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On SHMP scheduling of surfaces treatment line based on margins measures

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Abstract. *This paper deals with the single-hoist/multiple-products scheduling problem of the type Job Shop and particularly the problems of surfaces treatment workshop.*
Because of the time spent by a product in a tank have to be in a well defined interval , the proposed study of the process consider the constraint, called window of time, corresponding to the difference between the maximum and the minimal duration which called margin.
New results, obtained, by using margins calculations lead to an optimal cyclic schedule of the hoist moves.

Keywords. *Surfaces treatment line, Scheduling, single-hoist/multiple-products, Job Shop, margins measures, Gantt-Char.*

1. Introduction

Scheduling problems are in general difficult to solve. The realization of a project supposes the execution of multiple operations subject to many constraints. Solving a scheduling problem consists in determining the order and the calendar of execution of these operations in their resources and start time, so as to carry out the project. The principal problems are of type Flow Shop, Job Shop and Open Shop [4, 6].
The main aim in this paper is to solve the Single-Hoist/Multiple-Products (SHMP) scheduling problem on the surfaces treatment workshop of the type Job Shop. P products are introduced into the system, P products are left from the line each period.

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Most existing works consider the simple cyclic single-hoist/single-product problem, where the objective is to find the minimum cycle time, in order to increase the production [3, 8, 13, 16].
On the other hand, few works relate to the complex SHMP problem, which is the subject of this work. [9, 11, 12, 16].
The first part of this article presents formulation problem and specificities of the workshops in galvanoplasty. The second part exploits the characteristic of the surface treatment workshops and presents a new technique based on the margins calculation [10, 14] guaranteeing the optimality of the solutions found for the multiple-products scheduling with single- hoist in a surfaces treatment line.

2. Problem formulation

2.1. Notations

The notations and variables necessary to the problem formulation are defined below [1] :

S.T	surface treatment,
$T(i)$	quantity of parts type i to realize, $i \in \{1,...,\mathrm{I}\}$,
MP	time necessary to carry out the production (Makespan),
$RP_{\max}$	maximum number of permanent modes to carry out the production,
I	number of products to be manufactured,
RP_p	p[th] permanent mode, $p \in \{1,...,RP_{\max}\}$,
$E(RP_p)$	cyclic horizon of products to be realized during a production cycle relating to the p[th] mode,
$CT(p)$	optimal cycle time associated with the horizon $E(RP_p)$,
$X(p)$	number of repetitions of the horizon $E(RP_p)$ during RP_p,
$O_n(p)$	duration operation number assigned to the n[th] machine, $n \in \{1,...,N\}$ during RP_p,
O_{ji}^T	tank operation of product j associated with the tank i,
O_{ji}^H	hoist operation moves product j from tank T_i to tank T_{i+1},
P_{ji}	processing time of the operation O_{ji}^T, with $P_{ji}^{\min} \le P_{ji} \le P_{ji}^{\max}$,
$Z_i(p)$	occupation load assigned to the n[th] machine during RP_p, given by $Z_i(p) = \sum_{i=1}^{N}(\sum_{j=1}^{I} O_i(p)P_{ji})$,
S_{ji}^H	hoist operation start time,
S_{ji}^T	tank operation start time,

E_{ji}^{H} hoist operation end time,

E_{ji}^{T} tank operation end time,

θ_{ij}^{H} hoist move time from tank T_i to tank T_j ,

2.2. Surface treatment workshop functioning

The SHMP workshop, (fig.1), involves *P* products, which requires each one a sequence of chemical operations in N tanks. Each product departs from the loading tank, visits some tanks and finally arrives in the unloading tank.

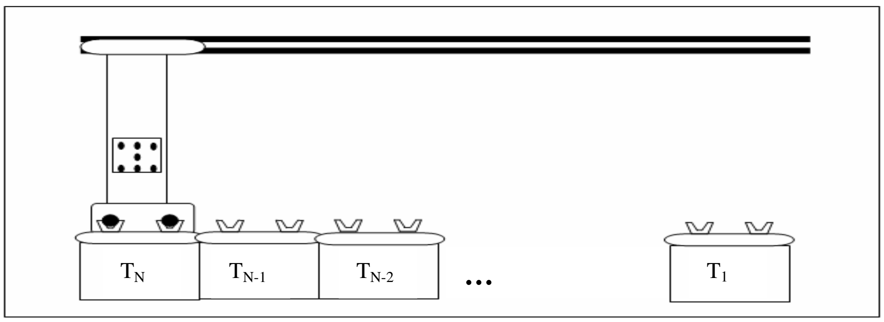

Fig. 1. The SHMP workshop

Product $j\,(j=1,2,...,I)$ consists of tank operations $O_{ji}^{T}(i=1,2,...,m_j)$ and has a processing time P_{ji} included between minimum and maximum time limits, $P_{ji}^{\min}$ and $P_{ji}^{\max}$, respectively. Each tank T_{ji} can carry out one and only one operation.

For each hoist operation O_{ji}^{H} and tank operation O_{ji}^{T} a starting time S_{ji}^{H} and S_{ji}^{T} and a completion time E_{ji}^{H} and E_{ji}^{T} are posed respectively.

The relations between the variables can be formulated as follows:

- $E_{ji}^{T} = S_{ji}^{H}$
- $E_{ji}^{H} = S_{ji}^{H} + O_{ji}^{H}$
- $S_{j,i+1}^{T} = E_{ji}^{H}$

Several types of resource conflict can arise [7, 11]:

- a tank conflict occurs when a job has to be moved to a tank that is already occupied,

- a hoist availability conflict arises when a job has to be moved while the hoist is busy transporting another job,
- a hoist location conflict happens when a job has to be moved, but the hoist is too far away to reach the job before the latter is spoilt.

2.3. Criteria formulations

Three criteria are considered. The first criterion is used for the optimization of the scheduling problem of a traditional production workshop.
The considered objectives are:

- the minimization of the cycle time, f1:

$$f_1 = CT(RP_p) = \max_{1 \le i \le N}\left(\sum_{j=1}^{I} O_i(p) P_{ji}^{\min}\right)$$
$$= Z_{i_C}(p) = \sum_{i=1}^{N}\left(\sum_{j=1}^{I} O_{i_C}(p) P_{ji_C}\right)$$

- the minimization of the total duration of the production, f2:

$$f_2 = MP = \sum_{p=1}^{RP_{\max}} X(p) CT(RP_p)$$

- the maximization of the production of products, f3:

$$\begin{cases} f_3 = \sum_{p=1}^{RP_{\max}} X(p) \sum_{i=1}^{I_{\max}} I(p) \\ with\ \forall p \in \{1,\dots,RP_{\max}\},\ X(p) \in \mathbb{N} \\ \sum_{p=1}^{RP_{\max}} X(p).\sum_{i=1}^{I_{\max}} I(p) \le T(I),\ \forall i \in \{1,\dots I_{\max}\} \end{cases}$$

3. Scheduling based on the calculation of the margins for line of surface treatment

3. 1. Basic idea

Generally in the scheduling problem, the first work step starts with manual modeling such as the Gantt-Chart, R.d.P, etc.
These representations are based on the guesswork until having a general idea on the scheduling workshop, the resources availability, the hoist availability, the temporal and technical constraints.

The second step consists on the formulation and the optimization of this scheduling using the optimization methods.
Unfortunately, we need time to seek a scheduling satisfying the criteria without reaching it, because this scheduling is not feasible for the considered constraints and there is no technique for testing a scheduling feasibility.
In this part, an efficient scheduling technique based on the margins calculations is presented.

The proposed approach consists of two phases. The first phase is based on the calculating of the various resources loads, the optimal cycle time and the various margins for which new concepts will be introduced in following. The second phase consists in making a test on the basis of margins calculations and the scheduling feasibility. In the case of the feasible scheduling, we can know also the point making this scheduling unfeasible.
The results of this new technique will be evaluated by a real production system.

3. 2. Presentation of the T.S line production

The production of zink product and nickel product and two silver products enables us to obtain the logical manufacturing process presenting the system of production according to figure 2.

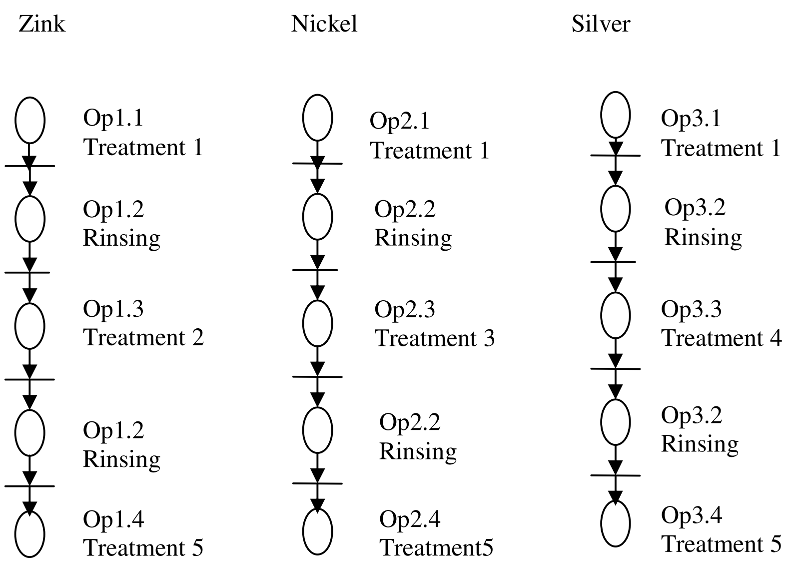

Fig. 2. Logical manufacturing process of production system

The table 1 presents the various operations, the tanks and processing time

Table 1. Different operations of S.T line proposed

Operation number	Operation type	Tank	Processing time [min, max]
Op1.1	Treatment 1	T1	[300, 600]
Op1.2	Rinsing	T2, T3, T4	[60, + ∞[
Op1.3	Treatment 2	T5	[1800, 1800]
Op1.4	Treatment 5	T8	[60, + ∞[
Op1.5	Move	Hoist	[60, + ∞[
Op2.1	Treatment 1	T1	[300, 600]
Op2.2	Rinsing	T2, T3, T4	[60, + ∞[
Op2.3	Treatment 3	T6	[1800, 1800]
Op2.4	Treatment 5	T8	[60, + ∞[
Op2.5	Move	Hoist	[60, + ∞[
Op3.1	Treatment 1	T1	[300, 600]
Op3.2	Rinsing	T2, T3, T4	[60, + ∞[
Op3.3	Treatment 4	T7	[180, 300]
Op3.4	Treatment 5	T8	[60, + ∞[
Op3.5	Move	Hoist	[60, + ∞[

Working assumptions

- Hoist time move is constant and equal to 60 seconds.
- Consequently, tank *Ti* treating a product will be available only after the completion of processing time of this product with hoist time move of this product to the following tank and will be occupied by a second product only after the completion of the hoist time move of the new product to the tank *Ti.*
- Generally, a tank *Ti* is accessible only after the processing time of the product with two hoist move time.

Thus, the loads occupation calculations of the various tanks are listed in table 2.

Table 2. Loads occupation calculations of S.T line proposed

Tank number	*Minimal Occupation load*	*Maximum Occupation load*
T1	4(300''+120'') = 1680''	4(600''+120'')= 2880''
T5	1800''+120''=1920	1920''
T6	1800''+120''=1920	1920''
T7	2(180''+120)= 600''	2(300''+120)= 840''
T8	4(60''+120'')=480''	+ ∞
T2, T3, T4	8(60''+120)=1440 2bains 540'' et 1 bain 360''	+ ∞
Hoist	20.60''= 1200''	+ ∞

Before using the methods of resolution, is presented some lower bound to locate the performances of the methods of resolution compared to the optimal value cycle time.

The lower bound of the cycle time is defined as follows:

$$
\begin{aligned}
CT(p) &= \max_{1\le i\le N}\left(\sum_{j=1}^{I} O_i(p) P_{ji}^{\min}\right) \\
&= Z_{i_C}\ (p) = \sum_{i=1}^{N}\left(\sum_{j=1}^{I} O_{i_C}(p) P_{ji_C}\right) \\
&= 1920s
\end{aligned}
$$

The lower bound of work-in-process number is defined as follows:

$$
\textit{Number}\ \text{work-in-process}_{\min} = \sum_{i=1}^{N}\left(\sum_{j=1}^{I} O_i(p) P_{ji}^{\min}\right) / CT(p) \approx 5
$$

3.3. A Gantt-Chart representation of the studied S.T line

During the scheduling phase, the dual Gantt-Chart is used. The proposed representation combines, at the same time, the execution of the tasks and the activities of the hoist [14].
A Gantt-Chart representation of the S.T line for a move time equal to 60 seconds is illustrated in figure 2.

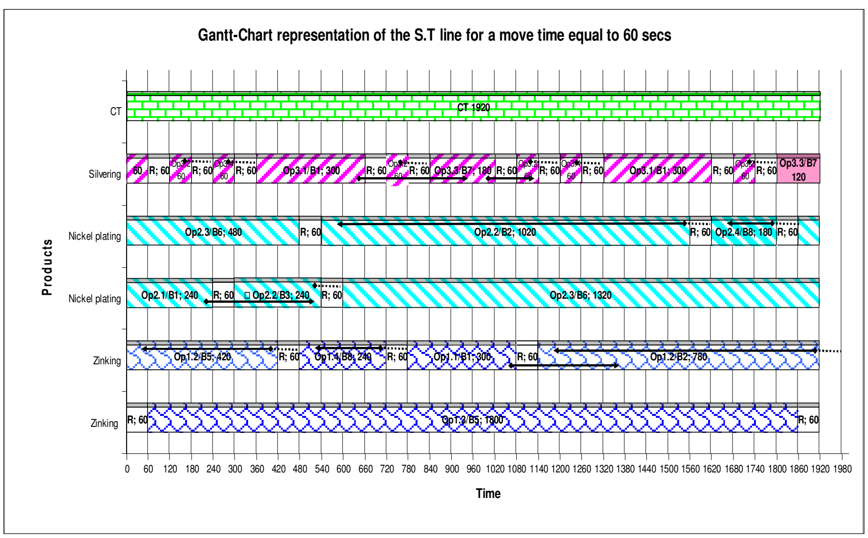

Fig. 3. A Gantt-Chart representation of the S.T line

The plot area consists of the horizontal axis which presents time in seconds and the vertical axis which presents the whole of the products in the S.T line. The rectangles represent the processing operations. The two arrows located at the edge of the end of each operation indicate the minimal and maximum margin of each operation. If the

arrow is in discontinuous line, the maximum margin tends to the infinity. If there is no arrow, it means that this operation has neither minimal margin nor maximum margin. This Gantt-Chart is of minimal width equal to the optimal cycle time. The transport resources are associated with the products throughout all their production.
This hypothesis enables us to combine the minimization of work-in-process with the minimization of the transport resources.
Thus, for the zink product, it is possible to have k work-in-process associated in the system to see a finished product by cycle (for this example k = 2). This number k represents the transport resources number used to produce the zink product [1, 10].

Consequently, the real duration of the manufacture of the product of Zink is k_Z cycles. The processing of all the product spends a cycle time equal to $K = p.p.c.m\ (k_z\ ,\ k_n\ ,\ k_s)$ multiplied by optimal cycle time. This phenomenon is with the fact that, often, the temporal length of a manufacturing process (operational durations) is higher than the cycle time. It is then necessary to use enough of work-in-process to respect this optimal cycle time and to saturate the critical machines. In fact, all occurs like if, during a cycle, each portion of a product is virtually and simultaneously produced by different transport resources.

3. 4. Formulation margins

In order to test a scheduling feasibility, all the margins defined have to be calculated.

Manufacturing process margin
For each manufacturing process, is introduced a lower bound of work-in-process, necessary to respect the minimal flow. Thus, with the scheduling beginning, the margin is equal to

$$\text{Manufacturing process } margin_j = (Number \text{ work-in-process } \times CT) - (\sum_{i=1}^{N} O_i(p) P_{ji}^{\min})$$

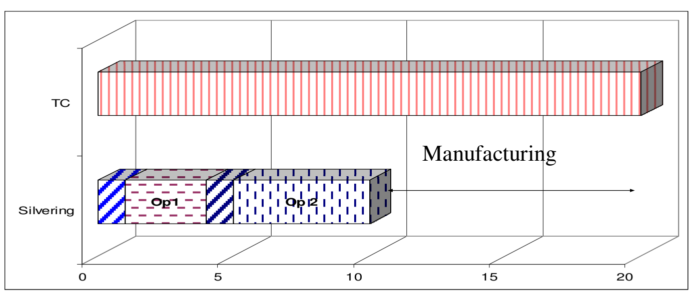

Fig. 4. Manufacturing process margin

Let us recall that during the calculation of the tank load of two cases are presented in following.

- A resource of treatment can be the driving resource of scheduling and its load is equal to the optimal cycle time.

- The hoist, having an occupation load, can be also the driving machine and its load becomes equal to the cycle time.

As previously said, the temporal length of a manufacturing process is higher than the cycle time, consequently, one cannot compensate it in only one work-in-process and cannot impose that the manufacturing process length is exactly divisible by the cycle time. Then, the addition of work-in-process often requires the extending of the manufacturing process concerned to saturate the vacuum and distribute the hoist occupation on the cycle time.
Margin extending is done, in the same time at exploitation of the minimal and maximum margins of the processing time of each tank operation.
As a remark, during scheduling, the hoist availability is the major constraint.
For single hoist, essential for the placement of the remaining operations, we can have many transport resources.
Consequently, are defined intervals of availability, considered as time intervals unit separating the various operations of scheduling. Then we make the processing time divisible by the hoist move time.
In this paper, we consider only the durations representing the smallest multiple *p.p.m* of hoist move time, θ_{ij}^{r} , knowing that *p.p.m* must be between the minimal and the maximum margins: $P_{ji}^{\min} \leq p.p.m \leq P_{ji}^{\max}$

Machine margin
Each machine admits initially a processing time P_{ji} between a minimal margin $P_{ji}^{\min}$ and a maximum margin $P_{ji}^{\max}$; so it is possible to extend this processing time while benefiting from this temporal flexibility. Thus, we define an absolute margin for each machine formulated as:

$$Absolute\ m\arg in_i = P_{ji}^{\max} - P_{ji}^{\min}$$

Each machine also admits an operate margin null for the critical machines. This margin, equal to the cycle time decreased of the load occupation of the machine, noted relative margin, is expressed as follows:

$$\mathrm{Re}\,lative\ M\arg in_i = CT(p) - (\sum_{j=1}^{I} O_i(p) P_{ji})$$

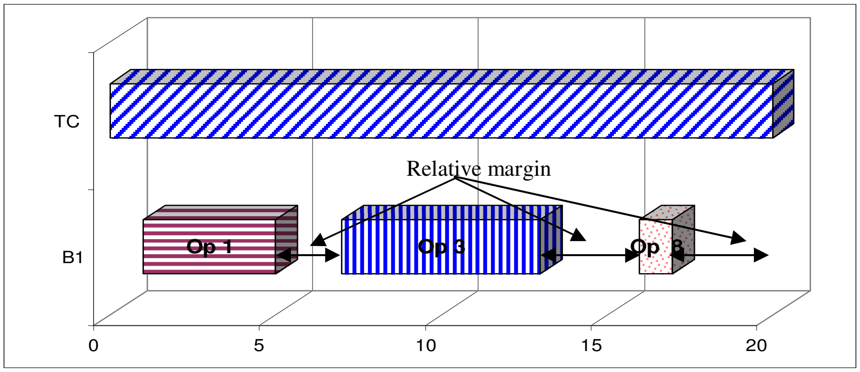

Fig. 5. Relative margin

Extending margin

Considering that relative margin often lower than the absolute margin, let define the extending margin as:

$$Extending\ margin_i = \min(Relative\ margin_i,\ Absolute\ margin_i)$$

3.5. Application of the margins calculation for a single-hoist/multiple-products of S.T line

Let us consider a Job Shop workshop of single-hoist/multiple-products S.T line presented in figure 3, with a move time equal to 60 seconds. The margins calculations are done in order to see the utility of the scheduling feasibility test according to lost time.

At the moment when the hoist lost time added the hoist minimal load exceeds the optimal cycle time, the scheduling becomes unfeasible.

Table 3. Test for the scheduling feasibility for a move time equal to 60 seconds

Tank	$P_{ji}^{\min}$	$P_{ji}^{\max}$	*p.p.m*	Minimal tank load	Optimal CT
T1	300	600	300	1680	1920
T2	60	INF	60	540	1920
T3	60	INF	60	540	1920
T4	60	INF	60	360	1920
T5	1800	1800	1800	1920	1920
T6	1800	1800	1800	1920	1920
T7	180	300	180	600	1920
T8	60	INF	60	720	1920
Hoist	60	60	60	1200	1920

Absolute Margin	Relative Margin	Extending Margin	Hoist lost time	Scheduling feasibility
300	240	240	0	1
INF	1380	1380	60	1
INF	1380	1380	120	1
INF	1560	1560	240	1
0	0	0	480	1
0	0	0	960	0
120	120	120	1920	0
INF	1200	1200	3840	0
0	720	0	7680	0

It is noticed that when hoist lost time is equal to 780 seconds, the cycle time of a feasible scheduling would be equal to 1980 seconds higher than the optimal cycle time equal to 1920 seconds. Thanks to these calculations, we know now in advance that it is difficult to find an optimal solution as soon as one exceeds a certain value of lost time.
For a hoist move time equal to 90 seconds calculations change and the use of *p.p.m* approach seems efficient.

Table 4. Test for the scheduling feasibility for a move time equal to 90 seconds

Tank	$P_{ji}^{\min}$	$P_{ji}^{\max}$	*p.p.m*	Minimal Tank load	Minimal Tank load with *p.p.m*	Optimal CT
T1	300	600	360	1920	2160	1980
T2	60	INF	90	720	810	1980
T3	60	INF	90	720	810	1980
T4	60	INF	90	480	540	1980
T5	1800	1800	1800	1980	1980	1980
T6	1800	1800	1800	1980	1980	1980
T7	180	300	180	720	720	1980
T8	60	INF	90	960	810	1980
Hoist	90	90	90	1800	1800	1980

Absolute margin	Relative margin	Lengthen margin	Hoist lost time	Scheduling feasibility
300	60	60	0	1
INF	1260	1260	60	1
INF	1260	1260	120	1
INF	1500	1500	240	0
0	0	0	480	0
0	0	0	960	0
120	1260	1260	1920	0
INF	1020	1020	3840	0
0	180	0	7680	0

We remark here the difference between the *p.p.m* column and the $P_{ji}^{\min}$ column. In fact, the extending of the minimal limit tank of each tank is made in order to have a *p.p.m* time between the minimal and maximum limits processing time. Calculations also show that it is impossible to present new scheduling with a ratio production of 112 (one zinc product, one nickel product, two silver products) since the tank load 1with *p.p.m* higher than the optimal cycle time; then we will pass to a ratio 111 (one zinc product, one nickel product, one silver product).
This test shows that an optimal solution can be obtained and then a new Job Shop Scheduling problem single hoist /multiple products of T.S line.

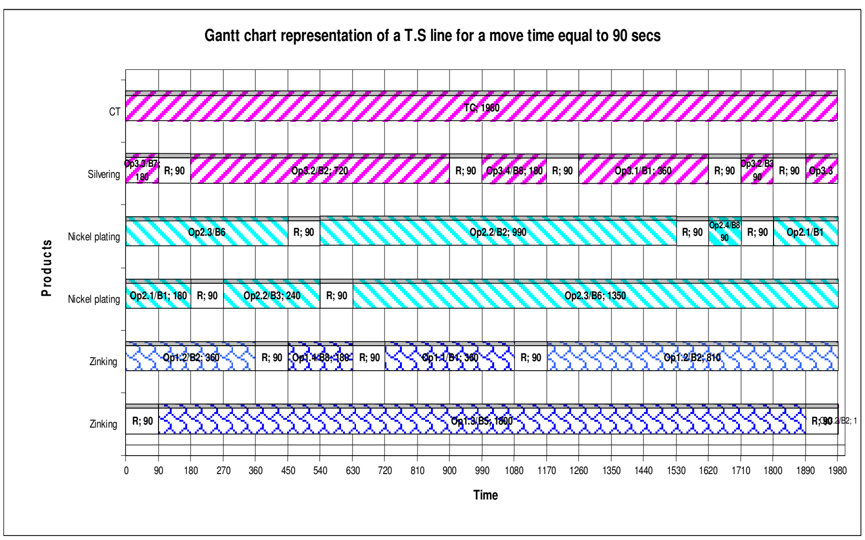

Fig. 6. A Gantt-Chart representation of the S.T line for move time equal to 90 seconds

At this stage, we don't work by groping. Indeed, this technique allows us to test, from the beginning, the optimal scheduling feasibility according to the estimated lost time.

4. Conclusion

This paper deals with Job Shop scheduling problem single-hoist/multiple-products of a T.S line. In such system processing time is included between a minimum and a maximum value. The difference between these two values is noted margin. A new technique based on the margins calculation is proposed for finding a feasible scheduling.

The approach developed in this work provides the possibility to test the feasibility scheduling on an optimal cycle time. Besides, the proposed approach mainly uses the extending margin to obtain an applicable scheduling.

In the near future, it is essential to develop an algorithm using this result and providing a feasible scheduling.

References

[1] Camus, H., «Conduite de Systèmes Flexibles de Production Manufacturière par composition de régimes permanents cycliques : modélisation et évaluation de performances à l'aide des Réseaux de Petri», Thèse de Doctorat, Université de sciences et techniques de Lille ,1997.

[2] Carlier, J., and Chrétienne, P., «Problèmes d'ordonnancement, Modélisation, Complexité, Algorithmes». Edition Masson, 1998, Paris.

[3] Chen, H., Chu, C., and Proth, J., «Cyclic scheduling of a hoist with time window constraints», IEEE Transactions on Robotics and Automation, 14/1 (1998) 144–152.

[4] Chu, C., Proth, J. M., «L'ordonnancement et ses applications», Série : Sciences de l'Ingénieur. Collection organisation industrielle, Masson, 1996

[5] Collette, Y., «Optimisation Multiobjectif», Editions Eyrolles, 2002, Paris.

[6] Esquirol, P., Lopez, P., « L'ordonnancement » Série : Production et techniques quantitatives appliquées à la gestion. Collection Gestion, Economica, 1999.

[7] Hindi, K.S., Fleszar, K., «A constraint propagation heuristic for the single-hoist, multiple-products scheduling problem», Computers & Industrial Engineering 47 (2004) 91–101.

[8] Kats, V., and Levner, E., «A strongly polynomial algorithm for no-wait cyclic robotic flowshop scheduling», Operations Research Letters, 21/4 (1997) 171–179.

[9] Kats, V., Levner, E., and Meyzin, L., «Multiple-part cyclic hoist scheduling using a sieve method », IEEE Transactions on Robotics and Automation, 15/4 (1999) 704–713.

[10] Korbaa, O., «Commande cyclique des systèmes flexibles de production manufacturière à l'aide des réseaux de pétri : de la planification à l'ordonnancement des régimes transitoires», Thèse de Doctorat, Ecole Centrale de Lille, 1998.

[11] Yih, Y., «An algorithm for hoist scheduling problem», International Journal of Production Research, 32(3), 501–516, 1994.

[12] Lei, L., and Wang, T.J., «Determining optimal cyclic hoist schedules in a single-hoist electroplating line», IIE Transactions, 26/2 (1994) 25–33.

[13] Levner, E., and Kats, V., «A parametric critical path problem and an application for cyclic scheduling», Discrete Applied Mathematics, 87 (1998) 149–158.

[14] Mangione, F., «Ordonnancement des ateliers de traitement de surface pour une production cyclique et mono-produit», Thèse de Doctorat, Grenoble, 2003.

[15] Phillips, L., and Hunger, P., «Mathematical programming solution of a hoist scheduling problem», AIIE Transactions (1976), 219–225.

[16] Song, W., Zabinsky, Z.B., and Storch, R.L., «An algorithm for scheduling a chemical processing tank line», Production Planning & Control, 4/4 (1993) 323–332.