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Static integration of a maintenance scheduling for a surface treatment process

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Abstract— **In reality, every machine requires maintenance, which will directly influence the machine's availability, and consequently the planned production schedule. The objective of this paper is to implement a method for the integration of recovery jobs in manufacturing system with time constraints. The proposed method allow to insert preventive and corrective maintenance operations when the machine is available in order to minimize periods of inactivity of these and try to increase the productivity rate. A computing algorithm allowing to insert the projected jobs in periods of machine availability, without changing the initial scheduling solution is established. Finally, we illustrate the implementation of the proposed approach on an example of a surface treatment unit.**

Keywords— ***Scheduling; Static insertion; Recovery; Machine availability, Time constraint; Surface treatment unit***

I. INTRODUCTION

As the industry evolved, keeping equipment running without failure became decisive. Loss in production due to equipment breakdown was no longer affordable due to the increasing demand [1]. In manufacturing industry, the initial concept of equipment maintenance policy was reactive maintenance. Recently, scheduled maintenance replaced reactive maintenance, resulting in better equipment availability. Less literature working on manufacturing scheduling problem consider the unavailability of machines. However, in most practical manufacturing environment, there are always some uncertainties inducing the unavailability of machines, such as the unavailability of staff, downtime of equipment, interrupted customer service …, etc.

Scheduling involves the allocation of resources to tasks over time subject to temporal constraints [2]. In some cases the scheduling reveals periods of inactivity of machine in flexible manufacturing systems with time constrains (intervals stop). The objective of this paper is trying to take advantage of these periods of inactivity to launch preventive and corrective maintenances actions.

We propose in this paper a method to insert these additional jobs in surface treatment line. The goal of the proposed method is the introduction of preventive or urgent tasks, taking into account all the constraints of production. Based on this concept, there are two methods of introducing additional tasks in scheduling. The first method known as "static insertion" is the introduction of a set of tasks in the availability of the machines; the second called "dynamic insertion" is to redo the scheduling if an event changes the data of the original problem. The ultimate goal is to optimize the impact of this integration on the total time and production cost.

The reminder of this paper is organized as follows. The second section uses the scientific literature to describe the position of the proposed approach in the state of the art. A functional description of surface treatment process is detailed in Section 3. The fourth section constitutes the contribution of this paper. A computing algorithm allowing to insert the projected jobs in periods of machine availability, without changing the initial scheduling solution is established. His application to the maintenance scheduling of a surface treatment process is outlined. Finally, conclusions and proposed future studies are presented.

II. RELEVANT LITERATURE

In manufacturing system failure cannot be avoided, especially in term of modern machine, which is always with a sophisticated structure. Thus, keeping machines in perfect condition attracts many researchers and manufacturing practitioners. There has been much research considering the integrated maintenance scheduling (IMS) in order to increase availability of machines.

Zhan [3] developed a Fast Group Search Optimizer (FGSO) algorithm to solve the problem of IMS model, whose objective is to minimize the total costs of maintenance and power production in transmission lines. Liu [4] is interested to the problem of jointly scheduling and imperfect preventive maintenance which can not restore a production line to an 'as-good-as-new' status. In this context two integrated models of scheduling with multiple demands and preventive maintenance are considered. In order to provide valuable guidelines for planning an enterprise system that monitors critical maintenance processes and asset, Pulido [5] presents a methodology for using Accelerated Life Testing techniques for evaluating and projecting preventive maintenance schedules. Considering the expectation of all internal and external stakeholders of the maintenance function, Turki et al. [6], proposed a process of high level planning that links maintenance strategy to business and productions strategies in order to avoid unnecessary costs. Other maintenance scheduling approaches and applications can be found in [7-9].

III. PRESENTATION OF SURFACE TREATMENT LINE

The real-world problem that motivated this research is an automated surface treatment line designed for processing a variety of steel parts in the industry.

A. Functional description

The system that motivated this study is typically a real chemical system composed of several tanks (resources). The production line, figure 1, is composed of six units that treat the following operations: cleaning, nickeling, silvering, galvanizing, rinsing and coating.

The displacement of work pieces is provided by a robot. The hoists are used to move jobs from resource to resource and to load/unload jobs on/from resources. The studied chain, figure 1, is composed of [10]:

- 22 treatment baths (B1 to B22),
- 1 discharge, loading and unloading bath, (B23),
- 1 robot (crane).

In the surface treatment facility, the robot is assigned to take, carry, and place a piece in the specified tank and then take another piece to be processed. In this way, some treatments can be processed in parallel to save time and energy used in process.

B. Modelling of surface treatment unit

In the system under consideration, the processing time, that is the times required to perform the operations, are interval-valued. Otherwise, a processing time is selected between two bounds which depend on the operation to be performed. So, Any deviations from the allowed lower and upper bounds will lead to the defective production. P-time Petri Nets (P-TPNs) are convenient tools for modelling this manufacturing system whose operations times are not precisely given, but are included between a minimum and a maximum value.

1) P-Time Petri Net

Definition 1 [11.]: The formal definition of a P-TPN is given by a pair < R; I > where:

R is a marked Petri net,

$I : P \rightarrow Q^+ \times (Q^+ \cup \{+\infty\})$

$p_i \rightarrow IS_i = [a_i, b_i]$ with $0 \leq a_i \leq b_i$.

IS_i defines the static interval of staying time of a mark in the place p_i belonging to the set of places P (Q^+ is the set of positive rational numbers). A mark in the place p_i is taken into account in transition validation when it has stayed in p_i at least a duration a_i and no longer than b_i. After the duration b_i the token will be dead.

In the studied workshop, for each operation is associated a time Interval ($[a_i, b_i]$ with u.t: unit time). Its lower bound indicates the minimum time needed to execute the operation and the upper bound sets the maximum time not to exceed in order to avoid the deterioration of the product quality. Consequently P-TPNs have the unique capability of modelling time intervals and deducing about the machine availability.

2) Modelling of surface treatment unit

Figure 2, shows a P-time Petri net (G) modelling the production unit. The obtained G is used to study the on-line maintenance scheduling of the studied treatment unit.

3) Functional decomposition

As the sojourn times in places have not the same functional signification when they are included in the sequential process of a product or when they are associated to a free resource, a decomposition of the P-time Petri net model into four sets is made using [12]:

While using [12], a functional decomposition of the Petri net model in four sets is established, figure 2:

- R_U is the set of places representing the treatment operation,
- R_N corresponds to the set of places representing the free robots which are shared between manufacturing circuits,
- $Trans_C$ is the set of places representing the loaded transport resources,
- $Trans_{NC}$ is the set of places representing the unloaded transport resources.

C. Computing of time windows

The determination of the time intervals and the effective residence time is elaborated taking into account these assumptions:

- The loading, unloading and transportation operations are non-negligible and must be taken into account.
- The distance between two successive baths is supposed to be about 5 meters, and the velocity of robot is 1m/s.

For each place, we denote $[a_{ij}, q_{ij}{}^e, b_{ij}]$ the lower bound of the time window, the expected sojourn time of tokens, and the upper bound of the time window, respectively.

The full set time intervals of immersion and transfer operations (figure 2), is summarized in table 1 (u.t: unit time). These time intervals are computed using the CPLEX 12.5 on a computer with Intel (R) at 1.6 GHz and 1 Go RAM.

D. Determination of process circuit

In surface treatment unit, the process circuit is defined as kind of elementary circuit which represents the operating cycle (treatment / transport of parts between baths/tanks).

According to figure.2, the P-time Petri net modelling a system is composed by three sequential processes GO_1, GO_2, and GO_3:

GO_1={ST1,B1,ST2,P1,ST3,B2,ST4,P2,ST5,B5,ST6,P3,ST7, B8,ST8,P4,ST9,B6,ST10};

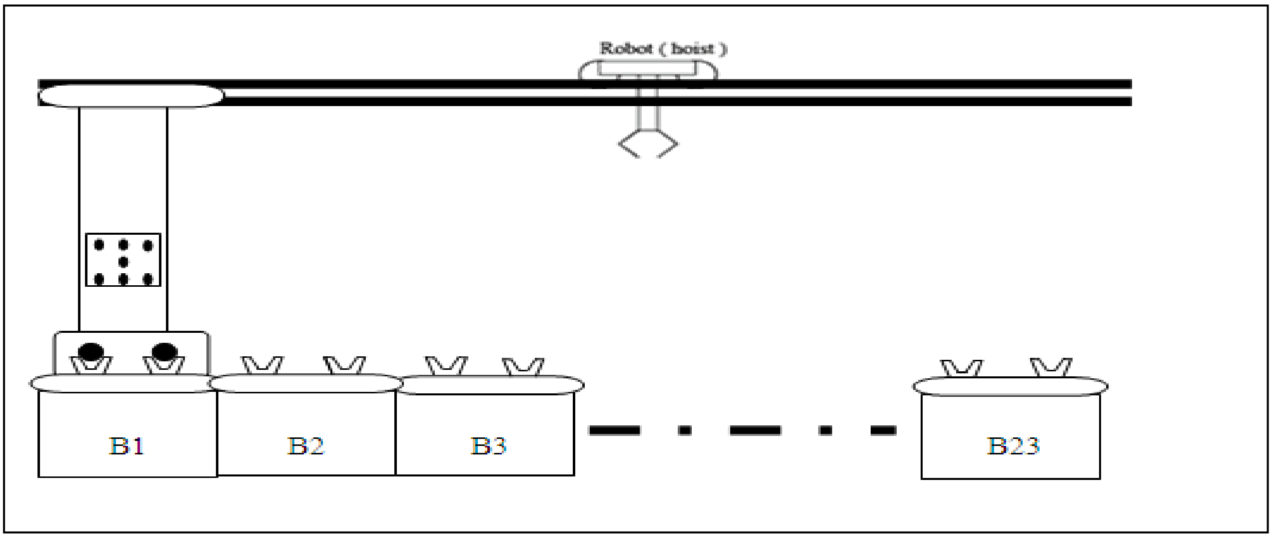


Fig. 1. Surface Treatment unit

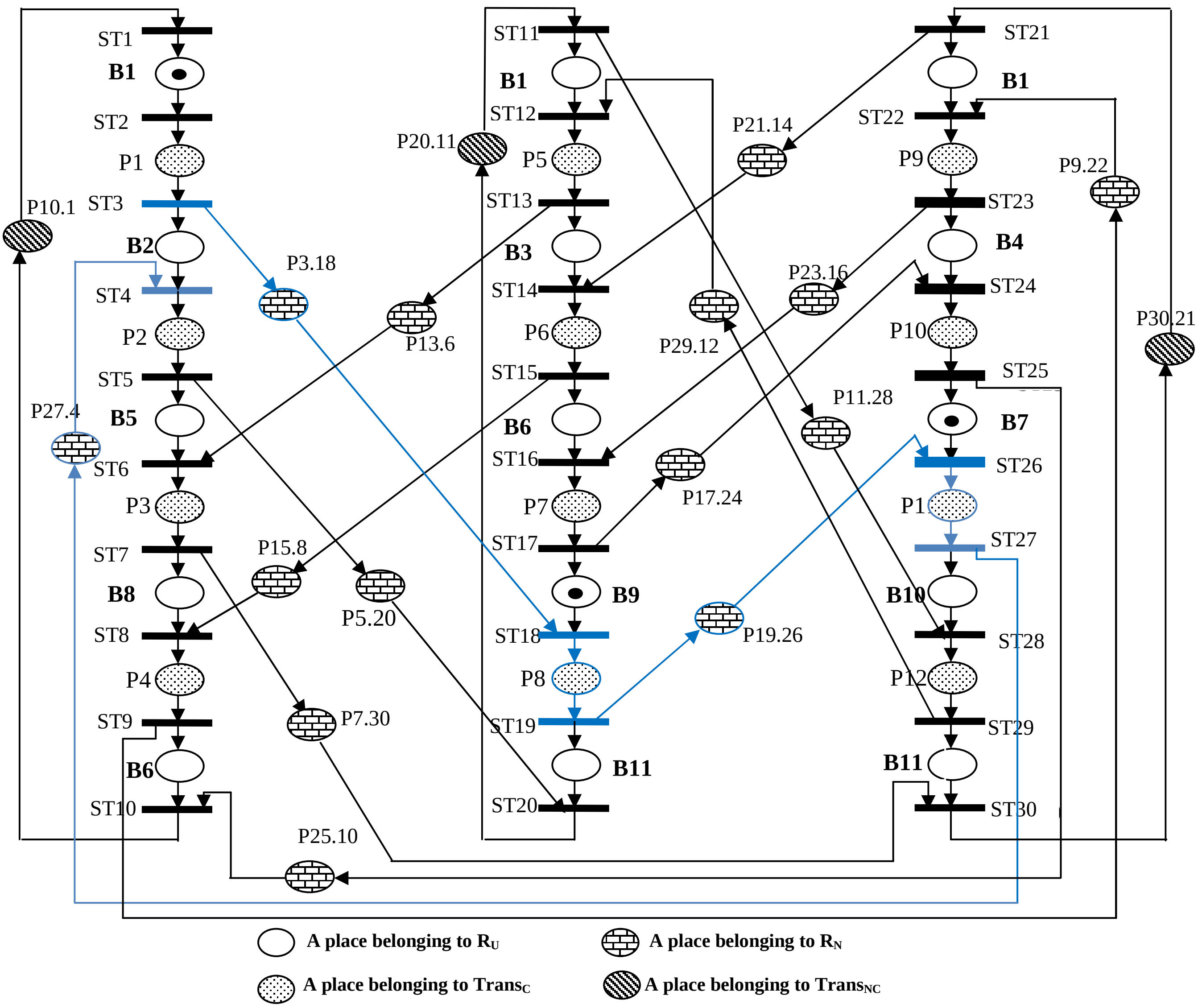


Fig. 2. Surface treatment unit modeled by a P-time Petri net

TABLE I. IMMERSION AND TRANSFER OPERATIONS

Place	Operation	Min time (u.t)	Max time (u.t)	Sojourn time q_i^e(u.t)
B1	Cleaning	20	27	23
B2, B3, B4	Rinsing	109	136	130
B5	Galvanizing	153	169	161
B6	Silvering	115	119	117
B7	Nickeling	15	20	16
B8, B9, B10	Rinsing	82	111	105
B11	Coating	74	75	74
P1	Transfer to B2 (loaded crane)	1	9	5
P2	Transfer to B5	13	20	15
P3	Transfer to B8	15	16	15
P4	Transfer to B6	9	13	10
P5	Transfer to B3	7	11	10
P6	Transfer to B6	14	15	15
P7	Transfer to B9	12	17	15
P8	Transfer to B11	9	14	10
P9	Transfer to B4	13	16	15
P10	Transfer to B7	13	20	15
P11	Transfer to B10	14	17	15
P12	Transfer to B11	4	7	5
P3.18; P5.20; P7.30	Free robot	0	Infinity	$q_{3.18}^e$ =33; $q_{5.20}^e$=31; $q_{7.30}^e$ =15
P13.6; P15.8	Free robot	0	Infinity	$q_{13.6}^e$ =8; $q_{15.8}^e$=7;
P21.14; P23.16; P29.12	Free robot	0	Infinity	$q_{21.14}^e$ =11; $q_{23.16}^e$=25; $q_{29.12}^e$=43
P11.28; P17.24; P19.26	Free robot	0	Infinity	$q_{11.28}^e$ =45; $q_{17.24}^e$=18; $q_{19.26}^e$ =5
P9.22; P25.10;P27.4	Free robot	0	Infinity	$q_{9.22}^e$ =26; $q_{25.10}^e$=3; $q_{27.4}^e$ =38
P10.1;P20.11; P30.21	Unloaded crane	1	Infinity	$q_{10.1}^e$ =8; $q_{20.11}^e$=19; $q_{30.21}^e$ =37

GO_2={ST11,B1,ST12,P5,ST13,B3,ST14,P6,ST15,B6,ST16, P7,ST17,B9,ST18,P8,ST19,B11,ST20};
GO_3={ST21,B1,ST22,P9,ST23,B4,ST24,P10,ST25,B7,ST26, P11,ST27,B10,ST28,P12,ST29,B11,ST30}.

The determination of process circuit can clearly present the precedence relations of operations in surface treatment unit, and can model in real time the maintenance scheduling which represents the subject of the next section.

IV. MAINTENANCE SCHEDULING

Given a set of maintenance tasks, it is interesting to find good schedules for all jobs to minimize the total out-of-service time and to simultaneously accommodate the unexpected events. Therefore, the specific objectives of the maintenance planning are: to minimize the interruptions in the equipment operating/service schedule and to maximize the utilization of the maintenance resources.

This paper proposes to use a static insertion of a set of maintenance tasks in the availability of the machines for the maintenance of the surface treatment unit equipments. The main contribution of this section is to propose a computing algorithm allowing the insertion of a set of corrective and preventive maintenance actions.

A. Maintenance based on static insertion

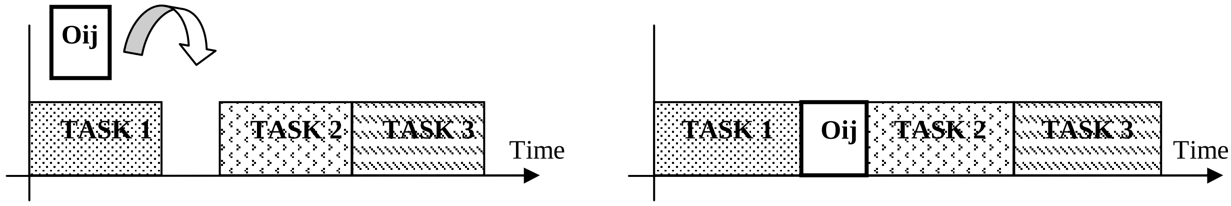
1) Principle

The insertion problem amounts to propose a new sequence of operations “Oij” (operation i associated to a job j) for a problem defined by the scheduling layer, figure 3. Therefore, this integration should resolve a new scheduling problem minimizing the impact of integration on the total time and cost production.

The goal of static insertion is to maximize the availability of production system and to decrease cost of unexpected failures. Inserting of an operation “Oij” in the initial scheduling is in accordance with the following conditions, figure 3:

- No change in the allocation of scheduled operations,
- No violation of the end dates of the programmed operations.

In this paper the static integration approach will be applied to the management and planning of maintenance operations in an automated surface treatment line.



A/ Before insertion **B/ After insertion**

Fig. 3. Principle of static insertion

2) Notations

The following notations are used to describe the problem studied throughout the paper,

- h: Index for machine, h=1,…, H, where H is the number of machine
- j: Index for job, j=1,…, J, where J is the number of job
- i: Index for Maintenance Operation (MO), i=1,…, I, where I is the number of operation .
- STj :Starting time of job j on machine h
- ETj: Ending time of job j on machine h
- ST_{MO} : Starting time of maintenance operation
- ET_{MO}: Ending time of maintenance operation
- Ah : Availability interval of machine h
- $P_{MOh}=\begin{cases} 1 \text{ Possibility of insertion of MO for machine h} \\ 0 \text{ otherwise} \end{cases}$
- $O = \begin{cases} \sup_h (\sum_{j=1}^{J} (ETj - STj)) & \text{if job j occupies largest time slot on machine h} \\ 0 \text{ Otherwise} & \end{cases}$

B. Algorithm (Procedure of static insertion)

1) Purpose

In order to insert the projected jobs in periods of machine availability, without changing the initial scheduling solution, a recursive algorithm based on the priority to the machine with Highest Operating Lead Time (HOLT), is proposed.

2) Algorithm

For (i = 1; i< I); P_{MOh} =0; A_h=∅

For (h = 1; h< H)

If

{

$$O = \sup_h (\sum_{j=1}^{J} (ETj - STj))$$

$MO_h \subset A_h$ (The duration of operation insertion corresponds to the period of machine availability)

Time constraints are verified

then

$P_{MOh}=1$; $MLTh = \sum_{i=1}^{I} (ET_{MO} - ST_{MO})$ (Maintenance Lead Time for a machine h)

}

End

Insert a maintenance operation on the machine h(MO_h)

End

Redo the same procedure for all machines.

C. Static integration of a maintenance scheduling for a surface treatment process

1) Cyclic scheduling of a surface treatment unit

The figure 4, shows the precedence relations of operations in surface treatment unit, and can easily model the time windows associated to each treatment and transfer operation. For 1-cyclic scheduling, the activities are repetitive in a period cycle time. So it just needs to study the processing activities in one cycle time instead of considering the activities in the whole production period. Let us take the example of process circuit “GO1” with the loading operation (P10.1) as its first transaction. According to the effective sojourn time “q_i^e” (table 1), the cycle time associated to the path “GO1” is 545 unit time (u.t), figure 4. Thus this figure represents the efficient allocation time indispensable for the displacement (Pi) and the treatment (Bi) of pieces in surface treatment chain.

2) Static integration of a Maintenance operation

The robot operation spaces represent the starting and finishing time of each job (e.g., moving, loading/ unloading work pieces on/from resources). During the chemical treatment of a job in a tank “Bi”, the robot may transport another job from one tank to another. This is modeled by a set of transit operation "TO" (unloaded robots) shared between manufacturing circuits, and a set of loaded robot “Pi” (transfer of pieces between baths belonging to the same sequential process GOi), figure 5. Thus, in the system under consideration, the no-wait constraint does not allow to a job to stay outside a resource (tank) before its completion other than during the time it is being transported by the robot from one tank to the next.

The proposed scheduling, figure 4, reveals periods of inactivity of robots (intervals of awaiting the end of the surface treatment operation). The main objective is to try to take advantage of these periods of inactivity to start additional jobs such predictive and corrective tasks. This method is referred to as "static insertion" (introduction of tasks when the machine is available). Thus, this procedure is used to insert a maintenance jobs in periods of robot availability, without changing the initial scheduling solution. The introduction of the maintenance tasks must necessarily take into account the production scheduling and time constraints. The figure 5, represent an integration of three additional jobs (MO1, MO2 and MO3) representing a sequence of maintenance operations. These operations, represents the time allocated for the maintenance of robot since it is available.

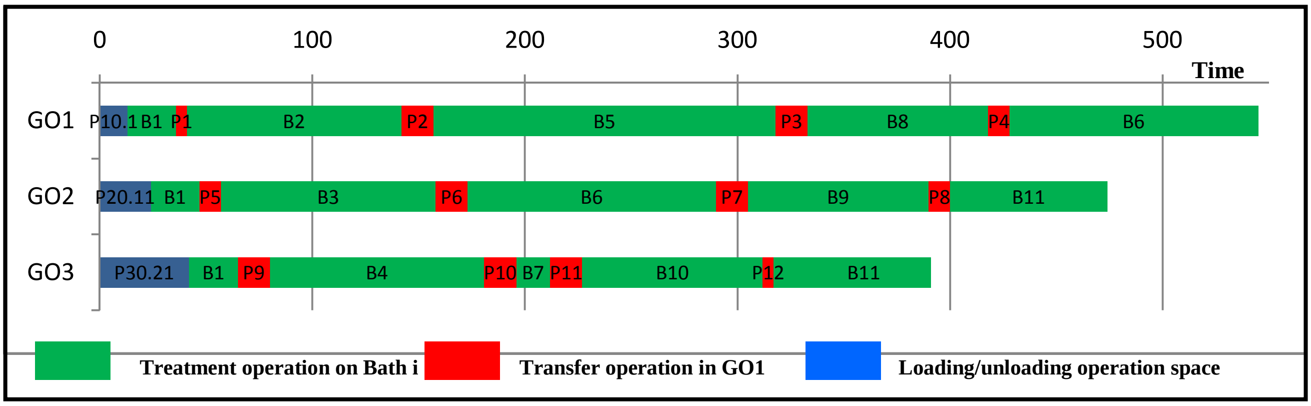


Fig. 4. Scheduling of surface treatment operations

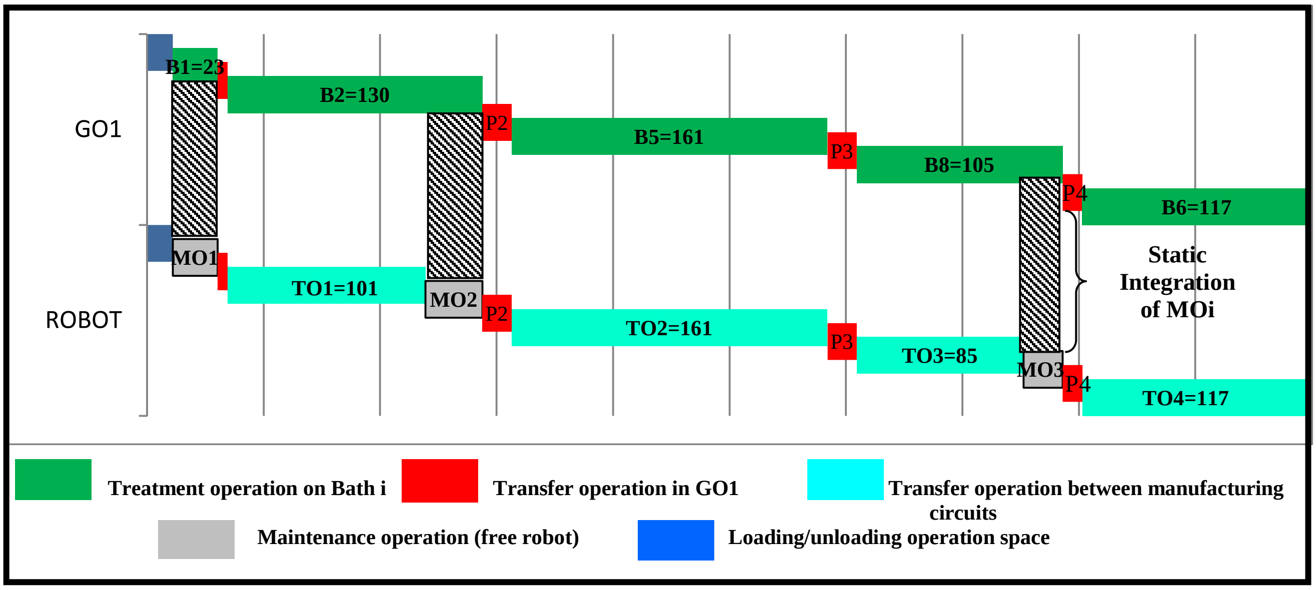


Fig. 5. Maintenance scheduling of robot

Example: Let us take the example of static integration of the maintenance operation "MO2". In the system under consideration, the processing times, that is the times required to perform the rising operation in the treatment bath "B2", is 130 u.t. (q_{B2}^e=O=130 u.t : see table 1). During the chemical treatment of a job in a tank "B2", the robot may transport another pieces from one tank to another. The elementary circuit "GO4" required to the transport of job during treatment operation is represented in blue in figure 2 (GO4=[ST3;P3.18;ST18;P8;ST19;P19.26;ST26;P11;ST27; P27.4;ST4]).

The cycle time "C" associated to the elementary circuit "GO4" is computed by accumulating processing time of operations belonging to "GO4" ($C = \sum q_{3.18}{}^e + q_8{}^e + q_{19.26}{}^e + q_{11}{}^e + q_{27.4}{}^e$). Thus the time required to the transport of workpiece from resource to resource is equal to 101u.t (C=101 u.t). Consequently the robot stays above treatment bath during 29 u.t. This time is allocated for the insertion of a maintenance operation "MO2" ($P_{MO2robot}$ =1) since the robot is available (A_{robot}=29u.t).

V. Conclusions

In this paper, we treated the scheduling problems of flexible workshops with time constraint. This problem comes from the manufacturing industrial sector, where resources can perform different operations, depending on varying durations on all machines.

For the stage of adding maintenance tasks, we propose an inserting algorithm. The established static integration allows in the general case to introduce additional maintenance tasks in the availability of the machines without changing the initial scheduling solution. This strategy allows in the worst case to continue the production in a degraded mode. This degraded functioning mode allows keep on producing while providing correct quality of the manufactured products.

The presented approach allows solving problems of integration of the estimated or urgent jobs in scheduling, with the goal of minimizing the time and cost of manufacture. The proposed insertion method shows how to integrate unforeseen maintenance actions and how to make a real-time scheduling of these recovery acts with respect of production constraint.

It would be interesting to apply the proposed approach to other problems, such as the scheduling of maintenance problems in transport networks in order to minimize the interruptions in the bus operating schedule. We intend in our future research, to propose a dynamic scheduling for manufacturing systems with time constraint, without predicted moment of maintenance task.

References

[1] S. Mahalungkar, and M. Ingram, “Online and manual (offline) vibration monitoring of equipment for reliability centered maintenance”. In Cement Industry Technical Conference, pp. 245-261, 2004. IEEE-IAS/PCA.

[2] R. Zhou, B. Fox, H. P. Lee A.Y.C. Nee, “Bus maintenance scheduling using multi-agent systems”. Engineering Applications of Artificial Intelligence, Vol.17(6), 2004, pp. 623-630.

[3] J. P. Zhan, Y. J. Yin, C. X.Guo and Q.H. Wu, “ Integrated maintenance scheduling of generators and transmission lines based on fast group searching optimizer”. IEEE In Power and Energy Society General Meeting, pp. 1-6, 2011.

[4] L.Hua, L. Miaoqun and L. Shan, "Scheduling Problems with Preventive Maintenance on Two Parallel Production Lines”, IEEE International Conference In Management and Service Science (MASS), pp. 1-4, 2010.

[5] J. Pulido, “Using Accelerated Life Testing techniques for preventive maintenance scheduling”, IEEE In Reliability and Maintainability Symposium (RAMS), pp. 1-6, 2014.

[6] U. M.Al-Turki, T. Ayar, B. S.Yilbas and A.Z.Sahin, “Integrated Maintenance Planning”. In Integrated Maintenance Planning in Manufacturing Systems. Springer International Publishing, pp. 25-57, 2014.

[7] L.M.Duc, C. Ming Luo ; I.Leng, “Maintenance Scheduling of Plasma Etching Chamber in Wafer Fabrication for High-Yield Etching Process”, IEEE Transactions on Semiconductor Manufacturing, Vol.27 (2) pp. 204-211, 2014

[8] Y.Wang, H. Zhong, Q.Xia, Q.Chen, Y.Bai and J Zhu, “Generation maintenance scheduling considering shiftable loads”, IEEE International Conference on In Power System Technology (POWERCON), pp. 139-144, 2014.

[9] S. M. Hussin, and M.Y Hassan, “Coordination of short-term maintenance scheduling with hourly security-constrained unit commitment, 8th IEEE International conference InPower Engineering and Optimization (PEOCO), pp. 73-78, 2014.

[10] B. Sammoud,"Modélisation par Réseaux de Pétri d’une ligne de traitement de surface réduite", Research master, ENIT, 2010.

[11] W.KHANSA, J.P. Denat and S. Collart-Dutilleul, “P-Time Petri Nets for Manufacturing Systems”, IEEE Workshop On Discrete Event Systems (WODES’96), pp. 94-102, 1996. Edinburgh

[12] J. Long , “Flow Optimization Method for Control Synthesis of Flexible Manufacturing Systems Modeled by Controlled Timed Petri Nets”, IEEE International Conference on Robotics and Automation, Atlanta, Georgia, USA, vol. 1, pp. 598-603,Mai1993.