Simulation and Control of Siphon Petri Nets for Manufacturing Systems

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***Abstract* - In this paper we develop concepts to configure deadlock prevention supervisors for Petri Nets (PNs) with an example in Flexible Manufacturing System (FMS). We focus on a subclass of Petri Nets: Systems of Simple Sequential Processes with Resources, S3PR, which allows multiple resource acquisitions and flexible routing. Sequential events have a significant impact on PNs in the dynamics of FMS, presented here as siphons control model. Several trials are required to determine the set of elementary siphons to provide the required effect on the final supervisor in the structurally complex system. Siphons play an important part in Petri Nets applications in representation analysis to resolve deadlock problems in FMS. The control dynamics of FMS are developed based on the structural analysis used in siphons to configure and control supervisors of the system.**

Keywords - Simulation Petri Net, Siphons Petri Net, FMS, S3PR, Petri net controller, Reachability graph

I. INTRODUCTION

An FMS is concurrent and dynamical systems whose flexibility and integration is achieved through cooperation and competition in resource sharing. The FMS is characterized by asynchronous or unbalanced assembly lines implying that work doesn't speed at a fixed rate processing time of operations vary from resource to another resource (such as machines, buffer, and robots), though expensive are indispensable. On the physical level, the manufacturers have to be reconfigurable the Resource Allocation System (RAS) [1, 2] and the factory with its technologies, including different advantages' such as increased productivity, reduced lead times, increased machine utilization, and reduced set-up costs. An FMS have several types of products are designed and built-in a priory for predefined anticipated product variants procedure practicability simultaneously [3, 4] executing of resources, and external disturbances. This method is based on the synchronize distance request such integrated subsystems described by their capability to make different parts of products must be produced in synchronous practicability. In the case, a finite set of shared resources like machines or robots are the performance to analysis procedure, it is lead to deadlocks. For instance, two components or more processes compete for a limited number of resources, the system can evolve into a deadlock situation. Petri nets (PNs), one of the important tools with modelling and decision powers, are effectively used in FMS. Petri nets have been extensively applied to supervisory control problems [5–9], planning, and performance evaluation.

Deadlocks arise partially deteriorating a set of processes are unlimited resources waiting, analytically intractable. For deadlock control purpose, markings Petri Net is liveness in FMS modeled by Ordinary Petri Nets (OPN) is closely related to empty-able siphons. Elementary siphons are one of the many extensions of PNs. They fall in the class of System of Simple Sequential Processes with Resources, S^3PR Petri nets [2] and allow a compendious representation of the systems modelled. Thus, it is necessary for researchers to avoid dead-locks in FMS, and further perform effective deadlock-free. Chao [1, 2] develops a so-called one-sided approach policy of an S^3PR with various degrees of unsettling influence to guarantee that the siphon is always marked. Tokens in PN can leak out lead to structure siphons on a PN modelling an FMS.

Due to, the siphons contain more resource locations can be made up of those containing some resource allocations are needed a small number of monitors or control places during the control process in order that the solved siphons that contain the minimum number of resources places. Both analytical structure and the simulation PNs are utilized to check this model work accurately without blocking. There are some appreciations of Petri nets of an FMS is recently utilized can be modeled by subclasses of PNs, such as S^3PR [3, 5, 6, 10], and application of S^4PR-net [7– 9]. Petri nets are an excellent practice to handle deadlock problems with a Resource Allocation System (RAS) of FMS are a systematic model of recent technical systems. Therefore, it is impractical for large-sized Petri net models are extensively studied in the FMS supervisory control of concurrent systems. Furthermore, it is also possible to visualize the distributions of the process are described as a sequence of RAS used PN-tool. Petri Nets are a well-established method of modeling and analyzing deadlock of FMS processes are perfectly related to some structural objects of siphons. The reachability graph (RG) examination became a strong one to check specific properties of FMSs, such as deadlock, liveness, boundedness, concurrency, and synchronization.

The authors [11] investigated the classification of ordinary Petri nets, use the system of simple sequential

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processes with resources (S^3PR) which are developed the deadlock prevention on FMS. The siphons are an essential basic idea of Petri nets have a control framework to all empty of siphon S to keep it from being unmarked. They built up a methodology where liveness is authorized by included monitors, to employ strict minimal siphons (SMSs) in an S^3PR net dependent on resource circuits from being emptied marking. Recently, Li *et al*. [12] pioneered work to utilize the concept of Elementary Siphons (ESs) and resource circuits to compute SMS. They have to reduce the structural complexity of a supervisor is adding a control places for each elementary siphon S. The work of Hu *et al.* [13] has presented an analytical approach based on modified particle swarm optimization is presented to show its efficiency the elementary siphons PN and integer programming can be solved deadlock prevention of FMS. As an outcome of a series of simulation, testing different decisions, it is possible to select the best solution or to provide to the complexity that involves computing the resources siphon of PN model.

The author [3, 5, 6] presented a formalism design of FMS models is detecting problems of deadlocks based on the siphons policies, and reachability graph based policies. A Petri net theory offers analysis techniques and graphical tools to study the modeled systems are designed in application siphon PN and control by S^3PR. Besides siphons technology, the simulation approach is another effective method to analyze deadlock and other properties of PNs such as Reachability Graph (RG). Petri nets has been extensively used in the analysis of manufacturing systems, simulation PN completely with an S^4PR-net [7–9]. The reachability graph of PN is simulated in MATLAB environment [5–9], critical in highlights of the fact that considerable control issues in FMS [14]. The design and control systems have been traditionally carried out using PN techniques validated by simulation and the dynamics of automatic control systems, reachability graphs of PN's are a commonly used tool.

Petri ets are a great instrument for the displaying, examination and plan offbeat, simultaneous frameworks, for example, FMS, and its capacity to distinguish great conducted properties of the system demonstrated, for example, liveness. It is important to note that the liveness with the controller is doing in terms of the siphon. For the purpose of research on the state of the liveness Petri net, we can search out "strict minimal siphons" in order to obtain a solution to the deadlock-free. The dynamical properties of Petri net reachability, liveness as long as reversibility is of special attention to modeling and analyzing the FMS performance. The common approaches to deadlock detection are included in Petri nets and a graph-theoretic procedure.

Integrated Model of Distributed Systems (IMDS) is used to specify systems with communication duality (resource sharing/ message passing) in [15, 16]. In the formalism, in combination with model checking technique, automatic communication deadlocks and resource deadlocks can be detected. The formalism distinguishes deadlocks from distributed termination, which is another form of processes discontinuation. Additionally, partial deadlocks, in which not all processes participate, may be automatically identified. A shape of verified systems can be arbitrary: terminating, purely cyclic, lasso-shaped or hybrid. The connection to the IMDS with Petri nets siphons analysis identifies total and partial deadlocks, in communication or over resources, without restriction to cycling systems such as FMS, terminating (Workflow Nets–WFNets) or other. The multiple deadlocks can be observed in a single realization run. Therefore, resource dead- locks and communication deadlocks are highlights communication duality in distributed systems.

Organization: In section II, we give a brief overview of the introduction the basic of PN and formulations of S3PR's. The elementary and dependent of siphons are considered in Section III. The experimental results that are based on the simulation example of an S^3PR are illustrated with our applications of FMS proposed concepts in Section IV. Section V, concluding remarks.

II. PRELIMINARIES

A. Petri Nets [3-5]

A Petri net is 4-tuple N =(P, T, A, W) where P and T are finite and non-empty sets. P is a set of places and T is a set of transitions with $P \cap T = \Phi$. $A \subseteq (P \times T) \cup (T \times P)$ is called a flow relation of the net, directed arcs. $W:(P \times T) \cup (T \times P) \rightarrow N$ is a mapping that assigns a weight to an arc: $W(\dot{x}, \dot{y})>0$, if $(\dot{x}, \dot{y}) \in F$ and $W(\dot{x}, \dot{y})=0$, otherwise, where $(\dot{x}, \dot{y}) \in (P \times T) \cup (T \times P)$ and N is the set of non-negative integers. N =(P, T, A, W) is said to be an ordinary net, denoted as N = (P, T, A), if $\forall f \in F$, W(f) =1. Let $\dot{x} \in P \cup T$ be a node in N =(P, T, F, W). The preset of $\dot{x}$, denoted by $\bullet\dot{x}$, is defined as $\bullet\dot{x} = \{\dot{y} \in P \cup T \mid (\dot{y}, \dot{x}) \in A\}$, and $\dot{x}\bullet = \{\dot{y} \in P \cup T \mid (\dot{x}, \dot{y}) \in A\}$ is called the protest of $\dot{x}$. A marking M of a Petri net N =(P, T, A, W) is a mapping M : $P \rightarrow \hat{Z}$, where M is an n-dimensional vector, and n=|P| is the number of places in the net. A marking M of a Petri net N =(P, T, A,W) is a mapping M: $P \rightarrow N$, where M is an n-dimensional vector, and n=|P| is the number of places in the net. Let $t \in T$ be a transition of N = (P, T, A,W) at a marking M. Transition t is said to be enabled if $\forall p \in \bullet t$, $M(p) \geq W(p, t)$. An enabled transition t can fire, leading to a new marking M' , denoted by M[t⟩M' , that is:

$$\forall p \in P, M'(p) = M(p) - W(p, t) + W(t, p).$$

For a net system (N, M0), a nonempty subset of places S is a siphon if $\bullet S \subseteq S\bullet$ holds. A siphon is minimal if there is no siphon included in S as a seemly subset. A minimal siphon S is called a strict minimal siphon means as (SMS) for short.

B. Class of the S^3PR Petri Net Models

Petri nets are convenient tools to deal with such problems with their strong abilities to describe FMSs with properties such as concurrency, processes simultaneously, and interactions. The elementary and dependent siphons are new concept originally in [12], [13], which are aimed at selecting the basic siphons for control net. As it mentions' before, the distinguishing situation, we can extend the definitions class of S^3PR.

Definition 1. Let $N = O_{k-1}^{k} N_i = (p_A^{\cdot} \cup p_0^{\cdot} \cup p_R^{\cdot}, T, A_i)$ be an S^3PR net where is defined in [11] as the union of a set of nets: $N_i = (p_A^i \cup \{p_0^i\} \cup p_R^i, T_i, A_i)$, sharing common places, where the following statements are true:

1). p_0^i is called the process Idle place of net N_i. The elements in p_A^i and p_R^i are called activity (or Operation) and ℜsource places respectively.

2). $p_A^i \neq \varnothing; P_R^i \neq \varnothing; P_0^i \notin P_A^i; [P_A^i \cup \{p_0^i\}] \cap P_R^i = \varnothing;$

3). $\forall p \in p_A^i, \forall t \in {}^{\bullet}P, \forall t' \in p^{\bullet}, \exists r_p \in p_R^i, {}^{\bullet}t \cap p_R^i =$
$t'^{\bullet} \cap P_R^i = \{r_p\};$

4). $\forall r \in P_{R_i}, {}^{\bullet\bullet}r \cap P_A^i = r^{\bullet\bullet} \cap P_A^i \neq \varnothing, {}^{\bullet}r \cap r^{\bullet} = \varnothing;$

5). ${}^{\bullet\bullet}\{P_0^i\} \cap P_R^i = \{P_0^i\}^{\bullet\bullet} \cap P_R^i = \varnothing;$

6). $\forall i \in N_k$, the subnet N_i *is* generated by $P_i \cup \{p_{i0}\}$ and T_i is a strongly connected state machine, and every circuit of N_i, contains P_{i0}.

7). $\forall p \in P, \forall t_1 \in {}^{\bullet}p, \forall t_2 \in p^{\bullet}, {}^{\bullet}t_1 \cap P_R = t_2^{\bullet} \cap P_R = \{r\},$
denoted as R(p) = r. We say that p uses r.

8). $H(r) = {}^{\bullet\bullet}r \cap P_A$ denotes the set of holders of r (operation places that use r). The resource r is correlating with a minimal P-invariant whose support is indicated by $P_r = \{r\} \cup H\{r\}$.

Definition 2. Let $N_i = (P_A \cup P^0 \cup P_R^{\cdot}, T, A)$, be an S^3PR. The initial marking M_0 is called an acceptable initial marking for N if: (i) $\forall p \in P_i^{0.}, M_0(p) \geq 1$,

(ii) $\forall p \in P_A, M_0(p) = 0$, and

(iii) $\forall p \in P_R^{\cdot}, M_0(p) \geq 1$.

III. ELEMENTARY AND DEPENDENT SIPHONS

In this section, we give the definitions of an S^3PR [11], [12] that we will deal with.

Definition 3. Let N = (Ƥ, T; A) be a net with |Ƥ|= ḿ , |T|= ň, and κ siphons, S_1, S_2, ... , and S_k, ḿ, ň, κ∈**N**. Let λ_{Si} ($ή_{Si}$) be the distinguishing by *Ƥ(T)*–vector of siphon S_i, i∈{1, 2, . . . , k}. We realize $[\lambda]_{k \times m} = [\lambda_{S1} | \lambda_{S2} | \ldots | \lambda_{S\kappa}]^T$ and $[ή]_{\kappa \times ń} = [\lambda]_{\kappa \times ḿ} \times [N]_{ḿ \times ň} = [ή_{S1} | ή_{S2} | \ldots ή_{S\kappa}]^T$. [λ]([ή]) is called the distinguishing by *Ƥ(T)*–vector matrix of the siphons in N.

Lemma 1: Let (N, M_0) be a marked S^3PR net, N= (Ƥ,T,A), and S be a siphon in N:

1) S can never be marked if ∃ M∈R (N, M_0) in which M(S)=0, S is said to be emptied.

2) S cannot be empty if it is invariant-controlled.

3) The liveness is existence if no emptied siphon in N is found.

Proposition 1: The Ƥ-invariant-controlled Petri net [12] is control a siphon S.

Lemma 2: The number of elements in any set of elementary siphons in net N equals the rank[η].

Theorem 1. Let N_{ES} be the number of elementary siphons in $N = (P, T, A)$. Then we have N_{ES} < min {| P |, | T |}.

Theorem 2**.** Let S be a siphon if net N =(P, T, A, W). T-vector is presented by η_S . The transitions are state {t∈T| η_S(t)> 0}, {t∈T| η_S(t) = 0}, and {t∈T| η_S(t) < 0}.

IV. EXPERIMENTAL RESULTS AND SIMULATION

An illustrative example is provided the manufacturing cell (Figure 1) from Hu *et al.* [13], which is the approach produces their part types of *J*1– *J*3. There are three machines and three robots, are connected by AGV and designed to produce an assortment of product the system. The performance of the proposed experiment was examined using Petri net simulation of FMS. The Petri net techniques and the concepts to the study siphons, deadlocks, and deadlock-freeness are represented under worked Petri net system. We consider a parallel manufacturing system to be in an even larger FMS.

Figure 1 presents the layout of a hypothetical FMS cell possessed with three robots (ℜ1– ℜ3) that are used for moving parts in machines (M1–M3).

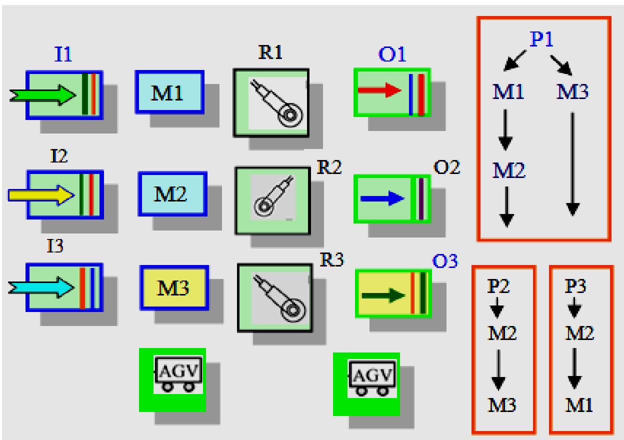

Figure 1. Layout of a Manufacturing Cell

In Figure 1, the planning processes can produce three types of parts need to follow to accomplish their processing. There are three loading conveyors I1–I3 and three unloading conveyors O1–O3 to load and unload the FMS. For instance, a raw part of J1 is taken from I1 by R1, selects two options:

1) it is processed in M1.

Thereafter, it is moved to M2 by R2, i.e. the raw product of type P1 is taken from R1 can load part: $I1 \rightarrow R1 \rightarrow M1 \rightarrow R2 \rightarrow M2 \rightarrow R3 \rightarrow O1$; or (2) it is first processed in M3, and further moved to O1 by R3, i.e. $I1 \rightarrow R1 \rightarrow M3 \rightarrow R3 \rightarrow O1$. In the wake of being handled by M2 or M3, this piece of J1 is moved to O1 by R3. For the raw, a raw part of J2 (type P2) is taken from I2 to M2, M3 by R2, i.e. $I2 \rightarrow R1 \rightarrow M2 \rightarrow R2 \rightarrow M3 \rightarrow R3 \rightarrow O2$. For third type P3, raw part of J3 is given from I3 by R3. subsequently, being manufactured in M3, and M1, i.e. $I3 \rightarrow R3 \rightarrow M3 \rightarrow R2 \rightarrow M1 \rightarrow R \rightarrow O3$. Obviously, as shown in Figure 2, part type J1 has two processing routes; while part types J2 and J3 have only one each. In this system allows multiple resource acquisitions and flexible routes, this FMS's PN model is an S^3PR, as shown in Figure 2, where the sets of Idle, $\Re$resource and ooperation places are:

$P^0 = \{p_{31}, p_{32}, p_{33}\}$, $P_R = \{p_{35}, p_{39}, p_{47}, p_{48}, p_{49}, p_{50}\}$, $P_{A1} = \{p_{34}, p_{36}, p_{37}, p_{38}, p_{40}, p_{41}\}$, $P_{A2} = \{p_{42} - p_{46}\}$, and $P_{A3} = \{p_{51} - p_{55}\}$ respectively, where applied definition 2.

The initial marking $M_0 = 10p_{31} + 10p_{32} + 10p_{33} + p_{35} + 2p_{39} + 2p_{47} + p_{48} + 2p_{49} + p_{50}$ is acceptable.

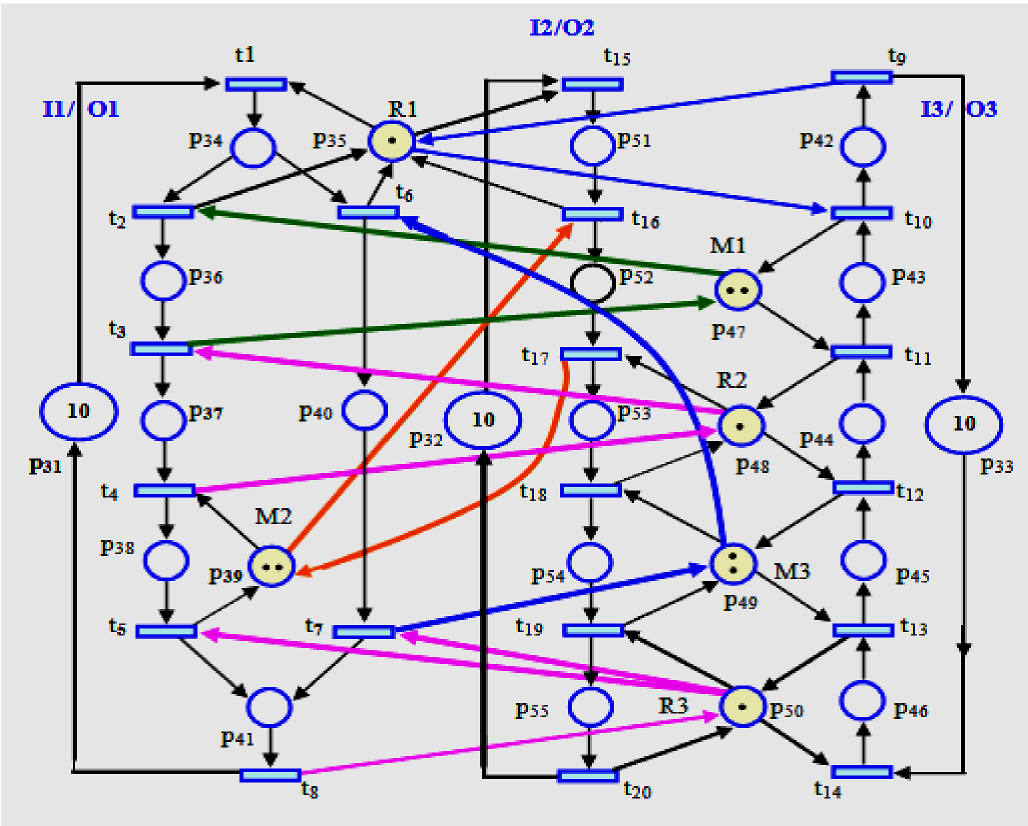

Figure 2. Petri Net Modelling System of Figure 1, [13].

In this example, the Reachability/Cover-ability Graph results show it has 18339 states with 59098 arcs. The Graph is too large to be shown appropriately. To completely utilize the running of the above example model, refer to Figure 2 in "PIPE"[17]. As a result, there are six P-invariants as follow:

$I_{p_{35}} = p_{34} + p_{35} + p_{42} + p_{51}$, *where* $M(p_{35}) = 1$,

$I_{p_{39}} = p_{38} + p_{39} + p_{52}$; *where* $M(p_{39}) = 2$,

$I_{p_{47}} = p_{36} + p_{43} + p_{47}$; where $M(p_{47}) = 2$,

$I_{p_{48}} = p_{37} + p_{44} + p_{48} + p_{53}$; *where* $M(p_{48}) = 1$,

$I_{p_{49}} = p_{40} + p_{45} + p_{49} + p_{54}$; *where* $M(p_{49}) = 2$, and

$I_{p_{50}} = p_{41} + p_{46} + p_{50} + p_{55}$; *where* $M(p_{50}) = 1$.

This structure is based on some performance of FMS that is represented as a Petri-net model. We use analytical structures of several behavioral properties of PN in order to find SMSs. A Petri nets system example is described in Figure 2, which is an S^3PR that contains deadlocks. In the PN model shown in Figure 2, there are 17 SMSs: $S_1 = \{p_{41}, p_{45}, p_{49}, p_{50}, p_{55}\}$, *where* $M(S_1) = 3$,
$S_2 = \{p_{38}, p_{39}, p_{44}, p_{48}, p_{53}\}$, *where* $M(S_2) = 3$,
$S_3 = \{p_{37}, p_{40}, p_{44}, p_{48}, p_{49}, p_{54}\}$, *where* $M(S_3) = 3$,
$S_4 = \{p_{37}, p_{43}, p_{47}, p_{48}, p_{53}\}$, *where* $M(S_4) = 3$,
$S_5 = \{p_{37}, p_{41}, p_{44}, p_{48}, p_{49}, p_{50}, p_{55}\}$, *where* $M(S_5) = 4$,
$S_6 = \{p_{38}, p_{39}, p_{40}, p_{44}, p_{48}, p_{49}, p_{54}\}$, *where* $M(S_6) = 5$,
$S_7 = \{p_{38}, p_{39}, p_{43}, p_{47}, p_{48}, p_{53}\}$, *where* $M(S_7) = 5$,
$S_8 = \{p_{37}, p_{40}, p_{43}, p_{47}, p_{48}, p_{49}, p_{54}\}$, *where* $M(S_8) = 5$,
$S_9 = \{p_{39}, p_{41}, p_{44}, p_{48}, p_{49}, p_{50}, p_{55}\}$, *where* $M(S_9) = 6$,
$S_{10} = \{p_{37}, p_{41}, p_{43}, p_{47}, p_{48}, p_{49}, p_{50}, p_{55}\}$, *where* $M(S_{10}) = 3$,
$S_{11} = \{p_{35}, p_{37}, p_{40}, p_{42}, p_{47}, p_{48}, p_{49}, p_{51}, p_{54}\}$, $M(S_{11}) = 6$,
$S_{12} = \{p_{34}, p_{35}, p_{38}, p_{39}, p_{42}, p_{47}, p_{48}, p_{53}\}$, *where* $M(S_{12}) = 6$,
$S_{13} = \{p_{35}, p_{37}, p_{41}, p_{42}, p_{47}, p_{48}, p_{49}, p_{50}, p_{51}, p_{55}\}$, $M(S_{13}) = 7$,
$S_{14} = \{p_{38}, p_{39}, p_{40}, p_{43}, p_{47}, p_{48}, p_{49}, p_{54}\}$, *where* $M(S_{14}) = 7$,
$S_{15} = \{p_{39}, p_{41}, p_{43}, p_{47}, p_{48}, p_{49}, p_{50}, p_{55}\}$, *where* $M(S_{15}) = 8$,
$S_{16} = \{p_{35}, p_{38}, p_{39}, p_{40}, p_{42}, p_{47}, p_{48}, p_{49}, p_{54}\}$, $M(S_{16}) = 8$,
$S_{17} = \{p_{35}, p_{39}, p_{41}, p_{42}, p_{47}, p_{48}, p_{49}, p_{50}, p_{55}\}$, $M(S_{17}) = 9$.

Definition 4. Let $\eta_{S\alpha}, \eta_{S\beta}, \ldots,$ and $\eta_{S\gamma}$ be a linearly independent maximal set of the matrix $[\eta]$. Then, $\Pi_E = \{S_\alpha, S_\beta, \ldots, S_\gamma\}$ is called a set of Elementary Siphons (ESs) in N.

Definition 5. Let $S \notin \Pi_E$ is called a strongly dependent siphon if $\eta_S = \sum_{S_i \in \Pi_E} a_i \eta_{S_i}$ holds, where $a_i \geq 0$. In this case, the T-vector can be linearly represented indicate by ESs with non-negative coefficients.

A PN model is shown in Figure 2., contains four SMSs such as: $\lambda_{S1} = \{p_{41}, p_{45}, p_{49}, p_{50}, p_{55}\}$,
$\lambda_{S2} = \{p_{38}, p_{39}, p_{44}, p_{48}, p_{53}\}$,
$\lambda_{S3} = \{p_{37}, p_{40}, p_{44}, p_{48}, p_{49}, p_{54}\}$, and
$\lambda_{S4} = \{p_{37}, p_{43}, p_{47}, p_{48}, p_{53}\}$.

Similarly, the vectors $[\eta]$ is presented as the linearly independent conducted as:
$\eta_{S1} = -t_1 + t_2 + t_7 + t_{13} - t_{14} - t_{15} + t_{19}$;
$\eta_{S2} = -t_1 + t_4 + t_6 - t_{15} + t_{17}$;
$\eta_{S3} = +t_{12} - t_{14} - t_{15} + t_{18}$;
$\eta_{S4} = -t_1 + t_3 + t_6 + t_{11} - t_{14}$;
$\eta_{S5} = \eta_{S1} + \eta_{S2} = -2t_1 + t_2 + t_4 + t_6 + t_7 + t_{13} - t_{14} - 2t_{15} + t_{17} + t_{19}$;
$\eta_{S6} = \eta_{S2} + \eta_{S3} = -t_1 + t_4 + t_6 + t_{12} - t_{14} - 2t_{15} + t_{17} + t_{18}$, and
$\eta_{S7} = \eta_{S1} + \eta_{S3} = -t_1 + t_2 + t_7 + t_{12} + t_{13} - 2t_{14} - 2t_{15} + t_{18} + t_{19}$.

In order to design a controller of a given deadlock prevention problem with FMS, we find SMS used for the particular class of S^3PR net that is utilized the elementary siphons to check the control system by simulation in tool [17] is obtained three control places are saturated as follows:

		t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	|
$\eta_{S1} =$	|	-1	1	0	0	0	0	1	0	0	0	0	0	1	-1	-1	0	0	0	1	0	|
$\eta_{S2} =$	|	-1	0	0	1	0	1	0	0	0	0	0	0	0	0	-1	0	1	0	0	0	|
$\eta_{S3} =$	|	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	-1	0	0	1	0	0	|
$\eta_{S4} =$	|	-1	0	1	0	0	1	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	|
$\eta_{S9} =$	|	-1	0	0	0	1	0	1	0	0	0	0	1	0	-1	-1	0	0	0	1	0	|
$\eta_{S11} =$	|	-1	0	1	0	0	1	0	0	0	1	1	0	0	-1	-1	0	0	1	0	0	|
$\eta_{S12} =$	|	-1			1		1				1				-1	-1		1				|
$\eta_{S16} =$		-1			1		1				1				-1	-1			1			|
$\eta_{S3} + \eta_{S4}$		-1		1			1					1	1		-2	-1			1			|+
$\eta_{S5} =$	|	**-2**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**-1**	**-2**	**0**	**1**	**0**	**1**	**0**	| +
$\eta_{S6} =$	|	**-2**	**0**	**1**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**-1**	**-1**	**0**	**1**	**0**	**0**	**0**	| +
$\eta_{S7} =$	|	**-2**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**-2**	**-1**	**0**	**0**	**0**	**1**	**0**	| +
$\eta_{S18} = \eta_{S9} + \eta_{S16}$	|	-2			1	1	1	1	0	0	1	0	1		-2	-2			1	1		|+

We choose the monitors as follows:
1). $\eta S_1 = -t_1 + t_2 + t_7 + t_{13} - t_{14} - t_{15} + t_{19}$; for monitor VS_1.
2). $\eta S_7 = \eta S_3 + \eta S_4 = -t_1 + t_3 + t_6 + t_{11} + t_{12} - 2t_{14} - t_{15} + t_{18}$; for monitor VS_2.
3). $\eta S_{18} = \eta S_9 + \eta S_{16} = -2t_1 + t_4 + t_5 + t_6 + t_7 + t_{10} + t_{12} - 2t_{14} - 2t_{15} + t_{18} + t_{19}$; for monitor VS_3.

We have a choice of three monitors (Control places) as follows:

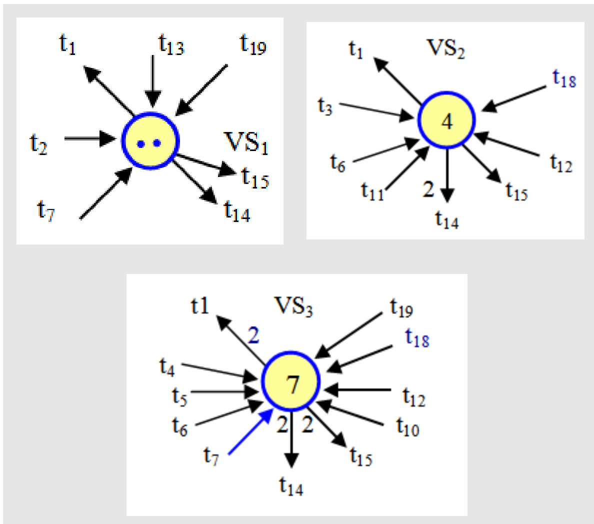

Figure 3. Control system of Fig. 2.

While applying algorithm [11], [12] monitors or (control places) are used to generate a deadlock control method. An S^3PR consists of some state machines holding and discharging some normal resources. Consequently, the siphons (S_1–S_3) are elementary siphons while (S_4 –S_{17}) are dependent once. In this example, the monitor-based methods focus on the feasibility application, and we add two monitors or control places VS_1 and VS_3 for control siphons S_1, S_6, and S_{16}, respectively. In particular, coverability can be used to verify that is PN liveness and display the reachability graph (RG) of Figure 2, has 4275 states reachable. It is straightforward to verify that the third monitor's VS_2 adds to the net in order to reduce RG, and the system also is live.

Furthermore, the three control places can be developed in this work can be suitably modified obtained the controller siphons S_3, and S_4 the system is liveness and has a total (4109) reachable states used a tool of [17], (see Figure 4). Subsequently, by adding three control places (VS_1–VS_3) the reachability graph liveness is examined in the "PIPE" tool [17]. The resultant net shown is live by adding 3 monitors and 26 control arcs, and the reachability graph has 4109 good states. The Petri Net modeling approach of the resources demonstrates the deadlock prevention strategy targets for an S^3PR are detected the resources block in order to design structurally simple Petri net supervisors whereas verification the better control. The implementation of every conceivable emptiable minimal siphon requires a monitor to be added to prevent it from being emptied marking. The application siphons Petri net is presented to satisfy the sufficient control problem is formulated.

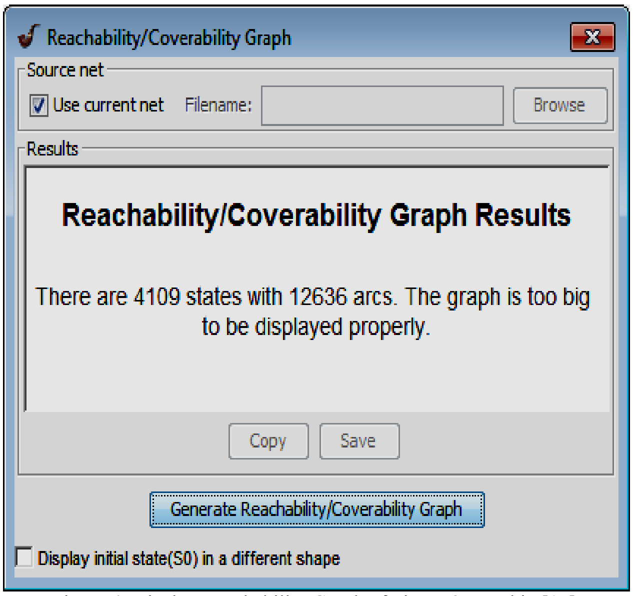

Figure 4. Display Reachability Graph of Figure 2 tested in [17].

A simulation result is another approach presents the new guaranteeing existence of solutions to the system indicates with three monitors are liveness Petri net, and has 4109 reachable states. We can be compared to the corresponding resulting algorithm from [11] requests controlled all SMS that has 17 controlling places. This paper aims to use the found results when the comparison between the other authors, the supervisors presented in [13] had good results from eight control places are liveness and 4358 reachable states. In our methodology, we are planning technique can possibly diminish the modest number of control places are introduced to demonstrate the adequacy of the proposed methodology. Hence, our method is much more efficient in this example, when compared to the other authors in Hu *et al.* [13] algorithms. The simulation technique aimed at providing guidelines on the optimal production planning can be considered as an experimental analysis and allows parts programming to be current methods. In this model of the system has been constructed, the proposed method consists of a few control places needs to avoid the system of the deadlock state.

In previous work [5–9], [18–20], Petri Net liveness enforcement showed by simulation results it can be utilized to check how this model works accurately without bottlenecks. The motivation has more interest in the reachability graph Petri Nets, and simulation of FMS representation was running in computer to describe the net model can completely reflect the behaviors and the evolution of a system as has already been investigated. The results of total execution demonstrate that the resource blocked utilization the strategy is a successful method to compute SMS for S^3PR is utilized modeling FMS. The liveness in Petri net system concerns the existence of any activity from any reachable (tokens) state of the system, and it is often part of the specification of concurrent systems. The result is a general structure utilized to siphon based deadlock Petri nets to prove the correctness system by using simulation and reachability analysis. This paper will focus on the absence of deadlock, which is utilized from siphons S unmarked, control place VS_i and some control arcs are added to {S}. For the control net, the employment tokens in the control place are the point of by [$M_0(VS_i)$]. The approach present in this paper is our contributions can be an automatic synthesis of concert processes, models where is the implementation of siphon-based deadlock control techniques for modern FMS is reasonable.

V. CONCLUSION

This paper investigates a novel solution and effective deadlock prevention policy for a subclass of Petri nets, S^3PR, which allows multiple resource acquisitions and flexible routing. The displaying procedure is useful in concentrating the executions into FMS. Nonetheless, this displaying procedure can likewise be utilized in a configuration stage to check the accuracy of FMS. This technique is used interactively to discover maximal unmarked siphons. The illustrative example of S^3PR application was presented. Therefore, it is possible to reuse the deadlocks which are a class of the structural classes of siphons, including the possibility of validating qualitative properties Petri-nets like liveness that can be an important issue when the system is controlled. Future work will focus on the determination of improvement strategies for progressively nonexclusive classes of Petri Nets to use a novel way to deal with and accomplish deadlock-freeness, and more general classes of PNs.

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