Modeling and analysis of resource sharing approach in common platform strategy using petri net theory

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Abstract

The most competitive advantages in business and manufacturing is resource-sharing.We must share common resources to produce a group of product family with using common platform strategy. This strategy helps us to increase profit and value in business. It is necessary to apply this strategy to model and analyze resource achievability in different situations. In this paper we try to develop a practical model for analyzing common resource behavioral in platform area with using Petri net theory. Petri Nets have been successfully used for modeling and control the dynamics of flexible manufacturing systems.This paper presents some important concepts about common platform and petri net theory and then presents numerical examples to show how to use Petri net for modeling and analysis in common platform. This model is very useful for common platform strategy and can be used to determine reliability of common platform systems in an effective way.

Keywords

Modeling, analysis, resource sharing, common platform, Petri net

Introduction

In a dynamic competitive environment, resource sharing and common platform (CP) strategy have been a focal point of attention for companies. In this situations we must consider rapidly changing technology, market and customer needs, high variety product, with restrict resource to obtain success. Many companies are using common platform strategy, to create product families which provide sufficient variety for the market while maintaining economies of scale and minimizing product resources within their manufacturing processes. Thus, the basic question is" how we can manage and control product resource in companies? "One of the best answers to this question is common platform strategy. Common platform is a class of manufacturing system (another view: philosophy and strategy) which can be quickly configured to produce by use of resource sharing. A CP system is a high variety manufacturing system. It can be used to produce a variety of products whit rapid changes in production plan due to product and market demand fluctuation. CP must share components, subsystems, processes and other critical resources to minimize development costs for the manufacturer. While the increased complexity of market provides greater productivity under various production scenarios, it imposes increased complexity in managing and controlling of resources to be used in different operations. Manufacturers ought to control of critical factors in manufacturing area for example material flow, resource assignment, machine performance and so on. In manufacturing based on common platform, resources not only critical but also rare. Therefore, producers must develope managing and controlling tools for monitoring resources in an effective way.

The platform concept

In most industries, firms increasingly are considering common platform strategy to resource sharing to reduce complexity in management and controlling, manufacturing, marketing & etc. The logic reasoning common platform is to (1) simplify the product offering and reduce part variety by (2) standardizing components and resource sharing so as to (3) reduce costs, time and other non value added factors and (4) reduce manufacturing variability, i.e. the variety of parts, tools, materials, etc, that are produced in a given manufacturing facility, and thereby (5) develop market share and improve loyalty and customer satisfaction. Therefore one must try to understand and apply CP concept. In literature review we fined variety of concepts related to common platform. For examples: product platform, process platform, technology platform, brand platform. In this paper we focus on the concept of common platform which has been related to common physical component or hardware in manufacturing for example machines, robots, AGVs, transfer line, tools, pallets, etc. Presently several authors have developed this concept, Reviewing some definitions of the platform concept, which are provided in the literature as follows [1, 2]:

"A product platform is a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced"

(Meyer, 1997; Meyer and Lehnerd, 1997).

"A collection of assets, components, processes, knowledge, people and relationships -that are shared by a set of products" (Rbertson and Ullrich 1998).

On the other hand, we will provide definition for hardware oriented platform which refers to some physical elements in manufacturing as following:

A physical platform is the set of hardware elements that are shared among a family of products - a group of related products derived from a common product platform – and allow the development of maximum derivative products with common tools or machines with minimum type of hardware for increasing value with cost and time saving.

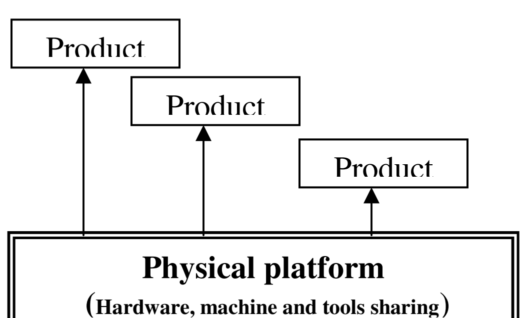

Figure 1: Physical platform

Figure 1 illustrates the concept of physical platform. Companies can share different kind's hard wares with a basic platform, which shared among them.

Common Platform Conceptual Model

Common platform as a new paradigm in production and manufacturing can be divided to six basic factors. Hence it is tried to provide an eye bird view of CP in the first step. Components of this puzzle are as follows (Figure 2): [3]

1. Enterprise architecture (organization and information systems)
2. Production process and operation management
3. Production technology and machinery
4. Product architecture and modularity
5. Strategy and management
6. Supply chain and logistics

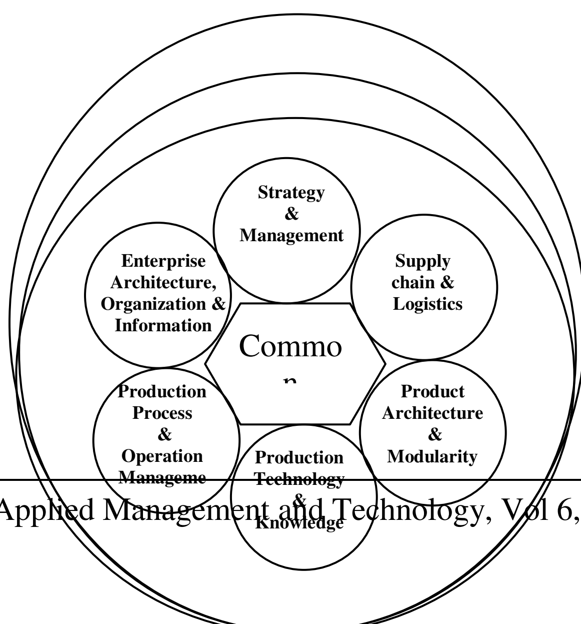

Figure 2: Common Platform Conceptual Model

Advantages of physical common platform

Facing increasing manufacturing competition in today's global market, many companies realize that common platform strategy provide significant advantages. The issues discussed below relate to benefit of CP such as: price/cost consideration, competitive advantages, integration and proactively and also achieving manufacturing requirements in synergy. Some competitive advantages and benefits of CP are as follow: [4]

- Improve maintainability
- Volume economics
- Faster innovation
- Adjust for use
- Increase assets availability and standardized
- Productivity of product development
- Easy to work and training for operators
- Reusable engineering
- Reduced time-to-repair and supplying spare parts
- Rapid development and change machine
- Productivity and effectiveness
- Focus on technology
- Cost reduction
- Improve planning and control

• Increase volume or variety of products

Disadvantages of physical common platform

Although common platform has many advantages in manufacturing, but we must be considering some disadvantages that reported such as:

- Complexity of managing and control on common resource
- Increasing complexity in resources (hardware and software)
- High level qualifications and expertise in personnel
- Effect of Changing technology and knowledge
- Increasing initial cost and investigation
- Technical and operational restrictions
- High failure risk

As indicated in the previous paragraph, in this paper it is tried to reduce Complexity of managing and control on common resource in manufacturing by applying petri net theory as following.

Introduction to Petri Nets

Petri Nets are named after Professor Carl Adam Petri, University of Hamburg, Germany, who developed a schematic approach in 1962 in his PhD thesis for modeling and analyzing Discrete Event Systems (DES). In this approach we model discreet events in an illustrative and schematic manner.

Petri net models help us to analyze performance measures factors such as cycle time, work in process, or on-time delivery performance for different scheduling and work release policies, they maybe used as part of a real-time shop floor control system. The ultimate goal of the development of Petri net models in manufacturing systems is the application of these models as a control method that is able to cope with the most difficult and important aspects of supervisory control: uncontrollable events, unobservable events, and deadlock.[5]

The following mathematical definitions are used in this theory [6].

Definition: A Petri net graph (or Petri net structure) is a weighted bipartite graph where:

PN = {P, T, I, O, M} that P = {p1, p2. . . pn} is the finite set of places n>=0 , (one type of node in the graph), = {t1, t2, . . . , tm} is the finite set of transitions m>=0, (the other type of node in the graph) . The set of transitions and the set of places are disjoint.

I: an input function, (T * P) → {0, 1} and O: an output function, (T * P) → {0, 1}

M: P →N, where N= {0, 1, 2…}, M is component marking vector whose ith component, m (p i) is the number of tokens in the ith place. M0 is an initial marking. Sometimes we can consider W as a weight functions on the arc. The weight relating to an arc is a positive integer number; otherwise if no weights are indicated on the arcs, assume the weighting is one. Conditions that can either be true or false represented by places and token. Also, events that can occur represented by transitions. Conditions and event are connected by arcs. (Figure 3)

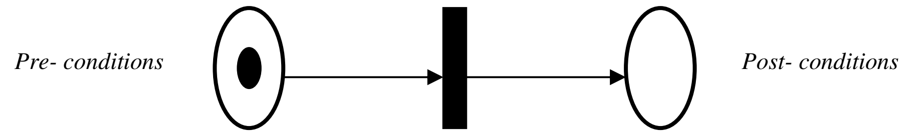

Figure 3: Place, token, transition and arcs (before firing)

In petri net, one event is enabled (can fire or can occur) if and only if: all its pre- conditions are true and all its post –conditions are false. (Figure 4)

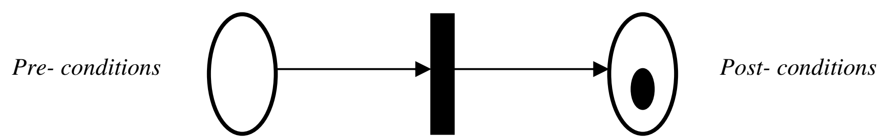

Figure 4: After firing

Some different types of Petri Nets

Untimed Petri Nets: The sequencing of the events is reduced to simply ordering their occurrences. The simulation runs by firing the transitions one-by-one, in accordance with the transition-firing rule.

T-timed Petri Nets: For transition-timed PN (T-timed PN), time durations can be assigned to the transitions; tokens are meant to spend the time as reserved in the input places for the corresponding transitions. In simulation, all the transitions that fire due to the current marking are fired at the same time.

P-timed Petri Nets: For place-timed PNs (P-timed PN), time durations can be assigned to the places; tokens are meant to spend the time as reserved in the corresponding places, immediately after their arrival. In simulation, all the transitions that fire due to the current marking, fire at the same time. A transition can fire several times, in accordance with the marking of its input places and, from a theoretical point of view, an infinitesimal delay is considered to separate any two successive firings. For the time durations assigned to the places, appropriate functions can be used to generate random sequences corresponding to probability distributions with positive support.

Stochastic Petri Nets: For stochastic PNs (SPNs), only exponential type distributions can be used to assign the time durations of the transitions. For conflicting transitions, it is the shortest time duration that allows the choice of the transition to fire, without using priorities or Probabilities. Multiple firing of the same transition is not permitted, even if the token content of its input places allows this; i.e. the transition fires once and after the allocated time elapses, it will fire again if the current marking is appropriate.

Generalized Stochastic Petri Nets: Generalized Stochastic PNs (GSPNs) have two different classes of transitions: immediate transitions and timed transitions. Once enabled, immediate transitions fire in zero time. Timed transitions fire after a random, exponentially distributed enabling time as in the case of SPNs. For timed transitions, the firing rate (i.e. the inverse of the mean time-duration) is, by default, marking dependent, but the user can select a marking-independent operation (the same way as for SPNs).

Initial mathematical rules in petri net

We had brief review of petri net in previous paragraph. One of the events in petri net models is change of marks. We know that the marking changes when a transitions fires. A transition fires, when its input states are marked. Formally a transition tj is enabled in marking M if: M (Pi)>= I (Pi, Tj)

Therefore, when a transition tj fires, it results in a new marking M' which occurs by removing

I (Pi, Tj) tokens from each of its input places and adding O (Pi, Tj) tokens to each of its output places. Formally M' is reachable from M according to the equation [7]:

$$M'(Pi)=M(Pi) + O(Pi, Tj) - I(Pi, Tj) \qquad (1)$$

We assume matrix form for this equation. The matrix [O-I] is an n*m matrix. It referred to the incidence matrix A which defines the topology of the petri net. The columns of A indicate the input places (-1) and out put places (1) of each transitions. One can imagine a sequence of firing given by u1+u2+u3+… to arrive at some destination marking Md from an initial marking M0 then we have this equation: $Md=M0 + A \sum Uk$ (k=1 to d) (2)

Let $\sum Uk = Y$ and $Md-M0= \Delta M$ then: $AY= \Delta M$ and Y is called the firing count vector. It is a vector whose elements are the number of times each transition firs in going from M0 to Md.

Modeling and analysis by using petri net theory

Petri nets have been widely used for analysis and modeling of common platform systems due to their capability of modeling concurrency, sequencing and synchronization in discrete event systems. The system at first modeled as a petri net and then it is analyzed. Understanding the performance of this system, which results from the analysis, will lead to a hopefully better system design (Figure 5).

In this situation we must share physical component in order to coordinate their actions. General common resource in petri net modeling shown in figure 6 [8].

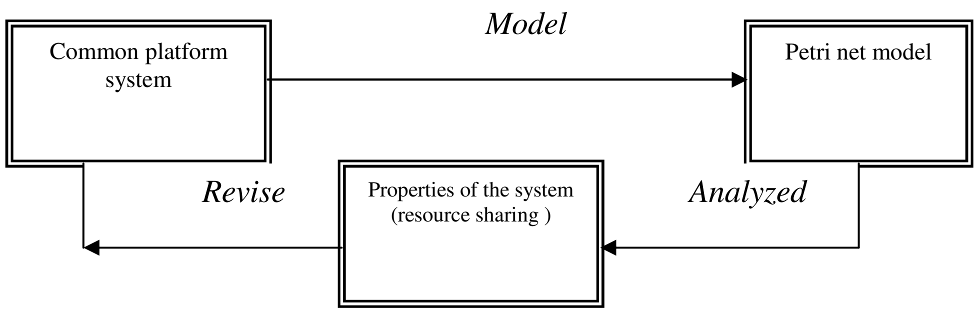

Figure 5: Conceptual model

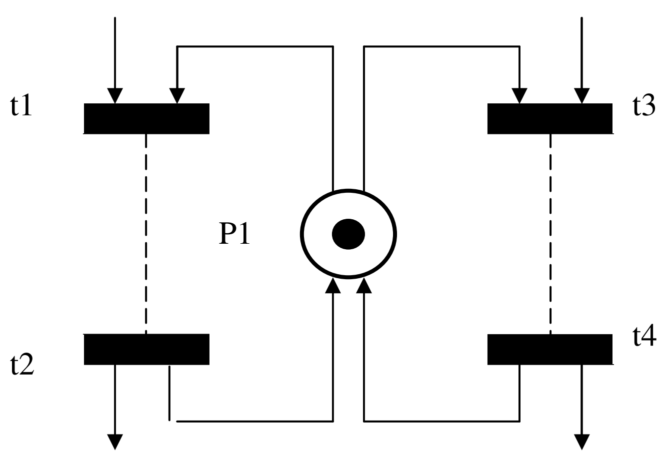

Figure 6: General common resource in petri net model

In modeling and analyzing in petri net, we can exhibit two different properties:

1- Behavioral 2- Structural

Behavioral properties depend on the initial state or marking of the petri net and structural properties depend on the topology or structure of the petri net. Therefore, we can analyze petri net models by focusing on these critical properties:

- Reachability
- Boundedness
- Safeness
- Liveness
- Conservativeness
- Deadlock
- Invariants
- Coverability
-

Concept of control in manufacturing

The new manufacturing environment needs a strategy, which facilitates planning and controlling in an effective way. Although there are many researches about manufacturing control, for example: Fs. Hsieh (2004) presented a framework to model and control Holonic-manufacturing systems (HMS) based on fusion of Petri net and multi-agent system theory [9]. N. G. Odrey and G. Mejia (2005) discussed the issues of incorporating recovery trajectories into the control logic of a workstation control agent by petri net model [10]. S. Mohan, A.Yalcin and S. Khator (2004) described the design of a deadlock avoidance controller by using of colored Petri nets [11]. K. Feldmann and A. W. Colombo (1999) focused on the development and implementation of feature- and model-based monitoring methods using high-level Petri net specifications of flexible production systems [12]. But there is no attention about control in common platform area. As indicated in the previous sections Common platform is an interesting filed for manufacturing because of resource sharing concept that promote. Some important effects of this concept are:

- Faster changing products (because of reduced product life-cycles),
- Faster introduction of products (because of reduced time-to-market and modularity),
- A different type of output and products, and
- Reduced investment and cost (because of resource sharing concept) and so on.

On the other hand:

- High decision management risk (because of dependency with rare resources)
- High degree of complexity and cost (because of multi purpose resources) and so on.

The effects of these trends can be summarized as increasing complexity and the need to better controlling and managing under decreasing costs.

Hence one important characteristic for manufacturing success based on common platform is the ability to share resource in manufacturing area such as: materials, tools, spaces, machines, labors, knowledge and so on. Hence some critical success or the failure factors of the platform in firms, depend on management systems. Managers like to manage and control systems in an effective way. Therefore, it is necessary to apply tools and approach for monitoring systems and it is important that managers have tools and knowledge for applying preventive and predictive control systems because of high-level cost of uncorrected decisions. petri nets provided a predictive methods to monitoring and controlling Discrete Event Control Systems (DECS) before those implemented.[13]

Hence, one can say that, petri nets can increase possibility of predictive control in manufacturing. In this way, not only achieving these objectives is expected, but also satisfying the manager's needs are guaranteed. Hence we try to apply this method for controlling systems based on common platform.

Control systems in platform area should focus on the following issues:

- Is the implementation correct?
- Is the chosen algorithmic approach feasible?
- Is the resource assignment feasible?
- And so on
- Is the system working correctly?
- Is the sequencing of activity correct?
- Are the material flow and information flow correct?

Comparison of Petri net and Traditional Control Systems shown in Table one.

Table 1: Comparing Petri net and Traditional Control Systems

Petri net control	Traditional control approach
Predictive and preventive control before event	**Condition based control after event**
Sensitivity analysis	**Cause and effect analysis**
Simulation and Monitoring of behavioral systems in future	**Analysis of performance systems in future**
Simple tools for visual and graphical representation	**No tools or complex approach for representation**
Low risk implementation system	**High risk implementation system**
Virtual monitoring and decision support system	**Real time monitoring and decision making**
Repeatable for analysis	**Try and error practices**
Decisions building feasible (based on future ev	**Decisions making feasible**
Problem formulation is simp	**[illegible]d static**

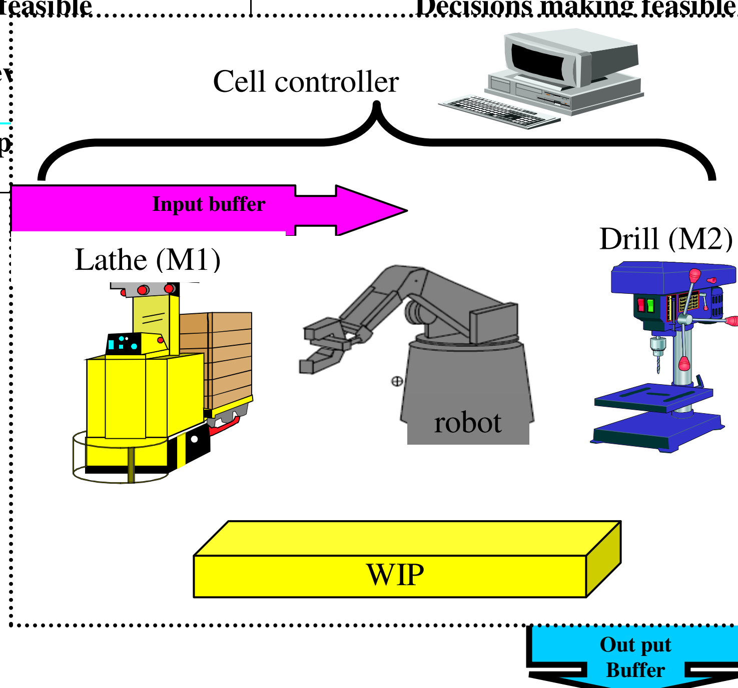

Figure 7: Automated work shop components

Problem definition and formulation

We now introduce a practical example to illustrate common platform modeling with petri nets. This example will facilitate the upcoming analysis of resource sharing. Consider an automated workshop consisting of two machines and one robot for loading and unloading the machines (figure 7). In this shop there are three buffers for holding parts and one central control for coordinating the overall activities of the cell. The details of procedure to manufacture a product are described as follows:

- A part is present and the lathe (M1) is available
- The robot (R) can load the lathe
- The lathe start machining
- When the lathe completes its machining cycle the robot can unload the lathe and put the turned part into the work in process buffer (WIP)
- When the drill machines (M2) is available and a part is in the work in process stock , robot can load the M2 The drill machine start operation
- When the drilling operation is complete the robot will unload the machined part to the out put buffer where it is taken away by workers who clear the finished parts buffer when refilling the input buffer**.**

There are several assumptions in this example:

1. The WIP inventory increased by one each time the lathe is unloaded TL5
2. The PO inventory is increased by one each time the drill is unloaded TD5
3. The robot R is available when its place is occupied by a token
4. The lathe and drill also be included in the net but it is only necessary to show shared resources, such as the robot.

Now for constructing the model we must define places, events and relations between them. Considering that the robot share between lathe and drill machines as a common resource. (Figure 8) .

Definition places and events

PLACES:

PL1: lathe available

PL2: lathe being loaded

PL3: lathe machining

PL4: lathe waiting to be unloaded

PL5: lathe being unloaded

PD1: drill available

PD2: drill being loaded

PD3: drill machining

PD4: drill waiting to be unloaded

PD5: drill being unloaded

PA: part available

PNA: part not available

PW: work in process buffer

PO: out put buffer

PR: robot

EVENTS:

TL1: robot starts loading lathe

TL2: robot completes loading lathe

TL3: lathe completes machining

TL4: robot starts to unload lathe

TL5: robot completes unloading lathe

TD1: robot starts loading drill

TD2: robot completes loading drill

TD3: drill completes machining

TD4: robot starts to unload drill

TD5: robot completes unloading drill

TI: part inputs the workshop

TO: part output the workshop

Problem analyses

In this problem we are interested in knowing any unknown about behavioral workshop; at the same time we try to analyze boundedness property of the problem.

A petri net said to be K bounded if the numbers of tokens in each place dose not exceed a finite number K for every reachable marking from M0. A petri net is said to be safe if it is one bounded.

In the above definition, boundedness depends on the initial marking. Stronger condition for boundedness is structural boundedness, which means that the petri net is bounded for any finite marking M0.

This petri net is structurally bounded if there exist a non zero vector X, of non negative integers such that:

*X (TRANSPOS)*A <= [0]*   *(3)*

Solving the set of above inequalities may require on exhaustive search. A solution can be formulated as an integer program as follows:

$$Min \ \sum Wi \qquad (4)$$

St:

*X(TRANSPOS)*A <= [0]*

Wi >=1 and integer

Let the weighting vector X be defined as: *X=[PL1, PL2,… PO, PR]*

Then: *X (TRANSPOS)*A = [0]*

To solve this equation, we must calculate matrix O, I and O-I=A (table 2, 3 & 4).

Then we have: (table 1, 2 and 3)

Table 4: [A]=[O (Pi, Tj) - I (Pi, Tj)]

O-I	TL1	TL2	TL3	TL4	TL5	TI	TD1	TD2	TD3	TD4	TD5	TO
PL1	-1	0	0	0	1	0	0	0	0	0	0	0
PL2	1	-1	0	0	0	0	0	0	0	0	0	0
PL3	0	1	-1	0	0	0	0	0	0	0	0	0

Table 2: I (Pi, Tj) matrix

I	*TL1*	*TL2*	*TL3*	*TL4*	*TL5*	*TI*	*TD1*	*TD2*	*TD3*	*TD4*	*TD5*	*TO*
PL1	1	0	0	0	0	0	0	0	0	0	0	0
PL2	0	1	0	0	0	0	0	0	0	0	0	0
PL3	0	0	1	0	0	0	0	0	0	0	0	0
PL4	0	0	0	1	0	0	0	0	0	0	0	0
PL5	0	0	0	0	1	0	0	0	0	0	0	0
PA	1	0	0	0	0	0	0	0	0	0	0	0
PNA	0	0	0	0	0	1	0	0	0	0	0	0
PW	0	0	0	0	0	0	1	0	0	0	0	0
PD1	0	0	0	0	0	0	1	0	0	0	0	0
PD2	0	0	0	0	0	0	0	1	0	0	0	0
PD3	0	0	0	0	0	0	0	0	1	0	0	0
PD4	0	0	0	0	0	0	0	0	0	1	0	0
PD5	0	0	0	0	0	0	0	0	0	0	1	0
PO	0	0	0	0	0	0	0	0	0	0	0	1
PR	1	0	0	1	0	0	1	0	0	1	0	0

After calculateing A matrix, we can solve X (TRANSPOS)*A = [0] Equations and find X vector as following:

-PL1+PL2-PA+PNA-PR=0

-PL2+PL3+PR=0

-PL3+PL4=0

-PL4+PL5-PR=0

PL1-PL5+PW+PR=0

$PA-PNA=0$

$-PW-PD1+PD2-PR=0$

$-PD2+PD3+PR=0$

$-PD3+PD4=0$

$-PD4+PD5-PR=0$

$PD1-PD5+PO+PR=0$

$-PO=0$

The above equations have the following solutions (table 5):

Table 3: O (Pi, Ti) matrix

TL1	TL2	TL3	TL4	TL5	TI	TD1	TD2	TD3	TD4	TD5	TO
0	0	0	0	1	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0
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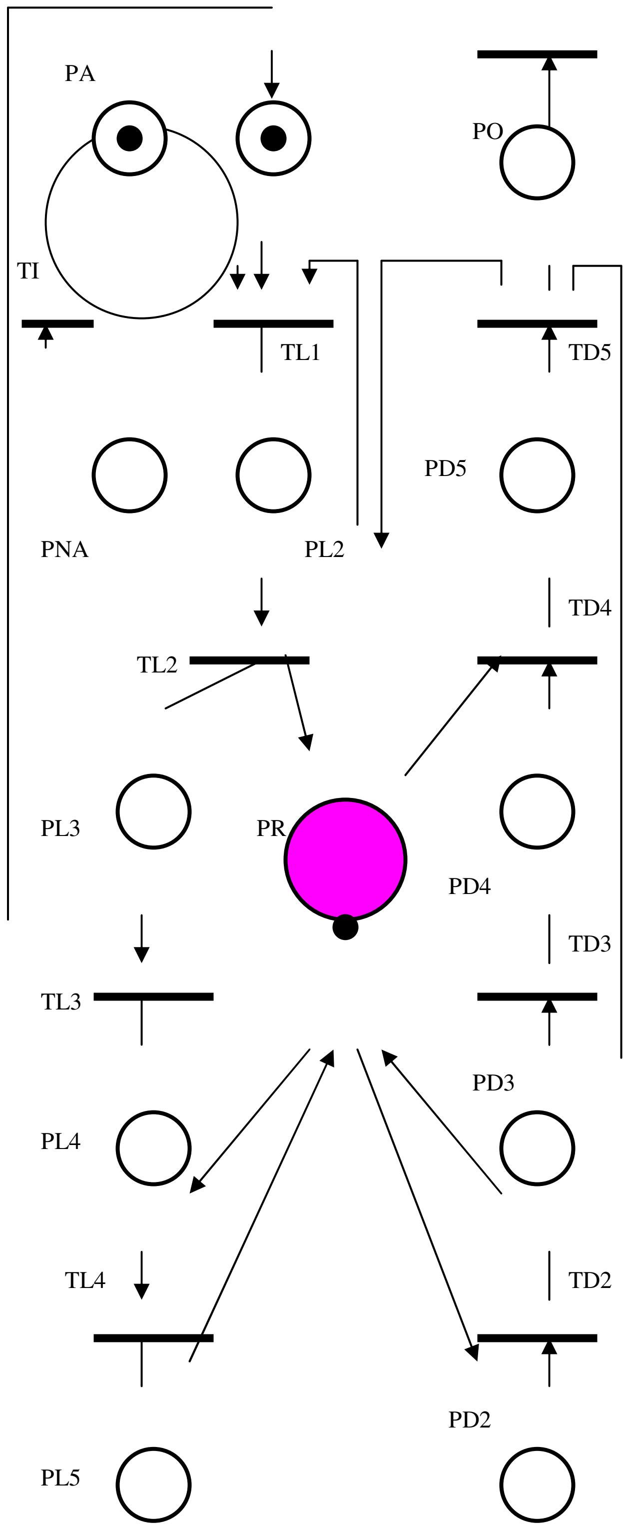
0	1	0	0	1	0	0	1	0	0	1	0



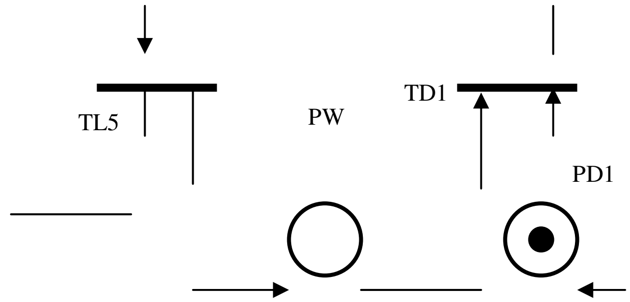


Figure 8: petri net model

	PL1	PL2	PL3	PL4	PL5	PA	PNA	PW	PD1	PD2	PD3	PD4	PD5	PO	PR
X1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
X2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
X3	0	1	0	0	1	0	0	0	0	1	0	0	1	0	1
X4	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0
X	1	2	1	1	2	1	1	0	1	2	1	1	2	0	1

Table 5: solution vector

Although in this paper we solved the problem without using of software tools, because of small scale, but in large-scale problems we can use some different software tools that developed such as: Petri Net Toolbox (PN Toolbox). It is a software tool for simulation, analysis and design of discrete event systems, based on Petri net (PN) models. This software is embedded in the MATLAB environment and its usage requires the MATLAB version 6.0 or higher. After solving the problem we can analyze the situation as follows:

- X1shows that Place PL1, PL2, PL3, PL4, PL5 share a token. This is the token that circulates through the states of the lathe.
- X2 shows the two states of input buffer either a part is available or it is not available.
- X3 shows the sharing of robot. A token circulates among the state of robot availability and the loading and unloading of the lathe and the drill.
- X4 indicates the parallel activities of the drill.

The sum of X indicates that the petri net is not covered. In particular the WIP and out put buffer inventories do not have a solution with positive non zero integers.

This can be quite easily seen for the case of PO by referring to last equations which has the solution PO=0. An interpretation of this solution results that PW (WIP) and PO (out put buffer) my be unbounded.

This can be seen by referring again to the petri net model of figure 8. Nothing prevents transition TL5 from firing an infinite number of times before TD1 fires. Thus, the WIP buffer can theoretically grow without bound. Hence, there is a fault in the logic of this workshop.

Conclusions

There are many literatures available on petri nets, but its applications in common platform strategy modeling and analyzing is rare. The main contribution of this paper is to present the petri net model in common platform area for control and analyzing in factual conditions. In recent years, it is envisaged that common platforms are the most fundamental concepts in Strategic Product Planning and Management.

The logic reasoning platform design is to (1) simplify the product offering and reduce part variety by (2) standardizing components and resource sharing so as to (3) reduce costs, time and other non value added factors and (4) reduce manufacturing variability, i.e. the variety of parts, tools, materials, etc, that are produced in a given manufacturing facility, and thereby (5) develop market share and improve loyalty and customer satisfaction. Therefore one must try to understand and apply common platform concept and effective practical methods for managing in manufacturing. In this situations we must consider rapidly changing technology, market, customer needs and high variety product, with restrict physical component resource for example machines, robots, AGVs, transfer line, tools, pallets, etc to obtain success.

Hence, managers have to learn how they can plan and control discrete event systems that occurred in shop floor. Therefore, petri net models can be used for simplifying managing and control for manufacturing, operation and production planning and activity control in common platform area. Because of complexity in real world, petri net theory helps us to rapid modeling, simulation and analyzing dynamic conditions with high accuracy by using software tools.

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