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# Systematic modeling and implementation of a resource planning system for virtual enterprise by Predicate/Transition net

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**Abstract**

While fierce competition impels many of the commercial markets into a low-profit environment, virtual enterprise (VE) appears as a business strategy for small and medium-sized enterprises (SMEs) to alley together. However, to support the operations of a VE, a resource planning system (RPS) is required. In this study, a systematic and hierarchical approach which consists of top-down modeling and bottom-up implementation steps is proposed and used for developing the RPS. Following this approach, a Predicate/Transition (Pr/Tr) net model for resource planning is derived. In addition, activity-based costing (ABC) is applied to provide a financial measure, profit, which is believed to be more meaningful in a collaborative environment. The Pr/Tr net model is further transformed into Horn clauses, and implemented by a logical programming language, Visual Prolog. Finally, a RPS which contains graphical user interface, model and knowledge database is developed. In the RPS, the goals and dispatching rules can be easily included and evaluated. In addition, the schedules based on the best dispatching rule can be generated. An example of horizontal collaborative manufacturing is used to illustrate the application of the RPS and the generation of the schedules.


*Keywords:* Resource planning system; Virtual enterprise; Predicate/Transition net; Activity-based costing; Horn clause

## 1. Introduction

Many of today's commercial markets are increasingly moving toward a low-profit environment, as a result it is hard for an independent firm to survive, especially those of small and medium-sized enterprises (SMEs). Usually, a SME is difficult to compete with a big one thus applying business strategies is sometimes crucial. Among the strategies, forming a virtual enterprise (VE) is recognized as one that may improve the competitive advantages of the participants, hence it becomes important. In an allied environment, VE is usually formed by distributed partners (or participants) and conceptually entitled by a nominal name so that a dedicated organization is not necessary. However, to realize the benefit of a VE, coordinating the participants' resources is critical. This implies that a Resource Planning System (RPS) is required.

Two aspects are important to develop a RPS for VE: the collaboration type and the approach. The collaboration type relates to the scope and functions the RPS is going to support while the approach relates to the model and procedure used to develop the RPS. Basically, three types of collaborations (horizontal, vertical and lateral collaborations) can be applied. However, to apply the collaborations, the features of each type must be first investigated and the RPS can then be developed properly. Definitely, a RPS can be designed and developed to support multiple collaborations simultaneously. In past research, Koestler (1989) introduced a theoretical framework for autonomous and decentralized manufacturing based on classical holonic paradigm; Huang and Leachman (1996) proposed a framework for VE control. In addition, Mezgar, Kovacs, and Paganelli (2000) proposed a co-operative manufacturing network model to coordinate the production of SMEs.

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Moreover, Huang, Hu, and Li (2004) applied timed colored Petri Net (TCPN) to model distributed manufacturing processes of member enterprise of a virtual manufacturing organization (VMO). However, these researches mainly focused on the modeling phase thus the implementation phase was not detailed; still there is a gap between the modeling and implementation phases. Thus, a procedure which can systematically support and closely link both of the modeling and implementation phases is required.

In addition to the procedure, modeling tool is another critical factor impacting the development of a RPS. In this study, Predicate/Transition (Pr/Tr) net is selected as the modeling tool due to its powerful modeling capability supported by two important features emphasized by Janneck and Naedele (1998): the ability of abstraction and refinement as well as the ability of configuration support. The former provides basic functions for modeling a system while the later enables system variants to be included flexibly. Moreover, Pr/Tr nets represent knowledge and reasoning rules (by predicates and transitions) graphically, thus they can be easily transformed into Horn clauses. Additionally, along with some other (expert) knowledge, a (expert) knowledge-based planning engine of the RPS can be established.

In the past, it is found that dispatching rules have been widely used for planning, and non-financial measures (such as maximum throughput, maximum utilization of workstations, minimum production cycle time, least tardiness or maximum wafer movements) have been used to evaluate the planning results (Glassey & Resende, 1988; Johri, 1993; Spearman, Woodruff, & Hopp, 1990; Uzsoy & Lee, 1992; Wein, 1988). Non-financial measures, however, cannot dollarize the amount of improvement (Fisher, 1992), nor can they directly link to an enterprise's financial vision, such as a company-level profitability, which is much emphasized by small firms (Laitinen, 2002). Fortunately, activity-based costing (ABC) was found can cover the shortages. ABC was firstly introduced by George and Stabus in 1977 and was believed can provide visibility to cost behavior (Ong, 1995; Pirttila & Hautaniemi, 1995). Moreover, ABC was further suggested could be adapted to provide profit information (Salafatinos, 1996), a financial measure, which is believed to be more meaningful in a collaborative environment because it seems hard to sustain a partnership without a profitable foundation. Thus, this study includes cost/profit concept into the RPS, differing to most of the past research.

This study aims to propose a systematic approach which can be used to develop a RPS for VEs to operate in a collaborative environment. This paper is organized as follows. The types of collaborations, ABC, Pr/Tr net, Horn clauses and Prolog program are reviewed in Section 2. The modeling of the RPS by Pr/Tr net is conducted in Section 3. The implementation of the RPS is conducted in Section 4. An example used to illustrate the application of the RPS is presented in Section 5. Finally, conclusion and future research direction are presented in Section 6.

## 2. Literature review

### 2.1. Collaborative environment and types of collaborations

Xu, Ye, and Li (2005) regards the VE as a dynamic alliance, which integrates the resources from one/many real enterprise through information infrastructure to respond rapidly to business opportunity. Fig. 1 illustrates a collaborative environment, in which a VE is formed to accept orders and coordinate the operations of the participants (companies A, B and C). Before start planning, the information of available resources are forwarded to the VE by the participants via the Internet. Thereafter, a RPS is used to plan and create the schedules that are further sent back to the participants for manufacturing. By the Internet, the visibility on the available resources of the participants can be easily enhanced; this facilitates the resource planning and cooperation of the participants.

Basically, there are three types of collaborations: the horizontal, vertical and lateral collaborations (Togar & Sridharan, 2002). The type of collaboration is mainly decided by the collaboration scenario and the attributes of the participants. Each type of collaborations is defined below:

- *Horizontal collaboration*: occurs when two or more unrelated or competing organizations cooperate to share their private information or resources, such as joint distribution centers.
- *Vertical collaboration*: occurs when two or more organizations such as the manufacturer, the distributor, the carrier and the retailer share their responsibilities, resources, and performance information to serve relatively similar end customer.
- *Lateral collaboration*: aims to gain more flexibility by combining and sharing capabilities in both vertical and horizontal manners.

### 2.2. ABC

Basically, ABC model describes product (cost object) consumes activities and activities consume resources, therefore from the two stage the product cost can be derived. Cooper and Kaplan (1988) categorized costs into unit-level, batch-level, product-level and facility-level cost, each of them is further detailed:

- *Cost object*: an object that consumes activities, such as product or order. Costs of the consumed activities can be rolled up to the object.
- *Cost driver*: the factors incur costs for a specific activity, such as process time, quantity of product, or quantity of material consumed.
- *Unit-level cost*: is defined as inputs increase in proportion to the number of units processed, such as number of wafers to be grinded, etc. Most of the activities occurred on the production line can be attributed to unit-level cost.