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MODULAR MODELING OF MAINTENANCE ACTIVITIES FOR MULTI-SITES STRUCTURE

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Abstract: This paper concerns the modelling of maintenance activities in a distributed context. In this work we study the particular case where the maintenance activities are executed by two workshops: a central maintenance workshop (CMW) and a mobile maintenance workshop (MMW). The (CMW) concerns the repairing process for the corrective maintenance and the (MMW) execute all preventive maintenance in several sites according to a defined scheduling. The aim is to take in account the resources (spare parts in the (MMW) and maintenance actions for a given operating budget. A modular approach for modelling a multi-site structure is proposed to achieve the aim of improving the availability of production sites while minimizing the cost of maintenance. *Copyright © 2008 IFAC*

Keywords: Distributed maintenance, Modelling, Petri Stochastic Nets (SPNs), Availability, Scheduling, Cost.

1. INTRODUCTION

The concept of Maintenance Workshop has developed in the sectors of activities where the availability of equipment is really important. A maintenance workshop (MW) supports not only the equipment repairing but also the preventive maintenance activities which related with the inspection and changing. In the distributed context, this workshop (MW) can be used to maintain equipment from different production sites. To reduce the failures occurrence, the (MW) must manage resources (operators, tools and spare parts), achieving the real-time of the equipment status in different sites and preventive maintenance activities plan. To improve the availability of production equipment and minimize maintenance costs it is necessary to determine the resources and well-planned preventive actions.

The resources determination related with the management of maintenance team as far as the tools and spare parts. To achieve the preventive action it is necessary to set a robust schedule, capable of absorbing the operating hazards and having a good security level.

In this distributed context, the maintenance activities are divided on these two following structures:

- Central (CMW) which realizes the process of reparation - corrective maintenance;
- Mobile (MMW) which carries out inspections and replacement on the various production sites.

Fig. 1. illustrates the context of the study and highlights the relationship between the various sites [Simeu-Abazi, 2007].

As a result, this distributed context requires the development of new modelling techniques and scheduling maintenance tasks. The simulation models can take into account the interactions between different sites and determine the resources. More oriented research in the marine field focused on optimizing the availability of merchant ships by proposing the determination of spare parts with a limited cost investment [Rustenburg, 2000], [Lau et al. , 2006], [Keizers et al., 2001]. Others concern in spare parts determination in space [Caggiano and Muckstadt, 2000].

A methodological approach on the implementation maintenance which is centralized at the production systems has been developed recently. It relates more particularly with the design of a maintenance workshop within an integrated production system [Abbou, 2003], [Abbou et al., 2004]. The (MW) is then integrated and dedicated to the maintenance of certain and specific equipment which includes repairing several phases (diagnosis, disassembly, repair itself depending on the type of failure, assembly and test).

This paper focuses particularly in cases where one has a Central (CMW) and Mobile (MMW) that can involve making replacements at several sites according to a predefined scheduling. It is a question of dimensioning the various resources (spare parts in the Central or Mobile (MW) and the maintenance team). A modular approach for modelling of a multi-site structure is proposed. The aim is to minimize the average cost by applying an appropriate inspection policy for the mobile workshop (MMW).

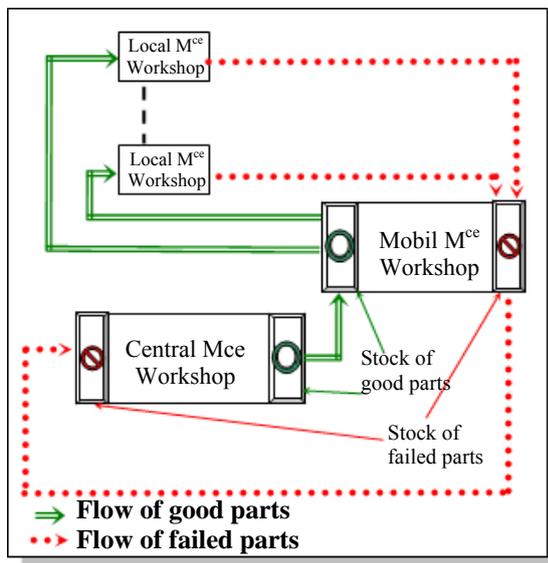


Fig. 1. Relations between the different production sites and maintenance workshops.

After a brief presentation of the framework, the chosen modelling tool (Petri Nets) is presented. For proposing a case study, a model of maintenance workshops (central and mobile) is proposed and illustrated with some simulation results. Some perspectives on the directions of this work will be at the end of this article.

2. MODELING TOOL

Petri Nets are tools well appropriate to modelling and analysis of complex discrete events systems by introducing the competition and the synchronization. They were introduced by Carl Adam Petri in 1962 to describe the overall behaviour of complex systems and to carry out the qualitative analysis.

A (PNs) is composed of:

- An assembly seats which is representing various states of the system (represented by circles).
- A set of transitions explain the possibility of system state change (represented by rectangles).
- A series of oriented arcs link between places and transitions.
- Marks (or chips) are represented as black dots in places of constituent's network.

This tool has very descriptive power to represent and analyze the manners and behaviour of complex system, including the phenomena of synchronisation, parallelism, competition or the sharing of resources.

Later in 1978, Stochastic Petri Nets (SPNs) were introduced [Natkin, 80] and [Molloy, 81]. They can calculate probabilities and statistics, and taking into account random events as the occurrence of failures. Taking the immediate transitions (unstable transitions) and the transitions stochastic (stable or delayed), has identified an extension of the (SPNs) which is called Generalized SPNs (GSPNs).

Several modules (PNs) can be synchronized by external events. This dependence is achieved through the linkage between the various modules, which determine the transition firing. This is the global notion of Synchronized PN (SyPNs) [Moalla, 78]. In this article we have extended the concept of Synchronization events with other events from both the outside and inside the system. In this case it is called the Internal SyPNs (GS²PNs).

3. APPLICATION OF DISTRIBUTED CONTEXT

The objective is to propose an approach to modeling and performance evaluation of many of production sites with taking into account the interactions between these sites. The expected performance is more related with improving the availability of production sites, minimizing the number of failures and minimizing maintenance costs.

Taking into account the corrective actions is made through using Stochastic Petri Nets (SPNs). They can model systems subjected to random parameters such as failure or repairs. To take into account the preventive actions, the Generalised SPNs (GSPNs) are used. Indeed, it is necessary to take into account the immediate transitions (unstable) where the staying time is deemed null (Zero) and stochastic transitions (stable or delayed). When marking valid at the time of immediate transitions and delayed transitions, priority is given to immediate crossings transitions. Exchanges between the different sites (production and maintenance) are achieved through signals synchronization. We use this case the GSPNs with Internal Synchronization where the different modules are synchronized by external or internal events.

The tool GS²PNs is well adapted to the distributed context. The decomposition of the complete system in different module, allows a modular analysis for our system. It is a way we propose a representation

and a hierarchical analysis of the system which is decomposed as follows:

1. A generic model which represents the production sites SP_i (i : number of the site).
2. A generic model which represents the central maintenance workshop (CMW).
3. A model representing the mobile maintenance workshop with the associated routing (MMW).
4. A generic model of the stock of the mobile maintenance workshop (MMW).

Table 1 lists the various data which are used in the proposed models and their objectives.

Type of system	Data	Objectives
CMW	-The arrival rate of these faulty parts. - Tasks Characteristics.	- Average time means of minimum staying - Size of the repaired stocks
MMW	- Storage capacity : (η) - Distances between production sites : ($d_{i, i+1}$) - Time of replacement : (τ_p)	- Scheduling tasks - Determination of resources operators and equipment
SP	- equipment references - Distance of the CMW : (d_{0i})	Time of replacement

Table 1 - Summary data and targets for each type of workshop

4. MODULAR MODELING: PRINCIPLE

The decomposition of the system in several modules makes them better and simple in the analysis phase. It is supported by GS^2PNs .

To obtain the model of the whole system from different modules it is necessary to follow these steps: [SASSINE Ch, 1998] :

1. Make a structural division of the system: a system of (n) production sites can be decomposed (n) cells.
2. A generic model is associated with each cell using GS^2PNs .

At each cell, synchronization signals are generated: places where they are active send signals that determine the transitions that receive them.

5. ASSUMPTIONS (HYPOTHESES)

Our work focuses on the application of centralized maintenance of multi-site production workshop which include a central (CMW), several production sites and a (MMW). To evaluate the performance of this complex system, we made some assumptions.

5.1 Assumptions on production sites.

1. All SP_i are identical, using equipments with identical characteristics.

2. No resources are shared between production and maintenance sites.
3. If the equipment is failed, the production in the site is stopped.
4. The preventive maintenance (PM) is executed only if SP in the rest state and at the date of predefined occurrence of a PM. (Preventive Systematic maintenance).

5.2 Assumptions on the Central MW.

1. The failed equipment is repaired with the time duration corresponding to the average repairing rate (μ).
2. In the (CMW), there is always a sufficient stock of the repaired parts that are ready to be loaded.

5.3 Assumptions on the Mobile MW.

1. At each site, there is only a standard replacement for one single type of part.
2. When the number of parts in stock is higher than the security stock level, mobile MW continued its scheduled maintenance operation.
3. When the number of parts in stock is less than or equal to the security stock level, mobile MW follows a predefined scenarios.
4. The staying time at the site is characterized by the average replacement time.

6. THE GENERIC MODELS

The multi-site system is composed of various generic models which are based on GS^2PNs .

- The production sites SP_i : is a model that must take into account the internal workings of the site i but with also maintenance tasks.
- The central maintenance workshop (CMW) is a model that must take into account the complete process of repairing in addition to the arrival rate of defective parts.
- The mobile workshop (MMW) is a model that must take into account the storage capacity of the (MMW).
- The maintenance policy is a model that must take account of corrective or preventive maintenance tasks.
- The routing is a model that represents the planning of maintenance tasks of the following (MMW) with well defined scenarios.

6.1 The model of production sites.

It is a model that represents the various models of production site operation SP. It is synchronized by the scheduled preventive maintenance events (preventive maintenance and presence of (MMW) on the site).

The GS²PNs of this model (see Fig. 2.), generates all the signals which indicate the site state: in production, failure state and waiting state for preventive maintenance.

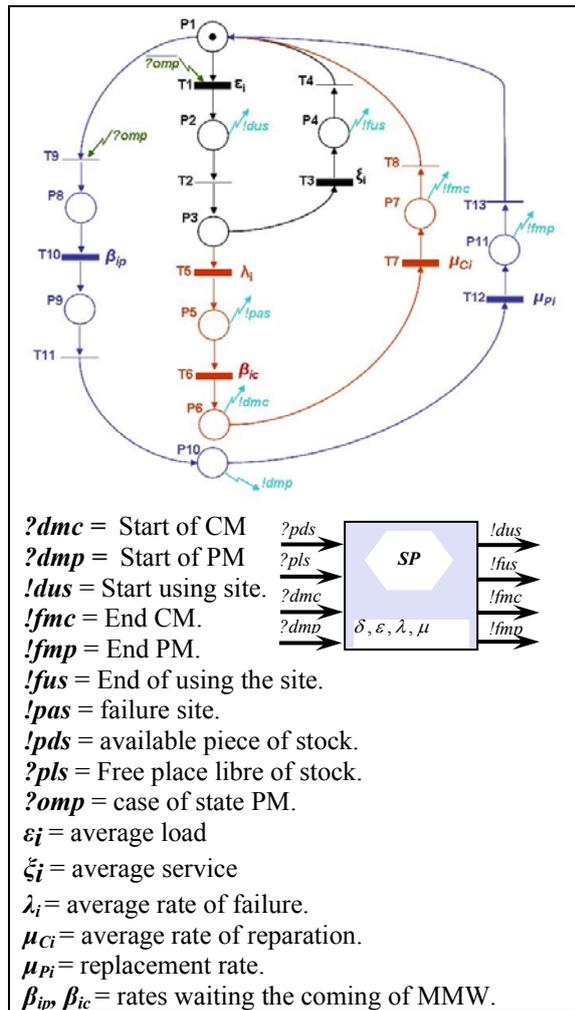


Fig. 2. Model GS²PN for production Site

The P1 place represents the state rests or the state of SP is ready to start one of its operation modes. If any PM is programmed, the production operation can be launched (crossing T1) with sending the signal (*!dus*) corresponding to beginning of production cycle to the place P2. . The operating state in production mode is represented by the place P3.

After the average time of service associated to the transition T3, the system returns to its waiting position through P4 which sends the signal (*!fus*) corresponding to the end of the production cycle.

In the case of a date PM, SP stop its production cycles, it will run as PM. The presence of (MMW) allows launching the process of replacing (P10 instead of sending a signal-from beginning PM).

The staying length in this position P10 depends and the replacement average time associated with the transition T12. At the end of replacement a signal is generated by P11.

An average waiting time (β_{ic}), is associated with the transition T6. It corresponds to the time needed to availability of resources (new parts in (MMW), tools and operators).

Throughout corrective maintenance, beginning signal of the corrective maintenance (*!dmc*) is transmitted. The duration of the CM corresponds the repairing average time (μ_{Ci}), is associated with T7.

When the time is finished, a signal corresponding to the end of maintenance (*!fmc*) is sent.

The model for the production site consists of two representing cycles, the different modes of operation of the site:

In the production phase, it is following closed cycle (loop) :

(P1 → T1 → P2 → T2 → P3 → T3 → P4 → T4 → P1).

In corrective maintenance phase the loop is :
(P3 → T5 → P5 → T6 → P6 → T7 → P7 → T8 → P1),

In the case of preventive maintenance the loop is :
(T9 → P8 → T10 → P9 → T11 → P10 → T12 → P11 → T13 → P1).

Note1:

It was considered that the failure can happened only during he running, not the state of rest.

Note 2:

Signals the beginning and end of maintenance are used for stock management of (MMW).

6.2. Model of the CMW.

The model of (CMW) is detailed in the thesis of ABBOU [Abbou R, 2003]. It consists of several items needed to repair failed equipment

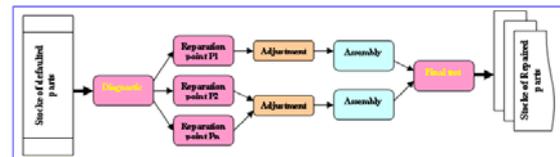


Fig. 3. Module of the central MW

6.3. The Stock of MMW

It is a model that allows managing the new and failed parts to be presented in the (MMW). It is synchronized with the model representing the policies of this maintenance.

The stock of (MMW) is represented by a GS²PNs with two states and two transitions as shown in (Fig. 4.). The place P1 sends a signal (*!pds*) which indicates that there is at least one part available in stock. n_j is the number of marks in place P1 which represents the maximum capacity of the (MMW) stock. The transition T2 is conditioned by the beginning of operation of corrective or preventive Maintenance. When T2 is crossed, a new part is got-out from stock and a place is getting free to receive a defective part by sending the signal (*!pls*) from the place P2.

When the replacement is finished, depending on whether the maintenance is corrective or preventive, the signals (*?fmc* or *?fmp*) validate the transition T1. The marking of P1 represents the number of parts in proper functioning (n_b), marking P2 represents the number of defective parts (n_d).

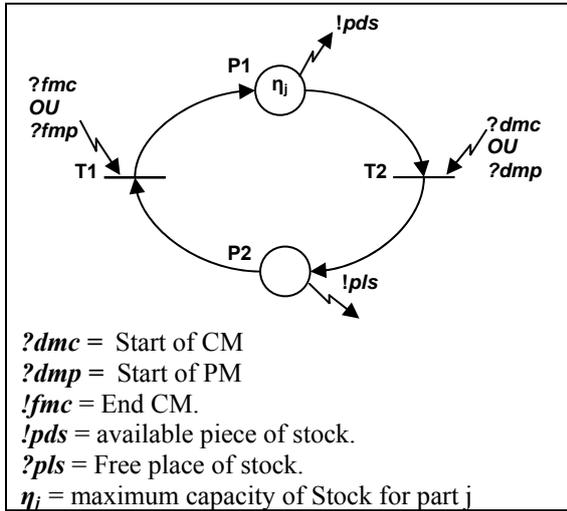


Fig. 4. Module Stock

Note 3:

The non-appearance of the signal (*pds*, available place in stock) reflects the fact that the stock is zero.

Note 4:

Initially $n_b = n_d$

6.4 Maintenance Policies

The model of PNs consists of two parts, the policy of maintenance corrective CM (CMW), and policy maintenance preventive PM (MMW).

6.4.1 Model Corrective Maintenance CM.

It is a model consists of three places and three transitions as shown in Fig. 5. It is synchronized with the random occurrence of a failure issued by the model of the production site and the availability of resources.

P1 represents the state of rest of the maintenance team. The corrective maintenance starts only if there is reported (*pas*) and that (MMW) is present on the site (*asp*). Note that the signal (*pas*) contains all the information on the type of failure and associated with SP.

Throughout repair a signal is emitted by the place P2 indicating the beginning of maintenance (*dmc*). After an average time of repairing (τ_c) associated with the transition T2, a signal of end of this activity (*fmc*, the end of the CM) is issued.

6.4.2 Model Preventive Maintenance PM.

As a model of corrective maintenance, the model consists of three places and three transitions as it is shown in Fig. 6.

The Model Preventive Maintenance is synchronized with the scheduled case of preventive actions. The place P1 represents the state rest of the maintenance team. The preventive maintenance doesn't starts up to the date of occurrence of an PM (*omp*) according to a predefined planning and if (MMW) is present on the site (*asp*).

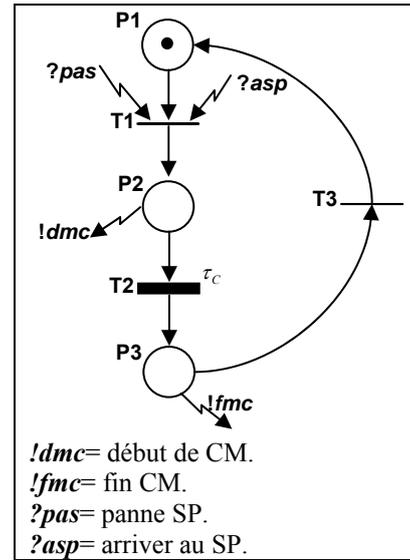


Fig. 5. Module of CM policy

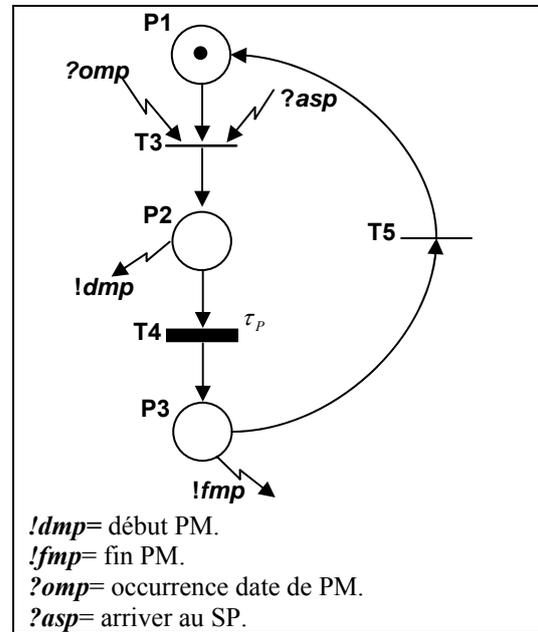


Fig. 6. Module of CM policy

When T3 is reached, the operation of replacement of failed equipment with a new one is launched by sending the signal (*dmp*). The average replacement time (τ_p), is associated with the transition T4. The signal of end of this replacement procedure (*fmp*) indicates that the SP has been sent within function of maintenance is available for other maintenance operations.

6.4.3 Model of overall maintenance.

To address the problem of conflict which can reach in a case of the preventive maintenance, we offer a single module which includes maintenance models CM and PM. Whenever the event occurs, the priority is given to corrective maintenance. Therefore, the displacement from (MMW) to SP (failure) has always given priority.

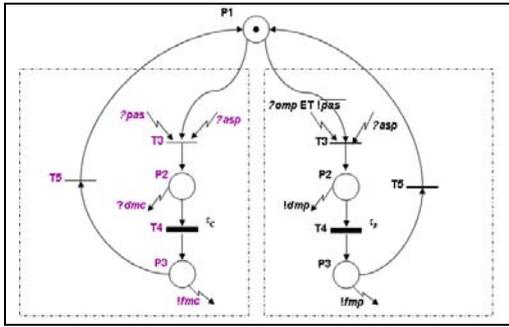


Fig. 7. Model ,GS²PN of Maintenance

Note 5:

In these models we take into account the condition of available part in stock because the displacement of (MMW) to the production site is already conditioned by the presence of non-defective parts.

Note 6:

At each signal the beginning of maintenance (*dmc* or *dmp*), a piece of the new parts stock is consumed, and each signal of end of maintenance (*fmc*, *fmp*) refers that there is a piece in the stock of defective parts is added.

6.5 Model of routing the MMW

It is a model that represents the sequence of actions of maintenance (corrective or preventive) to be performed by the mobile workshop. It is synchronized with the dates of occurrence of PM, the case of a failure and the level of stock. The parameters are taken into account in the evaluation phase are:

- Distances between the sites
- Storage capacity of the (MMW)

The (MMW) deals with the supply of spare parts (new or repaired) at the (CMW) but also related with different sites for replacement operations. These activities are defined by the following algorithm (Fig. 8.).

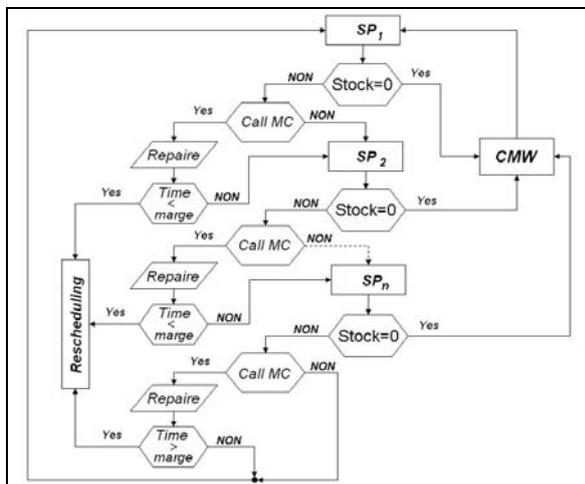


Fig. 8. Flow chart of routing

Note 7:

It is considered here that there is always the number of repaired the stock out of (CMW), it is also sufficient to meet the need for (MMW) (its maximum capacity).

From the Fig. 8. You can save the algorithm following:

```

Function routing "Centralization of maintenance for n
production sites"
Initialization "MMW is the site of the CMW"
n = finished, "the number of production sites"
Already visited=0
not visited yet=n

Repeat
  For loading time
  Wait until the end loading of new parts
  the MMW buys its stock to a new cycle
  End to
  i=0 ; "early stage of MMW"
  Until not visited yet < > empty set

  If η > = Ss « Stores security »
  Do
    Move ; to SPi
    Wait clock rate of displacement
    corresponds to the distance between SPi and
    SPi-1
    End movement, MMW came to SPi

    Replacement;
    Wait clock replacement rate
    End replacement
    Already visited=0
    If failure <> empty
      i = SP defaulting;
      Move; failing to SPi
      Wait clock rate move
      corresponds to the distance SPi defaulter
      End movement, arrived in failure
      Repair
      Wait clock rate of repair
      End repair
      i = déjàvisité;
    End If
    Update planning
    If modification planning
      then
        Consider the new list
      else
        Confirm the list of SP to visit
    End If
  Up to End
  i = i + 1;
  Update system
ELSE
  i = 0 ;
  Move; to CMW
  Wait clock rate of displacement
  corresponds to the distance between SP and
  CMW
  End displacement, MMW arrived at the CMW

  End If

  i = Already visited + 1 ;

End as

Until the end

End of function

```

By applying the algorithm above, we obtain the model in Fig. 9.

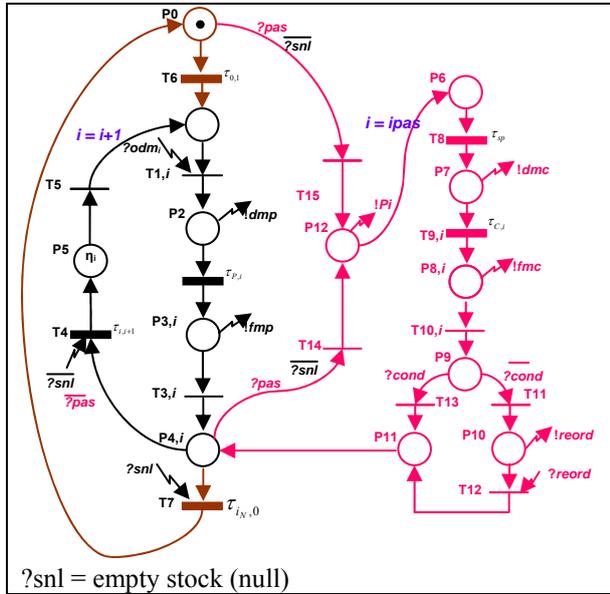


Fig. 9. Module of (MMW) routing

In P0, the (MMW) buys from the (CMW). without failure and if the level of stock exceeds the threshold (safety stock), routing is done according to predefined schedule. The occurrence of a failure is likely to require scheduling tasks.

Moving to production site → Replacement of failed parts with new ones → In the absence of failure, the moving to the following site if the stock level is higher S_s →

If planning is robust presence from the (MMW) to the SP, it must correspond to the time interval where the SP is in a state of rest.

Note 8:

Each model PNs may be represented by a black box with input / output of signals associated synchronization and other parameters such as timers, which will be associated with the crossing of transitions.

7. THE SIMULATION MODELS

The best tool suited for the simulation of various models proposed is Matlab. Indeed, the toolbox allows State-flow modelling and simulating such complex systems. We will limit the simulation part to a single production site, taking into account its various modes of operation. Thus, the normal operation, stops for corrective maintenance, stops for systematic preventive maintenance are modelled and simulated.

To represent the behavior of the site as well as different modes of operation, it is necessary to build some functions that generate random events as the occurrence of a failure. The occurrence of a failure leads to the stopping of the site awaiting repair. In addition, the duration of repair depends on the failure (we take it as random), a random time is associated with duration of repair (Fig. 10.).

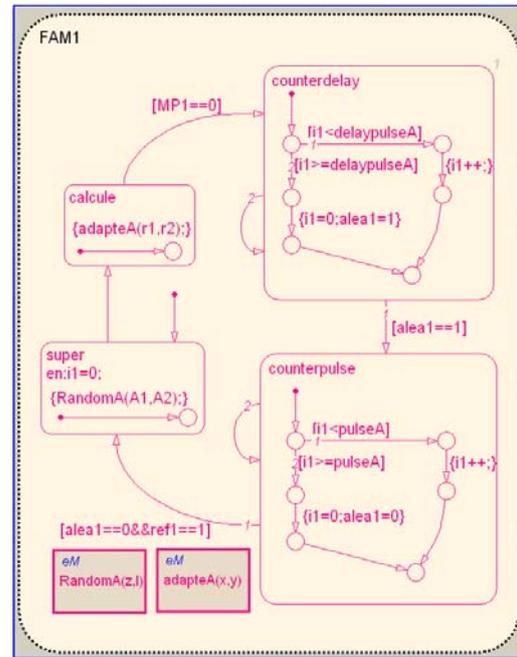


Fig 10. Generation a random function.

(Fig.11.) shows the model Stateflow of random events generator, and Fig. 11. model of a production site. The simulation Stateflow allow calculating the overall cost of maintenance and contributes to determine the storage capacity of the mobile workshop.

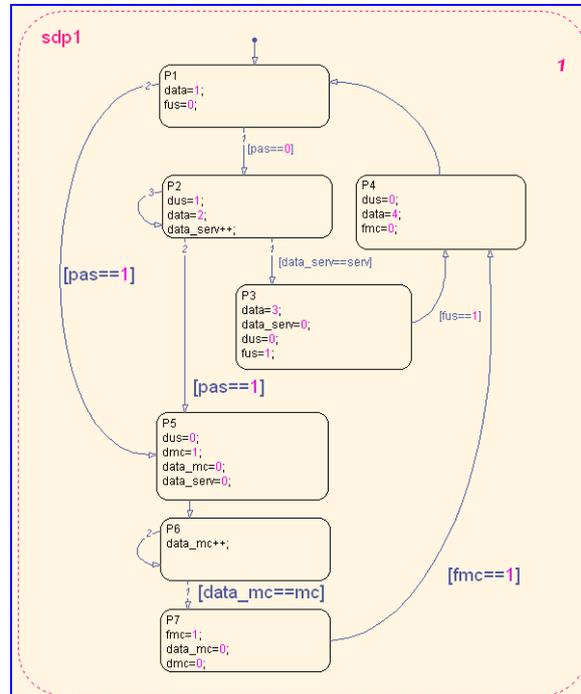


Fig. 11. Simulation Model for the production operation in each SP

8. CONCLUSION

In this article, we proposed a model to take into account maintenance operation in the multi-sites context. To simplify the number of constraints to

consider, the model for this system was built under certain assumptions. The model based on GS²PNs can better understand the distributed maintenance process, which is the main theme of this study. The simulation of various workshops synchronized (in progress) can analyse and evaluate the performances of maintenance (failure rate, availability, cost, rate of return synthetic...).

This work opens several perspectives. The first is to remove some of the assumptions in the modelling distributed maintenance system.

In the model proposed a single type of equipment is taken into account at each site (assumption1). This assumption restricts the field of distributed maintenance. It is necessary to take into account the diversity of equipment, and MW must be able to rehabilitate various types of equipment. The proposed generic models can be evolved from GS²PNs to the Colored GS²PNs (Co-GS²PNs). In addition, replacement of equipment can generate substantial costs, and then it is necessary to consider replacement multi-level equipment. In other words, it is important to take into account not only the replacement of the full equipment but only a section of the equipment.

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