturers in the each alternative. If a sequence is predicted to give rise to excessive transportation costs, it can be eliminated.

5.3. Schema for Collaboration Data

In order for the designer to effectively collaborate with manufacturers, the collaboration data must be clearly defined and generated. The designer must be able to send RFQs. Then, after receiving a quote from a manufacturer, the designer will assess it in terms of resource availability, manufacturing quality, manufacturing cost, delivery date, and so on. The RFQ and its related quote are the vessels for the collaboration data. The schema for the collaboration data are illustrated in Figure 4.

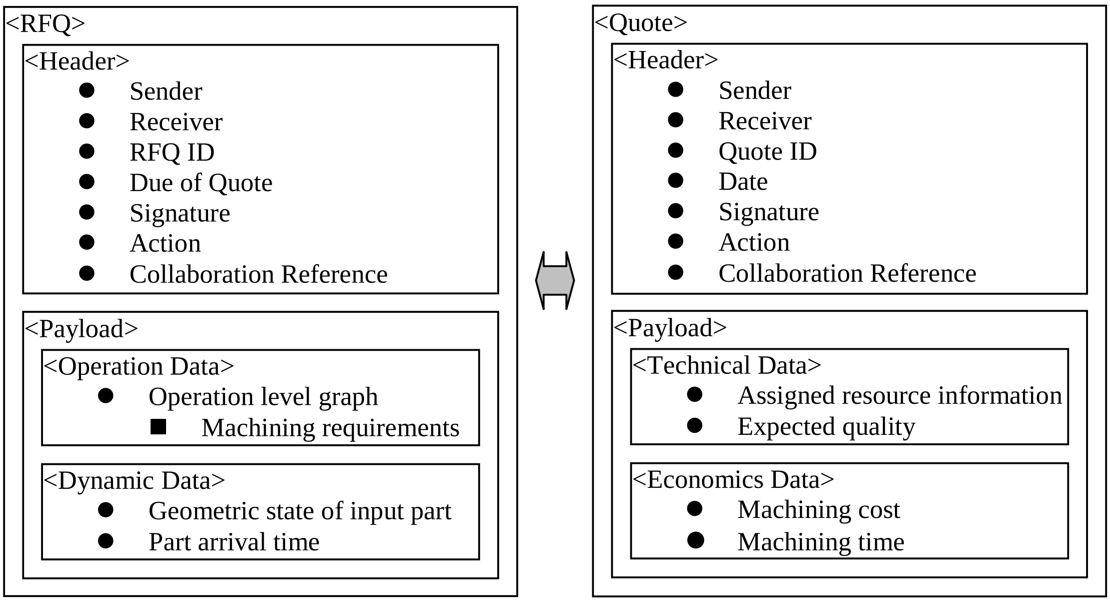
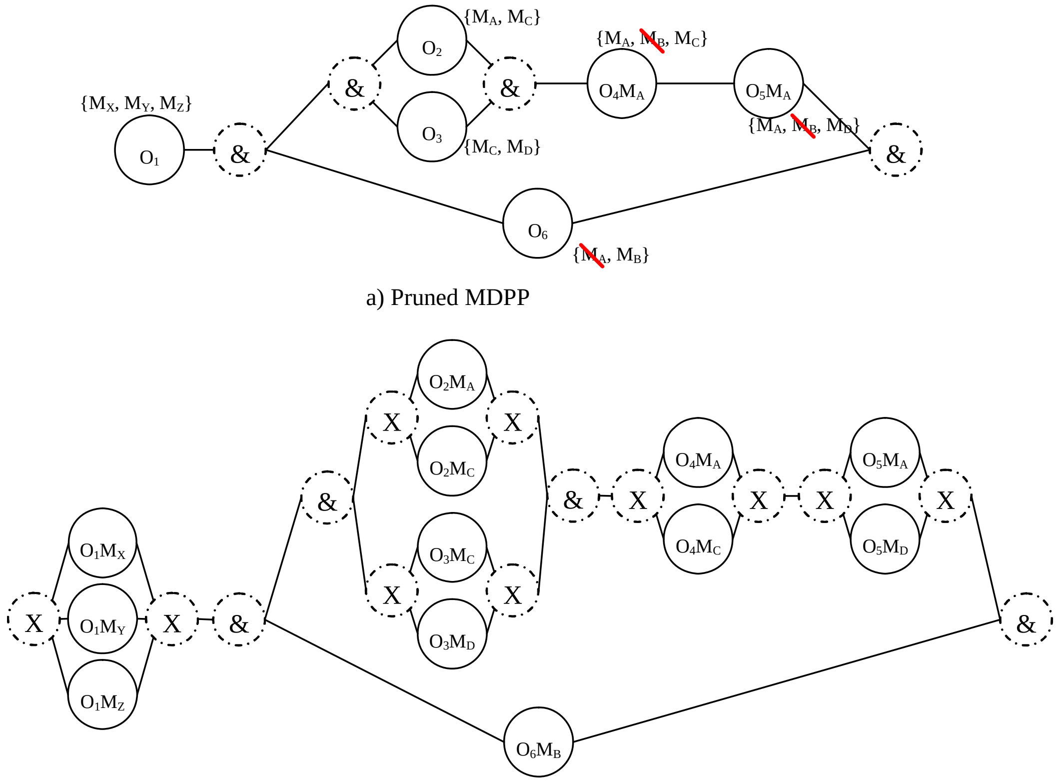


Figure 4: Schema for the collaboration data

The operation data in the RFQ contains a partial operation level graph to be sent to a particular manufacturer. The dynamic data in the RFQ contains the information on the geometric shape of the part and the arrival time of the part to the particular manufacturer. The technical data in the quote contains the information on the assigned resource and the expected quality of the part. The economics data in the quote contains the expected machining cost and time of the requested operation.

5.4. Case Study

The designer eliminates unavailable or uneconomical operations or manufacturer alternatives from the MDPP and expands the pruned MDPP by duplicating operation nodes, as shown in Figure 5.

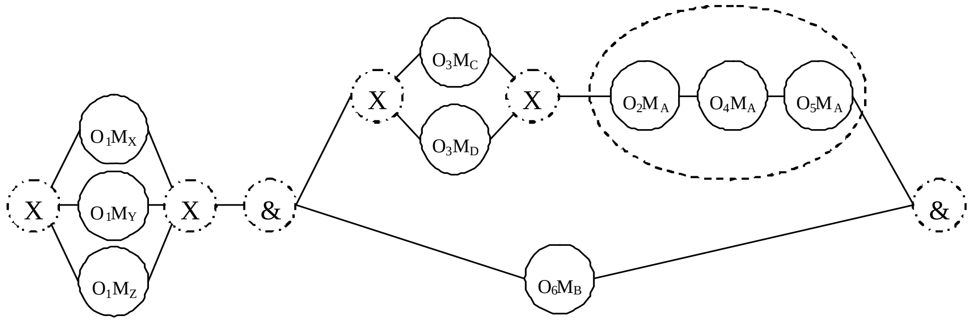


a) Pruned MDPP

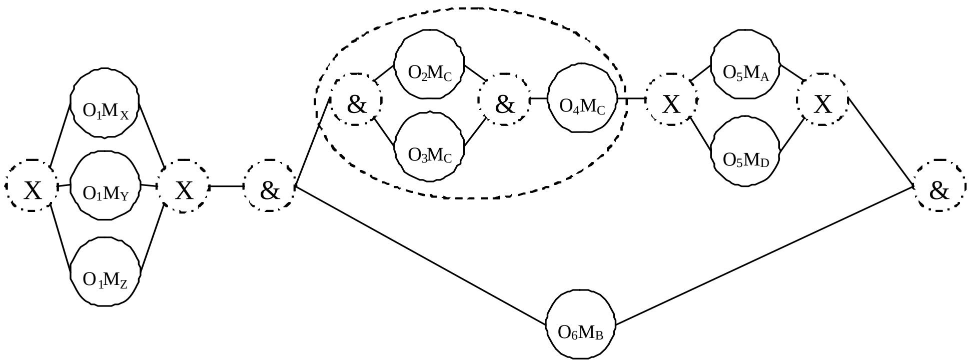
b) Expanded MDPP

Figure 5: Pruning and Expansion of MDPP

In Figure 5, the MDPP has many alternatives. With respect to the order of operations, the MDPP has four possible sequences: ‘O_1-O_6-O_2-O_3-O_4-O_5’, ‘O_1-O_6-O_3-O_2-O_4-O_5’, ‘O_1-O_3-O_2-O_4-O_5-O_6’, and ‘O_1-O_2-O_3-O_4-O_5-O_6’. On top of this, each operation has several manufacturer alternatives. For example, the MDPP of Figure 5 has 192 alternatives (4 * 48). In practice, however, it is impossible to consider this number of cases. To save on transportation costs, it is advantageous to allocate multiple operations to the same manufacturer where possible. Here, the order of operations of the MDPP must not be altered. In Figure 5, two manufacturers (M_A and M_C) can be grouped within the limits of the grouping roles. The other manufacturers are either capable of performing only a single operation, or the operations they can perform are at separated positions. The MDPP of Figure 5 is grouped as shown in Figure 6.



a) Grouped MDPP as M_A



b) Grouped MDPP as M_C

Figure 6: Grouping of the MDPP

After considering all the group nodes, the designer should generate the MOPP by transforming all the AND-junctions to OR-junctions. The MOPP generated in this manner from the MDPP in Figure 6, which contains only operation, group, and OR-junction nodes, is shown in Figure 7-a. This MOPP contains 24 alternatives (3*8). There are 8 sequences in the rear OR-junction, which are divided into two types: those with operation node 'O_6M_B' first and those with this node last. If the geographical information or manufacturers' resource utilization is known beforehand, then the AND-junction can be heuristically linearized, allowing the designer to avoid the time-consuming interactive evaluation of all possible sequences. For example, evaluation of the transportation cost based on the MOPP graph in Figure 7-a in conjunction with known geographical information (note that this is like using the transportation cost estimation from the UPS [http://wwwapps.ups.com/calTimeCost?loc=en_US] and Fed-Ex [http://www.fedex.com/ratefinder/home?cc=US&language=en&link=1&lid=//Ship//Pack+Rates+Corp] web sites) may show that it is always more economical to perform 'O_6M_B' first. This type of evaluation could potentially give a refined MOPP graph without any AND-junctions (Figure 7-b) without any additional computation. It should be noted that if other constraints are not met, such as delivery time, the procedure should be backtracked to re-evaluate the heuristic.

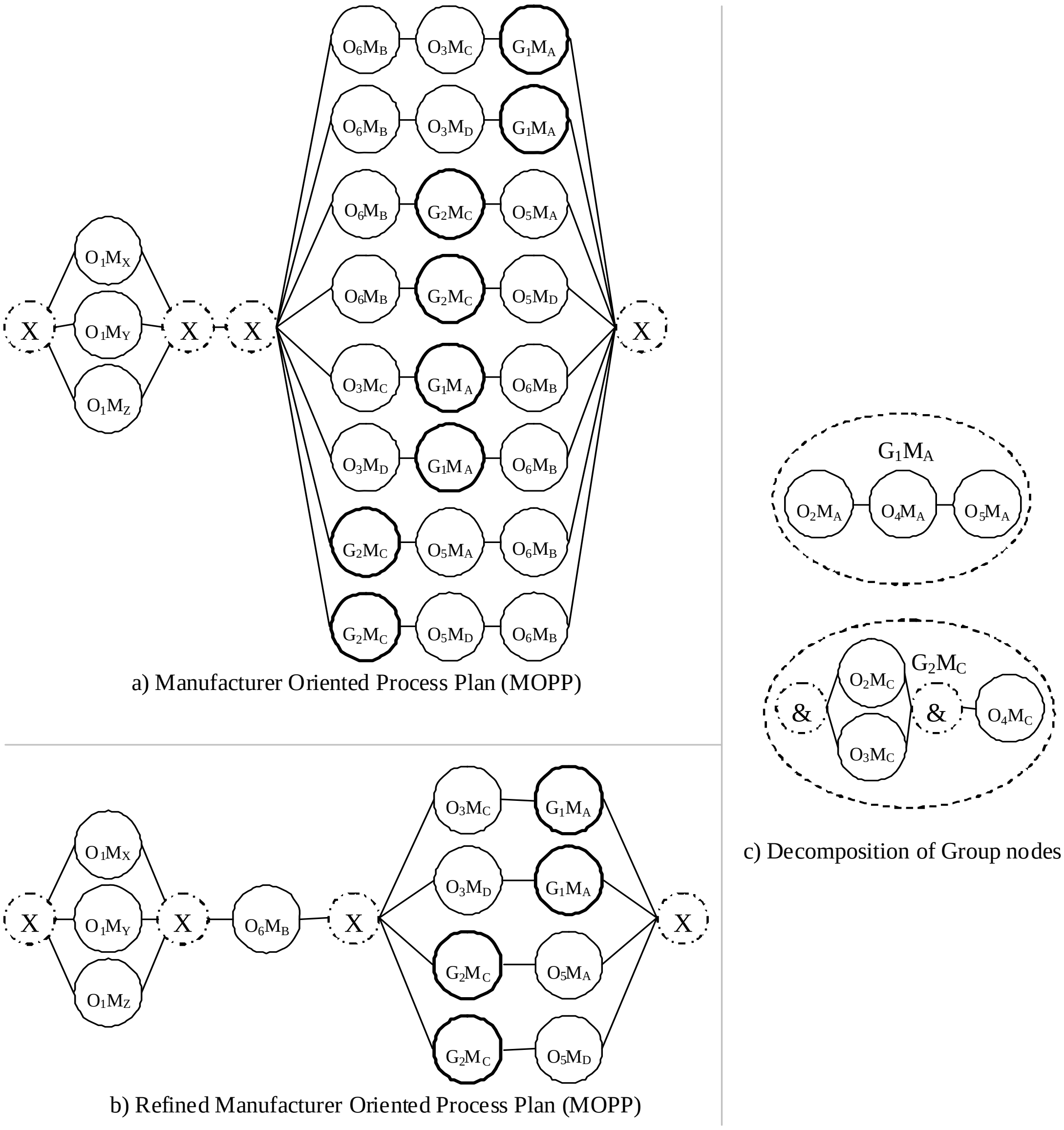


Figure 7: Graphical representation of an MOPP

The designer generates collaboration data on the basis of the operation nodes and group nodes of the MOPP. The operation is delivered to the manufacturer without the relationship to the precedence nodes, but the inherited data cannot be statically generated because it requires information determined at preceding nodes. Hence the designer generates only the operation data and defers the inherited data until later. Figure 8 shows an example RFQ generated by the designer and the quote sent in response by ‘Manufacturer C’ in Figure 7. The data may be exchanged using XML encoding. The designer must generate RFQs for each node of the MOPP before the allocation stage.

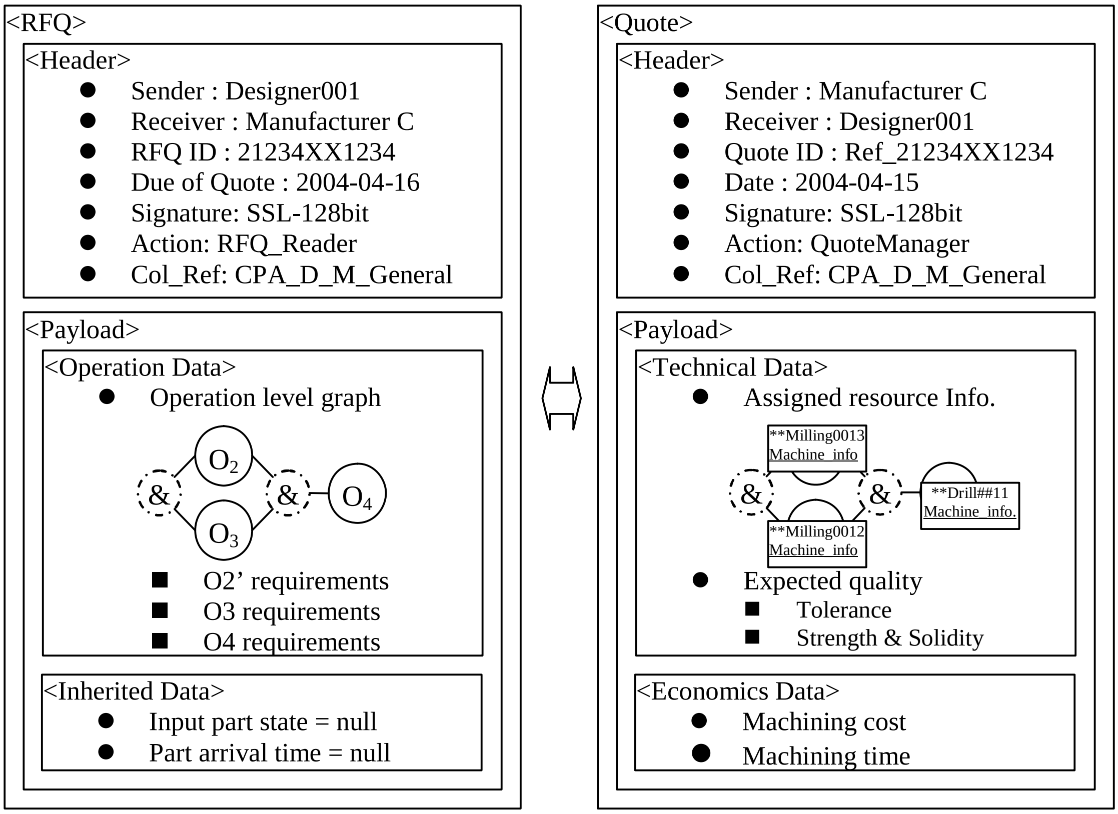


Figure 8: RFQ and its corresponding quote of Group node #13

6. Allocation of Manufacturers through Collaboration

After communicating with the manufacturers using collaboration data, the designer should evaluate all the quotes received to assign a manufacturer to each operation. This enables a single manufacturer to be assigned to multiple operations. Once every operation is assigned a manufacturer and its sequence is serialized, the distributed process plan (DPP) is finalized.

6.1. Problem Definition

An MOPP includes various alternatives for producing a given product. For example, the MOPP illustrated in Figure 7 includes 12 alternatives. The designer must be able to find the best manufacturer for each group of operations and also the sequence of the group. In this selection procedure, the designer uses production costs as the performance measure, where the production cost for a particular product is assumed to consist of manufacturing and transportation costs. The manufacturing cost associated with a particular operation is given in the quote submitted by the manufacturer. The transportation cost can be calculated based on the geographical distance between manufacturers.

The best alternative can be found by converting the problem into the following mathematical representation:

Objective function ***Min*** $\sum_{i=0}^{n-1}\sum_{j=1}^{n} S_{ij}C_{ij}$

Subject to $S_{01} = 1$

$\sum_{i=0}^{n-1} S_{ij} - \sum_{k=1}^{n} S_{jk} = 0$ *all j = 1 to n*

Where $S_{ij} =$ flow from node *i* to *j*

$C_{ij} = T_{ij} + M_j$

$T_{ij} =$ Transportation Cost from *i* to *j*

$M_j =$ Manufacturing Cost of Node *j*

Here, C_{ij} represents the total cost of node *j*, which is made up of the cost of transportation from node *i* to node *j* and the manufacturing cost of node *j*. S_{ij} represent the connectivity between node *i* and node *j*. in the alternative, if the product is operated in the node *j* after *i*, the value of S_{ij} is '1', otherwise '0'.

The above problem would be easily solved if the designer could consider all the alternatives and know the costs associated with all the nodes beforehand. However, the designer cannot know the precise cost of a node prior to knowing which nodes precede that node, because the designer cannot make a complete RFQ containing the arrival time and state of input materials at the node. To generate a complete RFQ, the designer must have received quotes from the manufacturers assigned to all nodes preceding the current node. Therefore, the problem must be solved node by node from the first node.

6.2. Finding an Optimal Distributed Process Plan

Because network communications are time consuming, the algorithm for solving the problem should find the optimal solution within the minimum number of iterations possible. Therefore we propose a search algorithm to solve the MOPP, as illustrated in Figure 9.

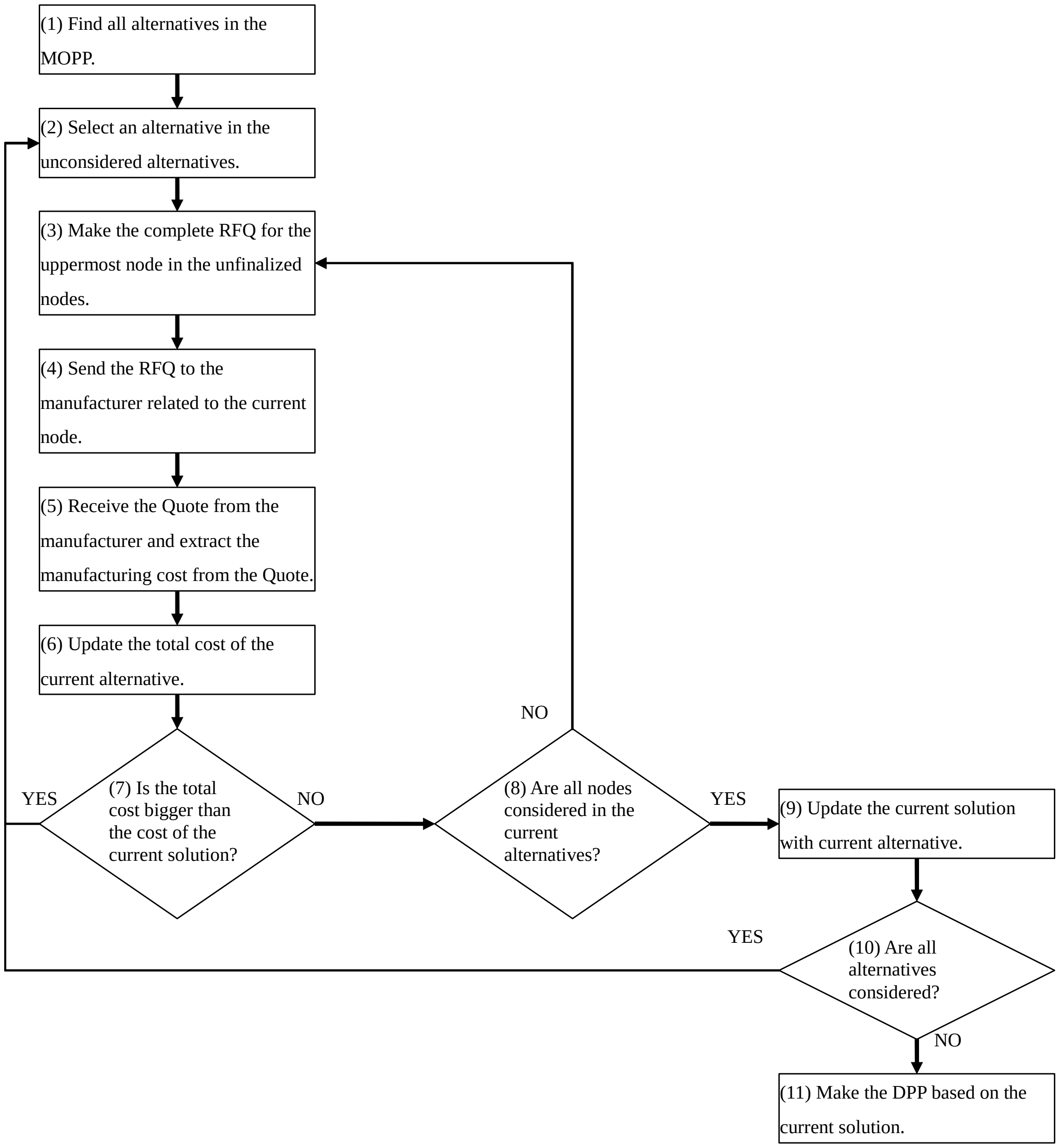


Figure 9: Proposed algorithm for solving the MOPP

- [Step 1] Find all alternatives: The designer should search all alternatives in the MOPP. Each alternative consists of operation nodes and group nodes without any junctions; that is, each alternative forms a linear sequence. This step creates a set of unconsidered alternatives, which is represented as a tree.

- [Step 2] Select an alternative: The designer selects an alternative from the set of unconsidered alternatives. The designer can use the shortest path algorithm as a selection criterion for this step, where this algorithm is solved based on known/static data such as transportation costs. He or she can select the most economical path from among the possible paths from the first node to the last node. The selected alternative is the current alternative.

- [Step 3] Generation of complete RFQ: The designer chooses the uppermost node from among the unconsidered nodes of the current alternative, since there may be already considered node in other alternatives. The selected node becomes the current node. As the designer knows the inherited information from the previous nodes, he or she can generate a complete RFQ for the current node.

- [Step 4 and 5] Transmission of collaboration data: The designer sends the RFQ to the manufacturer associated with the current node, and the manufacturer responds with the quote. From this quote, the designer can obtain the manufacturing information (cost, quality, etc.) of the current node.

- [Step 7] Update the total cost: The designer adds the cost of the current node to the total cost of the current alternative.

- [Step 8] Compare the performance: If the current accumulated cost exceeds the cost of the current solution, the designer discards the current alternative and moves to the next alternative. The current solution is the lowest cost among the alternatives examined so far.

- [Step 9] Terminate an alternative: If all nodes have been considered, the current alternative is removed from the set of unconsidered alternatives. The designer then moves to the next alternative.

- [Step 10] Terminate the iterations: If all alternatives have been considered, the iterations are terminated.

- [Step 12] Generate a DPP: The designer generates the DPP based on the current solution.

6.3. Case Study

The MOPP in Figure 7 has 12 alternatives. These alternatives can be represented in tree form, as shown in Figure 10, with the lowest nodes in the tree representing the final node of each alternative. In alternative #3, the designer must have the quote for node 'O_1M_X' in order to complete the RFQ for node '$O_{10}M_B$'. Thus, the designer should solve the nodes one by one. Also if a node has been considered before, it does not need to be considered again. In the algorithm, an alternative is discarded if the current cost of that alternative exceeds the total cost of the current solution. Due to this rule, all alternatives except alternatives 3 and 6 are stopped before reaching the lowest nodes. The optimal alternative is found to be alternative #3. The mathematical formulation of the objective function for this alternative is:

Total Cost of Alternative #3

$$= C_{S,O_1M_X} + C_{O_1M_X,O_6M_B} + C_{O_6M_B,G_2M_C} + C_{G_2M_C,O_5M_A}$$

$$= (T_{S,O_1M_X} + M_{O_1M_X}) + (T_{O_1M_X,O_6M_B} + M_{O_6M_B}) + (T_{O_6M_B,G_2M_C} + M_{G_2M_C}) + (T_{G_2M_C,O_5M_A} + M_{O_5M_A})$$

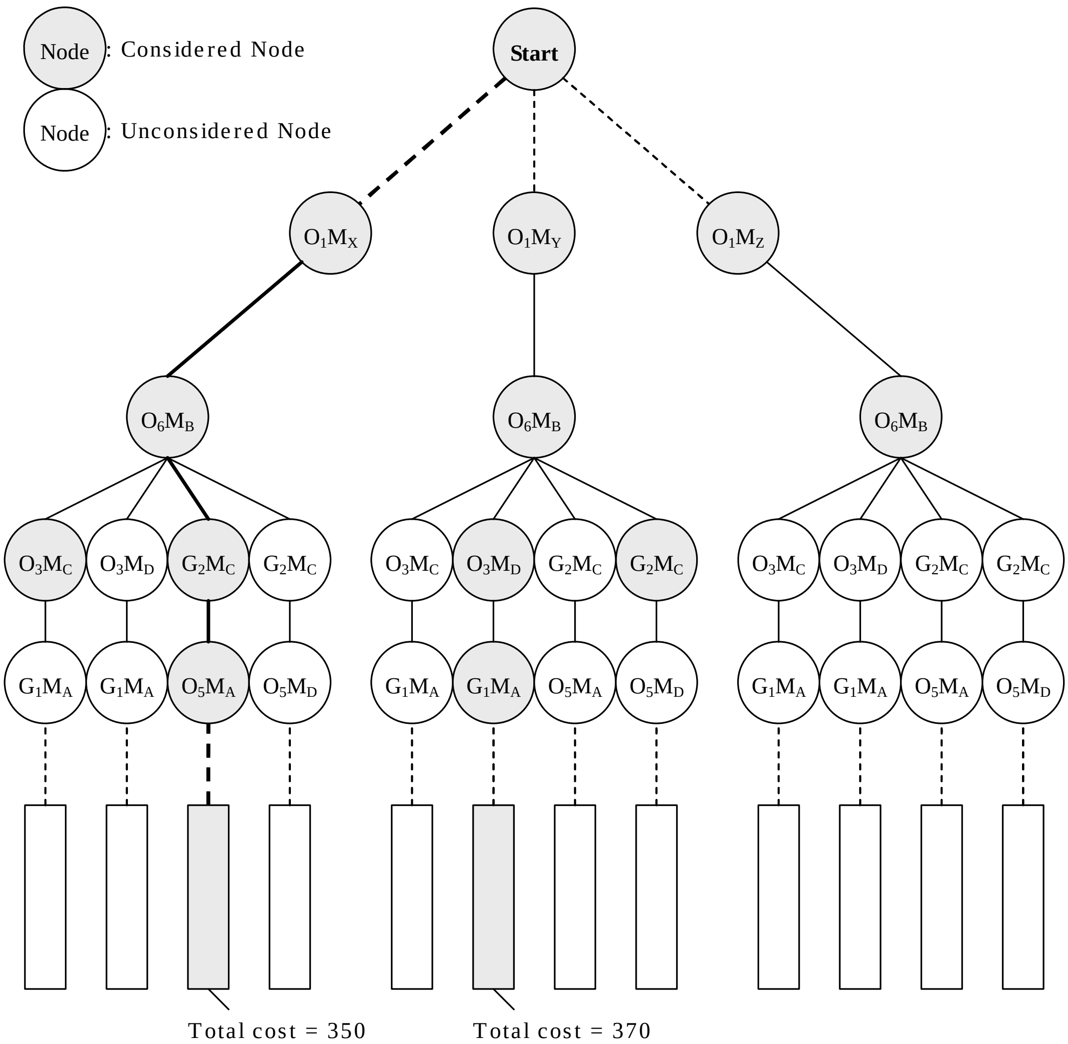


Figure 10: Alternatives of the MOPP

Solving the MOPP in Figure 7 using the proposed algorithm gives the DPP in Figure 11. The optimal solution has three operation nodes and one group node. The operation jobs are allocated to the manufacturers in order: M_X, M_B, M_C, and M_A.

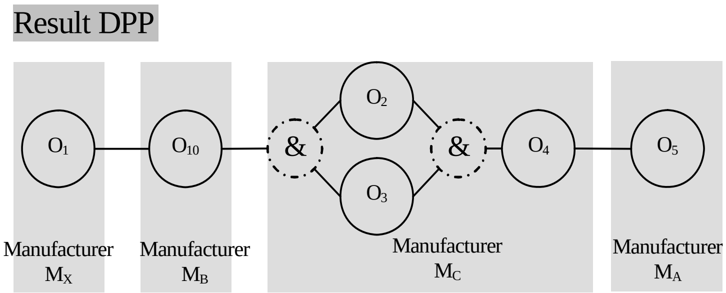


Figure 11: MOPP solving using the proposed algorithm

7. Conclusion

In the present study we have proposed a heuristic methodology to facilitate the evolution and evaluation of process plans for distributed manufacturing facilities. In this method, the designer first prepares a resource-independent process plan (RIPP) for a product. The designer then searches for a set of manufacturers that have the resource capacities and capabilities to adequately produce the product. The proposed method transforms the RIPP at the operation level into a manufacturer-dependent process plan and then a manufacturer-oriented process plan, from which the collaboration data are generated for RFQs (Requests for Quotes). On receiving the RFQs, the manufacturers investigate the manufacturability of the product and compute the manufacturing cost, time, and product quality. On the basis of the information provided by the manufacturers in response to the RFQs, the designer determines the best operation sequence and manufacturing facilities. In this last step, a simple heuristic algorithm is used to obtain the optimal sequence. The final operation sequence is represented as a distributed-process plan that can be used to manage the manufacturing chain of the product. The proposed methodology enables the integration of planning and manufacturing in a distributed manufacturing environment.

Disclaimer

Certain commercial software products are identified in this paper. These products were used only for demonstration purposes. This use does not imply approval or en-dorsement by NIST, nor does it imply that these products are necessarily the best available for the purpose.

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