# A Control and Integration Net Method for Manufacturing Systems

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**Abstract:** In this paper, an extended color Petri net method is presented. The presented control and integration net(CIN) method is supposed to solve the problems of uncertainities, resource sharing as well as dynamic interaction with external application programs in manufacturing system operation. An example of production system modeling using CIN is given. The CIN method is suitable to be used in the modeling of manufacturing system. It can also be used as basis for the development of cell control software platform kernel and the implementation of business process control of the integrating infrastructure (IIS) of computer integrated manufacturing open system architecture (CIMOSA).

**Key words:** Petri nets; control and integration net; production system; modeling

## 1 Introduction

Computer Integrated Manufacturing (CIM) system provides a very promising future for manufacturing industries. The successful implementation of CIM system requires the development of an integrated model of the overall system architecture, its control and information system. In order to design and implement a flexible, open integrated CIM system, generalized model and an open system architecture are required to reduce the system complexity to a manageable level.

Petri nets have been widely used in CIM system design, analysis and implementation. It provides valuable insight into the operation of the complex manufacturing systems. In the recent research of computer integrated manufacturing open system architecture (CIMOSA), Petri net method provides an approach to verify, simulate and execute CIMOSA models. Kotsiopoulos[1] has pointed out that Petri net can be used in the theoretical justification of the CIMOSA modeling environment. A Petri net based meta tool-McCIM[2] is developed and used for rapid prototyping of CIMOSA systems. The researchers of Loughborough University of Technology[3] have translated the CIMOSA model into Petri net and simulated the resulted Petri net model. But these works do not solve the problems for CIMOSA model execution. Our work is focused on developing a method which can solve the problems in CIMOSA model execution.

A Petri net is a directed bipartite graph composed of four parts: a set of places P, a set of

Manuscript received Aug. 23, 1995, revised Apr. 1, 1996.

transitions T, an input function I and an output function O. The input and output functions relate the transitions and places. If all input places are marked, the transition is enabled and can fire. Rules can govern the firing. When a transition fires the markers in the input places are eliminated and markers are created in the output places. The ordinary Place/Transition net as described above will become large and complex as the modeled system scale growing. So a high level Petri net called color Petri net (CPN) is introduced. A CPN is a compact description of the ordinary Petri net. The conciseness is achieved through merging analogous elements of the ordinary Petri net into a single place/transition and associating colors with tokens to distinguish among various elements. A transition can fire with respect to each of its color.

In our effort of modeling and controlling of manufacturing systems and in the representation of CIMOSA models using Petri nets, it is finded that the above defined CPNs are not sufficient enough to cope with the problems raised from the practical system operation and control, such as uncertainties which exist in the practical system operation, resource sharing and message transfer among different subnets and the dynamic interaction with external programs.

Uncertainty can be caused by the failure of machine breakdown, database query error, human intervention which is used to give new user decisions to the system, adjust system behavior, or make system error recovery. Interactions of Petri net model with external programs are also the sources of uncertainties. Because the feedback message or the new instruction from external programs is uncertain. The control system based on CPN must act according to the feedback message, i.e., it must have the ability to cope with the uncertainty problem. In our CIN definition, we introduce uncertainty arc which can cope with the uncertainty problem. The uncertainty arc is defined to appear with a special kind of transition called procedure transition. The definition of subnet transition is also extended.

Because there may exist uncertainties in the subnet, so the one to one mapping of the subnet transition is not valid any more. In order to solve the uncertainty problem, we extended the definition of subnet transition into two group of input-output mappings. The first is the relationship from input places of the subnet transition to input place (A special kind of place in the subnet used to receive tokens from parent net) of the subnet. The second is the relationship from the output place (A special kind of place in the subnet denotes the ending status of the subnet and is used to send tokens to the parent net) of the subnet to the output places of the subnet transition. There also exists resource sharing among different subnets. According to the normal definition, places of different subnets are distinct. This is useful in making a clear and simple level dividing. But it is hard to divide those parts which share some common resources and have some interactions among different subnets. This in fact made the hierarchical modeling a difficult task, because in practical system the different subsystems have more or less interactions among them. We introduce the definition of Global places to solve the problem of resource and information sharing among different subnets. All the Global places with the same name will be considered as the same place and the state change in one Global place will refresh all Global places with the same name.

In order to simulate and control the practical manufacturing systems, it is also necessary to introduce time, priority and inhibitor arc into Petri nets. The association of priority with all kinds of transition and the association of time with timed transition are adopted in our CIN definiton.

## 2 Control and Integration Net

In this section, we present the definition of CIN. Our defined CIN is a timed color Petri net including additional elements of input place, output place, Global places, subnet transitions, procedure transitions associated with uncertainty arc.

**Definition 1** A CIN is composed of a set of extended CPN(ECPN). Each ECPN is defined as a 6-tuple (Name, P, T, $C$, IO, $M_0$)where

1) Name is the name of the ECPN,

2) P = (PI, PO, GP, NP)is a set of places where

· PI is a unique place called input place,

· PO is a unique place called output place,

· GP = ($Gp_1, Gp_2, \cdots, Gp_l$)is a set of places called Global places, $l \geqslant 0$,

· NP = ( $p_1, p_2, \cdots, p_m$ ) is a set of normal places $m \geqslant 0$,

· T = (IT, TT, ST, PT)is a set of transitions where

· IT = ($It_1, It_2, \cdots, It_n$ )is a set of immediated transitions $n \geqslant 0$,

· TT = ($Tt_1, Tt_2, \cdots, Tt_k$ )is a set of timed transitions, $k \geqslant 0$,

· ST = ($St_1, St_2, \cdots, St_q$ )is a set of subnet transitions, $q \geqslant 0$,

· PT = ($Pt_1, Pt_2, \cdots, Pt_r$)is a set of procedure transitions, $r \geqslant 0$,

4) $P \cup T \neq \Phi, P \cap T = \Phi$

5) C( $p$ )and C( $t$ ) are the sets of colors associated with place $p \in P$ and transitions $t \in T$,

6) IO = (NIO, TIO, SIO, PIO)is a set of transition's mappings from input places to output places of the transition, where

· NIO = ($Nio_1, Nio_2, \cdots, Nio_n$)is a set of mappings of immediate transitions, $n$ is equal to the count of IT.

· TIO = ($Tio_1, Tio_2, \cdots, Tio_k$)is a set of mappings of timed transitions, $k$ is equal to the count of TT.

· SIO = (SI, SO)is the input and output mappings of subnet transitions, where

Ⅰ) SI = ($Si_1, Si_2, \cdots, Si_q$)is a set of input mappings of subnet transition from input places of subnet transition to the input place of the subnet, $q$ is equal to the count of ST,

Ⅱ) SO = ($So_1, So_2, \cdots, So_q$)is a set of output mappings of subnet transition from output place of subnet to the output places of the subnet transition in the parent net. $q$ is equal to the count of ST,

· PIO = ($Pio_1, Pio_2, \cdots, Pio_r$)is a set of input-output mappings of the procedure transitions, $r$ is equal to the count of PT,

7) $M_0 = (m_0(PI), m_0(PO), m_0(Gp_1), \cdots, m_0(Gp_l), m_0(p_1), \cdots, m_0(p_n))$is the initial marking of P.

It is better to describe Petri net in a graphical form, we give a set of graphical notation of the elements of our ECPN in Fig. 1 before we go further into detailed discussion about the ECPN properties.

The graphical interconnection of these symbols in Fig. 1 is quite simple. The place and transition symbols are nodes, the directed arcs are used to establish connection between places and transitions. The normal arcs have two kinds: 1) direction from place to transition arc which denotes that the place is the input place of the transition, 2) direction from transition to place which denotes that the place is the output place of the transition. The direction of Inhibitor arc is from place to transition. It is used to constrain the fire of the transition. The enabling conditions of a transition with a Inhibitor arc are: 1) the input place of the transition have the token colors required by the transition occurrence color, and 2) the origin place of the Inhibitor arc do not have the token colors which effect the Inhibitor arc. The direction of the uncertainty arc is only from procedure transition to place.

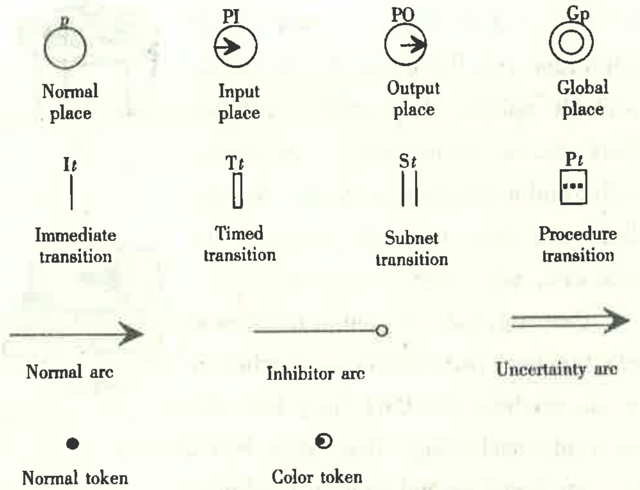

Fig. 1 Symbols for extended color Petri nets

**Remark 1** Input place in an ECPN can only be used as input place of transition and output place in an ECPN can only be used as output place of transition. Both the input place and output place can not be defined as Global place. It is only necessary to define input place and output place for subnet.

**Remark 2** Every ECPN is a part of the CIN. The whole net is connected through subnet transitions and Global places. In the subnet transition case, Name, Input place and Output place of the net are the hooks linking a subnet transition with a subnet.

**Remark 3** The uncertainty is introduced through uncertainty arc. Different from immediate and timed transition which have a definite input-output mapping for a transition occurrence color, the output of a procedure transition through uncetrainty arc is uncertain. The created token color in the destination place of a uncertainty arc is determined according to execution result of the procedure invoked by the fire of the procedure transition. The execution result is uncertainty, so the input-output mapping for the procedure transition can not be defined as a one to one mapping. For a Procedure transition, the input-output mapping is an uncertainty mapping which is shown as follows:

$$(\text{input places token colors}) \xrightarrow[\text{occurrence color}]{\text{fire with an}} \begin{array}{l}\text{one of (output places token colors)}\\ \text{from a set of(output places token colors)}\end{array}$$

**Remark 4** For every color of place, a data structure is associated. This is used to enable token to carry messages, data values, as well as pointers to the outside data block.

## 3 Example

Consider a production system shown in Fig. 3. It consists of a Load/Unload station, two machines, a robot, an inspection station and two common buffers. Load/Unload station has two fixture platforms and six available pallets. For every machine, there are an input buffer, an output buffer and a working platform. Assume there are two type of parts to be produced, $wp_1$, $wp_2$.

Part $wp_1$ has one step of machining which is performed either on machine 1 or on machine 2. Part $wp_2$ has two steps of machining, first step is on machine 2 and second step on machine 1.

The inspection station works only when the machining process has given an error message. On this condition, the produced part will be sent to the inspection station to be checked for its quality. A fault handing procedure will also be called when the machine reports an error message.

Assume at the beginning of the production, there are six raw parts (three $wp_1$, three $wp_2$) on the LU station. A new raw part will be sent to the LU station when a finished part or a bad part leaves the system. The type of the new part is given by scheduling system. In our CIN model, it is modeled as a procedure transition with an uncertainty arc.

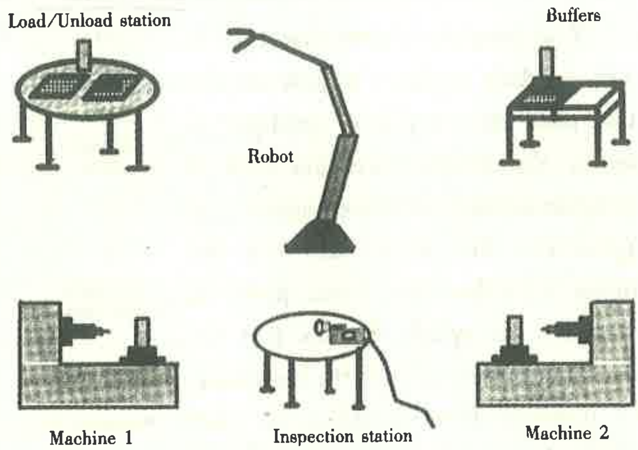


Fig. 2 Layout of a production system

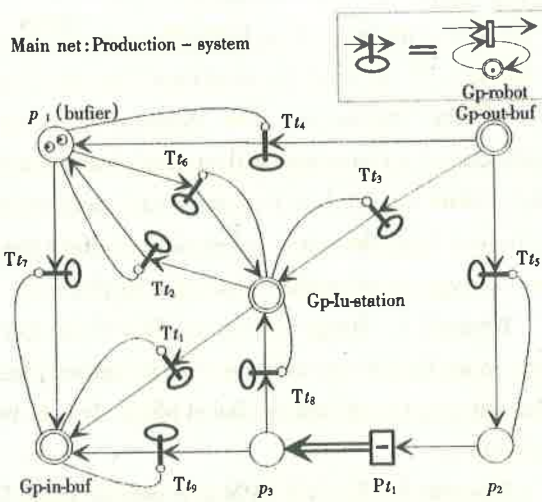


Fig.3 (a)

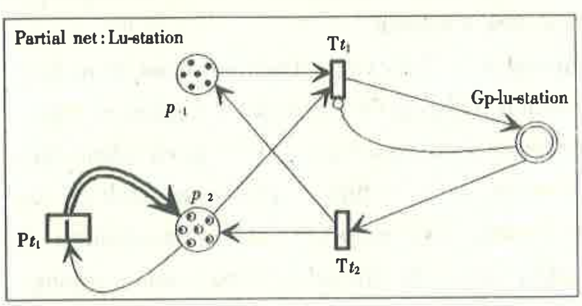


Fig.3(b)

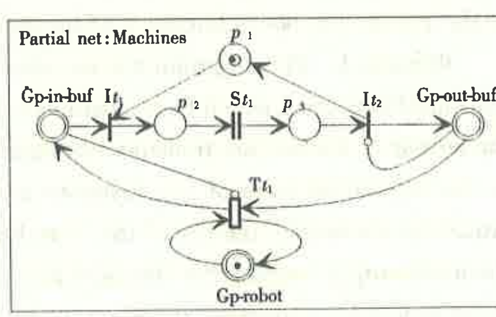


Fig.3(c)

Assume the moving time for the robot to move part from one place to another place is fixed.

Due to the length limit, the color set, transitions mappings and the token associated data structure are omitted. The interested readers can contact the first author for them.

The net structure of the CIN model of Fig.3 is unchanged in the following cases:

1) Increasing of machine number from current two to three, four or many;

2) Increasing of part types from current two to many;

3) Increasing of machining steps for part from two to many.

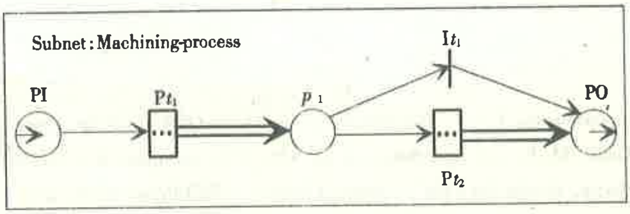


Fig. 3(d)

Fig. 3 CIN model of production system

The decomposition of the CIN model into a set of partial nets and subnets make it clear to see and distinguish different functional role of every part. It also simplifies the modeling process and makes the net easy to understand, because the user and designer of a partial net do not need to be forced to know those irrelevant partial nets, they can concentrate all the focus on the subject they are modeling. The modeling process for a complex systems can be done by many designers in parallel according to the functional and structural decomposition of the system.

It is an easy job to handling uncertainty through procedure transition and uncertainty arc. The introduction of procedure transition provides an natural interface to external application programs. The internal messages(event, request, error, …) among partial nets and subnets are transferred through Global place, the working principle of Global place is similar to that of DDE in real time programming and procedure invoking is similar to the subroutine call.

In most cases, the adding of new devices into the modeled production is a simple process. It can be done by two steps: 1) adding a new partial net for that device, 2) connecting the new net into CIN through Subnet transition and/or Global places.

For the modeled production system, the data information associated with the material flow (parts) and information flow(error message, inspection results) can be transferred with tokens through the associated token data structure. This will convenience the use in practical applications.

## 4 Conclusion

As the example shows, the CIN method has the following advantages in modeling and controlling of production system.

1) clear and easy extended net structure, 2) easy integration of new partial net, 3) natural interface with external applications, 4) uncertainty handling, 5) easy event message and data information transfer.

The above designed CIN model can be simulated through the CIN simulator and can be executed through CIN interpreter. The implementation of a simulation and execution tool based on CIN is our next step work. The CIN simulation and execution tool will be used in the construction of the execution and management kernel for a cell control platform as well as in the implementation of business process control of CIMOSA IIS.

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# 用于制造系统的控制和集成网方法

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**摘要**:本文给出了一种扩展 Petri 网方法.这种方法是为了解决实际制造系统运行和控制中存在的不确定性、资源共享及和外部应用程序的动态交互的问题.文中给出了一个用控制和集成网方法建立的生产系统模型.本文提出的控制和集成网方法适合用于制造系统的建模.它同样可以用作开发单元控制软件平台核心和实施 CIM 开放系统体系结构中集成基础结构的经营过程控制的基础.

**关键词**:Petri 网;控制和集成网;生产系统;建模

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