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Journal of Materials Processing Technology 173 (2006) 194–200

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

# A pragmatic approach for optimal selection of plant-specific process plans in a virtual enterprise

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Received 18 July 2002; received in revised form 5 December 2002; accepted 22 November 2005

**Abstract**

With the globalization of economic markets and the individuality of market demands, virtual enterprise is becoming an increasingly important organization since it can respond rapidly to market changes and make resource sharing more efficient among manufacturing partners. In this environment, potential partners may be located at different geographical locations and possess different core competition capabilities. Thus, how to select an optimal set of partners capable of responding to a given market opportunity—a new product or even a component, has become a challenging research topic for carrying out agile manufacturing strategy. This paper proposes a comprehensive cost function and establishes its mathematical formulation. The comprehensive cost function considers not only direct-processing cost, but also indirect-processing cost (transportation cost and time-factor cost including both earliness and tardiness). Based on the cost function, this paper presents a pragmatic approach for optimal process and partner selection in a virtual enterprise. This approach is composed of three stages: qualitative pre-qualification, quantitative evaluation, and comprehensive examination. A case study is implemented to illustrate these three stages. Compared with some traditional approaches in normal engineering activities, this approach can be expected to contribute to more efficiently reducing manufacturing cost, improving product quality, and shortening lead-time.


*Keywords:* Virtual organization; Process planning; Partner selection; Optimization

## 1. Introduction

Facing a competitive global market, industrial manufacturers are hard pressed to adopt some strategies and technologies to enhance product quality, to cut manufacturing cost, and to reduce product lead-time. Of these strategies, agile manufacturing is being paid an increasingly important attention [1–3]. In an agile manufacturing system, virtual enterprise (VE) is one of the most important organization manners [4,5]. It can be viewed as headed by a major firm that distributes the manufacturing tasks among a number of manufacturing partners sharing enterprise and resources. VE may contain several manufacturing partners dispersed over the world. They co-operate with each other in order to develop and manufacture products efficiently. VE plays not only the role of subcontracting among its companies, but also as partners who co-operate to lower product cost, improve quality, and reduce the amount of time necessary to bring the product to the market.

To form a proper partnership with subcontractors, a heading company needs to create feasible process plans and select suitable partners, based on product features and candidate partners' capabilities. Due to the complexity of manufacturing systems, process planning seldom considers resource capability and availability in normal manufacturing enterprises. In virtual enterprise environment, however, integration of process planning with partner selection by considering manufacturing partners' capabilities, cost, and timeliness is a critical issue. The concurrency between both of them can also eliminate redundant processes and optimize the entire production cycle.

Process planning can be defined as the systematic determination of detailed methods in which production activities are executed. It refers to a set of instructions that is used to manufacture components or parts so that the design specifications are met. It essentially determines how a product or component will be manufactured. In an attempt to increase the awareness of manufacturing considerations, some researchers developed several different approaches to reason manufacturing process plans. These approaches include direct or rule-based ones and indirect or plan-based ones [6,7]. But they are not suitable for alternative process plans in virtual enterprise environment. Some

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0924-0136/$ – see front matter 
doi:10.1016/j.jmatprotec.2005.11.026

researchers developed new frameworks and/or architectures of process planning for agile manufacturing systems [8,9]. Their reports are not involved in such an important issue as optimal manufacturing partner selection. Also, some researchers developed several approaches or methodologies for the selection and evaluation of partners [10–14]. However, there are, to date, few papers that give a practical and optimal solution, capable of meeting the requirements of real enterprise practices including processing time, partners' locations, and product due date, to the problem of concurrently executing process planning and partner selection in a virtual enterprise environment.

This paper addresses the problem of manufacturing a product or component in a virtual enterprise environment. A comprehensive cost function is proposed in Section 2. Based on the proposed cost function, a pragmatic approach is presented in Section 3 for the optimal selection of plant-specific process plans in a virtual enterprise. Section 4 provides a case study to illustrate the presented approach. Finally, some conclusions are described in Section 5.

## 2. Comprehensive cost function and its mathematical formulation

Cost effectiveness is the cardinal principle behind enterprise production. The main criterion of partner selection in a virtual enterprise environment is also the cost for manufacturing products. The due date requirement of manufactured products is also actually a pursuit for a minimum cost, because the earliness or tardiness of the lead-time will result in an increase of manufacturing cost. For this reason, different lead-time will be converted into a cost factor that includes both earliness cost and tardiness cost. Since manufacturing partners are usually located at different geographical locations under a virtual enterprise environment, in addition, both process cost and transportation cost should be considered when a set of optimal manufacturing partners is selected. Therefore, a comprehensive cost function is proposed so as to provide a quantitative analysis tool for the optimal selection of plant-specific process plans.

Suppose that for a given market opportunity, a heading VE has a set of potential partners ($K$) capable of manufacturing the product or component $p$ through a set of possible processes ($J$). Let $K$ denote the number of partners (indexed by $k$) and $J$ the number of processes (indexed by $j$), and define $\{\lambda_i\}$ as a set of possible plant-specific process plans ($i = 1, 2, 3, \ldots, I$). Then, the comprehensive cost $C(\lambda_i)$ should be the sum of direct processing cost $C_p(\lambda_i)$, transportation cost $C_s(\lambda_i)$, and time-factor cost $C_t(\lambda_i)$, that is,

$$C(\lambda_i) = C_p(\lambda_i) + C_s(\lambda_i) + C_t(\lambda_i). \tag{1}$$

In order to describe the proposed comprehensive cost function, the following terms are first defined:

- $(j, k)$ a set of process–plant combinations, where process $j$ is performed at partner $k$
- $T_p(\lambda_i)$ total processing time with respect to $\lambda_i$
- $T_s(\lambda_i)$ total transportation time with respect to $\lambda_i$
- $c_{jk}$ cost of process $j$ manufactured at partner $k$
- $t_{jk}$ time of process $j$ manufactured at partner $k$
- $E(\lambda_i)$ earliness amount with respect to $\lambda_i$
- $D(\lambda_i)$ tardiness amount with respect to $\lambda_i$
- $T_d$ due lead-time for manufacturing product $p$
- $T(\lambda_i)$ total completion time of performing $\lambda_i$
- $\alpha$ earliness penalties per unit time ($\alpha > 0$)
- $\beta$ tardiness penalties per unit time ($\beta > 0$)
- $t^s_{km}$ transportation time between partner $k$ and partner $m$
- $\theta$ transportation cost of a given batch of product $p$ through per unit distance
- $s_{km}$ transportation distance between partner $k$ and partner $m$.

Earliness and tardiness time can be expressed into:

$$E(\lambda_i) = \max\{0, T_d - T(\lambda_i)\}, \tag{2}$$

$$D(\lambda_i) = \max\{0, T(\lambda_i) - T_d\}. \tag{3}$$

Thus,

$$C_t(\lambda_i) = \alpha E(\lambda_i) + \beta D(\lambda_i). \tag{4}$$

If a constraint factor $z_{jk}$ (or $z_{lm}$) is introduced by

$$z_{jk}(z_{lm}) = \begin{cases} 1, & \text{if process } j \text{ (or } l\text{) is manufactured at partner } k \text{ (or } m\text{);} \\ 0, & \text{otherwise,} \end{cases}$$

then, the direct processing cost and time can be obtained from the following mathematical model:

$$C_p(\lambda_i) = \sum_{(j,k)\in\lambda_i} z_{jk} c_{jk}, \tag{5}$$

$$T_p(\lambda_i) = \sum_{(j,k)\in\lambda_i} z_{jk} t_{jk}, \tag{6}$$

subject to:

$$\sum_{k=1}^{K} z_{jk} = 1, \quad \sum_{m=1}^{K} z_{lm} = 1; \quad j, l = 1, 2, 3, \ldots, J,$$

$$\sum_{j=1}^{J} z_{jk} \le J, \quad \sum_{l=1}^{J} z_{lm} \le J; \quad k, m = 1, 2, 3, \ldots, K.$$

The former in the above constraints ensures that a process is performed at only one partner plant. And the latter ensures that one partner plant performs $J$ processes at most.

If process $j$ is assigned to partner $k$ and process $l$ to partner $m$ two constraint factors ($\delta_{km}$ and $\xi_{jl}$) are introduced by

$$\delta_{km} = \begin{cases} 0, & \text{if } k = m \text{ (it means that processes } j \text{ and } l \text{ are performed at the same partner } k\text{, and thus no transportation happens between the two processes);} \\ 1, & \text{otherwise.} \end{cases}$$