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Modeling of Mixed-Model Assembly System based on Agent Oriented Petri Net

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Abstract: In this paper, a mixed-model assembly system is modeled using ATPN (agent oriented timed Petri net) based on assembly resources classification. Firstly, the basic concepts and definition of ATPN is described. Secondly, with ATPN method introduced into mixed-model system research the modeling of a mixed-model assembly system is discussed. The development of an ATPN model for a MMAS consists of four phases: (1) agent-oriented assembly resources classification of MMAS, (2) development of universal ATPN model of each kind of assembly resource, (3) construction of mixed-model assembly cell centering about assembly robots or humans, (4) construction of the MMAS model based on mixed-model assembly cell after analyzing the system requirements. Thirdly, by studying the transforming from AUML (agent Unified Modeling Language) model towards ATPN-based model and its simplification the ATPN-based interactive protocol model is constructed for a mixed-model assembly system. Meanwhile, based on ATPN the performance indicators of mixed-model assembly System are analyzed. Finally, an illustrative example of a MMAS in certain enterprise demonstrates the steps and effectiveness of this approach.

Keywords: Agent oriented timed Petri net, Mixed-model assembly system, Modeling

1 Introduction

Nowadays manufacturers need to quickly respond to the variable demands of the customers owing to fierce competitive market. Mixed-model assembly system (MMAS) belongs to a kind of mixed-model manufacturing systems which is cost-effective because of its better ability to absorb frequent changes in product demands than other conventional manufacturing systems [1,2].MMAS is a highly complex concurrent system, composed of logistics system and information system. The method of MMAS modeling, which can reveal the stochastic dynamic process essentially of MMAS and make the structure of MMAS reconfigurable, intelligent and autonomic, is the foundation of MMAS technology. Therefore relative research on methods of MMAS modeling is significant.

In the modeling field, Petri nets have gained more and more attention in manufacturing systems because of their graphical and mathematical advantages over traditional tools to deal with discrete event dynamics and characteristics of complex systems [3,4,5,6]. Wang [7] presented a paradigm, called CTOPN (colored timed object-oriented Petri net), to model an automated manufacturing system (AMS). Kuo et al. [8] presented a resource-oriented distributed colored timed Petri net (DTCPN) modeling method to describe the controlled IC fab system. Ben [9] presented an enhanced expert high-level colored fuzzy Petri net model for assembly system, making the modeling, planning and operation of assembly system intelligent in some manners. Yu et al. [10] applied the knowledge-based Timed Colored Objected-oriented Petri net (TCOPN) to model reconfigurable assembly systems. Cai [11] analyzed the modeling requirements of reconfigurable manufacturing system and proposed a modeling methodology based on timed reconfigurable Petri nets. Zha et al. [12] proposed a concurrent intelligent approach and framework for the design of robotic flexible assembly systems with knowledge Petri net and functionCbehaviorCstructure model employed.

Unfortunately, the above modeling methods lack logic expression and performance analysis for complex scheduling and control process. In this research, an attempt has been made to describe the complex control logic of MMAS effectively in order to satisfy demands in assembly system analysis, optimization and

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reconfiguration, using the modeling method of agent oriented timed colored Petri net (ATPN).

The rest of this paper is organized as follows: section 2 describes basic concepts and the definition of ATPN. Section 3 discusses how ATPN is used to model a RAL based on assembly resources classification and the ATPN-based interactive protocol modeling of MMAS is given in section 4. Based on ATPN the performance indicators of mixed-model assembly System are analyzed in section 5, followed by an application instance in Section 6. Finally the future work will be pointed out.

2 Product function analysis preparation

Definition 1:

Mathematically, an ATPN model may be defined as $ATPN=(AP,CP,RF,MPR)$, where $AP=\{AP_i,i=1,2,,...,n,n\in N\}$,which represents a set of assembly resource agents and logic control agents; $CP=\{CP_i,i=1,2,,...,n,n\in N\}$,which represents the system protocol sub-net and can be used to analyze the boundness, liveness and safeness of interactive protocol of dynamic behaviors between agents based on description of the protocol in order to guarantee the effectiveness of multi-agent coordination, where CP_i is the ith decision agent of assembly resources scheduling of MMAS;RF is a map function, which maps the place of conflicting AP_i to multi-agent interactive protocol net for conflict resolution;$MPR=\{TG_{ij},i,j=1,2,,...,n,i\neq j\}$,which presents the message transitive relationship between AP_is or between AP_i and its outward, where TG_{ij} is the transition of connections between AP_is whose activation depend on the system protocol sub-net.

Definition 2:

A model encapsulates each agent model and is defined by a 9-tuple structure.

$AP_i=\{P_i,T_i,F_i,IM_i,OM_i,I_i,O_i,D_i,C_i,M_{0i}\}$, where $P_i=\{P_{ij},j=1,2,,...,n,n\in N\}$,which represents a set of resource state places denoting the inner status of agents;

$T_i=\{T_{ij},j=1,2,,...,m,m\in N\}$,which presents a finite set of transitions of certain physical object in MMAS;

$F_i=\{F_{ij},j=1,2,,...,r,r\in N\}$,which represents a finite set of input/output arcs between places and transitions, denoted by $F_i=(P_i\times T_i)\cup(T_i\times P_i)$;

$IM_i=\{IM_{ij},j=1,2,,...,l,l\in N\}$,which represents a set of input message places for AP_i;

$OM_i=\{OM_{ij},j=1,2,,...,s,s\in N\}$,which represents a set of output message places for AP_i;

D_i represents the time delay of transitions;

$I_i(O_i)$:$P_i\times I_i\rightarrow\{0,1\},IM_i\times T_i\rightarrow\{0,1\},OM_i\times T_i\rightarrow\{0,1\}$,is an input(output) function for transitions of state places and message places;

$C(P_i),C(T_i),C(IM_i)$ and $C(OM_i)$ represent a color set of state places P_i, activity transitions T_i, input message places IM_i and output message places OM_i respectively;

M_{0i} represents the initial marking of AP_i model, which is used to initialize the system state and reflect the distribution of initial tokens position in Petri net.

Definition 3:

A CP_i model is defined by a 6-tuple structure.

$CP_i=\{P_i,T_i,I_i,O_i,C_i,M_{0i}\}$ where,

P_i and T_i represent a set of state places and transition places for resource scheduling and control respectively, denoting the status variation of agent inference;

$I_i(p,t)$: $C(p)\times C(t)\rightarrow N$ is an input function for transitions of state places, which corresponds to the colored vector arc from state place p to transition t ;

$O_i(p,t)$: $C(p)\times C(t)\rightarrow N$ is an output function for transitions of state places, which corresponds to the colored vector arc from transition t to state place p;

$C(P_i)$ and $C(T_i)$ represent a color set of state places P_i and activity transitions T_i;

Definition 4:

For firing a transition, a transition T_i of CP_i about b_{jk} with a marking M may fire whenever it is enabled if and only if $\forall P_i\in\cdot t_j:M(P_i)(a_{i,h})\geq I(P_i,T_i)(a_{i,h},b_{j,k})$,where $a_{i,h}\in C(P_i)$ and $b_{j,k}\in C(T_i)$.Firing an enabled transition T_i results in a new M' defined by
$M'(P_i)(a_{i,h})=M(P_i)(a_{i,h})+O(P_i,T_i)(a_{i,h},b_{i,h})$-$I(P_i,T_i)(a_{i,h},b_{i,h})$, if $\forall P_i\in\cdot t_j\cup t_j\cdot$ and $M'(P_i)(a_{i,h})=M(P_i)(a_{i,h})$ or else

The performance of MMAS is measured by time, so the transition in ATPN model can be classified into immediate and deterministically timed transition. According to the places function, places are classified into resource places, message places and agent places. Resource places denote the attribute or status of equipment resources. Message places denote the sent/received status of the input/output message. Agent places denote the operation status of the agent whose inner behavior is encapsulated.

3 Modeling of mixed-model assembly system

3.1 ATPN model of assembly resources

According to the operation state of assembly cell, state transition diagram (STD) can be obtained which can be further converted into ATPN model. The sub net of each agent class represents entities similar in behaviors whose common sates and behaviors are encapsulated in the sub net of each agent class. Resource behaviors are mapped into transitions, while resource states or attributes are mapped into state places. Also the interactions between resources are mapped into input or output function for transitions of message places. An ATPN example of pallet agent model is shown in Fig.1.

3.2 ATPN model of mixed-model assembly Cell

After assembly resources classification and ATPN modeling of assembly resources, the ATPN model of

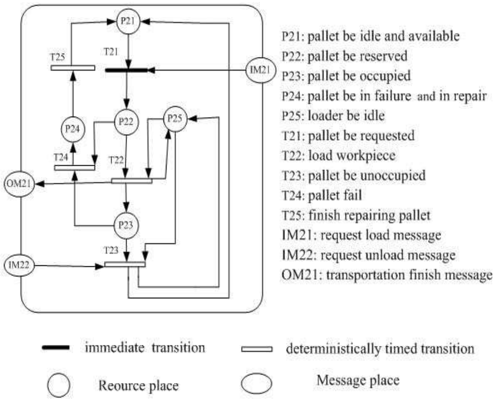

Fig. 1: ATPN-based pallet agent model

mixed-model assembly cell can be constructed using communication transitions to combine ATPN models of each kind of assembly resources. The number of assembly resource agents in the mixed-model cell depends on specified manufacturing system. The constructed reconfigurable cell is autonomous and intellectual. The message passing between resource agents can be realized by transient transition and the conflicts between resource agents can be settled by invoking multi-agent interactive protocol sub net.

3.3 *ATPN model of mixed-model assembly system*

Firstly, analyze the number of assembly cells in demand, and then determine the message passing relationship of the whole system according to the logical relationship between assembly cells. The connection between assembly cells can be realized by transient transition. Finally, multi-agent interactive protocols are needed to settle the deadlock and conflicts of communication transition in the system. A new mixed-model assembly system can be rapidly reconfigured based on the predefined ATPN models of mixed-model assembly cells. The cells can be connected by transient transitions and the conflicts in and between the mixed-model assembly cells can also be settled by invoking multi-agent interactive protocol sub net.

4 ATPN-BASED INTERACTIVE PROTOCOL MODELING OF MMAS

4.1 Rules for transforming AUML model towards ATPN model

AUML (Agent Unified Modeling Language) is a popular multi-agent modeling technology. The interactive protocol sequence diagram of MMAS is constructed using AUML technology in our research. In the AUML sequence diagram which supports messages concurrency, the passed messages include both simple unstructured messages and semantics-rich structured messages. The subjects in the AUML sequence diagram can be keep active all the time. However, in actual applications the interactions between agents are very complex and the accidents (e.g. deadlocks) should be prevented. In the case of the above, The AUML protocol diagram cannot describe the concurrent behaviors pretty well because of its limited ability. In contrast with AUML sequence diagram, ATPN model can describe the information flow in and between agents more visually and more clearly in describing the inner states and control process of agents. Although AUML diagram can represents protocol model more visually, ATPN model is predominates in software implementation and inspection. For the reason, some rules are defined to transform the AUML representation towards an ATPN model for model analysis and verification. So only by realizing the transition from AUML protocols graph to ATPN model can we analyze and verify the reassemble wire model. Aiming at the key problem, we define some transition rules to realize the transition from AUML protocols graph to ATPN model. Figure (a), (b), and (c) in Fig.2 expand the symbol of UML, respectively, (a) uses thick symbol to represent AND logic, which means send message to several Agent at the same time; (b) uses rhombohedra to represent an Or logic connection between messages, which means an Agent sends messages from zero to many; (c) uses a rhombohedra with a cross in it to represent XOR logic, which means an Agent is selective to send a message.

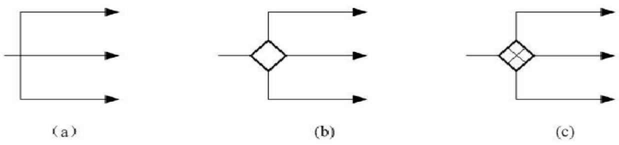

Fig. 2: Expanding symbol graph of UML

During the transformation process we fix attention on message passing mechanism, so we assume resources are sufficient and the following rules:

Rule 1:

In the AUML model shown in Figure 3(a), a lifeline represents an agent or a role or a group and corresponds to a sequence places and transitions, where transitions correspond to message processing cells. The type of places determines the type of tokens in it and tokens correspond to exchanged data between agents. Transformed element is mapped into vector arc from a place to a transition or form a transition to a place, which corresponds to the connection in and between agents. Places correspond to messages or the state of wait or reasoning of agent inner.

Rule 2**:**

The process of sending/receiving messages is shown in Figure 3(b), where place P1 and P2 correspond to the agent place of a sender and a receiver, transition TS1 and TS2 corresponds to the send-message arc in ATPN and place P3 and P6 correspond to the sent messages. P1 or P2 fires TS1 or TS2 to send messages and then enters wait state place P4 or P5. Further P4 or P5 fires TR1 or TR2 to receive messages and then enters wait state place P7or P8.

Rule 3:

Each message execution process can be separately transformed referring to Rule 1. The concurrency is denoted by transition T1, shown in Figure 3(c). T1 may have several output places the number of which is the number of messages in the concurrency group. Each output place corresponds to the start of each message in the concurrency group.

Rule 4:

Like the transformation of concurrency relation, the transformation to Petri net of selection relation begins with certain common input place P1 which corresponds to the state of P1 before selection relation start. The number of output transitions of P1 is the number of messages in the selection group and the fire of the output transitions denote the selected massages start to execute.

Rule 5:

Like the transformation of selection relation, the only difference of the transformation of exclusive or relation from the one of selection relation is that only one message among all messages sent by common input places can be sent.

4.2 Modeling of interactive protocol of ATPN-based MMAS

The interactive protocol of ATPN-based MMAS can be modeled under the following steps:

Step 1:

Analyze the interactive process between agents. Based on the contract net mechanism, determine buyer agent and seller agent and specify the message passing relation between them. The token passing between agents is handled by KQML (knowledge query manipulation language).

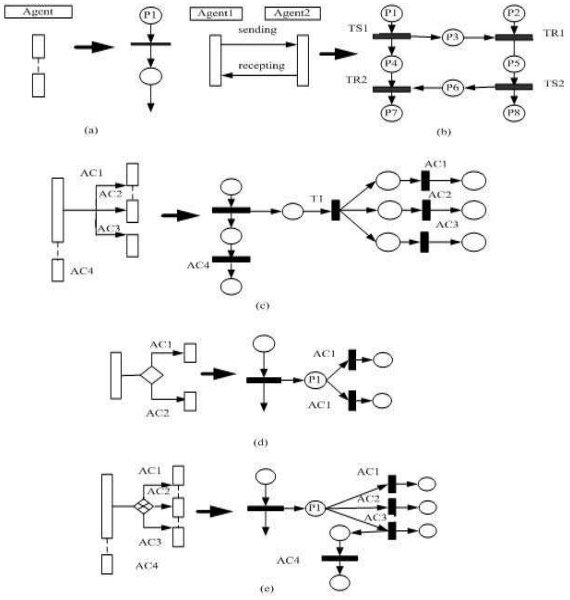

Fig. 3: Transforming diagram from AUML model to ATPN model

Step 2:

Construct the AUML protocol diagram. According to the concurrency, selection or exclusive or relation of message passing, the protocol diagram is constructed based on AUML.

Step 3:

Based on the rules defined in Section 3.1, transform the AUML protocol diagram to ATPN model orderly from top to bottom. The selection of lifelines (and, or and exclusive or) depends on the firing condition of transformations.

5 PERFORMANCE INDICATORS ANALYSIS OF MIXED-MODEL ASSEMBLY SYSTEM

Performance indicators of reassemble wire model major in the whole system, assembly equipment and workpiece. There are some specific indexes, such as the whole productivity, the equipment utilization ratio, the equipment failure rate, the assemble time, manufacture cycle and so on.

In the ATPN model, transition is divided into immediate transition, fixed delay transition and random delay transition. For ATPN model of MMAS, performance evaluation can be made after introducing time parameter. If the delay transition time is accurate, the manufacture cycle of making a workpiece is the whole process assembling time from the start to the finish. For certain equipment, recording the trigger counter and trigger time can get the working time of the equipment. Comparing with the whole system time, we can get the utilization ratio, and then the whole productivity can be worked out.If the time parameter of delay transition in the model is random variable, the calculation of performance indexes is based on stationary probability of Markov chain. The marking or state of model markup process is divided into tangible state T and vanishing state V,S=$T\bigcup V$,$T\bigcup V$=$\varnothing$,K_s=K_t+K_v,When analyzing the state of ATPN model, we regard parts which use little time as vanished state, and transition time can be neglected. And we regard the state which can enable the index transition as tangible state. The whole marking process is a semi-Markov chain with discrete state space. In order to calculate the performance index, we should calculate the stationary probability of tangible state at first.

The occurring time of random delay transition usually subject to negative exponential distribution (life distribution) whose parameter is λ,

$$F_{ij}(t)=\begin{cases}1-e^{-\lambda x}, & x>0\\ 0, & x\leq 0\end{cases} \tag{1}$$

where$F_{ij}(t)$ is the transition ratio from state to state.

Assume that there are n tangible states, the marking set of tangible state is M=$\{M_i|i=1,2...,n\}$,X=$(x_1,x_2,x_3,...x_n)$, where x_1 is the stationary probability of marking M_i, according to the theory of Markov stationary distribution, the following linear equations are established as :

$$\begin{cases}XQ=0\\ \sum_i^n x_i=1\end{cases} \tag{2}$$

where Q=$(q_{ij})_{n\times n}$ is a state transition probability matrix,$i=1,2,...n$,$j=1,2,...n$,when $i\neq j$, q_{ij} is the sum of transition stimulate probability of the whole output arcs from state m_i to state m_j, and when $i=j$, q_{ij}=$-\sum_{i\neq j}^{n} q_{ij}$.

Eq.(2) is a $n+1$ homogeneous equation, there are n unknown variables, and that is state stability probability vector X, and Q is unfilled rand, so there are $n-1$ stability state equations, along with the equation$\sum_i^n x_i=1$, then we can the state stability probability of reachable marking $P[M_i]=x_i(1\leq i\leq n)$.

On the basic of stability probability of each marking state is known, we can analyze the following performance indexes in depth as follows.

(I)Average dwell time of tangible state markingM_i. The dwell time of the model in each reachable marking M_i represents the average execution time of certain task, and its a random variable subject to index distribution. Its mean is as:

$$s_i=\left[\sum_{t_k e T_t}\lambda_{kj}\right]^{-1} \tag{3}$$

where λ_{kj} is stimulate ratio of transition t_k in the marking M_i.

(II)Token of place $p_i(i=1,2,3...)$ is the probability of k. Assuming $S=\{j\in(1,2,...,s):M_j(p_i)=k\}$, the probability meets this condition is

$$Prob(p_i,k)=\sum_{j_e S}x_j. \tag{4}$$

(III)Token expectation of place $p_i(i=1,2,3...)$. The expectation of tokens in bounded place K is:

$$E(p_i)=\sum_{k-1}^{K}kProb(p_i,k). \tag{5}$$

(IV)Send ratio of delay transition. Assuming $S_1=\{j\in(1,2,3...s);T_j isenabledbyMi\}$, so the send ratio of transition t_i is as:

$$Tr(t_i)=\sum_{j\in S_1}x_j\lambda_{ji}, \tag{6}$$

where λ_{ij} is stimulate ratio of transition t_i in the marking M_i.

(V)The average waiting time of place $p_i(i=1,2,3...)$ is as follows:

$$Tw(p_i)=E(p_i)/\sum_{t_j\in IN(p_i)}Tr(t_j)=E(p_i)/\sum_{t_j\in OUT(p_i)}Tr(t_j), \tag{7}$$

where $IN(p_i)$and $OUT(p_i)$ are p_i output transition set and p_i input transition set .

(VI)The average marking number of state place. For$\forall p_i\in P$, P is place set, $\overline{m_i}$ represents marking number that place p_i contain in any reachable state, so there is as:

$$\overline{m_i}=\sum_j j\times P[M(p_i)=j], \tag{8}$$

Where the average marking number of place set $P_j\subseteq P$ is the sum of evaluation marking number of $P_i\subseteq P_j$, it is as:

$$\overline{N}=\sum_{P_i\subseteq P_j}\overline{m_i}, \tag{9}$$

What should be stressed is that it doesnt make any sense unless the physical means above can be combined with reality. Generally speaking, the assembly delay transition send ratio in ATPN model is same to equipment productivity of this model. If place represents situation of the certain workpiece, the expectation of place tokens is same to the number of the product in process. The sum of average waiting time in model place is the production cycle. The place average marking number can not only estimate the utilization of this equipment, but also can analyze the performance index such as length of task queue in process.

6 APPLICATION INSTANCE

The illustrated model presented in this paper is based on a MMAS in certain enterprise. The MMAS is mainly in charge of assembling shafts, gears, trays, hydraulic torque converters, boxes and so on into driving cells. Although the driving cells differ from each other in types, they can be assembled in the same assembly line owing to much the same number of assembly components and much the same assembly sequence. The assembly tasks are mainly finished by assembly robots. The ATPN model of the MMAS can be derived by the mixed-model assembly cells described above, as shown in Fig.4.

The connections between the mixed-model assembly cells can be realized by transient transitions T1T̃11. When orders vary or assembly devices fail, the assembly line can drive the mixed-model assembly cells to reconfigure a new assembly line by adding/deleting assembly cells and the transient transitions between assembly cells simply and rapidly.

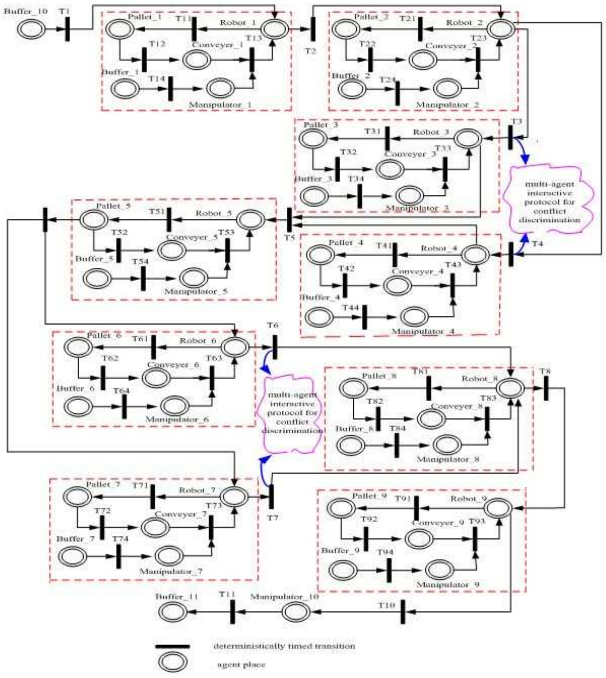

Fig. 4: ATPN-based MMAS model

7 CONCLUSIONS

MMAS is characterized by its reconfigurability, scale, adaptivity, intelligence, autonomy and so on. This research seeks to model an application MMAS based on ATPN. An initial round of investigation has been completed, and a model has been constructed. The next steps are to research on scheduling of MMAS for resource operation control and to put the MMAS into demonstration enterprise. Findings from the ongoing investigation will be reported separately in the near future.

The main tasks of this research are as follows:

(1) A kind of ATCPN-based RAL modeling technology is presented and a model for an application RAL is constructed using the technology.

(2) The multi-agent interactive protocol is introduced to resolve conflicts in the constructed model and the ATCPN-based modeling technology of the protocol is studied.

(3) The rules of transforming the AUML model towards ATCPN model are presented.

(4) Based on ATPN the performance indicators of mixed-model assembly System are analyzed

(5) The application steps of RAL modeling are illustrated by an example.

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References

[1] Koren Y, Heisen U, Jovane F, et al. Reconfigurable manufacturing systems , Annals of the CIRP **48**, 527-540 (1999).

[2] Kumar R, Kumar S, Tiwari M K. An expert enhanced coloured fuzzy Petri net approach to reconfigurable manufacturing systems involving information delays, Int J Adv Manuf Technol **26**, 922-933 (2005).

[3] Felix T.S C, Jie Z. Modeling for agile Manufacturing Systems, Int J Prod Res **39**, 2313-2332 (2001).

[4] Jeng M, Xie X. Modeling and analysis of semiconductor manufacturing systems with degraded behavior using Petri nets and siphons, IEEE Trans Robot Automat **17**, 576-588 (2001).

[5] SUN N P. Design Axioms and Quality Control, Robotics and Computer Integrated Mannufacturing, (1992).

[6] Cheng FT, Yang H-C Kuo T-L. Modeling and analysis of equipment managers in manufacturing execution systems for semiconductor packaging, IEEE Trans Syst Man Cybern **30**, 772-782 (2000).

[7] Lichin W, Shaoying W. Modeling with Colored Timed Object-Oriented Petri Nets for Automated Manufacturing Systems,Computers & Industrial Engineering **34**, 463-480 (1998).

[8] Kuo C H, Huang H P. Modeling and performance evaluation of a controlled IC fab using distributed colored timed Petri net, Proc of 2000 IEEE Int Conf on Robotics and Automation, PiscatawayInstitute of Electrical and Electronics Engineers, 2191-2196 (2000).

[9] Ben-arieh D, Rajeev R K, Tiwari M K. Analysis of assembly operations: difficulty using enhanced expert high-level colored fuzzy Petri net model, Robotics and Computer Integrated Manufacturing **S0736-5845**, 385-403 (2004).
[10] Jianfeng Y, Yuehong Y, Zhaoneng C. Modeling for Reconfigurable Assembly Systems, China mechanical engineering **14**, 1108-1113 (2003).
[11] Zongyan C, Xinmin Y. Case study on reconfiguration algorithm for reconfigurable manufacturing system, Journal of Computer-aided Design and Computer Graphics **15**, 162-173 (2003).
[12] Zha X F, Du H, Lim Y E. Knowledge intensive Petri net framework for concurrent intelligent design of automatic assembly systems, Robotics and Computer Integrated Manufacturing **17**, 379-398 (2001).

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