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Verification of Production Activity Control Architecture Using PETRI Net Tools

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Abstract: A Petri net is viewed as a valuable tool for studying and analyzing systems. Being a graphical tool, Petri nets can be used as a visual-communication aid similar to flow charts, block diagrams and networks. Beijing Institute of Technology-Production Activity Control (BIT-PAC) architecture has been developed to overcome the weakness of the former production activity control architecture. It facilitates the information flow from shop floor to the other areas of the organization and makes the organizations more integrated and productive. This architecture also facilitates in the expansion of the shop floor functions without disturbing the basic infrastructure. A Petri net tool is used to illustrate the communication between different entities specially Dispatcher, Producer and Sub-producer. To illustrate a sample protocol between Dispatcher, Producer and Sub-producer an available Petri net tool-HPSim is used to develop a model and then verify the effectiveness of the developed BIT-PAC architecture.

Key words: Petri net, Production Activity Control (PAC), shop floor information system, shop floor control

INTRODUCTION

Petri nets are a promising tool for describing and studying information processing systems that are characterized as being concurrent, asynchronous, distributed, parallel, nondeterministic and/or stochastic. In Petri nets, tokens are used to simulate the dynamic and concurrent activities of systems (Murata, 1989). Petri net was originated from Carl Adam Petri's dissertation, submitted in 1962 (Petri, 1962). The most important rule about Petri net is the transition enabling and firing. This is a simple rule but its implication in Petri net is very deep and complex.

A Petri net has two components: a net and an initial marking. A net is a directed graph with two sorts of nodes called places and transitions. Places are graphically represented by circles and transitions by rectangles. Places can store tokens represented by black dots. A distribution of tokens on the places of a net is called a Marking and corresponds to the state of the Petri net. A transition of a net is enabled at a marking if all its input places contain at least one token. An enabled transition changes the marking of the net; it removes one token from each of the input places of the transition and adds one token to each of its output places. Formally, a Petri Net is structured as a 4-tuple (P, T, F, W) where;

P = (p1, p2 …… pm) is a finite set of places;
T = (t1, t2 …….. tn) is a finite set of transitions;
$F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs;
W : $F \rightarrow \{1, 2, 3 \ldots\}$ is a weight function.

A marked Petri net is a 5-tuple PN = (P, T, F, W, M) consisting of a PN structure as defined above and a function
$M: P \rightarrow N$;
$Mo: P \rightarrow \{0, 1, 2 \ldots\}$; Mo is the initial marking with $P \cap T = \emptyset$ and $P \cup T \neq \emptyset$.

An essential feature of Petri net is that they can be executed. One can observe the interactions between the components and study the dynamics of the system modeled by a Petri net tool. Petri Net has been used successfully to model work flow and work flow systems by Salimifard and Wright (2001).

Manufacturing Systems generally contain some control levels to better manage the system. Each level in the manufacturing system consists of different primary activities. The first level usually contains information related to the production management to send, receive and control all the production data. The other two levels contain some commands to control the production as well as moving equipments.

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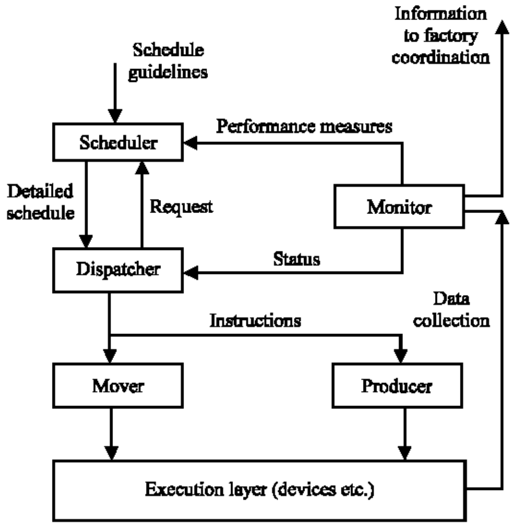

Fig. 1: Production activity control architecture

In a manufacturing system, the communication between two different levels is difficult. Not only the response time requests vary between each level but also the function requirements are varying from management to execution. Thus, it is not always possible to satisfy all the requests of all levels simultaneously. Centralization of information to a single point is not suitable. That is, different function modules should be able to communicate with each other directly. This direct communication should not create any bottleneck in the flow of information (Shean-Shyong and Yih-Ping, 2001). Initially a functional architecture was developed for shop floor control; its two main subsystems are the Production Activity Control (PAC) and the Factory Coordination (FC). Five basic modules of the PAC are the Scheduler, Dispatcher, Monitor, Mover and Producer as shown in Fig. 1 (Bauer *et al*., 1991).

The study of this PAC system reveals two weaknesses:

- Firstly, due to the role and position of the monitor, it is having a centralized information handling.
- Secondly, it is rather difficult to implement PAC on a specific manufacturing system due to the defined roles of Producer and Mover.

To overcome these weaknesses a further modified Beijing Institute of Technology-Production Activity Control (BIT-PAC) architecture (Fig. 2) was proposed which divides single station layer into two layers distributing it into the Producers and Sub-Producers, Movers and Sub-Movers (Shahid *et al*., 2006).

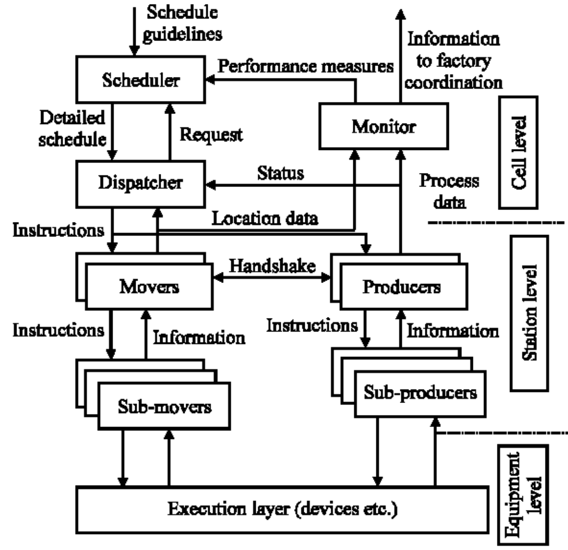

Fig. 2: Improved BIT-PAC architecture

The architecture proposed herein also solves the bottleneck as well as manufacturing system expansion problem thus adding the flexibility in the architecture according to the environment. Characteristics of the shop floor system must be preserved while using information technology.

BIT-PAC IMPLEMENTATION

There are two types of equipments in the shop floor: active and passive. Active equipment has its own machine controller e.g., CNC controller which is usually provided by the vendor. Equipment controllers are built to provide an interface between the physical equipment (machine controller) and the Shop Floor Control (SFC) software so that multi-vendor impacts on the development of the SFC software can be alleviated. There is one to one correspondence between equipment controllers and shop floor active equipment. An equipment controller is an instruction interpreter and executor. It converts the processing instruction data into a form directly usable by the specific machine controller and monitors the operation of the machine under its control. Passive equipment is particularly used to describe the two kinds of common storage equipment i.e., buffer units for the parts and buffer units for tools. Passive equipment requires no machine controllers. In the proposed Shop Floor Information System (SFIS), all the equipments including Sub-Producers and Sub-Movers are considered Passive. The dissemination of information from Sub-Producers and Sub-Movers is done manually through a PC.

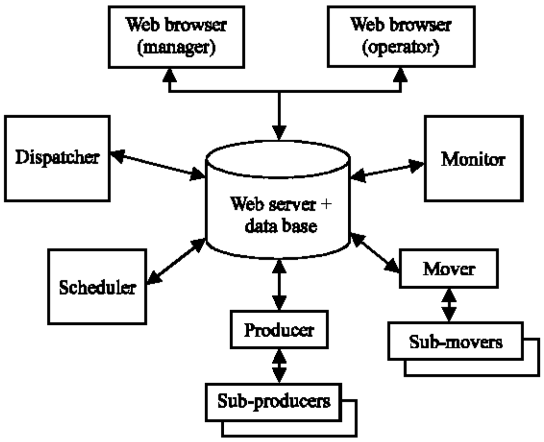

Fig. 3: Shop floor information system

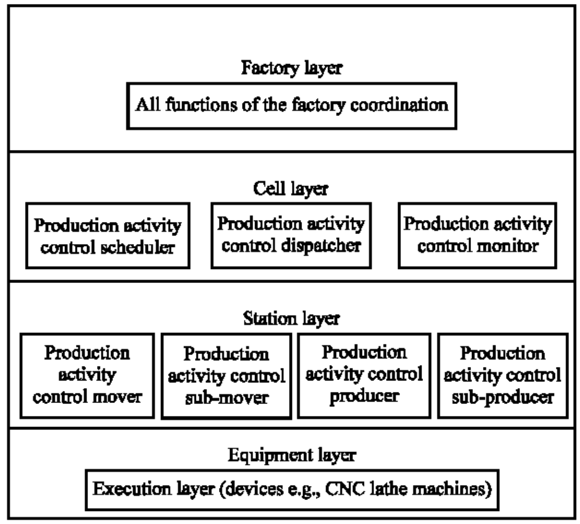

Fig. 4: Layered architecture for FC and PAC

According to the BIT-PAC architecture, the monitor module controls requests from outside the shop floor. Its data source is a common database. The other modules like scheduler, dispatcher, producer and mover communicate with each other along with the application logic through the Data Base server. Thus, if someone wants to access the activity status on the shop floor he requires only a web browser. The system architecture is shown in Fig. 3.

The BIT-PAC shop floor control architecture posses the following functions:

Reply time: The architecture is very effective to the reply time when high volume of information is carried out.

Efficiency: The efficiency of this architecture is not expected to be affected with the increase in system dimensions.

Simplicity: The architecture is simple and can be easily implemented by the organization's experts.

Expendability: The architecture also has the capability to expand by adding the new additional equipments as sub-producers or sub-movers, which are sub-parts of the Producers and Movers.

Adaptability: The architecture also has the ability to be adaptable according to the shop floor.

Cost: This architecture is expected to have low cost of implementation than any other architecture.

APPLICATION OF PETRI NET TOOL

Many Petri net tools have been developed during the last decade (The Petri Net World, 2007). Most of these tools are equipped with a graphical interface which also allows token game animation.

HPSim is a PETRI net tool used for the research and education purpose. HPSim was developed to support the design and simulation of Petri nets, both in a graphical and intuitive manner. The actual simulation is visualized as a Token Game Animation. This can be executed in single step or continuous mode. The software features Place/Transition Nets, Stochastic Petri Nets and Petri Nets with Time. This simulation tool is used to verify BIT-PAC shop floor architecture already developed.

Besides graphical functionality, some of the HPSim features are as follows:

Simulator: Along with stochastic simulation through token game animation, output of the marking vectors can be saved into one file.

Simulated network: Place-transition network can be created with different edge types with Weights and Timed transitions.

Size and complexity: The size and complexity of a developed Petri net is only limited by the performance of the used computer e.g., with an ordinary PC (let us say: PII, 300 MHZ, 128 MB), it is still convenient to edit and simulate a project with several nets and each net with 1000's of objects.

If we look closely at BIT-PAC architecture of shop floor control, it represents a layered architecture, which can be divided into different layers. Each layer consists of different entities, as shown in the Fig. 4.

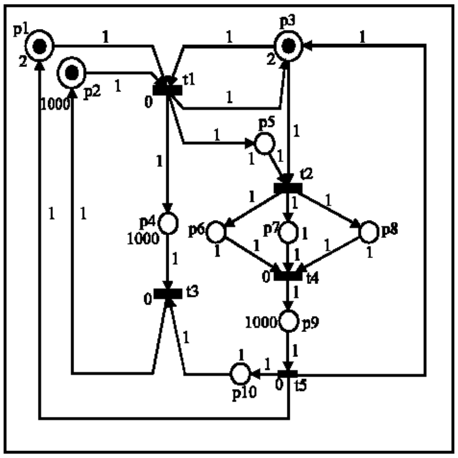

Fig. 5a: A petri net model for dispatcher and producer interaction-initializing

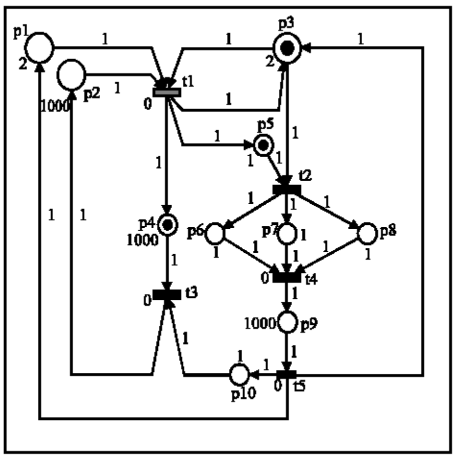

Fig. 5b: A petri net model for dispatcher and producer interaction-t1 fired waiting t2 to fire

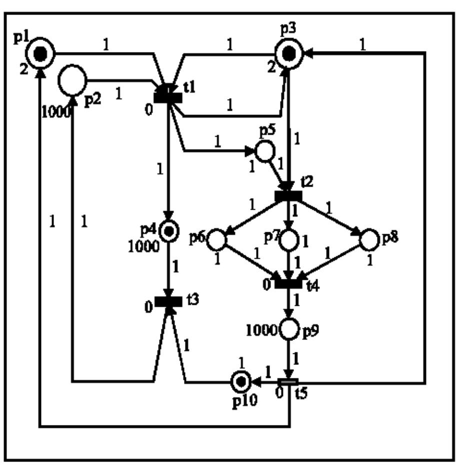

Fig. 5c: A petri net model for dispatcher and producer interaction-t5 fired waiting t3 to fire

Table 1: Petri net model conditions description

Condition	Description
p1	Job waiting
p2	Dispatcher availability
p3	Producer availability
p4	Dispatcher waits producer
p5	Producer receives command
p6	Sub-producer 1
p7	Sub-producer 2
p8	Sub-producer 3
p9	Sub-producers feedback to producers
p10	Dispatcher receives producer feedback

Table 2: Petri net model transitions

Transitions	Description	Pre-conditions	Post-condition
t1	Dispatcher commands producer	p1, p2, p3	p4, p5
t2	Producer commands sub producer	p3, p5	p6, p7, p8
t3	Dispatcher resumes	p4, p10	p2
t4	Sub-producers finish operations	p6, p7, p8	p9
t5	Producers finish operations	p9	p2, p3, p10

There are different distinct functional entities and services of each layer of the reference layered architecture for Factory Coordination (FC) and Production Activity Control (PAC). Here, the main concern is with the PAC, which consists of two layers; namely Cell Layer and Station Layer. These layers consist of five entities scheduler, dispatcher, monitor, mover and sub-movers, producer and sub-producer, which provide unique services so that tasks of the PAC can be performed (Fig. 4).

Factory layer controls the Cell Layer by providing it with the guidelines necessary to achieve the overall manufacturing goal. The Cell Layer consists of the main planning and control tasks of PAC and along with the Station Layer; it forms the complete PAC architecture in the information technology reference model. Functioning of different entities in the Cell Layer can be found in (Bauer *et al.*, 1991) in detail.

A protocol is generally considered as a set of rules and formats which determines the communication behavior of entities in the performance of functions. In this paper, Petri net model (Fig. 5a-c) is used to illustrate the communication between different entities specially Dispatcher, Producer and Sub-producer. A Petri net is viewed as a valuable tool for analyzing systems. Table 1 of Conditions and Table 2 of Transition are created to clarify a sample protocol between Dispatcher, Producer and Sub-producer.

CONCLUSIONS

This study introduces the use of Petri net and Petri net tools to verify animation modeling and analysis. Graphical representation of sample protocol is shown between Dispatcher, Producer and Sub-producer as a part of BIT-PAC through the use of HPSim. While modeling Petri net, only one token in each place is used to activate the transition. Moreover, weight value is also given as one (1) in the Petri net model. It is evident from the representation that Petri net tool provides an effective way to verify the information flow of an architecture developed for the shop floor.

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