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Modeling of Robustness Margins of the Control of a Predictive Control-Supervisory Architecture

Achraf Jabeur Telmoudi
(SEPE, Ecole Supérieure des Sciences et Techniques de Tunis
5, Avenue Taha Hussein, Montfleury BP 56 - 1008 Tunis, Tunisia
achraf-j.telmoudi@topnet.tn)

Lotfi Nabli
(ATSI, Ecole Nationale d'Ingénieurs de Monastir
Rue Ibn Eljazar, 5019 Monastir, Tunisia
lotfinabli@yahoo.fr)

Radhi M'hiri
(RME, Institut National des Sciences Appliquées et de Technologie
Centre Urbain Nord BP 676 - 1080 Tunis Cedex, Tunisia
radhi.mhiri@yahoo.fr)

Abstract: In this article a new Control-Supervisory architecture of Flexible Manufacturing Systems (FMS) is presented. We are interested particularly in construction and modelling of FMS robust control of flow-shop type to time constraints. Other than the control of production system, the goal is to observe and interpreted the robustness of resources and of manufacturing system. The P-time Petri Nets which is used for modeling of the time constraints. A methodology of construction of a robust control system generating the margins of passive and active robustness is elaborated. The redundancy of the robustness of the elementary parameters between passive and active leads us to define the ways ensuring the total robustness of the system. To do so, a set of definitions lemmas and theorems are developed and affirmed by examples of applications.

Keywords: Control-Supervisory architecture, Modeling, Robustness, time constraints, P-time Petri Nets, FMS
Categories: D.2.2, G.4, I.2.3, I.6.5, J.6

1 Introduction

Generally, the manufacturing systems are subject to disturbances which influence the prescribed output. To manage and minimise these disturbances effect, different Control-Supervisory architecture were presented in the literature. Each one solves the problematic in its way. This to minimize a number of constraints which depend on the internal or external environment of the manufacturing system. Indeed, we can distinguish three classes of works related to this problematic: the first fusions the Supervisory to the Control system such as the works of [Kazushi 01], [Toguyéni, 05], [Bonhomme, 05], etc.; the second separates the Supervisory to the Control [Ly, 00], [Collart, 03], [Dhouibi, 05], etc.; the last is between separation and fusion [Da Silveira, 03]. An efficient architecture is that which has a robust control ensuring the perfect management of the disturbances.

For a manufacturing system, the robustness is defined as its aptitude to preserve its specified properties against foreseen or unforeseen disturbances [CORINE, 96]. Indeed, we distinguish two types of robustness: passive robustness and active robustness. The passive robustness responds if no modification in control is necessary so that the specified properties are preserved in the presence of variations [CORINE, 96]. The active Robustness corresponds if the specified properties can be maintained, but at the price of a total or partial calculation of control [CORINE, 96].

Indeed, the robustness is the consequence of two intrinsic elements which are the type of variations and the definition of qualities necessary for the exit of the system. To react to these disturbances, a system must have decision criteria enabling it to take into account the concept of robustness. The determination of this robustness provides a decision criterion.

Problematic of robust systems to discrete events is frequently met in the literature. Majority of this works have been interested in the robustness of the production manufacturing systems to time constraints [Bonhomme, 00], [Bonhomme, 05], [Collart, 97], [Collart, 03], [Jerbi, 06], etc. In all these works, the authors are interested in one type of robustness (passive or active). They did not involve a hybrid model that generates both the passive and active robustness.

It is within this context that we present our study. Our objective is to develop a hybrid control model able to take into consideration, in the same time, the passive and active robustness. Also, this model has a role of an observer which allows the interpretation of the type of global robustness of products flows in manufacturing systems of flow-shop type. The subjacent idea is to develop local models relating to the entities of system. This allows the maintenance of modular robustness for each subsystem so as observe and generate the total system robustness.

The modeling of these processes requires specifying, for each operation of production process, an interval of the authorized duration.

Considering the performance of the Petri Nets tool in terms of modeling synchronizations, parallels, conflicts and sharing of resources, this tool is seen as an important research way for modeling and evaluation of robustness. P-time Petri Nets are much exploited in works relating to this problem [Bonhomme, 00], [Bonhomme, 05], [Khansa, 96], [Khansa, 97], [Jerbi, 06], etc.

This paper includes four parts. In the first part, we start by the presentation of our architecture Control-Supervisory will be presented. In the second part, A reminder on the P-time Petri Nets will be presented. In the third part, we will present our model for the generation of robust modular of flow. Finally, we present a design methodology of the robust control laws of system.

2 Robust control for indirect supervisory

Our architecture Control-Supervisory is developed under the constraints of minimizing the use of corrective maintenance. This is to avoid interruptions causing fatal events influencing the overall performance of the company at the technical and/or economic level.

We suppose thus that if a margin of passive robustness is not respected, the manufacturing system could generate by events leading to the suspension of normal functioning in future moment. On the other hand, the repetition of the reconfiguration tasks on control can be considered as a bad indicator of the manufacturing system performance.

This architecture is therefore a preventive indirect supervisory following a robust Control of the systems.

When talking about preventive supervisory, we end up to avoiding the occurrence of events ceasing Process functioning.

This type of supervisory is based on the study of the representative parameters reflecting the process state. This, in order to ensure: the evolution follow-up, the drifts detection, the identification of the drift origin and finally the cause analysis of this drift. The term "indirect" requires to be based on the representative functional models of the process by supervising the resources starting from the disturbances that they are generated on the products such as: the flow parameters, the quality parameters, etc.

For our approach, a hypothesis is posed. It is to link the disturbances of products flow during the production to the degraded state of equipments (Figure 1).

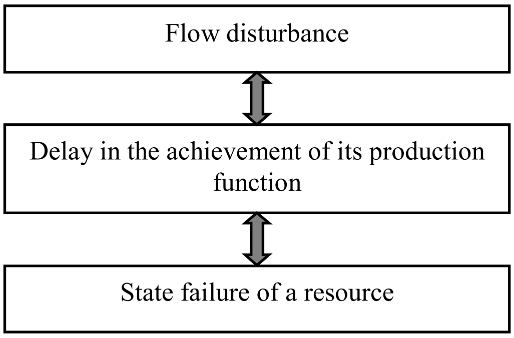

Figure 1: Hypothesis

To control a production system consists in imposing to it a set of the control laws. The objective is to meet the market needs. The disturbances which influence implicitly the prescribed exits must be taken into evidence. This requires a robust control. Indeed, the definition of conformity intervals of the system parameters must always anticipate the design phase of the target control law.

The architecture that we propose is approached in two principal blocks: Control block and supervisory block. This architecture is presented by figure 2.

The principle of functioning of this architecture consists in managing the information of the system by an intelligent and collective manner which allows to satisfy the informational needs of all entities constituting the Control-Supervisory system and its auxiliaries (process and product). The auxiliary of the Control-Supervisory system present at the same time the subject of our problematic.

Thus it is a question of a good study of the system specificities and the environment obligations in order to establish a robust control being based on laws allowing the management of constraints. Once this order is established, the other blocks and functions can be created and located. In the continuation, we will define, in a first stage, the role of each entity of this Control-Supervisory system. Next, we present an explanation of the informational functioning and exchange between these different entities.

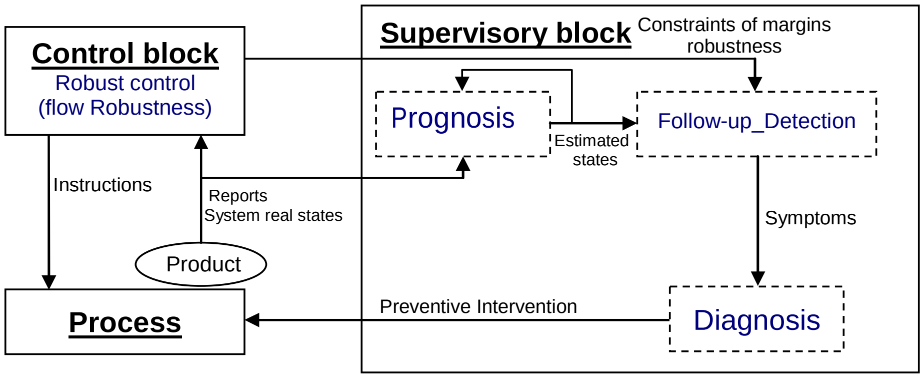

Figure 2: Control-Supervisory architecture

Control block: it makes it possible to define the representative parameters of the system. It defines the constraints put on the products such as flow sequencing and robustness margins which are equivalent to the margins of the desired performance. It has the role of control and observer. The modeling of these constraints allows us to control the interaction between different uncertainties of the parameters representative of the system. The control, which one wants to establish, takes into account, at the same time, the modeling of the passive and active robustness margins. This allows to observe the robustness at local level (resources) and to interpret it at total level (manufacturing system). Also, the modeling of the margins of active and passive robustness at the same time on the same model allows us to define thresholds which reach then to the determination of the probable cases leading to the recourse to the preventive maintenance. This is known as considering the definitions of the passive and active robustness.

Supervisory bloc: it has the role to prevent the system states considered to be abnormal. This block consists of three functions which are: Prognosis, Follow-up_Detection and Diagnosis. The Prognosis function allows to predict the future values of the control variables. Indeed, this function did not the classical role defined in various supervision works. This is due to the predictive nature of our architecture Control-Supervisory. The follow-up_detection function acts to follow the estimated states by the prognosis function and to detect the deviations. Finally, the diagnosis function has the role to seek, to analyze and to recommend the origin, the nature and the cause of the deviation.

Explanation of informational exchange: once architecture is established, information circulates in the following way: control instructions will be sent by the control block towards the process, these instructions translate the control laws. Information "reports", translating the process state, extracted from products will be transmitted towards the control block and the prognosis function of the supervisory block. Those information relate to the parameters of the modelled control laws. The prognosis function ensures the processing of these data through a predictor which allows the estimation of the future states of these parameters, therefore of system. Other than these estimated states, the robustness constraints will be too the entry of the follow-up_detection function. If there are symptoms detected by the predictor, the relative information will be sent towards the diagnosis block. In this stage, an information request indicates, if necessary, the preventive interventions to be realized on the process. In every iteration, the control model provides observed and interpreted information on the robustness type of resources and system.

In the continuation of this article, we are interested only in the control block. We present a modeling methodology of the parameters of the control law. The interactions between uncertainties will be treated. For this, we utilize the P-time Petri Nets.

3 P-time Petri Nets for the robust control

The theoretical bases of the P-time Petri Nets were elaborated by Khansa in his thesis [Khansa, 97]. He has shown that they represent a powerful and recognized formalism for modeling the respect obligation of setting times (synchronization under obligation) [Khansa, 97].

Definition 1. [Khansa, 97] P-time Petri Nets is a t-uple <*P, T, Pre, Post, M0, IS*> where < *P, T, Pre, Post, M0* > is a marked Petri net provided with an initial marking M0 and IS is a definite application per:

$$IS : P \to (\mathbb{Q}^+ \cup 0) \times (\mathbb{Q}^+ \cup \infty)$$

$$p\,x \to IS_x = [a_x, b_x]; \quad with \quad 0 \le a_x \le b_x$$

IS_x defines the static interval of sitting time of a mark in the place p_i ($\mathbb{Q}^+$ is the set of positive rational numbers). A mark in the place p_x takes part in the validation of output transitions only if it remained at least the duration a_x in this place. It must leave the place p_x at the latest when its setting duration becomes b_x. If it cannot do so, we would say that the mark is *"dead"* and will not take part in the validation of transitions.

In the initial state, the interval associated to marks is $[0,\infty[$ and as soon as a mark arrives in a place by firing of a transition, it takes the interval associate at the place.

Definition 2. [Khansa, 97] At any given moment, the state is defined by a doublet *E* = <*M, G*>, where:

- M is a marking application, assigning for each place of the network a certain number of marks $(\forall p \in P, M(p) \ge 0)$;

- *G* is a residence time application which associates for each mark k in the place p_x a real number g_x^k where g_x^k is the age of this mark (the time passed since its arrival in the place p_x).

Let $[a_x, b_x]$ the static interval associated to the place p_x, a mark *k* can take part in the validation as of its exit transitions if and only if:

1- g_x^k is not lower to a_x: $g_x^k \geq a_x$;

2- g_x^k is not higher to b_x: $g_x^k \leq b_x$.

The mark k died when his age is strictly superior to b_x.

Definition 3. [Khansa, 97] Leaving the state *E (M, G)*, a transition t_a is validated if and only if:

1- $\forall p_x \in {}^{\circ}t_a : m(p_x) \geq Pre(p_x, t_a)$;

2- $\forall p_x \in P$, there are at least $Pre(p_x, t_a)$ marks in this place such as:

$min(b_x - \theta_x^k) - max(0, max(a_x - \theta_x^k)) \geq 0$ where:

$k = 1,2,3,...,Pre(p_x, t_x)$

$[a_x, b_x]$ it is the associated interval to the place p_x

θ_x^k it is the age of a mark k in the place p_x.

Note: within the framework of this work, we use the Petri Nets with inhibitor arcs.

Definition 4. *[HAC 75]* Petri Nets with inhibitor arcs is a Petri Nets: *R = <P, T, Pre, Post>*, which we modify only the definition of *Pre:*

$$Pre : P \times T \to \mathbb{N} \cup \{\varnothing\}$$

for a Petri Nets with inhibitor arcs, a transition $t \in T$ is fired for has marking M if:

$$\forall p \in P : Pre(p,t) \leq M(p) \quad if \quad Pre(p,t) \in \mathbb{N}$$

$$M(p) = 0 \quad if \quad Pre(p,t) = \varnothing$$

Pre (p,t) = Ø are represented graphically by an arc and by a small round replacing the arrow.

4 Model of the modular robustness

The concerned systems are the manufacturing systems of flow-shop type. A finished product cannot pass more than only once by every machine to be finished.

We assume that in the case of violation of a temporal constraint the product will be rejected.

Definition 5. [Telmoudi, 08] A basic circuit C_i is defined as a whole of ordered machines influencing, directly or indirectly, by the variation of their production times, one of the specificities of the production system.

Let us consider a manufacturing system *S* constituted of *n* basic production circuits. Each circuit includes m_i production resources.

Definition 6. [Telmoudi, 08] The modular robustness is defined as the capacity to maintain locally the specific properties of a basic circuit in the presence of variations or uncertainties foreseen or unforeseen due to internal or external disturbances in order to preserve the total robustness of the production system.

We indicate by RM_i the modular robustness of a basic circuit C_i with $i \in \{1, 2, ..., n\}$.
The temporal parameters that we seek to maintain are:
$Tm_{i,j}$: the time of transformation matter of each machine j de C_i ; $j \in \{1, 2, ..., m_i\}$;
Tce_i: the time cycle of elementary circuit;
Tc: the time cycle necessary to product a finished product.

In the continuation of this paragraph, by the exploitation of the P-time Petri net tool, we seek to generate the modular robustness through the redundancy of the robustness of the quality parameters between passive and active. The privilege will be allotted to the passive robustness since it does not require any change in control.

We seek to exploit the control model to observe the robustness of resources and interpret the type of modular robustness.

Let us consider a basic circuit C_i including m_i resources (machines) of transformation matter $R_{i,1}, R_{i,2}, ..., R_{i,mi}$. the margin of passive robustness (respectively of active robustness) for the resource $R_{i,j}$ is defined by the time interval $Ip_{ij}=[a_{pi,j}, b_{pi,j}]$ (respectively $Ia_{ij}=[a_{ai,j}, a_{pi,j}[\cup]b_{pi,j}, b_{ai,j}]$); with $a_{pi,j} \geq a_{ai,j}$ and $b_{pi,j} \leq b_{ai,j}$.

Seen that the time function is monotone increasing and that we are studying independently robustness flow and quality we can suggest that $Ia_{ij}=]b_{pi,j}, b_{ai,j}]$.

The modeling of a modular control law relative to C_i meeting to our objective can be presented in a pyramidal primary form. The skeleton of such a model is formulated by Nsp_i parallelism structures; each one is composed by a transition and two places modeling respectively the passive and active robustness.

$$Nsp_i = 2^{m_i} - 1 \qquad (1)$$

Definition 7. We indicate by P_i^- (respectively P_i^+) the function determining the places modeling the passive robustness (respectively active) for the resources belonging to a network specifying a basic circuit C_i.

P_i^- and P_i^+ are defined as follows:

$$P_i^- : P_i \rightarrow EP_i^-$$

$$p_{i.k..\ell} \mapsto P_i^-(p_{i.k.\ell}) = Pp_{i.k.\ell}$$

$$P_i^+ : P_i \rightarrow EP_i^+$$

$$p_{i.k..\ell} \mapsto P_i^+(p_{i.k.\ell}) = Pa_{i.k.\ell}$$

Where:
P_i : set of places of the network modeling C_i;
EP_i^- : set of places of the network modeling the passive robustness of the resources constituting the basic circuit C_i;
EP_i^+ : set of places of the network modeling the active robustness of the resources constituting the basic circuit C_i;
i,k,l : indicate the index of l^{th} parallelism structure of k^{th} resource of C_i; $l \in \mathbb{N}$ and $k \in \mathbb{N}$.

Definition 8. [Telmoudi, 2008] *Pc* is named control course. It is defined as an oriented way that connects the marked transitions and places modeling the nature of the robustness, starting from the ones modeling the entry of a basic circuit towards those of the exit.

Note: We suggest, when a synchronization of the tokens remained in the places modeling a temporal variable , that only the place which has the smallest upper limit allocated interval would be hypothetically considered marked. If, during the evolution of the network modeling C_i, all places of *Pc* are marked and relative transitions of exit are fired, *Pc* would be called *"marked"*.

<u>Notation</u>

$Pc_{i,q}$: control course number q of C_i ; $q \in \mathbb{N}$ and $q \in \{1, \ldots, 2^{mi}\}$;

$Pc_{Pi,q}$: the set of the subordinate places of $Pc_{i,q}$ and pertaining to EP_i^- ;

$Pc_{Ai,q}$: the set of the subordinate places of $Pc_{i,q}$ and pertaining to EP_i^+ .

The intervals allocated at these three places of the parallelism structure are:

$I'p_{ij} = [a_{pi,j}, b_{pi,j}]$: interval assigned to the place that models the passive robustness of $R_{i,j}$;

$I'a_{ij} = [a_{pi,j}, b_{ai,j}]$: interval assigned to the place that models the passive active robustness of $R_{i,j}$.

Lemma 1. Let $Pc_{i,q}$ be a marked control course of a basic circuit C_i. *If* ($Pc_{Ai,q}=\varnothing$) then (C_i is passively robust).

<u>Proof:</u> As long as:

all resources of C_i have kept their specificities at the time of the operations of transformation while respecting the margins of passive robustness;

the margin of passive robustness of each resource is selected at the beginning under total constraints translating the passive robustness of C_i;

$\Rightarrow$ Definition 2 is applicable.

Lemma 2. Let $Pc_{i,q}$ be a marked control course of a basic circuit C_i. If ($Pc_{Ai,q} \neq \varnothing$) then ($C_i$ is actively robust).

<u>Proof:</u> As long as one (at least) of the resources of C_i is actively robust, the specified properties of C_i can only be maintained after a total or a partial calculation of control. Definition 3 is applicable.

Theorem 1. There is only one control course Pc_i^- reaching the passive robustness C_i. The others reach the active robustness.

Definition 9. Pc_i^+ is named set of actively robust control courses. For a structure modeling Ci regrouping m_i resources, the set Pc_i^+ assembles NPc_i^+ courses with:

$$NPc_i^+ = 2^{m_i} - 1 \qquad (2)$$

Other than the control nature of this model it is clear that has a role of a robustness observer. The marked places carry the imprint of robustness of resources and basic circuits. Indeed, it can be interpreted through the marked control course.

Figure 3 illustrates the modeling of a modular robust control law in the pyramidal form related to a basic circuit composed of two resources of which the variations of processing time in product influence the specific greatness Tce_1 of a system S with $a_{pi,j} \geq b_{ai,j+1}$.

The principle of evolution of this model consists in ensuring, initially, the passive robustness of the resource.

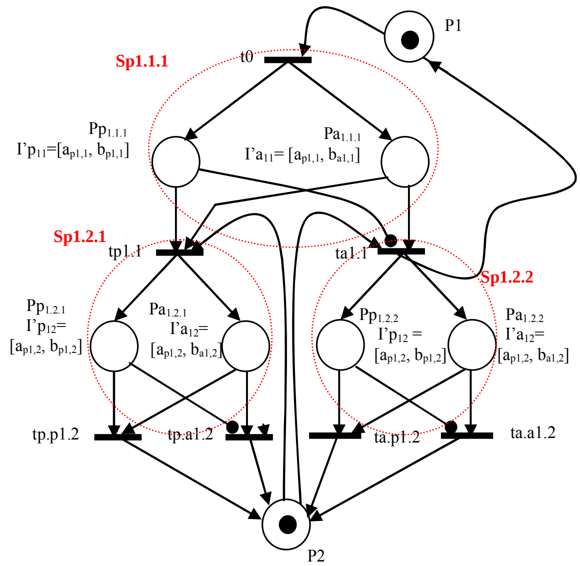

Figure 3: Flow robustness redundancy (pyramidal structure); $a_{pi,j} \geq b_{ai,j+1}$

<u>Notation</u>

$Pp_{1,j,s}$: place modeling the passive robustness of the s^{th} parallelism structure of the j^{th} resource of C_1.

$Pa_{1,j,s}$: place modeling the active robustness of the s^{th} parallelism structure of the j^{th} resource of C_1.

$I'p_{1,j}$: time interval assigned for the place $Pp_{1,j,s}$.

$I'a_{1,j}$: time interval assigned for the place $Pa_{1,j,s}$.

$P1$: place modelling the resource availability of $R_{1,1}$.

$P2$: place modelling the resource availability of $R_{1,2}$.

Progression principle of the Petri Net of the figure 3

Following the firing of the transition $t0$, the places $Pp_{1.1.1}$ and $Pa_{1.1.1}$ be marked each one by a token. If in $t \leq b_{p1,1}$ the transition $tp1.1$ is fired, the places $Pp_{1.2.1}$ and $Pa_{1.2.1}$ would be marked and the resource $R_{1.1}$ would be considered passively robust. Else, since $t > b_{p1,1}$, only the place $Pa_{1.1.1}$ would be marked. The firing of the transition ta1.1 à $t \leq b_{a1,1}$ indicate that the resource $R_{1.1}$ is actively robust.

Sp1.2.1 and *Sp1.2.2* have the same progression principle.

For this example:

$EP_i^- = \{Pp_{1.1.1}, Pp_{1.2.1}, Pp_{1.2.2}\}$;

$EP_i^+ = \{Pa_{1.1.1}, Pa_{1.2.1}, Pa_{1.2.2}\}$.

Control courses:

$Pc_{1,1}$= (t0, $Pp_{1.1.1}$, tp1.1, $Pp_{1.2.1}$, tp.p1.2) ;

$Pc_{1,2}$= (t0, $Pp_{1.1.1}$, tp1.1, $Pa_{1.2.1}$, tp.a1.2) ;

$Pc_{1,3}$= (t0, $Pa_{1.1.1}$, ta1.1, $Pp_{1.2.2}$, ta.p1.2) ;

$Pc_{1,4}$= (t0, $Pa_{1.1.1}$, ta1.1, $Pa_{1.2.2}$, ta.a1.2).

Number of active control courses:

$NPc_i^+ = 2^2 - 1 = 3$.

Passive control course:

$Pc_i^- = \{Pc_{1,1}\}$.

Active control courses:

$Pc_i^+ = \{Pc_{1,2}, Pc_{1,3}, Pc_{1,4}\}$.

Lemma 3. Let two successive resources $R_{i,j}$ and $R_{i,j+1}$ of a basic circuit C_i; each one treats only one item (product) at the same time. If ($a_{pi,j} < b_{ai,j+1}$) then (each place of parallelism structures modeling the passive robustness of $R_{i,j}$ (respectively the active robustness of $R_{i,j}$) should be obligatorily followed by a place $Psp_{i,j,s}$ (respectively $Psa_{i,j,s}$) modeling the stock of the intermediary products on standby). the static interval allocated to $Psp_{i,j,s}$ and $Psa_{i,j,s}$ is $Is_{i,j} = [0, +\infty]$; where the index *i,j,s* is associated to the s^{th} parallelism structure of the j^{th} resource of C_i.

Proof: (lemma 3)

Two cases can be considered:

- First case: $a_{pi,j} \geq b_{ai,j+1}$

Whatever the marking age $t_{i,j+1}$ of $Pa_{i.j+1.s}$, the mark of $Pa_{i.j.s}$ would never be dead.

- second case: $a_{pi,j} < b_{ai,j+1}$

If a token stays a date strictly superior to $a_{pi,j}$ in $Pa_{i.j+1.s}$, the mark of $Pa_{i.j.s}$ would be dead at the moment $t_{i,j} = a_{pi,j}$.

$\Rightarrow$ For $a_{pi,j} < b_{ai,j+1}$: a places modeling stock between $Pa_{i.j.s}$ and $Pa_{i.j+1.s}$ are indispensable.

Figure 4 present a modeling of a modular robust control law of the same system with $a_{pi,j} < b_{ai,j+1}$.

Notation (figure 4)

$Psp_{1.1.1}$: place modeling the intermediary stock between $R_{1,1}$ and $R_{1,2}$ if $R_{1,1}$ is passively robust.

$Psa_{1.1.1}$: place modeling the intermediary stock between $R_{1,1}$ and $R_{1,2}$ if $R_{1,1}$ is actively robust.

This structure (in the figure 3 and figure 4) seems to be more complex when the number of the resources of a C_i is large (for m_i=6; Nsp_i=63 and NPc_i^+ =63). The figure 5 presents a parallel structure. It is equivalent and more simplified to the pyramidal structure.

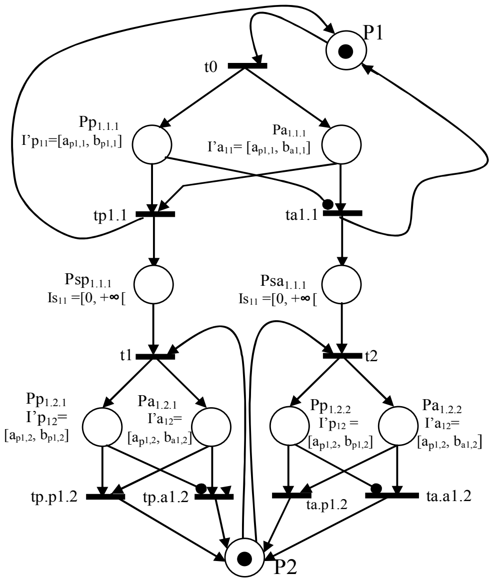

Figure 4: Flow robustness redundancy (parallel structure); $a_{pi,j} < b_{ai,j+1}$.

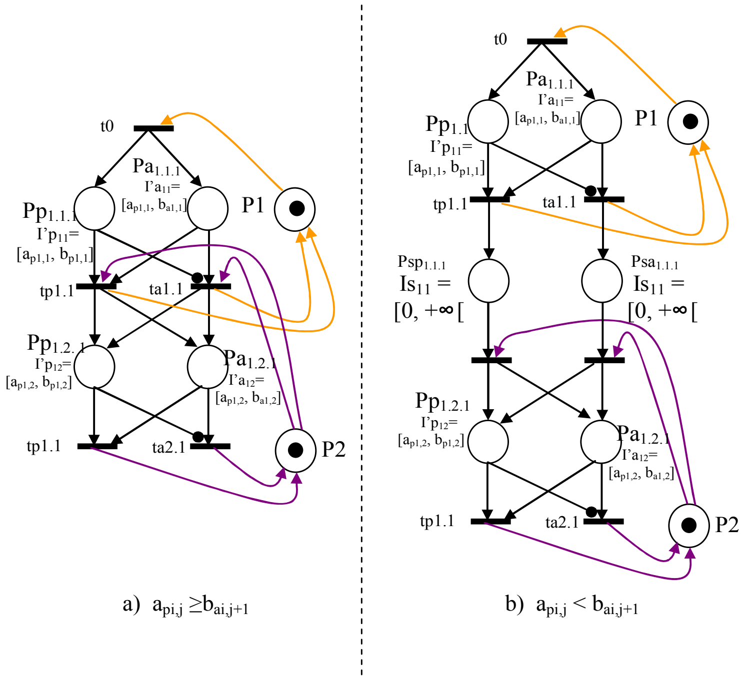

Figure 5: Modeling of robustness redundancy (parallel structure)

5 Generation and observation of the total robustness

These models developed above tend to the observation and the generation of the modular robustness by use of the principle of robustness redundancy of resources, founding the entities of the basic circuits between passive and active. In what follows, we seek to develop a model treating the robustness of the whole system by the generalization of the properties developed and of the principles of modeling in the previous part.

Lemma 4. Let a manufacturing system S be constituted of an n basic circuits. If ($\forall\ i\in\{1, 2, ..., n\}$, $Pc_{Ai,q}=\varnothing$) then (S is passively robust).

Proof: Same reasoning as proof of lemma 2.

Lemma 5. Let a manufacturing system S be constituted of an n basic circuits. If ($\exists$ for $i\in\{1, 2, ..., n\}$ at least $Pc_{Ai,q}\neq\varnothing$) then (S is actively robust).

Proof: Same reasoning as proof of lemma 3.

These lemmas can be also practised by the industry assemblers. The modular robustness, for these systems, can be reserved at the superior level by the installation of coupling points.

Illustrative example

Let a manufacturing system S be constituted of three basic circuits C_1, C_2 and C_3.
C_1 is used to produce a first semi-finished product A. C_2 allows the production of a second semi-finished product B. C_3 allows, in a first order, to assemble A and B by a resource $R_{3,1}$, after this, to achieve a mechanical transformation by $R_{3,2}$. C_1 is composed of two successive transformation resources $R_{1,1}$ and $R_{1,2}$; with $b_{a1,2}>a_{p1,1}$. Also C_2 is made up of two successive transformation resources $R_{2,1}$ and $R_{2,2}$ but $a_{p2,1}\geq b_{a2,2}$. Finally we indicate that $a_{p3,1}\geq b_{a3,2}$.
The decoupling of A and B flows is guaranteed by a synchronisation structure made up of two places Ps_{C1} and Ps_{C2} modelling respectively the two-product stocks A and B and of a transition $t2=Ps_{C1}°= Ps_{C2}°$ (Figure 6). So that S is passively robust, it is necessary that the control courses Pc_1^-, Pc_2^- and Pc_3^- are marked.

6 Conclusion

An approach of modeling of the robust control laws of Flexible Manufacturing Systems (FMS) of flow-shop being based on the use the P-time Petri Nets is presented. The model developed is also an observer, which allows the observation of the resources robustness and interpretation of the robustness of elementary circuits and of manufacturing system. The principle of redundancy of the robustness is used. The model describes the constraints on the parameters flow integrating the margins of the passive and active robustness. The goal is to satisfy the quantitative and qualitative dimensions of market. The redundancy of the local robustness between passive and active, we bring to define ways ensuring the modular robustness of the basic circuits, hence the finding of the nature of entire system robustness.

We prospect, following this work, to develop a method of construction of robust control laws allowing the interpretation of the total robustness type of a whole manufacturing system vis-a-vis temporal disturbances (flow) and non temporal disturbances (quality).

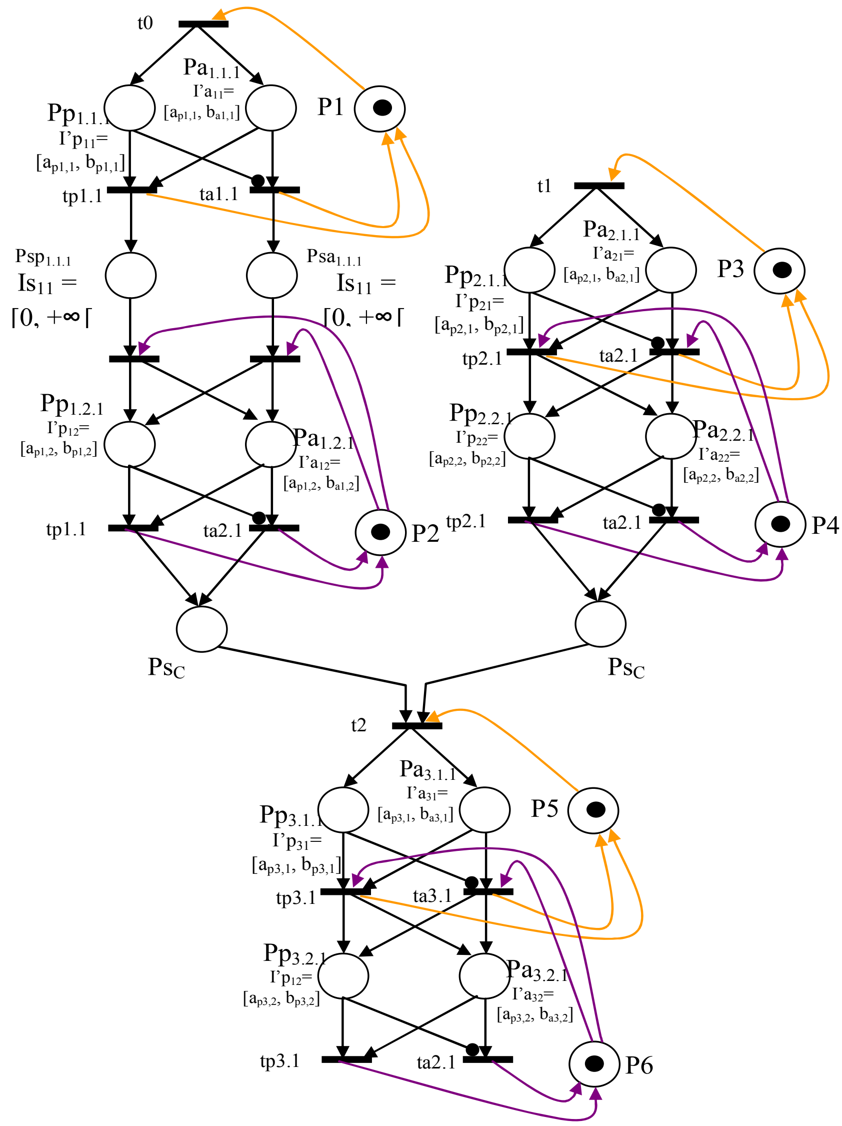

Figure 6: Modeling of a robustness of an assembly system (parallel structure)

References

[Berthomieu, 04] Berthomieu, B., Ribet, P. O., Vernadat, F.: The tool TINA – Construction of Abstract State Spaces for Petri Nets and Time Petri Nets, International Journal of Production Research, Vol 42, Number 14, pp. 2741-2756, July 2004.

[Berthomieu, 91] Berthomieu, B., DIAZ, M.: Modelling and verification of time dependant systems using time Petri nets, IEEE transactions on software engineering, Vol. 17, No. 3 pp. 259 – 273, 1991.

[Bonhomme, 00] Bonhomme, P., Aygalinc, S., Calvez, S.: Using Robustness Properties for Multi-Products Processing, IFAC/IFIP/IEEE, 2nd Conference on Management and Control of Production and Logistics MCPL'2000, Grenoble, France, 5-8 July 2000.

[Bonhomme, 05] Bonhomme, P.: Control of time critical systems using partial order, *IMAC'05*, CD ROM, Paris, France, July 2005.

[Boufaied, 05] Boufaied, A., Subias, A., Combacau, M.: Distributed Time Constraints Verification Modelled With Time Petri Nets, 17th IMACS Word Congress on Scientific Computation, Applied Mathematics and Simulation, CD ROM, Paris, July2005.

[Collart, 03] Collart Dutilleul, S., Dhouibi, H., and Craye, E.: Internal Robustness of Discret Event System with internal constraints in repetitive functionning mode, ACS'2003, Miedzyzdroje, Poland, 2003.

[Collart, 97] Collart Dutilleul, S. : Commande Robuste d'Ateliers à Contraintes de Temps de Séjour : Application à la Galvanoplastie, PhD thesis , University of Savoie France, December 1997.

[CORINE, 96] "CORINE", ARTEMIS-IMAG, ERIHST, LAG, LAMII-CESALP : COnduite Robuste et INtelligente dans les Entreprises manufacturières, technical Report, France, May 1996.

[Da Silveira, 03] Da Silveira, M. R., Combacau, M., Boufaied, A.: Prognosis and recovery evaluation on flexible manufacturing supervision, Journal of Decision Systems, vol. 12, No. 1, 2003.

[Dhouibi, 05] Dhouibi, H., Collart Dutilleul, S., Craye, E., and Nabli, L.: Computing Intervals of Intervals Constrainted Petri Net: a tobacco manufacturing application, IMACS 05 conference, CD ROM, Paris, July 2005.

[Jerbi, 06] Jerbi N., Collart Dutilleul, S., Craye, E., Benrejeb, M.: Time Disturbances and Filtering of Sensors Signals in Tolerant Multi-product Job-shops with Time Constraints. International Journal of Computers, Communications & control, Vol. I, n° 4, pp. 61–72, 2006.

[Kazushi, 01] Kazushi, O., Kang, G.: Model-based Control for Reconfigurable Manufacturing Systems, ICRA 2001-IEEE, International Conference on Robotics and Automation, , CD ROM, Séoul, Corée, 21-26 May, 2001

[Khansa, 96] Khansa, W., Aygalinc, P., Denat, J. P.: Structural analysis of P-Time Petri Nets, CESA'96, Lille, France, pp. 127–136, July1996.

[Khansa, 97] Khansa, W.: Réseaux de Petri P-temporels: contribution à l'étude des Systèmes à Evénements Discrets, PhD thesis , University of Savoie France, march 1997.

[LY, 00] Ly F., Toguyeni, A. K. A., Craye, E.: Indirect predictive monitoring in flexible manufacturing systems, Robotics and Computer-Integrated Manufacturing, Volume 16, Issue 5, Pages 321-338, October 2000.

[Mahulea, 08] Mahulea, C., Giua, A., Recalde, L., Seatzu, C., Silva, M.: Optimal Model Predictive Control of Timed Continuous Petri Nets, IEEE Transactions on Automatic Control, Volume 53- Issue 7, pp. 1731 - 1735, August 2008.

[Murata, 89] Murata, T.: Petri nets: Properties, analysis and applications, Proceedings of the IEEE, Volume 77, Issue 4, pp. 541 – 580, April1989.

[Telmoudi, 08] Telmoudi, A. J., Nabli, L., Bourjault, A.: The use of redundancy to evaluate the manufacturing system total robustness: A quality approach. 3rd IEEE International Symposium on Communications, Control and Signal Processing, ISCCSP 2008, pp.440 - 446 St. Julians, Malta, March 2008.

[Telmoudi, 09] Telmoudi, A. J., Nabli, L., M'hiri, R.: Modeling Method of Robust Control Laws for Manufacturing System to Temporal and non Temporal Constraints through Petri Nets, International Review on Computers and Software, Volume 4 Number 2, pp. 266 - 277, Mars, 2009.

[Toguyéni, 05] Toguyéni, A. K. A., Korbaa, O.: Indirect monitoring of the failures of a flexible manufacturing system under cyclic scheduling, Robotic and Computer-Integrated Manufacturing, Vol. 21, pp. 1-10, 2005.

[Xia, 06] Xia, CL.: Analysis of properties of Petri synthesis net, Lecture Note in Computer Science, 3959: pp 576-587, 2006.