Variability of production in flexible manufacturing systems: petri net modelling and simulation

José Eloundou,
M'hammed Sahnoun
and Anne Louis
CESI - IRISE Laboratory
1, Rue G. Marconi,
Mont-Saint-Aignan, France
Email:{jeloundou,msahnoun,alouis}@cesi.fr

David Baudry
CESI – LUSINE Laboratory
1, Rue G. Marconi,
Mont-Saint-Aignan, France
Email:dbaudry@cesi.fr

Abdelaziz Bensrhair
LITIS laboratory
INSA ROUEN
Avenue de l'Université
76800 Saint Etienne-du-Rouvray, France
Email: abdelaziz.bensrhair@insa-rouen.fr

***Abstract*—The simulation of complex production systems is widely used for the evaluation of any change of the production system and the prediction of their behaviour. However, simulation models are subjects to several errors. The model verification and validation of through a real case study is a very effective way to get reliable models. This contribution aims to present the processing of validation of a model of a real production system. We propose the its modelling and simulation using Hierarchical Coloured Petri Nets (HCPN). HCPN allow the analysis and description of the production system. The simulation allows to make predictions about performance during the production (simulation period). We illustrate our methodology through a real case of CESIs' manufacturing system and the simulator developed on CPN TOOLS. A verification and validation step is performed using several scenario of production. Results shows that the use of deterministic modelling gives interesting performance of the model.**

I. Introduction

Simulation models are used for a variety of purposes such as in the design of systems, in the development of system operating policies [1], and in research to develop system understandings [2]. In the field of manufacturing system, the simulation models are used for several need such as the evaluating of manufacturing systems performance, the testing production scenarios, the determination of feasible solution, etc. At the time where modeling of physical system are usually subject of verification and validation to cope with the real model [3], the modelling of discrete systems such as production systems are defined by observing the elementary operation of the system without a rigorous validation of the global model of the system in different situations [4].

This problem can be resolved if the steps of model verification and validation, which are part of the model development process, are executed correctly. Model verification is defined as *ensuring that the computer program of the computerized model and its implementation are correct*. Model validation is defined as the *substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model*[2].

Several formalisms of modelling for manufacturing systems have been used such as: Automata [5] and Petri Nets, formalism based on oriented object approach [6], [7], multi agent systems [8], [9], Discrete Event System Specification (DEVS) [10], etc.

The use of automata and Petri Nets is a good way for the modelling analysing and simulating of discrete events systems such as manufacturing production line. The object oriented approaches allow the reuse of model, The use of properties like inheritance, aggregation, composition, specialisation give the possibility to construct complex models, and make top-down/bottom-up modelling development. Among this three approaches we have chosen Hierarchical coloured Petri Nets for the following reasons:

- Hierarchical Coloured Petri Nets combine Petri Nets properties and object oriented approach. Petri Nets allow the description and the analysis of concurrent systems, and the hierarchical coloured petri Nets the reuse, inheritance and specialization of the models.
- Contrary to Multi agent systems, Petri Nets have behavioural properties [11] such as liveness boundedness, reachability, reversibility and home state .... These properties allow the analysis of manufacturing easier. For this reason we have prefered Petri Nets in this case, because the major part of tools based on Petri Nets gets tools for studying the properties of Petri Nets, but it is not the same thing for tools based on multi agents systems.

According to the characteristics of the system, two types of simulation models can be used, the deterministic and stochastic simulation model. Deterministic models of manufacturing systems are used to evaluate manufacturing with known and deterministic parameters for example: deterministic processing times, deterministic transportation times, a constant demand of suppliers, ... This kind of models are suitable for the definition of global performances. They are widely used because of their easy implementation and the definition of the model

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parameters with small simple of data. The use of stochastic models for simulation is necessary to when the totality of a part of production system parameters are not known and can be defined thanks to a stochastic law. Their implementation is complex and requires sufficient measurement in several situations of the system. The most important luck of the models is the risk to get a large difference between real and simulated model. The step of validation is then necessary to obtain a reliable simulated manufacturing system, but it is not obvious because of the discrete and unpredictable behaviors of the system.

The engineering school of CESI of Rouen gets a manufacturing line of six workstations. This production system is used for the development of teaching and research activities. Several modifications on the organization of this manufacturing system should be made to optimize its performance and to test different scheduling algorithms, transportation systems, product range, ... However it is not obvious to change the production system for each manipulation because of the big size of machines and the sensitivity of installation. In order to avoid such problem, a simulator has been developed to allow the development and test of several configurations before the change of real production system.

This paper is interested by the importance of the step of verification and validation for flexible manufacturing systems. For that we propose to model and simulate the production system of CESI. We will use an approach of modeling and simulation based on deterministic HCPN [13] of this production line. We will apply the step of verification and validation by the comparison of the makespan of the simulated and real system.

The next section II we present Petri Nets and especially Hierarchical coloured Petri Nets, and the methodology that we use for evaluating manufacturing systems. In the section III-A we present the case study, and its model using HCPN developed model. In the section IV we present the results of the simulation of our model and discussions based on this results. This paper ends by a conclusion and future works.

II. Hierarchical coloured Petri Nets

Petri Nets is a mathematical and graphical tool for the description of the asynchronous systems with concurrent evolutions [14]. According to this interpretation the PN is used for description, analysis and simulation of manufacturing process by many researchers [15], [16], [17], [18].

Graphically PN is an oriented graph where nodes are places and transitions interconnected through oriented arcs. When a place p is connected to a transition t, the oriented arc is noted $a(p \rightarrow t)$ and this place is called input place, and in the contrary when it is connected to a place, the oriented arc is noted $a(t \rightarrow p)$ and the places p is called output place. Each place contains one or more tokens. Acording to [11] a Petri Net (PN) is a five-tuple $\mathcal{R} = (P, T, Pre, Post)$ where:

1) $P = \{P_1, P_2, \dots, P_n\}$ is a finite set of places
2) $T = \{T_1, T_2, \dots, T_n\}$ is a finite set of transitions
3) $F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs (flow relation)
4) $W : F \rightarrow \{0, 1, 2, 3, \dots\}$ is a weight function
5) $M_0 : P \rightarrow \{0, 1, 2, 3, \dots\}$ is the initial function, $P \cap T = \emptyset$ and $P \cup T \neq \emptyset$

This Petri Net definition of Murata[11], is the basic definition of the PN. This type of Petri Nets is used for the description of system where flows (material and/or information) are not complex. In addition basic PN don't take into account systems with time constraints. For analysing systems with complex flows and timed constraints Coloured Petri Nets were defined [19]. Classical Petri Nets are used to model systems taking into account a low level of information. For example they are used to model a product line with on type of product. If there is no differentiation between products, each token of the manufacturing systems is considered as the same product. In contrast, if there are several type of products it is important to have for each product the information concerning its type, and the use of simple PN don't allow that. For this reason Coloured Petri Nets (CPN) (also called non-hierarchical CPN) has been developed.
A non-hierarchical CP-net is a nine-tuple : $CPN = (P, T, A, \Sigma, V, C, G, E, I)$ where:

1) P is a finite set of places
2) T is a finite set of transitions such as $P \cap T = \emptyset$.
3) $A \subseteq P \times T \cup T \times P$ is a set of oriented arcs.
4) Σ is a finite set of non-empty types, called colour set.
5) V is a finite set of typed variables such as $Type[v] \in \Sigma$ pour tout $v \in V$.
6) $C : P \rightarrow \Sigma$ is a colour function.
7) $G : T \rightarrow EXPR_V$ is a guard function which assigns to each transition a condition of firing t such as $Type[G(t)] = Bool$
8) $E : A \rightarrow EXPR_V$ is an expression arc function such as $Type[E(a)] = C(p)_M S$ where p is the place connected to arc a
9) $I : P \rightarrow EXPR_\emptyset$ is the initialization function which assigns to each place p an initialization expression $I(p)$ such as $Type[I(p)] = C(p)_M S$

While Petri nets used to model the structure and flow in a production system,the Coloured Petri Nets allow the introduction of analysis and information processing. It is this property which allows the differentiation of products on a multi-product production line for example.

CPN are used to model systems with high level of information and timed constraints.
In the modeling process of a system that has elements having the same characteristics and the same properties; it should develop object models in order to reuse them. Colored Petri nets do not allow to define the components of a system with an object-oriented formalism. This implies that to model a sytem with identical features with "colored Petri Net"; each model must be developed manually each time, and this lengthens the time of modeling and can lead to multiply design errors. In addition to that when a system have a High number of

elements using colored Petri Networks defaces the model. To address these two problems, [20] proposed hierarchical colored Petri networks. Hierarchical colored Petri nets are an object-oriented approach Petri net. In the hierarchical coloured Petri Nets the concept of class is replaced by the concept of Coloured Petri Net Module (CPNM). A colored Petri Net Module is a four-tuple .

$CPN_M = (CPN, T_{sub}, P_{port}, PT)$ with:

1) $CPN = (P, T, A, \Sigma, V, C, G, E, I)$ a coloured Petri Net
2) $T_{sub} \subseteq T$ a set of substitutions transitions.
3) $P_{port} \subseteq P$ a input ports set or output places
4) $PT : P_{port} \rightarrow \{IN, OUT, I/O\}$ is an assignment port type function which assigns a type to each port type.

In the CPNM concept, Petri Net is considered as an output/input systems. In this case there are some places which are used as output places and other as input places. CPN module is developed as model class supposed to be used as an object inside a global model. This global model is called Hierarchical Coloured Petri Nets (HCPN).

A Hierarchical CPN is a four-tuple.

$CPN_H = (S, SM, PS, FS)$ where:

1) S is a set of Coloured Petri Nets Modules. Each module is defined as follow: $s = ((P^s,T^s,A^s,\Sigma^s,V^s,C^s,G^s,E^s,I),T^s_{sub},P^s_{port},PT^s)$. $(P^{s_1} \cup T^{s_2}),\cap(P^{s_1} \cup T^{s_2}) = \emptyset \forall s_1, s_2 \in S$ such as $s_1 \neq s_2$
2) $SM : T_{sub} \rightarrow S$ is a sub-module function which assigns to a sub-module a transition substitution.
3) PS is the function of the port-connector relation.

Hierarchical coloured Petri Nets is a set of Transition substitution which are instances of Colour Petri Nets Modules, and places. Among places there are some places which are used as output/input places of transition substitution and the other places are just simple places as in any Petri Net. Hierarchical coloured Petri Nets models are used to model globally a manufacturing systems, without taking into account the details of the components of the systems.

The framework of the performance evaluation of a production system using HCPN follows the following steps:

- **Collect of operating data** : the collect of operating data allows the analysis of the process flow and the processing time of operations. Data collect also helps in the setting of the manufacturing system model.
- **Identification of elements of the manufacturing system and constraints of processes**: there are many constraints in a manufacturing process such as congestion constraints, disjunctive constraints, transport constraints, precedence constraints. The identification of the elements and the determination of these constraints is essential for a good development of simulation models
- **Development of the Coloured Petri Nets modules**: by developing CPN Modules, we build objects packages for modelling and simulating manufacturing process. For a manufacturing system, it's possible de define two big types of modules: (1) CPN Machine Module, (2) CPN Transport Module. The choice of developing module depend on the complexity of the system and the model designer.

Fig. 1. The assembly system of IRISE laboratory in the CESI

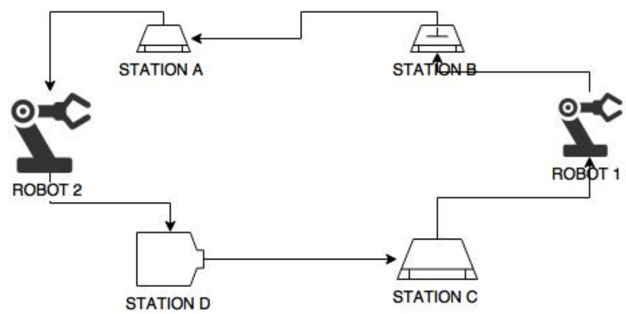

Fig. 2. Illustration of production line of CESI

To illustrate our framework, we have study a real case of the production line of the laboratory IRISE of the engineering school CESI.

III. Study case and proposed approach

A. Presentation of case study

The IRISE laboratory of engineer school CESI has a production assembly system of phones composed of six workstations (c.f Figure 1) a furnace ($Station_A$), a drill ($Station_B$), a press ($Station_C$), a workstation of laying top cover of the cell phone($Station_D$), and two robots. Figure 2 represents the position of each workstation of the assembly system.

The task of the first robot, $Robot_1$ is laying the bottom cover of phone in the beginning of the assembly process of one product. The second robot, $Robot_2$ fastens the electronic components on the inner face of the bottom cover placed by $Robot_1$ during a previous assembly step. Typically during an assembly process the product must go through the following steps:

1) **Operation 1** : beginning of the process, laying of the bottom cover of the phone on the production line by the $Robot_1$ represented on the Figure 3.

TABLE I
DURATION OF OPERATION OF WORKSTATIONS WITH CONSTANT PROCESS TIME

Workstation	Duration of operation
DC ($Station_D$)	2 sec
$PRESSE$ ($Station_C$)	6 sec
$DRILL$ ($Station_B$)	7 sec
$FURNACE$ ($Station_A$)	5 sec

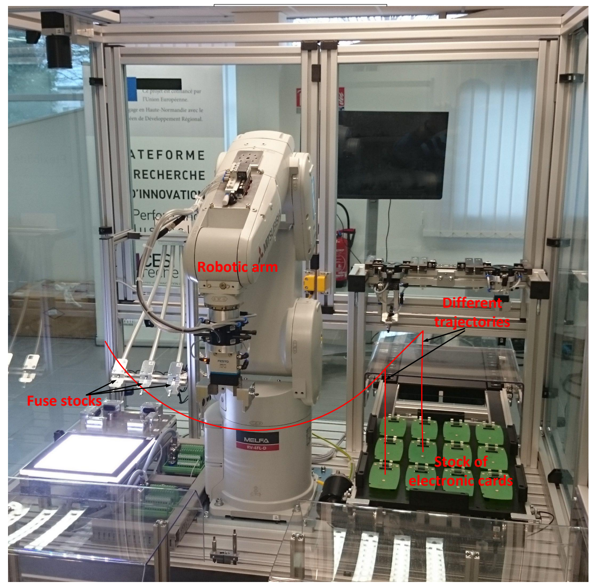

Fig. 3. The real robot 2 for the installation of electronic cards and fuses.

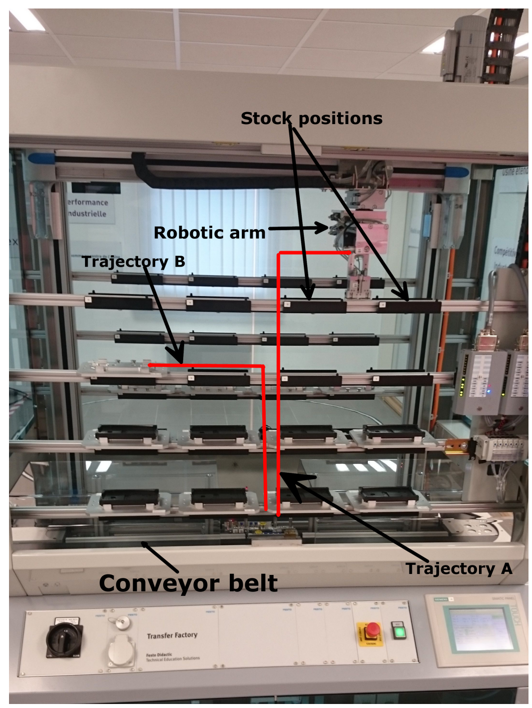

Fig. 4. The real robot 1 responsible of the drop off and pick up if input/output stock.

2) **Operation 2**: Drilling by the $Station_B$.
3) **Operation 3**: Fastening of the electronic components on the inner face of the cell phone by the $Robot_2$represented on the Figure 4.
4) **Operation 4:** Laying the top cover of the cell phone by the $Station_D$
5) **Operation 5:** Pressing by the $Station_C$
6) **Operation 6:** Thermo-welding by $Station_A$
7) **operation 7:** The final product is removed from the production line by the $Robot1$.

The main constraints of this production line are: (1) layout of production line; (2) re-entrant flow ; (3) variable processing time of $Robot_1$ and $Robot_2$; (4) limited capacity of buffers.

Our approach includes three steps: (1) Analyse and evaluation of the real assembly system performances; (2) modelling of the system using HCPN; (3) Simulation of the developed model and comparison of the obtained results with the real measurement on the real assembly system.

B. Determination of the processing times of workstation

The Analysis of the manufacturing process through experimentation shows that the processing time of $Robot_1$ and $Robot_2$ are variable and the processing time of others workstations can be considered as deterministic. In addition the number of product in intermediate stocks make the waiting time variable. We begin by measuring the processing time of the workstation with constant duration of the operation. The Table I gives the results of the measurement of the processing time of workstation DC, $PRESSE$, $DRILL$ and $FURNACE$. After the determination of the deterministic processing time of workstations, we studied the variable processing time workstation namely the $ROBOT1$ and $ROBOT2$

1) Determining the variability of the processing time of $Robot2$: The processing time of the Robot2 is changing due to the following causes:

- Position of the lower lid, the first action of the robot 1 is to check the correct positioning of the bottom cover and return it if it is upside down.
- Number of fuses: the producer can insert up to two fuses on the electronic card.
- Position of the fuses: if the manufacturer decides to insert a single fuse, it can be placed either on the left or right of the electronic card. The time of installation of the fuse is then depending on its position on the electronic card and its drop off stock. The robots tacks different times for each trajectory.
- Stock fuses there are three fuse storage locations, during an operation on a product, the robot 1 selects one of the locations and withdraw a fuse. Depending on the location chosen the setting time of the fuse will be variable.

2) Determining the variability of the processing time of Robot1: The causes of variability of the $ROBOT2$ processing

TABLE II
DURATION OF OPERATION OF ROBOT 1 & ROBOT 2

Operation	mean Duration	Standard deviation
ROBOT 2 (entry)	14 sec	1 sec
ROBOT 2 (exit)	14.21 sec	1.23 sec
ROBOT 1	90.7 sec	3.04 sec

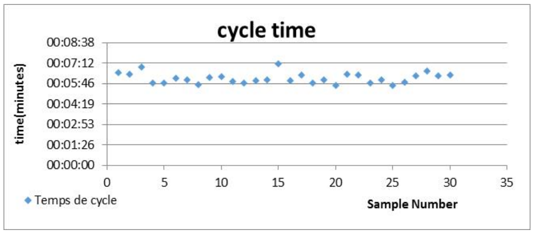

Fig. 5. production cycle time of the line

time are as follows :

- Filling of the storage zone: when the mechanical arm retrieves a lower cover, the operation time will depend on the position of the cover in its storage area. For example, if the lid is taken in position 1 or in position 16, the operating time will be different

To determine the processing time of Robot 1 and 2, we conducted several measurements to assess variability of this two workstations. The results of the measurements is shown in the table III

We can observe that the the mean value of the operation duration of ROBOT 2 is 90.7 and the standard deviation is 3.04 sec. This variability is justified by the hypothesis explained in section III-B1

The mean value of operation process of ROBOT 1 is 14 for the operation of entrance of the product in the production line (*entry* in the Table II) for the second operation of the ROBOT 1 (*exit* in the table II) the mean processing time is 14.21 and the standard deviation is 1.23 sec.
Now we have evaluated the performance of the entire production line. For this, we have measured the total production time in three cases: one product, two products and seven products. The Figure 5 gives the measurements results of a production cycle of one product.

The Figure 5 gives the production cycle times of a sample of 30 product. We observe that the cycle time is variable. We have computed the standard deviation and the mean value of the cycle time. The mean value of cycle time is *6.4minutes* and the standard deviation is *0.6 minutes*. We have taken this value as reference for the initialization of the developed HCPN model. We have also measured makespan for several lots of products, the Table III gives the makespan of production of three lots with different sizes. (1 product, 2 products and 7 products).

TABLE III
MAKESPAN FOR LOTS COMPOSED OF 1, 2 AND 7 PRODUCTS

Number of products	mean Duration of total production time	Standard deviation total production time
1 product	6.4 min	0.6 min
2 products	7.45 min	0.8 min
7 products	18.01 min	1.3 min

IV. MODELLING, SIMULATION AND RESULTS

A. Evaluation of the production line

The production line is composed of two types of workstations: workstations with constant processing time and workstations with variable processing time. We identified the durations of operations at workstations that don't have variability namely the DC workstation "$Station_D$" (Filing of the top cover), $PRESS$ "$Station_C$", $DRILL$ "$Station_B$" and $FURNACE$ "$Station_A$" as shown in the Table I.
After, we have developed a Petri nets model including the constraints defined in the section III-A.

We used a Hierarchical Coloured petri Nets (HCPN) model because it allows development of Colour Petri Nets Module(CPNM). The use of CPNM facilitate the re-use of a Petri Net model as objects. We have used results of analysis of manufacturing to implement duration of processing tasks inside the simulation model. We have decided to use in a first time the mean value of the processing time of $Robot_1$ and $Robot_2$ to determine the processing time of the simulated $Robot_1$ and $robot_2$.

The Figure 6 is the HCPN model of the assembly line. The substitution transitions $ROBOT1$, $ROBOT2$, FOUR, DC, PRESSE, PERCEUSE are respectively instances of Colour Petri Net modules of the workstations $Robot_1$,$Robot_2$, $FURNACE\ Station_A$, $CD\ Station_D$,$PRESS\ Station_C$, $DRILL\ Station_B$. The direction of the oriented arcs indicates the direction movement of products in the production line and the link between the workstations. The Colour Petri Net Module of a workstation is shown in the Figure 7. The table IV gives the description of model substitution transitions

TABLE IV
DESCRIPTION OF PRODUCTION LINE MODEL TRANSITIONS

Substitution Transition	Description
ROBOT1	Activity of ROBOT1
DC	Drop of the top cover by the DC workstation
PRESSE	Press activity
ROBOT2	Drop of the bottom cover and storage of the finished products in the warehouse
PERCEUSE	Drilling activity
FOUR	heat sealing activity

The Table IV lists the substitution transitions of the production line model of the Figure 6. Each substitution transition is

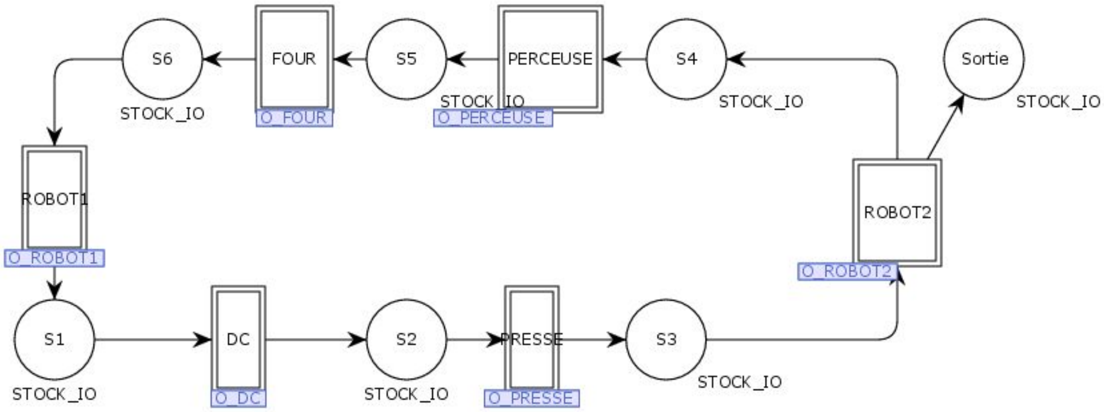

Fig. 6. hierarchical model of the production line

a CPNM of type machine model . For example the transition ROBOT1 is an instanciation of the coloured Petri Nets Module of a workstation defined in the Figure 7. The substitution transitions have the same property and the same input and output places

Places S1, S2,. . . , S6 are the input and the output places of substitution transitions. For example S2 represents the input place of the substitution transition PRESSE but also the output place of the substitution transition DC.

The Figure 7 is the Coloured Petri Net Module of a workstation. We have developed it for taking into to account constraints such as: disjunctive constraints of machine, congestion constraints, setup time of the workstation, multi-purpose. The signification of the places and transitions is given in the Table VI and Table V.

TABLE V
DEFINITION OF THE PLACES OF A COLOURED PETRI MODULE OF A WORKSTATION

Places	Description
DATA_INIT	This place contains machine parameter: machine name, machine location and the list of tools
Att	Contains information for changing tool.
Stck_I	input stock of machine
Stck_S	Output stock of machine
DTB	Data base of machine
M1	Contains machine parameters and products during the processing time MACHINE.
SP	The role of this place is to is to prevent that two products are found in the preparation area of the machine simultaneously .

In the model of the figure 7, we distinguish two categories of places and transitions. Indeed there are some places/transitions which are used for initializing the model or/and collect data, and other places and transitions which describe the model functioning. In the first category there are the transition INITIALISATION_ MACHINE, and the places DATA_INIT and **DTB**. When the transition INITIALISATION_ MACHINE is enabled it is the beginning of the machine models initialization. The condition that this transition is enabled is the presence of a token inside the DATA_INIT place. The colour set type of this place is InitMachine and it is defined such as follows:

colset InitMachine union Nom_machine:**STRING**+ Position_machine:**RxR**+Outils:**ListTool**+Temps_transport:**TIME**+ capacite:**NxN**;
colset is type constructor of colour set.
STRING is a colour set of string,
RxR is a colour set of couple of reals,
ListTool is a colour set of list of tools
NxN is a coloured set of couple of integers.
union is the operator $\cup$ such as $x \in A \cup B \Leftrightarrow x \in A \; or \; x \in B$.
Colset C = **union** a:**A**+ b:**B** means C = A $\cup$ B for the initialzation of the user has to provide some data such as the name of the machine, its physical position, the number of tools of the machine, the capacities of the pick up and drop off areas. When the transition INITIALISATION_ MACHINE is fired, the place **M1** and Att are initialized. The place **Att** contains the information about the tools list of the machine. The place **Att** also contains the next product which is supposed to be transformed by the machine. When a product is in the place **Att** it means that the machine is being set up for performing an operation on this product. Indeed it is important to verify that the current tool used by the machine for the previous operation is appropriate for the current product. The place **M1** represents the working in progress inside the machine. When a product is inside the place **M1** it means that the product is processing. The place **DTB** is used for collecting the data production about machines during the production.
For a good understanding of the model, we can take an example of simulation situation. Let a list of products in the input stock of the machine (place **Stck_I**); in this situation the transition **SCH** is enabled if the place **Att** contains information about the list of tools of the machine and also if this place does not contain any product. For avoiding to find two products in the place **Att** in the same time, we have used the place **SP**. This place is initialized with only one token. Once the conditions of enabling are satisfied, the firing of

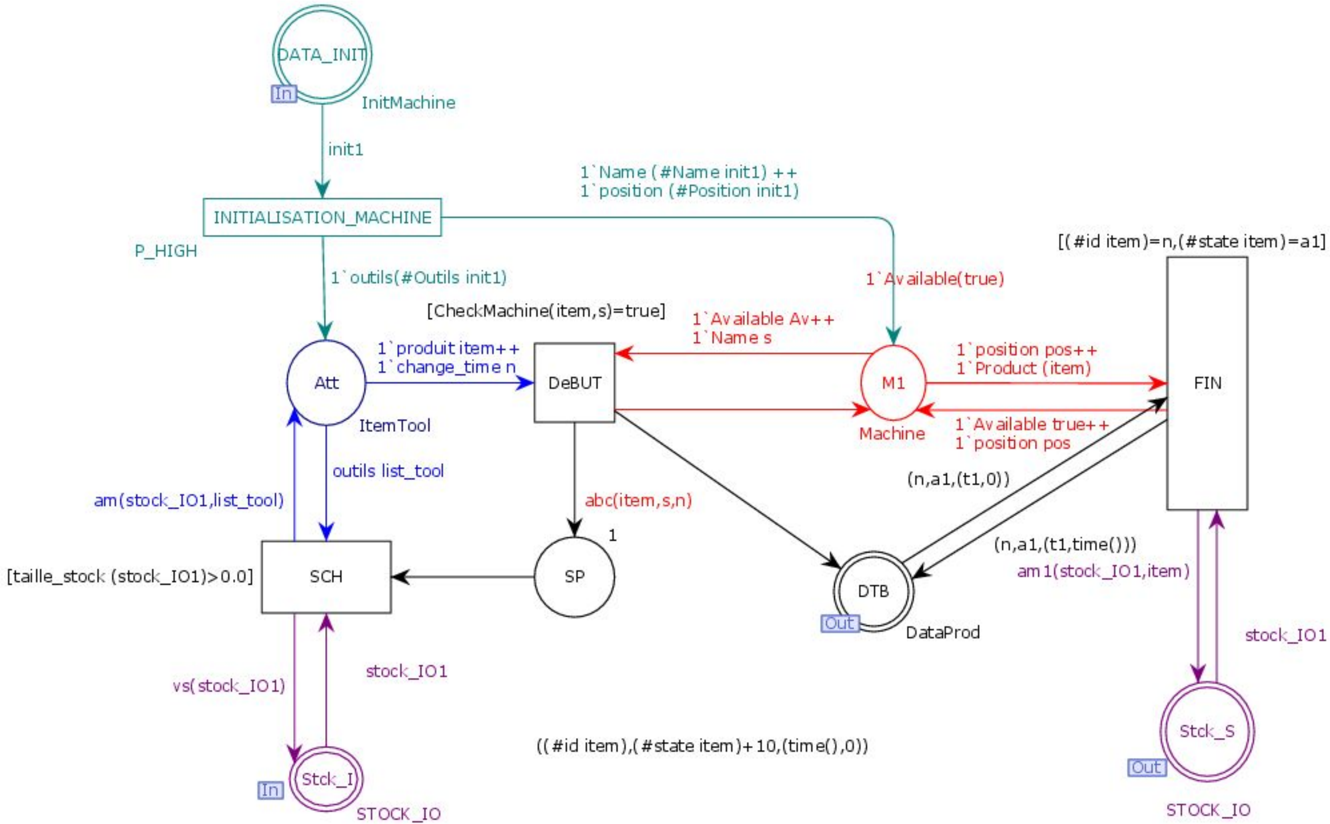

Fig. 7. Colour Petri Net Module of a Workstation

the transition **SCH** leads the presence of product in the place **Att**. After the product enters in the place **Att**, the transition **DeBUT** is enabled if there is no product in the place **M1**. In this case the firing of the transition **DeBUT** produces a token which represents a product in the place **M1**. The product inside the place **M1** wait until its processing time is completed. When the machine operation on the product is finished, the transition **FIN** is enabled and fired and the product goes to the place **Stck_S**

TABLE VI
TRANSITION OF A WORKSTATION MODEL

INITIALISATION_ MACHINE	Initialisation of machine parameters: machine name,machine location and the list of tools
DEBUT	Beginning of manufacturing operation
SCH	Setup of the machine,
FIN	End of a manufacturing operation and filling of output buffer

The place **Att** is a place of type **ItemTool** defined such as follows:
colset **ItemTool= union** produit:**ITEM** + outils:**ListTool** + change_time:**INT**;
It means that the colour set **ItemTool** is the union of the colour sets **ITEM**, **ListTool** and **TIME**. This place could contain a product, the tools list of the machine, and the setup time of the machine (represented by the variable change_time).
The place **M1** is a type **MACHINE** defined by
colset **Machine=** union Name:**STRING+** position:**RxR+** Available:**BOOL+** Product:**ITEM**;
The colour set **Machine** is an union of the colour sets **STRING**, **RxR** and **ITEM** Figure 7 shows that the input places of the CPNM module of the workstation are places **Stck_I** and **DATA_INIT**, and the output place is **Stck_S** output stock of the machine. the colour set type of **Stck_S** and **Stck_I** is **STOCK_IO** which is defined such as follows:
colset StringxListReal=product STRING*RxR*INT;
colset STOCK=product ListItem*StringxListReal;
colset STOCK_IO= product STOCK*STRING;
The colour set **STOCK_IO** is a couple of a colour set of type **STOCK** and a colour set of type **STRING**.The colour set **STRING** defined is the stock is an input or output stock. The colour set **STOCK** is a couple of two colour sets: the colour set **ListItem** which is a list of products inside the stock and a colour set **StringxListReal** which is a triple of colour sets **STRING**, **RxR** and **INT**.This triple represents respectively the name of the machine which gets this stock, the physical position of the stock, and the capacity of the stock.

The Coloured Petri Net Module of Machine has two input places (places **Stck_I**,**DATA_INIT**) and one output place (**Stck_S**) It means that for using the CPNM module of machine, the user should provide as entry, at least one product in the place **Stck_I** and information concerning the machine in place **DATA_INIT**, in this condition is not compulsory for the user to know how the CPNM module has been developed.

The CPNM takes into account the Process capability of the machine, the capacity of its input and output buffers, the transportation time and the availability of the machine. After the development of the CPN Module of workstation and the modelling of the entire Assembly line, we simulated the assembly line model and observe the time cycle of a production cycle of seven products in order to compare the makespan of the real system with that one obtained by simulation.

B. Simulation results and analysis

We have simulated the production line model presented in Figure 6. For the initialisation of parameters, we have used the processing time of workstation defined in section IV-A. For workstations with variable processing time; we have chosen the mean time determined in the Table II. We have simulated this model to observe and analyse the production cycle time and the makespan. In the lights of simulation results,The obtained results by simulation shows that there is a slight difference with the real measurement. However, this difference remains tolerable because it's is in the interval of variation of the real results, where $|mean(makespan_{real}) - makespan_{Simulation}| < \sigma$, where σ is the real standard deviation It is due to the fact that we used the mean value of workstation processing time ROBOT 1 and ROBOT 2.

TABLE VII
MAKESPAN OBTAINED BY SIMULATION

Number of products	1 product	2 products	7 products
makespan	6.33 min sec	7.4 min	17.9 min

Nevertheless the values from the simulation are in a range of values acceptable. Indeed, the values of the makespan are in the range of length twice the standard deviation, and the mean value. We note that the evaluation of the velocity of the conveyor and the size of buffers is another reason of the difference between the results of the simulation ans measurements. The measurement were done manually, which increase the risk of errors in measurements, this will contribute to this difference in results. The neglected phenomena like friction are also responsible of this difference. In conclusion we can consider the developed model as an acceptable model of this production line. However, the deterministic modelling and simulation demonstrate its limitation and incapacity to reproduce the same phenomena that happen in the real case.

V. CONCLUSION

The objective of this paper is the presentation of a Hierarchical Coloured Petri Nets Model for evaluating a manufacturing production line. For that, we have analysed the real production system of the CESI and developed its simulation model. The results of this measures campaign gives data useful for the initialization of our coloured Petri nets model before the simulation. We have chosen hierarchical coloured Petri Nets models because HCPN is an object approach of coloured Petri Nets. One of the most advantage of the object approach is the re-use of the model, which make the simulation easier. We have considered the manufacturing production line of CESI. We have analysed it and we have found that it presents some workstations with variable processing time. We have studied the variability of these workstations and determined the mean value of the processing time. The mean values that we have found are used to parameter the simulation model. The simulation results show that there is a slight difference between the makepsane of the real production line and the simulated one. This difference is due to that fact that mean values of parameters were used instead of the real values of the processing times of workstation. The second explanation is the difficulty to evaluate the size of buffer, the velocity of the conveyor and the variability of robots processing time. The prospoed model remain close to the reality, but it demonstrate the limitation of the deterministic modelling and simulation. In order to approach the real case we will developed in our next works Petri Nets models including stochastic values of the processing times of workstations.

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