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An Expandable Petri Net Framework for Method Behavior Evaluation of Reconfigured Equipment

Wan-Ling Li, Haw-Ching Yang, and Tomohiro Murata

***Abstract*—This paper proposed a design approach for evaluating the feasibility of Reconfigurable Equipment Behavior (REB) based on the Extendable Petri Nets Framework (EPNF). The approach can analyze equipment scenarios through developing and usage phases. Most importantly, EPNF is fully automatic to build a Petri nets (PNs) model according to equipment scenarios of Unified Modeling Language (UML). Moreover, it also can enhance efficiency of production system. Adopting a cluster tool (CT) of semiconductors was presented as a case study to illustrate the proposed approach.**

***Index Terms*—Petri-Nets, Reconfigurable Equipment, Behavior Model.**

I. Introduction

Recently, the manufacturing industry of Taiwan have not only rapidly expanded but also gradually become one of the most important industries. Present-day goods were involved requires of quality and variety, these requires are becoming more and more critical influences on the competitive market. On the market, efficient processing needed comprehensive to survey various elements of assortment such as highly customizable, time-in-market, complex manufacture schedule, and so on. The requirement of automation for reconfiguring processes after changed requirements according to different products is rather serious. To adopt mainstream method nowadays is the reconfigurable manufacturing system (RMS) which modified equipment behaviors with less cost; moreover, integrating different equipment into a cluster-like or FMS-like operation system. Otherwise, RMS is very difficult evaluated because RMS needed to be terminated to evaluate the feasible configurations, as well as decreasing overall efficiency of the RMS.

In order to better ability of reconfigure equipments, we discussed that was based on specifications to divide those into three parts as follows: verifying specification, transformation specification, and reconfigurable equipment behaviors. In addition, semiconductor manufacturing usually adopted CT to configure many wafers of process module, and suggested production schedule [1]-[3]. In other words, literatures are easily able to reconfigure plants of the RMS domain, but, ensuring schedules feasibility is still a thorny question. Thus, in the aspect of verifying specification, evaluating feasibility of system was based on equipment behaviors to determine [4] [5]. But, aforementioned literatures had an adapted constraint that could not be utilized in a diversity environment. Another, a common model [6] was adopted requirement oriented approach to analyze different scenarios. However, aspect of verifying specification was needed to take time for reconstruct and re-verify latest system after requirements changed. As above results, constructing model of the RMS which is usually used specifications and/or requirements. Therefore, transforming specifications to construct model is a critical issue. A hierarchy architecture [7] was proposed to transform and analyze equipment behaviors. Besides, a scenarios-based [8] was efficiently able to cope with unexpected states likes factors of human or environment. On the one hand, above results could quickly build model, and on the other how to usefully reconfigure model of system according to different goods. Thus, a logic controller [9] was adapted to re-verify and reconfigure equipment behaviors in a RMS. An architecture of PNs [10] was proposed to verify specifications by high-level PNs, which used relaxation techniques to decide what to accept states through developing and usage phases.

The rest paper is organized as follows. Section II describes the requirements and behaviors of equipment analysis. Section III proposes machine design support system. Section IV proposes the methodologies for Petri Nets transformation. Section V describes general form test case. Section VI applies approach to simulate an example of a cluster tool. Finally, Section VII presents the main conclusions of this research and its perspectives.

II. Requirements and Behaviors Analysis

Actually, factories usually have not evaluated re-building model after equipment requirements changed. In the other hand, conventional evaluation methods needed to be contemplate feasibility of thorough requirements. In other words, there are many instable risks would bring indirect losses. Therefore, we had planned an automatic model to correspond to actually equipment requirements. It avoided losses of time and costs. On the other hand, how correctly ensured consistency mapped it between automatic model and actual equipment for reconfiguration is a critical problem, and another the other how completely transformed actual equipments requirements into a model for decreasing

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uncertainty of model. How to evaluate behaviors of equipments of the feasible operation sequences (paths) after requirements reconfigured. As regards simulating and analyzing equipment behaviors carry some issues as follows: first, solving the constraint which the model needs to be rebuild after requirement changed. Secondly ensuring the behavior consistency between the equipment model and the actual equipment and thirdly, to correctly map and symbol the identified errors on the corresponding paths of equipment.

On the other hand, the system was adapted to the life-stage which includes phases of developing, operating and transferring. Each of the above of system is a production machinery or manufacturing equipment. The purpose of this paper was to propose an adaptable model to conform adjusting and changing in different phases of the system, as shown in Fig. 1 [16].

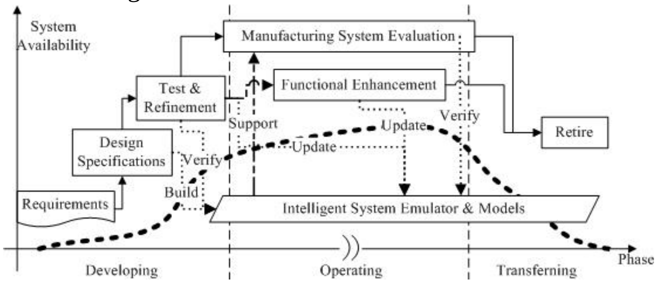


Fig. 1 Multi-stage system development process

As mentioned regards above, we provided architect to solve difficult and annoying issues. In the developing phase, we chose different components of Reference model (RM) to build a framework according to requirements. Automatic model used RM to assist building model which found corresponding to component of requirements, then correctly integrate these into a framework. In the usage phase, we used Reconfigurable Equipment Behavior (REB) based on the framework to reconfigure models of machine behaviors. In addition, model of requirements was combined and updated by RM that it was able to partial verify every component. Outline of the approachology architecture is shown in Fig. 2. It could quickly accomplished ensuring of feasibility of the reconfigured scenarios and reducing replacement cost of the RMS. In general, traditional method exist thorny problems of consistency and completeness about models of machine. Hence, we raised the proposal to reform it becoming automatic model that could avoid some questions.

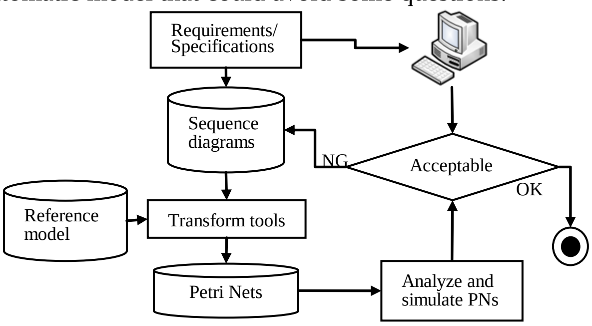


Fig. 2 Evaluating flowchart of requirements/ specifications of the machine

III. Propose Machine Design Support System

In the Extendable Petri Nets Framework (EPNF), a variety of REB components were constructed to specify various equipment behaviors. The specific scenarios of equipment are described by Unified Modeling Language (UML) [11], which was based on sequence diagrams (SD), transformed into models of Petri Net (PN). Consequently, practitioner was able to apply transform tools which were assisted to construct the specific model by corresponding REB of components.

Regardless of developing, reconfiguration, and extension of equipment scenarios, these results of scenario analyses were limited from the conventional models which should be reconstructed and re-evaluated by change to answer whether the reconfigured scenario is feasible. RM was not only used to support building framework which was shown in the Fig. 3 according to independent equipment requirements, but also assisted reconfiguring model based on the framework. Consequently, in the developing phase, constructing framework brought an advantage that practitioner could effortlessly evaluate reconfiguring equipment in the usage phase.

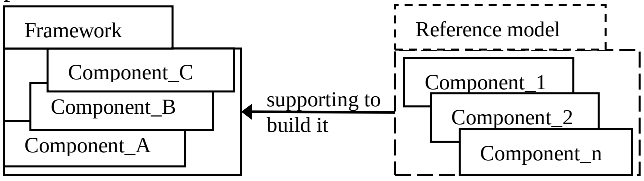
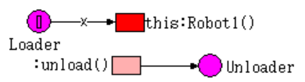
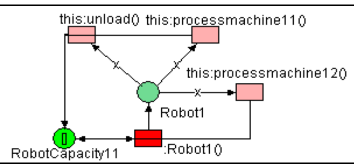
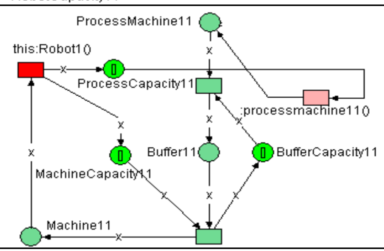


Fig. 3 Relationship between Framework and Reference model

Besides, RM was made up of various components that are partial shows as table 1. As regards RM, we adopted PN to design each component. Moreover, P# and R# of table1 are equal to a workstation and a robot of component of the RM, respectively. The # is a number among workstations or robots.

Table 1 Components of RM of the Petri-Net model

Name	Model of PNs	Description
Load & Unload		Loading wafer to Robot1 or not.
Robot (R#)		Transforming wafer to Unload or Workstation.
Workstation (P#)		Receiving wafer from Robot1. Processing and sending wafer to Robot1.

The paper considered how to construct effectively a model of equipment behavior, especially paths, to analyze the scenario with a framework. As above result, categories of paths were defined by PN that was efficiently able to evaluate and simulate behaviors of equipment. In developing phase, constructing a model and estimating paths of equipment adopted a hierarchical method and a partial reachability tree. According to the above we used reachability tree and tool of Renew [13] to simulate and analyze Feasibility Paths (P_F) of the equipment requirements. As regard the P_F that we determined Permitted Path (P_P) or Forbidden Path (F_P) to locate error requirements based on corresponding paths. Furthermore, we also defined Infeasible Path (P_I) to describe equipment behaviors, which is showed as Table 2.

TABLE 2 CLASSIFYING ARCHITECTURE OF PATHS

Path	P_F	P_P	Bounded Liveness Reachable
		F_P	Unbounded Deadlock-free
	P_I		Unreachable Deadlock

In addition, evaluating specifications is a difficult task. In order to resolve above issues, SDs were transformed into PNs model according to mutually relationship. Thus, we formulated strategy that the RM was assisted by SDs to transform PNs model with transform tools. Then it ensured properties of completeness and consistence. In the meantime, components of RM would be updated with relational objects according to latest scenarios.

IV. PETRI NET TRANSFORMATION

PNs are graphical and mathematical tools applicable to systems that are characterized as being concurrent, asynchronous, distributed, parallel, nondeterministic, and/or stochastic [15]. We defined elements of paper which was based on Ordinary Petri Nets (OPN) [4]. Petri net is a 5-tuple, $\mathrm{PN} = (P, T, I, O, M)$ where:

$P = \{p_1, p_2, \ldots, p_m\}$ is a finite set of places.

$T = \{t_1, t_2, \ldots, t_n\}$ is a finite set of transitions.

$I^{b_j} : P \times T \rightarrow [N]_{m \times n}$, N is an input function which defined direct arcs from places to transitions, matrix element c_{xy}^{+} triggered different tokens, and $p_x \in P$, $t_y \in T$, N is non-negative integer.

$O^{b_j} : T \times P \rightarrow [N]_{m \times n}$, N is an output function which defined direct arcs from transitions to places; matrix element c_{xy}^{-} triggered different tokens, and N is non-negative integer.

M^{b_j} is the state of token system, $M^{b_j} \rightarrow [N]$ is an vector of $(1 \times m)$, $M^{b_j}(P) = \sum_{x=1}^{m} M^{b_j}(p_x)$, $M_0^{b_j}$ is an initial state of token in the P.

A. *Forward Transformation*

Although scenarios of equipment were presented with SDs, System Analyst (SA) could not quickly analyze feasibility of scenarios. Hence, we constructed Forward transformation that this transforms SDs of scenarios to PNs model with RM to support transforming. Another, flowchart of forward transformation is showed as Fig.4. Using the tool of Renew to simulate model of PN, and store results.

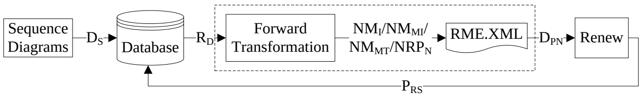


Fig. 4 Forward transformation transforms scenarios into PN model

Approach of Forward transformation is listed as follows,
Input datum: Reference model and Sequence Diagram.
Output datum: XML files of Petri Net, D_{PN}.

$$\begin{cases} \mathrm{RM} = (M_I,\ M_{MI},\ M_{MT},\ RP_N) \\ \mathrm{R_D} = (O_c,\ M_e,\ O_{bS},\ O_{bR}) \end{cases}$$

, as above defining parameters of RM model of the PNs were including,

$$\begin{cases} \text{Incidence Matrix} : A = \{M_I[i][j]M(0,\ldots,j-1),\ldots \\ \qquad ,M(i-1,\ldots,j-1)\} \\ \text{Place} - \text{name} : B = \{RP_N[1][i]O_1,\ldots,O_i\} \\ \text{Initial Matrix} : C = \{M_{MI}[1][i]M_I(0,0),\ldots,M_I(0,i-1)\} \\ \text{Target Matrix} : D = \{M_{MT}[1][i]M_T(0,0),\ldots,M_T(0,i-1)\} \end{cases}$$

Another, defining parameters of R_D of the SD as follows, the Lifeline is equal the Object, and then the Order is equal to the Message of the SD. Besides, Objects are categorized into sending and receiving object, respectively.

$$\text{Object} : O_{C2,m} = \begin{Bmatrix} \text{name} \\ \text{number} \end{Bmatrix} = \begin{bmatrix} x_1 & \ldots & x_m \\ x'_1 & \ldots & x'_m \end{bmatrix}$$

$$\text{Message} : M_{e2,n} = \begin{Bmatrix} \text{name} \\ \text{number} \end{Bmatrix} = \begin{bmatrix} y_1 & \ldots & y_n \\ y'_1 & \ldots & y'_n \end{bmatrix}$$

$$\begin{cases} \text{Sending objects} : \mathrm{S} = \{\mathrm{O_{bS}}[1][k]x_1,\ldots,x_k\} \\ \text{Receiving objects} : \mathrm{R} = \{\mathrm{O_{bR}}[1][m-k]x_{k+1},\ldots,x_m\} \end{cases}$$

$$\Leftrightarrow O_C = S \cup R, O_C = \{O_C[1][m]x_1,\ldots,x_m\}$$

New objects of SD to update sets of *A*, *B*, *C*, and *D*.

$$\begin{cases} Object_{new}[1][i'], O_C \notin B \\ B, O_C \in B \end{cases} \Leftrightarrow OB = \{Object_{new}[1][i']O_{i+1},\ldots,O_{i'}\}$$

$$\Rightarrow \begin{cases} NB = B \cup OB \quad \ldots\ldots\ldots\ldots\ldots(1) \\ NB = \{NRP_N[1][i+i']O_1,\ldots,O_i,\ldots,O_{i'}\} \end{cases}$$

Besides, *OB* has different variance in each matrix,

$$OC = \{OC[1][i'], \forall OC[1][i'] = 0 \mid x_{C1},\ldots,x_{Ci'}\}$$

$$OD = \{OD[1][i'], \forall OD[1][i'] = 0 \mid x_{D1},\ldots,x_{Di'}\}$$

Another, computing sets of *C* and *D* to update them,

$$NC = C \cup \mathrm{O}C \quad \ldots\ldots\ldots\ldots\ldots(2)$$

$$ND = D \cup \mathrm{O}D \quad \ldots\ldots\ldots\ldots\ldots(3)$$

$$\Rightarrow \begin{cases} NC = \{NM_{MI}[1][i+i']M_I(0,0),\ldots,M_I(0,i-1), \\ \ldots,M_I(0,i+i'-1)\} \\ ND = \{NM_{MT}[1][i+i']M_T(0,0),\ldots,M_T(0,i-1), \\ \ldots,M_T(0,i+i'-1)\} \end{cases}$$

Finally, calculating and updating set of *A*, let *q*=*n*-*p*

$$AR_{3,p} = \begin{bmatrix} x_1 & \ldots & x_p \\ y'_1 & \ldots & y'_p \\ -1 & \ldots & -1 \end{bmatrix}, AS_{3,q} = \begin{bmatrix} x_1 & \ldots & x_q \\ y'_{p+1} & \ldots & y'_n \\ 1 & \ldots & 1 \end{bmatrix}$$

$$NA = \begin{cases} A_R = \{AR[3][p]-1,\ldots,-1\}, AR[1][p] \in NB \Rightarrow A \cup A_R \\ A_S = \{AS[3][q]1,\ldots,1\}, AS[1][q] \in NB \Rightarrow A \cup A_S \end{cases}$$

$$NA = \{NM_I[i+i'][j+j']M(0,\ldots,j+j'-1),\ldots,$$
$$M(i+i'-1,\ldots,j+j'-1)\}$$

$$NA' = NA - A \ldots\ldots\ldots\ldots\ldots(4)$$

From above equations of (1)-(4), we could obtained the table

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3.

TABLE 3 THE SD IS TRANSFORMED NEW A MODEL OF PN

NB^T	NA		NC^T	ND^T
B^T	A		C^T	D^T
OB^T	NA'		OC^T	OD^T

Finally, models of PN was transformed into XML of formatting which applied rows variance of the *A* to set the parameter of Place (*P*) of the PN, and then Transition (*T*) also to become columns variance of the *A*, respectively. Therefore, each unique number was corresponding to each *P* and *T* of the XML files. Another, defining arc of the model of PNs was based on *NA*. In other words, arcs were divided two properties which is responded input($P \rightarrow T$) is -1 and output($T \rightarrow P$) is 1. Thus, gradually we acquired diagram of the model of PN which was called D_{PN} according to XML of formatting. Another, $D_{PN} = (P, T, NA, Input, Output)$.

B. Backward Transformation

EPNF provided diverse evaluation to obtain paths which collected to make a form. Approach of Backward transformation was easily understood relationship both paths and SDs. It disclosed error paths including fault, cause fault, and fault position according to evaluation result. An approach is listed as follows,

Input datum: Path, $P_{RS} = (IO_C, IM_e)$

Output datum: Sequence Diagram, $D_{RS} = (O_c, M_e, O_{bs}, O_{bR})$

Step1. Finding all of the objects and messages from P_{RS}.

$$\begin{cases} \forall(\text{objects of paths}) \in IO_C \\ \forall(\text{messages of paths}) \in IM_e \end{cases}$$

Step2. Revealing error places were corresponded to objects, operation sequences, and messages in the SDs. In other words, each relationship of objects of the scenarios which were included messages among each object. As regards results, an approach could easily acquire the D_{RS} of the SDs.

V. GENERAL FORM TEST CASE

Because the EPNF was applied properties of PN to analyze, it can efficiently integrate and unify the scenarios reconfigured into the behavior model to evaluate variety combinations of the equipment behaviors. Especially, on acquiring the feasible sequences, the REBs can be derived by the partial reachability tree to avoid the explosion problem in searching sequences. Tools of evaluation and analysis which were developed respectively, the Completely Developed Tree (CDT) and the Partial Developed Tree (PDT) with a reachability tree were applied to evaluate paths of equipment scenarios. Although the CDT was developed complete reachability tree based on framework of PNs, evaluation results was shown marking of the model of PNs which was not easily observed. Thus, we also developed the PDT of evaluation tool to correspond identifying behaviors of equipments. The CDT completely evaluated latest framework once every each experiment. Another, the PDT also could evaluate models which merely focus on updating or combining segments of the latest framework. In addition to, practitioner merely needed to look for sectional components of the paths while behaviors of operation of the equipment were required to estimate sectional components. In the other words, practitioner could assume particular components (diagonal circles) to examine which is showed as Fig.5. The PDT has a property of stochastic based on a Renew; thus, it quickly achieved screening paths to avoid the explosion problem in searching sequences. Moreover, the PDT also obtained equipment behaviors whole paths through repeated experiments. Consequence, it would conspicuously enhanced efficiency. Hence, the CDT might take time of evaluation more than the PDT sometimes.

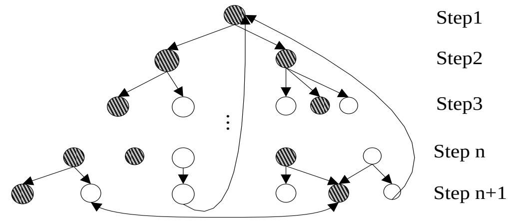

Fig. 5 Analyzing and indicating partial components of the paths based on reachability tree

VI. CASE STUDY

We adopted that Chemical-Mechanical Planarization (CMP) is one of processes all over processes of semiconductor manufacturing. CMP uses abrasive, corrosive slurry to physically grind flat, and then chemically remove the microscopic features on a wafer so that subsequent processes can begin from a flat surface. CMP is applied to manufacturing of polishing wafer with the cluster tool (CT) which is shown as Fig. 7. Equipment of CMP was established model which consider connection issues among each component; moreover, confirmed a model whether it was completely disposed all equipment requirements. The Fig. 7 used four clusters to process, a wafer was processed via processes of multi-stage of the four clusters to finish task, and unloaded it in the C2 of cassette modules.

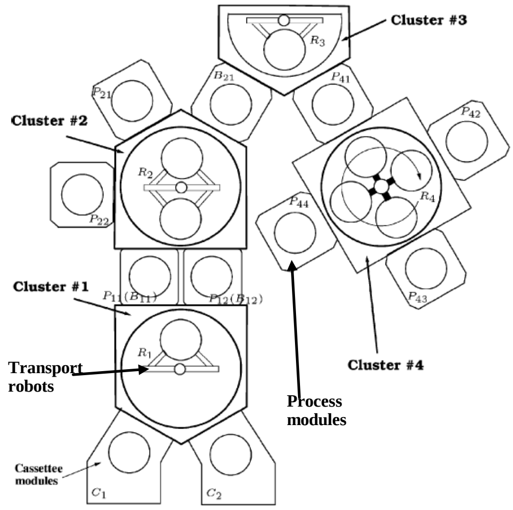

Fig. 7 Skeleton diagram of the Equipment of CMP [14]

As regards CMP provided many production schedules to resolve problems of optimal production time [14], but it had not discussed schedules about their questions. Thus, these schedules might influence efficiency of production. In order

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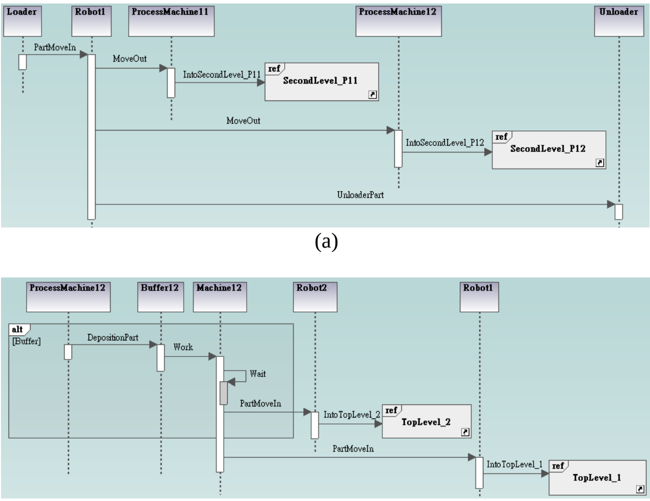
to resolve above issue, we described equipment specifications with SDs, which is partial shown in the Fig 8. The scenarios are hierarchy architecture, as the Fig. 8 (a) described wafer which was transported from loader into one of the ProcessMachine12 (P12) of cluster #1. A P12 is marked in the cluster #1 of Fig. 7. Another, the Fig. 8 (b) described wafer which transported it to Robot2 after wafer finishing processed. According to the Fig. 7, between the Fig. 7 and components of RM had a mutual relationship as follows. A C1/C2 of the Fig. 7 is equal to the Load/Unload component of RM. A R1 of the Fig. 7 is equal to the Robot component of RM; another, a P11 is equal to the Workstation component of RM, and so on. According to a table 1, we chose adapted components of the RM via transform tools to establish the framework of PNs of the specifications of Fig. 7. Consequently, SDs were transformed into formatting of PNs which applied the forward transformation and synthesize to construct the framework of equipment. As above results, we achieved the framework of CMP, which was composed as follows eight components of workstation, one component of load and/or unload, and four components of robot.



(a)

(b)

Fig. 8 Sequence diagrams of CMP are includes (a) Scenario of Cluster#1 in the TopLevel_P1 of hierarchy diagram, and (b) Scenario of Cluster#1 in the SecondLevel_P12 of hierarchy diagram

A. *Evaluation results of case study*

The framework of CMP was simulated and evaluated feasibility, and results could be corresponding to the equipment of CMP. Consequently, practitioner was easily able to understand behaviors of equipment of the CMP; moreover, results of evaluation were included many operation sequences, that results would help practitioner with operated equipment was as easy as pie. Hence, practitioner gained on mostly phenomena of occurrence actually. The EPNF was carried out to provide relational properties for reconfigured system based on table 1; thus, a model of CMP had various properties such as bounded, liveness, and reachable according to paths of evaluation. Practitioner carried out the backward transformation to look for actual operation sequences of equipment. Subsequently, information of equipments were edited the form to correspond to operation sequences of the equipment based on paths. Thus, the form could assist practitioner in operating equipments conveniently. As regards experiment results, the case study had already discovered 15 paths of the feasible operation sequences. We collected these and sort out partial results which are shown in the table 4. In terms of aforementioned, the EPNF have not only conveniently reconfigured scenarios but also efficiently improved model when paths had any faults. In addition, applying the PDT to reveal equipment behaviors, because practitioner was quickly able to comprehend performance of equipment based on property of PNs.

TABLE 4 EVALUATION LISTS OF RESULTS

<table>
<tr><td colspan="3">Unbounded</td></tr>
<tr><td>Number</td><td>Name of place</td><td>Unbounded Path</td></tr>
<tr><td>1</td><td>Unloader</td><td>Loader→Robot1→ … →Unloader</td></tr>
<tr><td colspan="3">Description: The Unloader is a place of sink of the Petri Nets; moreover, it which had not sent any messages was corresponded to SD. Thus, the state was not considered a state explosion.</td></tr>
<tr><td colspan="3">Deadlock</td></tr>
<tr><td>Last Marking</td><td>Deadlock Path</td><td>Last fired transition</td></tr>
<tr><td>Null</td><td>Null</td><td>Null</td></tr>
<tr><td colspan="3">Description: A model has not state of deadlock.</td></tr>
<tr><td colspan="3">Feasible operation sequences</td></tr>
<tr><td>Number</td><td colspan="2">Operation sequence</td></tr>
<tr><td>1</td><td colspan="2">$\text{Loader} \xrightarrow{\text{PartMoveIn}} \text{Robot1} \xrightarrow{\text{MoveOut}} \text{ProcessMachine12} \xrightarrow{\text{DepositionPart}} \text{Buffer12} \rightarrow \ldots \xrightarrow{\text{PartMoveIn}} \text{Robot1} \xrightarrow{\text{UnloaderPart}} \text{Unloader}$</td></tr>
<tr><td colspan="3">Description: The path (P_F) is one of reachable paths.</td></tr>
</table>

B. *Evaluation of case time with the CDT and the PDT*

Besides, we compared efficiency between the CDT and the PDT so that assuming coped with some specific components for execution time of calculating, that is shown as Fig 9. Another, according to a reachability tree, behaviors of equipment could be thorough simulated by the CDT and the PDT. Thus, this chose them to serve an evaluation tool. As regards evaluation efficiency, the framework of CMP used 13 components to combine it, and clearly observed the CDT accompany time of addition after raise component. Thus, we inferred that efficiency of PDT would be better than CDT to acquire feasible paths. Hence, we applied EPNF to reconfigure and increase some components based on the framework of CMP. In addition, the specific model of behavior of the PNs was extended by corresponding REB components. Integrating the EPNF and the REBs into the framework were respectively accomplished using the re-configuration and combination equipment in a new model. Besides, in a part of changing requirements, the paper have had indeed confirmed latest system include properties of original system already. As regards above, CDT had high-quality efficiency in a small system which includes little components. But, PDT had better than CDT in the large-scale system. In other words, CDT was carried out to simulate and discover complete reachability tree of CMP. The PDT applied stochastic property to estimate result of simulation, it was avoided states explosion. Anyway, the CDT or the PDT took time to search assigning marking of components when components were extended. Consequently, practitioner also was justly able to assign partial combination of marking of the reachability tree based on different association of components so that it efficiently reduced evaluation time.

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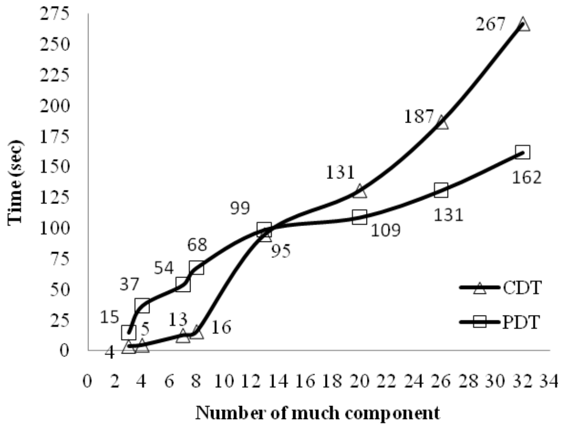

Fig. 9 CDT and PDT usually accompany time of addition after raise component

C. Discussion of EPNF of the case study

Whichever methods of evaluation were chose, it would deeply affected production efficiency. We proposed the machine design support system that indeed improved schedule to accomplish feasible paths. Finally, we listed properties and improving methods about EPNF and relation papers which owns as following:

1) In the aspect of developing phase, a model was built according to current equipments [3] [8]. But, that lacked for method to cope with emergency after frequently changed production. Another, applying specifications and/or requirements to build model [4]-[7]. But, that was needed reconstructing model to re-evaluate. Nevertheless, the EPNF proposed automatic method to determine components which are able to auto-construct framework so that easily changed scenario in the usage phase.
2) In the aspect of usage phase, logic controller [9] does not exist extensibility. In other words, it could not increased or adjusted models of equipments as wish. In addition, task structures [10] were ignore partial tasks of minor weight; thus, whether it is feasible after reconstruct. Furthermore, EPNF quickly reconfigured latest model based on framework.
3) Evaluating feasible paths could supported schedule to completely enhance efficiency, because schedules of [1]-[3] had not verified those. However, EPNF could provide evaluation method for behaviors of equipment.

VII. Summary and Conclusions

Generally speaking, equipments requirements could not facile and precise simulation and analysis. The paper purposed the EPNF that is the evaluation tool in developing and usage phases. It is suitable for products change and system update; moreover, reducing production costs and time. Especially, EPNF could improve fault of conventional models which were reconstructed and re-evaluated whether they are feasible. Another, risky operation sequences were found and located by the method of backward transformation. In the developing phase, EPNF could support PN model to diagnose equipment behaviors efficiently. Besides, a developed framework was used to build and evaluate reconfiguration of equipment in usage phase. As regards a complicated system, PDT of evaluation method performs great efficiency than CDT was in the some particular conditions. In addition to developing phase, the paper had a significant orientation towards usage phase. Consequently, the EPNF was suitable for evaluation of system reconfiguration. Another, paths of feasible and infeasible were suggested practitioner to decide operation sequences by the EPNF; and furthermore, behaviors of equipment used backward transformation to look for scenarios about position, operation path, and fault states. Consequently, practitioner effortlessly understands faults of machine behaviors about relationship paths of output. As regards further work, in the one hand, operation paths were corresponded to behaviors of equipment, we had not provided method to improve error behaviors. On the other hand, so far we consider adopting OPN to simulate behaviors of equipment so that practitioner found difficulty question under the time delay; moreover, that might be occurred product of stocks at any time. Therefore, we should be capable of adopting Time Petri Net (TPN) and Color Petri Net (CPN) to join the EPNF leading better tool.

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