International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 04 - Issue 08 || August 2018 || PP. 100-118

Identification and measurement of lost time as an indicator of the performance of the industrial system

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Abstract: Nowadays, competition forces companies to continually evaluate their performance, in order to investigate the lost time in hierarchically organized industrial systems, a number of hypotheses have been formulated to clearly describe the periodic treatment of an unknown event that can disrupt the normal functioning of the system. In every circumstance, the time lost depends on the parameters of a given system. A methodology to help simulate and reduce the time lost has been proposed prior to the development of an indicator as a function of the variation of the periodicity of event management. Finally, observable data collected from a case study of a sugar-processing unit were compared to the testing and implementation of the theoretical model. The empirical data showed only minor deviations from the simulated results. Therefore, it was concluded that the model can be used to predict and optimize mechanical maintenance performance.

Keywords: Performance indicators, periodic processing, simulation, time loss.

I. INTRODUCTION

The complex industrial environment with large and deregulated markets requires a company that remains dynamic and innovative in order to secure its future. In this context, the focus is more on performance indicators [1][2][3] as a means of acquiring information to achieve the objectives of the enterprise and inform the actors to achieve these objectives.

The concept of performance indicators and their uses has some important characteristics. The first notion is the quantifiable aspect of an indicator [4][5][6][7] which underlies all the measures. Although the intrinsic quantification of performance indicators does not require such an approach, it usually involves a search at higher and lower levels of the evaluated system. The second key concept underlying the performance indicators is their objectives [8]. This aspect of the indicator is considered fundamental because the evaluation is mainly done by comparison to a reference. The main goal of most system performance is to measure the difference between the actual performance and the performance the system aspires to and evaluate the acceptability of that difference. Another obvious concept in the concept of performance of indicators, above the aspect of performance contained directly in a specific definition, is that the indicators are necessarily related to the likely action induced [9]. Indicators are therefore characterized by an objective, a measure of effectiveness, and action variables [10][11][6][12][13][14].

The following discussion examines the performance of indicators in a more general workshop control framework, to which many industrial production tasks have been attributed [11]. Although different in their methodologies, performance-based approach indicators all have the same end goal; to improve the performance of the studied system.The majority of services in the industrial system are placed in the context of a hierarchical organizational plan. [13][14] In practice, when an unknown event occurs, the decision to intervene, mitigate the disturbance and bring the system to its normal state comes from a level higher than that in which the event occurred. As a result, several levels of decision-making help to respond to an event. This is the responsiveness of the system to a problem and it can be measured as a function of the time that passes from the occurrence of an unknown event to when the system returns to its normal state. This aspect of the study of the performance of the indicators is hardly taken into account. In some studies, Regnier P.[15] and Menye J. B.[16] propose a model of responsiveness as indicator performance based on a multi-level control system using a GRAI decision-making model (Graphs with results and interconnected interactions) [17][18]. The design of our model is based on the dynamism described in this work.

Any given structure has the advantage that the general objectives are divisible into sub-objectives of acceptable size and complexity. However, the often-heterogeneous aggregation of information, as well as insufficient communication between different levels of decision-making, pose challenges. In the worst case, this weakness could mean that the impacts of the disturbance extend to the highest level of the structure, thus increasing responsiveness. In addition, when managing an unknown event, the transfer of information is not instantaneous between the different levels involved; lost time exists that is part of the process but does not add value.

The lost time mentioned above is a reality in industrial circles and requires further research. We have therefore identified a performance indicator, the response time of a system to an event.

The purpose of this article is to establish and study the lost time for an industrial system, including the hierarchical organizational plan that does not add value to the identified objectives of the structure.To do this, we first want to make certain assumptions, a simulation that helps to identify the procedures to reduce the time lost and, consequently, proportionally reduce the response time of the system following an event. We also validate the results with a case study of a sugar-processing unit.

II. HYPOTHESES

On the basis of the GRAI model, the lost time model is defined according to the hypotheses presented below:

- Propagation of the event: the event appears at a level where it is untreated and has repercussions at higher levels. Impacts move from one level to another until the level at which the event is processed.

- The function is periodic: the repercussions of the same level involve two phases, an upstream phase, which is the ascending phase (from the lower levels to the higher levels) and a downstream phase, which corresponds to the repercussions of the levels where the event is addressed to lower levels where it is processed. In these two phases, the pass from one level to another occurs at the end of the period. The behavior is periodic.

- The transmission of the event from one level to another or the transmission of the reaction from one level to another is not instantaneous. A transmission delay (non-zero) occurs upstream and downstream between two consecutive levels.

Each level implies an offset (which could be zero) between the reference date, the time origin (t_0) and the start date of the reference period of the level k, considered as $x^k(0)$. Change is not necessarily equal for each level.

- We consider the worst case of an event, which appears at level 0, and which is untreated and has repercussions on the level N where it is finally processed. This approach has the longest reaction time.

The objective is first to express the reaction time T of the system according to the date of occurrence of an unexpected event and according to the parameters of the system, in particular the start dates of the reference period of the different levels involved in the treatment of the event. This is expressed in the equation (1).

$$T = f\left[u^0, \{x^k(0)\}_{k=0,1,\dots,N}\right], \qquad (1)$$

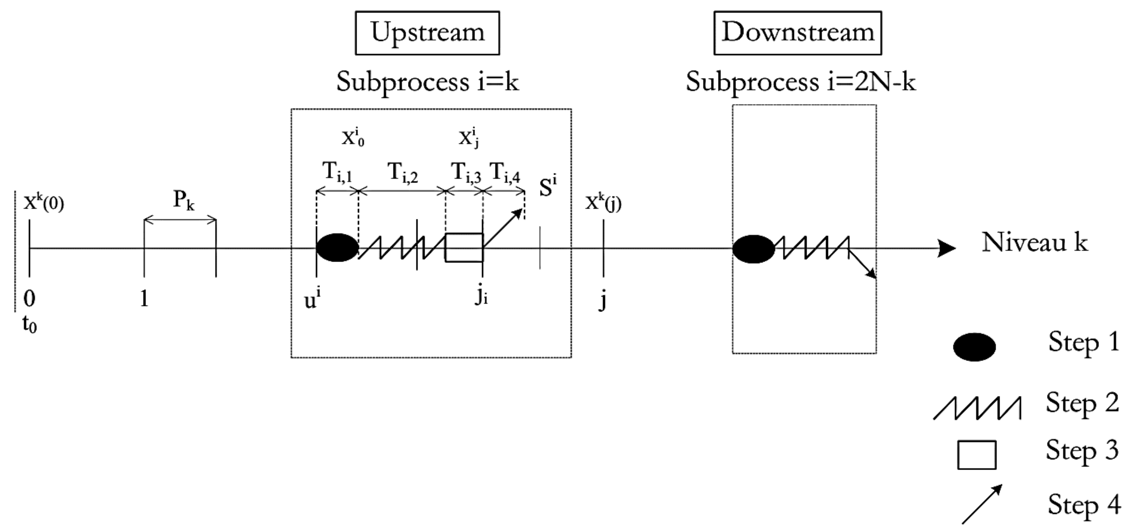

Figure 1: Duration and state change in a spi sub-process for a k level

Where $x^k(0)$ is the initial date of the reference period, $u^o$the occurrence date of the event and T the reaction time of the system.

We designate by a sub-process each passage of an event through a level. Then, every level k, except the highest level (k=N), is composed of two sub-processes spk and sp_{2N-k} , which treat the event upstream and downstream, respectively (Figure 1). The level N where the event is finally treated has just a single sub-process, *spN.*

The process therefore has a total of 2N+1 sub-processes (0, 1,......., 2N). In each sub-process *i*, sp_i, except in the last (i=2N), the event in the upstream phase passes through four successive stages; the reaction in the downstream phase equally passes through four successive stages (Table 1). The last sub-process *2N*, sp_{2N}, has only first three stages.

Table 1. Different stages of treatment in a sub-process.

Stage	**Designation**		**Duration**
	Upstream Phase	**Downstream Phase**	
E_1	Evaluation of the gravity	Verification for coherence	$T_{i,1}$
E_2	Preliminary treatment	Elaboration of the decision framework	$T_{i,2}$
E_3	Wait for end of period	Wait for end of period	$T_{i,3}$
E_4	Transfer to superior level	Transfer to inferior level	$T_{i,4}$

III. MODELING LOST TIME TATT

We define the parameters of the model of Figure 1 as:

t_0 : reference date;
k : level considered;
i : index of the sub-process considered ;
l : index of the state of the event;
j : number of order of the period
N : level where the event is treated;
sp_i : sub-process *i* of the event;
E_l : stage l of treatment of the event;
P_k : duration of the period of level *k*;
j_i : synchronisation period at which the event is treated in sp_i;
$x^k(0)$: start date of the reference period at level *k*;
x^i_0 : arrival date of the event in the sub-process sp_i;
$T_{i,,l}$: duration of stage l in sp_i;
S : execution date of the reaction;
T : reaction delay of the system to the event;
u^i : entrance date of the event into sp_i;
$x^k(j)$: finish date of period *j* of level *k*;
x^i_l : finish date of stage El, of the event, of *spi*;
si : exit date of the event (end of the last stage) of *spi*;
T_{att} : sum of the wait times

All processes *i* (i = 0, 1… 2N) belong to a level *k* which we determine as follows to equation (2).

$$k = \begin{cases} i & \text{si } i \le N \\ 2N - i & \text{if not} \end{cases} \quad (2)$$

There are two distinct dynamics in the process of treatment. The first (step change) is executed in irregular cases depending on the duration of the different steps (Table 1), intrinsic characteristic of the system with respect to a given event. The other is decision-making, which is regular because it is periodic at each level. Both dynamics must be synchronized for the event to proceed from step E3 to E4 (Figure 1) before a decision about event processing is made. One of the two dynamics must adapt to the other. This distinguishes periodic conduct from factual conduct.

In factual conduct, it is the dynamics of decision-making that is adapted to the disturbance because it is regular, the factual conduct must be. On the other hand, in the periodic conduct, it is the dynamic of the event that adapts to that of the decision-making. This adaptation will involve a lost time before the treatment of the event.

Mixed conduct is a periodic conduct; but for critical disturbances, a decision is made without waiting for the end of the period.

$$x^k(j)=P_k+x^k(j-1) \qquad (3)$$

or

$$x^k(j)=jP_k+x^k(0) \qquad (4)$$

The transition from the next period j to j + 1, on a given level k, is done at the end of the period k, $x^k(j)$, which is given by equation (3) or (4):
In periodic control, the event is processed in the spi sub-process, at period ji, of level k (where in the spi sub-process appears), which is determined as follows by equation (5):

$$\begin{cases} j_i = \lambda \quad \text{if } \exists\, \lambda \in \mathbb{N} \text{ such that } u^i + T_{i,1} + T_{i,2} - x^k(0) = \lambda P_k \\ j_i = E\left(\dfrac{u^i + T_{i,1} + T_{i,2} - x^k(0)}{P_k}\right) + 1 \quad \text{if not} \end{cases} \qquad (5)$$

E represents the real part of *x*.

The dates of change of the step between the event (transition from step El to step El + 1), for each of the four steps of the sub process spi, xil, are given by equation (6):

$$\begin{cases} x_l^i = x_{l-1}^i + T_{i,l} \quad \forall l \in \{1,2,4\} \\ x_3^i = x^k(j_i) \quad l = 3 \end{cases} \qquad (6)$$

For l = 3, the equation we have established is the synchronization between the two dynamics. It allows us to determine the date on which the decision to transfer the event is made. This date coincides with the end of the synchronization period ji, of the spi sub-process.
Entrance $u^i$and exit si in the upstream phase of the periodic process is such that by equation (7):

$$\begin{cases} u^i = x_0^i \\ s^i = x_4^i \end{cases} \qquad (7)$$

We then obtain equations (8).

$$\begin{cases} x_1^i = x_0^i + T_{i,l} \\ x_2^i = x_1^i + T_{i,2} \\ x_3^i = x^k(0) + j_i.P_k \\ x_4^i = x_3^i + T_{i,4} \end{cases} \qquad (8)$$

The exit date is therefore:

$$Si = x^k(0) + j_iP_k + T_{i,4} \qquad (9)$$

This result is valid for all sub-processes i, except the last one, i = 2N, for which state E4 does not exist. As a result, T2N, 4 = 0. We have equation (10):

$$S^{2N} = x^{2N}(0) + j_{2N}P_0 \qquad (10)$$

The processing process has N + 1 levels and 2N + 1 sub-processes. The event traverses all sub-processes.
The event entry date in a sub-process is equal to its exit date from the previous process. Input datais show by equation (11) and parameter by equation (12)
Input data

$$\begin{cases} u^0 \\ x^k(0) \quad \forall k = 0,1,\ldots,N \end{cases} \quad (11)$$

Parameters

$$\begin{cases} P_k \quad \forall k = 0,1,\ldots,N \\ T_{i,l} \quad \forall l \in \{1,2,4\} \text{ and } i = 0,1,\ldots 2N (\text{except } T_{2N,4}) \text{ which does not exist} \end{cases} \quad (12)$$

Calculations:

For i=0,1,…,2N-1 we have equation (13)

$$\begin{cases} s^i = x^k(0) + j_i P_k + T_{i,4} \\ u^{i+1} = s^i \end{cases} \quad (13)$$

For i=2N we have equation (14)

$$S^{2N} = x^0(0) + j_{2N} P_0 \quad (14)$$

The reaction time represents the time elapsed since the occurrence of the event until the reaction was executed. For our model, this is the difference between the exit date of the reaction process event (the output date of the last sp2N sub-process) and the occurrence date of the event at the first level 0. This is written as: No more by equation (15) or (16).

$$T = S^{2N} - u^0 \quad (15)$$

or

$$T = \left(x^0(0) + j_{2N} P_0\right) - u^0 \quad (16)$$

On each decision-making level k, phase E3 in the upstream and downstream phases is lost for the end of the period. The cumulative time lost T_{att} we propose to establish is a delay in the processing of the event. For this, we will establish another expression for the previous reaction time. It is obtained by expressing the sum of all the processes, the duration of the events in all the steps of each sub-processshow by equation (17):

$$T = \left(\sum_{i=0}^{2N} T_{i,3}\right) + \left(\sum_{i=0}^{2N}\sum_{l=1}^{2} T_{i,l} + \sum_{i=0}^{2N-1} T_{i,4}\right) \quad (17)$$

Which is of the form: (i)+(ii) show by equations (18) and (19).

$$(i) = T_{att} = \left(\sum_{i=0}^{2N} T_{i,3}\right) \quad (18)$$

$$(ii) = \left(\sum_{i=0}^{2N}\sum_{l=1}^{2} T_{i,l} + \sum_{l=0}^{2N-1} T_{i,4}\right) \quad (19)$$

This expression shows us that the reaction delay is done:

- From Part (i), constituting the waiting times

From part (ii), constituting the characteristic moment of the process, which is incompressible.

Approaching this expression of reaction time with that obtained previously, the lost time (1) is written:

Either as equation (20) or equation (21)

$$T_{att} = T - \left(\sum_{i=0}^{2N}\sum_{l=1}^{2} T_{i,l} + \sum_{i=0}^{2N-1} T_{i,4}\right) \quad (20)$$

$$T_{att} = (j_{2N} P_0) - \left(u^0 - x^0(0) + \sum_{i=0}^{2N}\sum_{l=1}^{2} T_{i,l} + \sum_{i=0}^{2N-1} T_{i,4}\right) \quad (21)$$

In this equation that gives us lost time, only j2N varies according to the start dates of the reference period of the levels. All other terms are constant for a given system and event, and the time lost is set as functions of the system parameters.

IV. STUDY CASE

The operating environment of the production units has undergone a tremendous transformation for many years. The demographic (aging of the population), social (unemployment, poverty) and economic changes (competition) have disrupted the economy of the production units. In addition, sugar production units are continuously subject to monetary constraints, which require considerable changes in management practices. In recent years, the techniques of the business world are increasingly adopted in sugar establishments. One of the main differences between the industrial and sugar sectors is that the sugar sector does not decide on the tariffs it uses, but must ensure efficient production of the best quality at the best possible cost. This explains why the sugar sector, especially the public sector, is constantly in deficit. It is therefore necessary to rationalize operational costs as well as investments.

Thus, the sugar production units face imperatives to develop operational tools, to evaluate and control performance, which involves defining and executing a system of performance indicators. The definition and model presented above is applied to the sugar sector, with some restrictions that are additional premises and which define the framework of our case study. The sugar production unit was chosen as a case study for this work on lost time. The close collaboration with this unit provided us with the information to carry out our numerical analyzes [19].

In order not to disrupt the operation of the unit, the following steps were followed:

- We have limited the model to a specific sugar unit, which in the hierarchical system has seven levels of decision-making.
- An event is represented by a failure whose state does not need to be factually considered.
- We consider the periods by levels and the dynamics of the treatment.
- We consider the chain of steps by levels and corresponding times. This view excludes the time lost during the reception. The process starts from the moment the failure is reestablished.

Taking into account the particular environment of our case study and for the purpose of equipment availability, the measurements of the different experimental parameters were made by the members of the unit. A comparative study was then carried out between the experimental results and those obtained by simulation.

4.1. Study of existing model

4.1.1 Methods

In the case of a breakdown that represents the event, the selection is based on the severity of the failure and the participation is factual or periodic. In this analysis, the process begins with the decision on the ability of the production operator to restore the industrial system or not. The flowchart is shown in Figure 2.

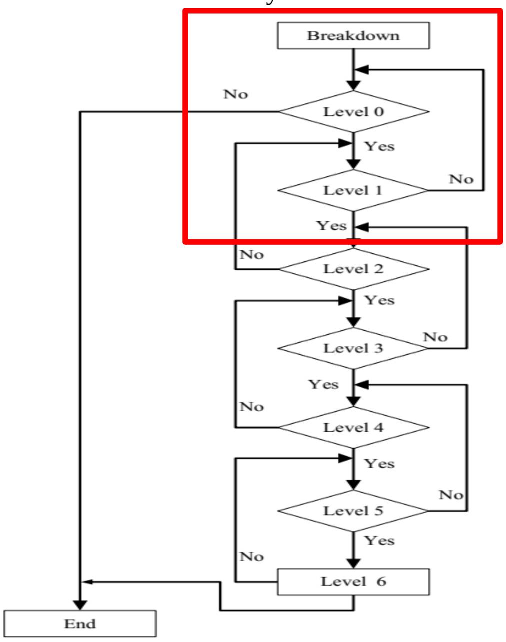

Figure 2: Flow diagram of the procedure

In our study, we will be focus on red area localized in figure 2.

Transmission occurs in the upstream phase of the event, from level to level from lower to higher levels each time a solution is not received. In the downstream phase, once the solution is received, the transmission takes place at the lower level.

The failure is thus diagnosed from a lower level to the highest level where the final solution is adopted and then transmitted to a lower level where the instructions are applied. The levels of decision-making and the different stages were defined by the organization chart of the company and discussions with the technical team of the processing unit in our case study (Tables 2, 3, 4 and 5).

At each decision level, although the chain of steps is the same as the decision level k, the description of the task executed is not the same. As an illustration, we consider the example of levels 0, 1 and 6.

Even if the chain of steps is the same regardless of the level of decision-making, the description of the task performed is not the same.

Table 2: level of decision-making

Level n	speaker
0	Production operator
1	Maintenance technician
2	Team Lead
3	Shift supervisor
4	overseer
5	Lead maintenance Manager department
6	Factory manager

Table 3: The different stages of information processing at level 0 (production operator)

Step	Information rise phase		Information descent phase	
	Description	duration	Description	duration
E_1	Failure finding	$T_{0,1}$	Reception of instruction (s)	$T_{12,1}$
E_2	(preliminary) Diagnosis (thanks to the appropriate tools)	$T_{0.2}$	Execution of the instruction	$T_{12,2}$
E_3	Decision making and analysis	$T_{0,3}$	Observation and follow-up	$T_{12,3}$
E_4	Execution or transfer of information to the next level	$T_{0.4}$		

Table 4: The different stages of information processing at Level 1 (Maintenance Technician)

Step	Information rise phase		Information descent phase	
	Description	duration	Description	duration
E_1	Reception information	$T_{1.1}$	Reception of instruction (s)	$T_{11,1}$
E_2	Analysis and treatment	$T_{1,2}$	Execution of the instruction	$T_{11,2}$
E_3	Decision-making and implementation of an intervention procedure	$T_{1,3}$	Observation and follow-up	$T_{11,3}$
E_4	Execution or transfer of information to the next level	$T_{1,4}$		

Table 5: The different stages of information processing at level 6 (Plant Manager)

Step	Information rise phase	
	Description	duration
E_1	Reception information	$T_{6,1}$
E_2	Analysis and treatment	$T_{6,2}$
E_3	Decision-making and implementation of an intervention procedure	$T_{6,3}$
E_4	Transfer of decisions to level 5	$T_{6,4}$

4.1.2 Results and discussions

A study of the existing model was performed with data collected from the measurements made by the people involved in study. It consists of fixed periods of common consent and is validated by the technical team and the times of the different stages for each level. The data is as follows;

- The unit of time is the minute
- The reference date is a given minute considered as the origin of time
- The date of occurrence of the event after the reference minute is u0 = 180 .
- The times for the different levels are P0 = 8 min, P1 = 38 min, P2 = 68 min, P3 = 98 min, P4 = 128min, P5 = 158 min and P6 = 188 min.
- The reference period of all levels is defined at the reference date $t_0 = 0$. That is,

x1 (0) = x2 (0) = x3 (0) = x4 (0) = x5 (0) = x6 (0) = x7 (0) = 0.

The duration dates of the different steps of each sub-process are given in Table 6.

Table 6: Duration of the different sub-processes of each stage[20]

Sub-process i	Duration $T_{i,1}$	Duration $T_{i,2}$	Duration $T_{i,4}$
0	5	10	2
1	15	45	2
2	12	15	2
3	10	20	2
4	9	25	2
5	7	30	2
6	5	10	2
7	2	20	2
8	2	15	2
9	2	15	2
10	5	10	2
11	15	45	2
12	12	15	2

The simulation performed gave results that have been grouped together in Table 7.

Table 7: Simulation results[20]

Input Data						**Calculation and Data**			
K	**spi**	**P_k**	**$T_{i,1}$**	**$T_{i,2}$**	**$T_{i,4}$**	**$U^i(n)$**	**$T_{i,3}$**	**J_i**	**S^i**
0	0	8	5	10	2	180	3	25	205
1	1	38	15	45	2	205	2	7	270
2	2	68	12	15	2	270	2	5	344
3	3	98	10	20	2	344	5	4	399
4	4	128	9	25	2	399	3	4	517
5	5	158	7	30	2	517	5	4	639
6	6	188	5	10	2	639	10	4	764
5	7	158	2	20	2	764	7	5	799
4	8	128	2	15	2	799	5	7	903
3	9	98	2	15	2	903	4	10	986
2	10	68	2	10	2	986	3	15	1025
1	11	38	2	120	2	1025	2	31	1182
0	12	8	2	10		1182	2	150	1202
Reaction time			**1022**						
Waiting time			**53**						

The release date of the event is T = 1022 min
The total waiting time is $T_{att} = 53$ min

The organizational model of the sugar processing unit SOSUCAM presents some shortcomings (overlapping stakeholders at failure prevents complete transmission of information illustrated by figure 3; the non-rational use of stakeholders involved in decisional levels 0 and 1 illustrated by figure 4).

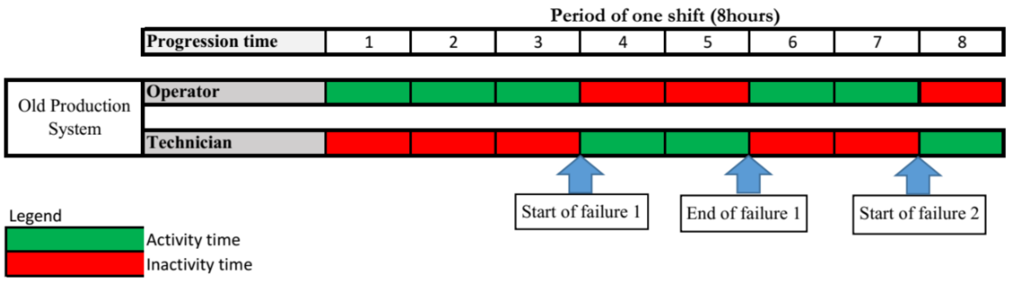

Figure 3: Current activity diagram of workers

4.2. Proposition of a theoretical model

4.1.3 Testing and implementation of the proposed theoretical model Hypotheses: (specify)

We propose a model where the focus is on dual qualification of the stakeholder by level: so instead of having an operator and an industrial maintenance technician, the profile will be more of a technical operator. This is illustrated by the figure 4.

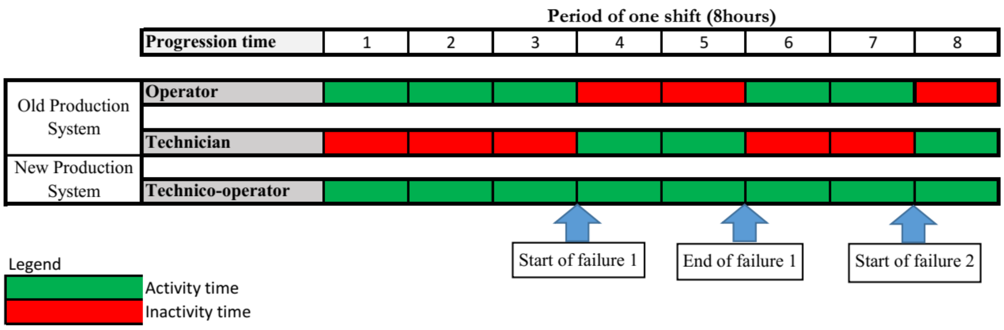

Figure 4: New activity diagram of workers

The flow chart template with level 0 and level 1 merge to form a new level 0 is shown in Figure 5.

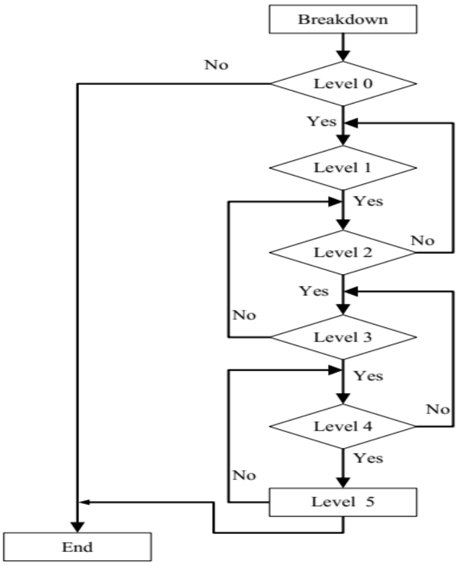

Figure 5: Flow diagram of the procedure

The tables 8, 9, 10 and 11 respectively present:

- The stakeholders of each decisional process level.
- The different stages of information processing at level 0 (Technico-operator).
- The different stages of information processing at Level 1 (Team Leader).
- The different stages of information processing at level 6 (Plant Manager)

Table 8: level of decision-making

Level n	Stakeholders
0	Technical operator
1	Leader
2	Shift supervisor
3	overseer
4	Maintenance Manager department
5	Plant manager

Table 9: The different stages of information processing at level 0 (Technico-operator)

Step	Information rise phase		Information descent phase	
	Description	duration	Description	duration
E 1	Failure finding	$T_{0,1}$	Reception of instruction (s)	$T_{10,1}$
E 2	(preliminary) Diagnosis (thanks to the appropriate tools)	$T_{0,2}$	Execution of the instruction	$T_{10,2}$
E 3	Decision making and analysis	$T_{0,3}$	Observation and follow-up	$T_{10,3}$
E 4	Execution or transfer of information to the next level	$T_{0.4}$		

Table 10: The different stages of information processing at Level 1 (Team Leader)

Step	Information rise phase		Information descent phase	
	Description	duration	Description	duration
E 1	Reception information	$T_{1,1}$	Reception of instruction (s)	$T_{9,1}$
E 2	Analysis and treatment	$T_{1,2}$	Execution of the instruction	$T_{9,2}$
E 3	Decision-making and implementation of an intervention procedure	$T_{1,3}$	Observation and follow-up	$T_{9,3}$
E 4	Execution or transfer of information to the next level	$T_{1,4}$		

Table 11: The different stages of information processing at level 6 (Plant Manager)

Step	Information rise phase	
	Description	duration
E 1	Reception information	$T_{5,1}$
E 2	Analysis and treatment	$T_{5,2}$
E 3	Decision-making and implementation of an intervention procedure	$T_{5,3}$
E 4	Transfer of decisions to level 5	

4.1.5 4.2.2 Numerical simulation model of the proposed model

4.2.2.1. Results and discussions

A numerical study was conducted with data collected from the measurements made by the people involved in the study. It consists of fixed periods of common consent and is validated by the team and the times of the different stages for each level.

The data is as follows;
- The unit of time is minimal
- The reference date is a given minute considered as the origin of time
- The date of occurrence of the event after the reference minute is u0 = 0.

- The durations for the levels are P0 = 40 min P1 = 68 min, P2 = 98 min, P3 = 128 min, P4 = 158 min and P5 = 188 min.
- The reference period of all levels is defined at the reference date t0 = 0.

That is, x1 (0) = x2 (0) = x3 (0) = x4 (0) = x5 (0) = x6 (0) = 0.
The duration dates of the different steps of each sub process are given in Table 12.

Table 12 - Duration of the different sub-processes of each stage

Sub-process i	Duration $T_{i,1}$	Duration $T_{i,2}$	Duration $T_{i,4}$
0	15	40	2
1	12	15	2
2	10	20	2
3	9	25	2
4	7	30	2
5	5	10	2
6	2	20	2
7	2	15	2
8	2	15	2
9	2	10	2
10	2	120	0

The simulation performed gave results that have been grouped together in Table 13.

Table 13: Simulation result

Input Data						Calculation and Data			
K	**spi**	P_k	$T_{i,1}$	$T_{i,2}$	$T_{i,4}$	$U^i(n)$	$T_{i,3}$	J_i	S^i
0	0	40	15	40	2	180	1	6	243
1	1	68	12	15	2	243	2	4	276
2	2	98	10	20	2	276	5	4	399
3	3	128	9	25	2	399	3	4	517
4	4	158	7	30	2	517	5	4	639
5	5	188	5	10	2	639	10	4	764
4	6	158	2	20	2	764	7	5	799
3	7	128	2	15	2	799	5	7	903
2	8	98	2	15	2	903	4	10	986
1	9	68	2	10	2	986	3	15	1025
0	10	40	2	120	0	1025	2	29	1162

Reaction time	982
Waiting time	47

The release date of the event is si = T = 982 min
The total waiting time is Tatt = 47 min.

4.2.2.2. Reduced waiting times for the theoretical model (reduction algorithm for optimizing wait times)

For the efficiency of the production unit, it is important to reduce the time lost. We propose a numerical study of the reduction algorithm. Before reducing the reaction time T, it is imperative to reduce the time lost, T_{k}, 3 and $T_{2N\text{-}k,\,3}$ (duration of the step E3) of the two sub-processes upstream and downstream, belonging to the level k by adjusting the start date of the level reference period, x^k (0), to cancel one of the two lost times. For the entire processing process, we successively apply the same principle at all levels of the sub-process, starting with the lowest of preference:

x^k (0) = 0 k = 0.1; ..., N
for k from 0 to N, do:
if min (Tk, 3, T2N-k, 3) = 0, then
k = k + 1
else if min (Tk, 3, T2N-k, 3) ≤ x^k (0)

$x^k(0) = x^k(0)$ - min (Tk, 3, T2N-k, 3)
else
$x^k(0) = Pk + [x^k(0)$ - min (Tk, 3, T2N-k, 3)]
End if
k = k + 1
End if
End

The reduction is calculated using the input data previously used (Table 7). Table 14 shows the results by levels.

Table 14: Result of the reduction algorithm

Level	**Sub process**	**Data**	**parameters**						**Results in mn**												
k	**sp_i**	**u^0**	**$x^0(0)$**	**$x^1(0)$**	**$x^2(0)$**	**$x^3(0)$**	**$x^4(0)$**	**$x^5(0)$**	**$T_{0.3}$**	**$T_{1,3}$**	**$T_{2.3}$**	**$T_{3.3}$**	**$T_{4.3}$**	**$T_{5.3}$**	**$T_{6.3}$**	**$T_{7.3}$**	**$T_{8.3}$**	**$T_{9.3}$**	**$T_{10.3}$**	**T**	**T_{att}**
			0	0	0	0	0	0	1	2	5	3	5	10	7	5	4	3	2	982	**47**
0	sp_0, sp_{10}	0	39	0	0	0	0	0	0	5	2	3	2	7	4	2	1	3	5	984	**34**
1	sp_1, sp_9	0	39	65	0	0	0	0	0	3	2	1	2	5	2	2	3	0	3	982	**23**
2	sp_2, sp_8	0	39	65	96	0	0	0	0	0	0	1	1	4	1	1	0	0	2	981	**10**
3	sp_3, sp_7	0	39	65	96	127	0	0	0	0	0	0	1	3	1	1	0	3	1	980	**10**
4	sp_4, sp_6	0	39	65	96	127	157	0	0	0	0	0	0	4	0	0	0	3	2	981	**9**
5	sp_5	0	39	65	96	127	157	184	0	0	0	0	0	0	0	1	0	3	2	981	**6**

The value of the lost time is restored to Tatt = 6min. This value is the column of values obtained without reduction (theoretical value of 47 min), which gives a time saving of 87% in theory.

4.1.6 4.2.3 Testing and implementation of the proposed theoretical model

4.1.7 The hypotheses are the same as those, which used in developing of the theoretical model.

4.2.3.1 Result and discussion

Tests were performed and data collected from the measurements made by the technical team involved in the study.

The durations for the levels are. P0 = 39 min, P1 = 69 min, P2 = 99 min, P3 = 129 min, P4 = 159 min and P5 = 189 min.

The reference period of all levels is defined on the reference date t0 = 0. That is, x1 (0) = x2 (0) = x3 (0) = x4 (0) = x5 (0) = x6 (0) = 0.

The duration dates of the different steps of each sub-process are given in Table 15.

Table 15: Duration of the different sub-processes of each stage

Sub process i	**Duration $T_{i,1}$**	**Duration $T_{i,2}$**	**Duration $T_{i,4}$**
0	17	55	2
1	10	17	1
2	10	21	1
3	8	28	2
4	6	32	3
5	5	15	4
6	2	25	2
7	2	13	1
8	2	12	2
9	2	10	3
10	2	125	0

The tests carried out gave results, which have been grouped together in Table 16.

Table 16 - Result of experimentation

Input Data						**Calculation and Data**			
K	**spi**	**P_k**	**$T_{i,1}$**	**$T_{i,2}$**	**$T_{i,4}$**	**$U^i(n)$**	**$T_{i,3}$**	**J_i**	**S^i**
0	0	39	17	55	2	180	3	7	278
1	1	69	10	17	1	278	1	5	347
2	2	99	10	21	1	347	6	4	403
3	3	129	8	28	2	403	5	4	523
4	4	159	6	32	3	523	4	4	643
5	5	189	5	15	4	643	8	4	768
4	6	159	2	25	2	768	8	5	805
3	7	129	2	13	1	805	5	7	909
2	8	99	2	12	2	909	4	10	996
1	9	69	2	10	3	996	3	15	1041
0	10	39	2	125	0	1041	2	30	1172
Reaction time		992							
Waiting time		**49**							

The release date of the event is si = T = 992 min
The total waiting time is T_{att} = 49 min.

4.2.3.2. **Reduction of waiting times of the practical model (reduction algorithm for** optimization of waiting times)

The reduction is calculated using the input data previously used (Table 7). Table 17 shows the results by levels.

Table 17: Result of the reduction algorithm

Level	**Sub process**	**Data**	**parameters**						**Results in mns**												
k	**sp_i**	**u^0**	**$x^0(0)$**	**$x^1(0)$**	**$x^2(0)$**	**$x^3(0)$**	**$x^4(0)$**	**$x^5(0)$**	**$T_{0.3}$**	**$T_{1,3}$**	**$T_{2.3}$**	**$T_{3.3}$**	**$T_{4.3}$**	**$T_{5.3}$**	**$T_{6.3}$**	**$T_{7.3}$**	**$T_{8.3}$**	**$T_{9.3}$**	**$T_{10.3}$**	**T**	**T_{att}**
			0	0	0	0	0	0	3	1	6	5	4	8	8	5	4	3	2	992	**49**
0	**sp_0, sp_{10}**	0	37	0	0	0	0	0	7	5	2	1	4	4	4	1	4	7	0	1027	**39**
1	**sp_1, sp_9**	0	37	64	0	0	0	0	4	0	5	4	1	1	1	4	1	4	0	988	**25**
2	**sp_2, sp_8**	0	37	64	98	0	0	0	3	0	4	3	1	1	1	3	0	3	0	988	**19**
3	**sp_3, sp_7**	0	37	64	98	126	0	0	3	0	1	0	4	4	4	0	0	0	0	988	**16**
4	**sp_4, sp_6**	0	37	64	98	126	155	0	7	0	5	0	0	4	0	0	0	0	0	988	**16**
5	**sp_5**	0	37	64	98	126	155	185	1	0	11	0	0	0	0	0	0	0	0	988	**12**

The value of the lost time is restored to T_{att} = 12 min. This value is the column of values obtained without reduction (theoretical value of 49 min), which gives a time saving of 75% in theory.

4.1.8 Comparison of the results of the proposed theoretical model with the results of the experiment

Experience 1: theoretical simulation of design model
Experience 2: test and implementation of design model
In accordance with the production technical team, we studied the lost time Tatt according to the variations of the periods of the initial level 0, at the last level of decision-making. The operator ... and the factory manager (level 5) represent these levels respectively. For this, we varied the periods P0 and P5 by a respective increment of 10 minutes and 30 minutes. In practice, it is difficult to apply and control smaller increments. The Figures 6 and 7 show the experimental variations in time lost depending on P0 and P5.
The results of the experiment are compared to the theoretical results with the study team. The maximum value of the level 0 and level 5 period has been set by the Director after consulting his team. Values were estimated at 80 minutes to the initial level and 308 minutes to level 5 (see figure 6 and 7).

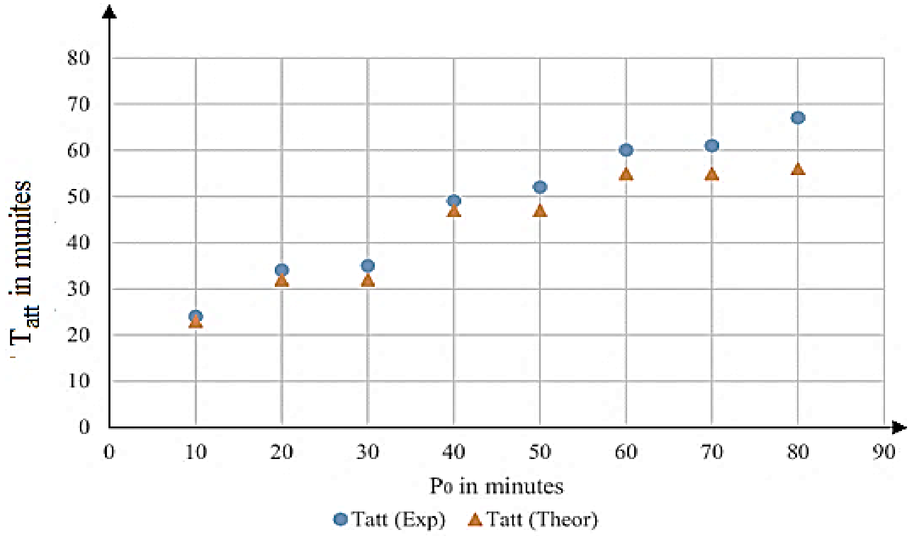

Figure 6: Evolution of the waiting time (Tatt) between experiment 1 and experiment 2 as a function of P0

The evolution of the waiting times for these two experiments is close to a polynomial function of degree 6 with respect to the variation of the parameter P0.

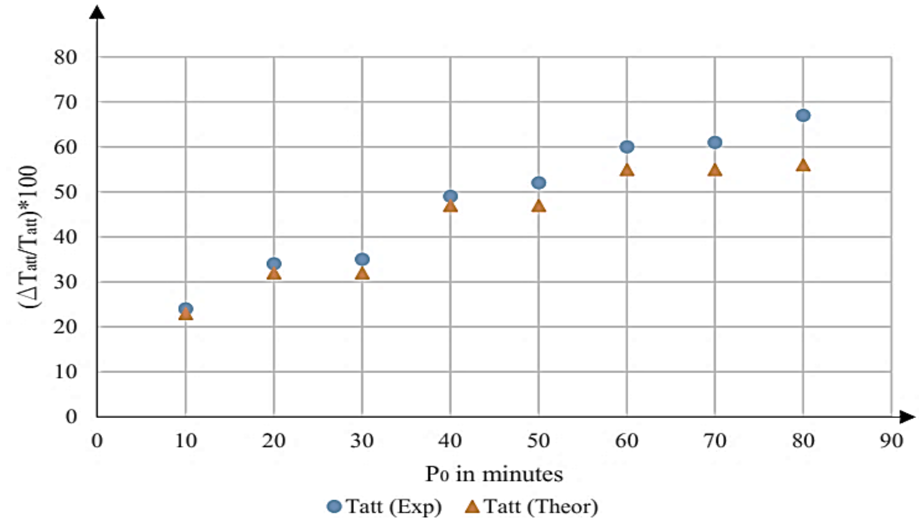

Figure 7: Evolution of the waiting time between experiment 1 and experiment 2 according to P5

For experiment 1, the evolution of waiting times is linear with respect to the variation of P5.
For a smaller mesh comb, Tall's evolution changes from a linear function to a polynomial function.
For experiment 2, the evolution remains that of a polynomial function of degree 6 with respect to the variation of P5. For a smaller mesh comb, the evolution remains unchanged from the variation of P5 and P0.

4.1.9 Evaluation of the errors committed between the experience 1 and experience 2

Figures 8 and 9 show the evolution of relative errors between the experience 1 and experience 2 results for k = 0 (Figure 8) and k = 5 (Figure 9).

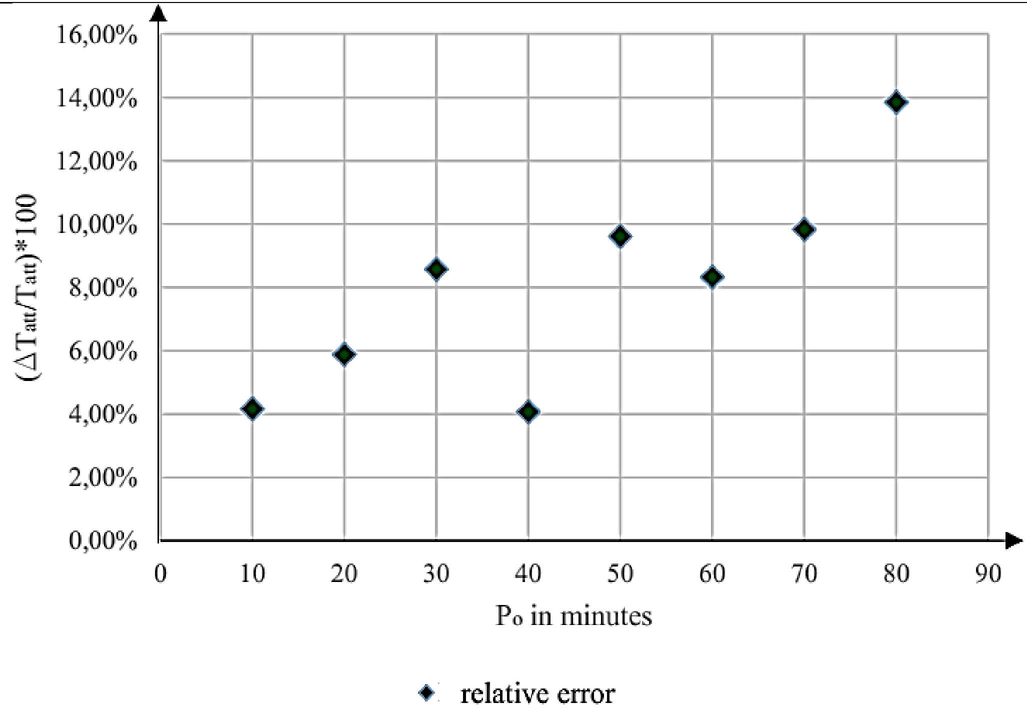

Figure 8: Evolution of the relative error made on waiting times between experience 1 and experiment 2 as a function of P0

The evolution of the relative error made on the waiting times is close to a polynomial function of degree 6 with respect to the variation of the parameter P0.

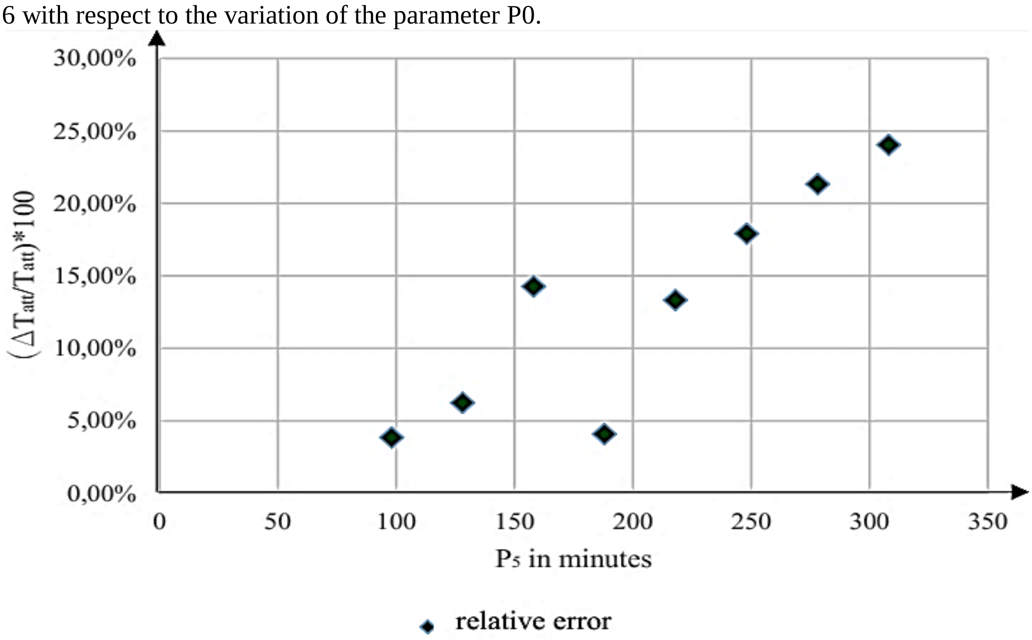

Figure 9: Evolution of the relative error made on waiting times between experience 1 and experiment 2 as a function of P5

The evolution of the relative error made on waiting times is close to a polynomial function of degree 2 with respect to the variation of parameter P5.

In both cases (for k = 0 and for k = 5), the evolution of the relative error remains is characterized by polynomial functions.

We observe that the relative error in measuring the sum of lost times decreases as the period of the level increases. In the variation interval of the level 0 period, the relative error is between 2% and 14%. For level 5, it is between 3% and 24%.

For a comb of smaller steps, the error made on the waiting time is smaller. In practice, the results obtained

Slightly higher than those of the forecasts (Table9).

Tableau 9: Result of comparison between calculation and modelisation

Parameters	Theorical value	Moderated values
T_{att} in minutes	47	49
T_{attRed} in minutes	6	12
(DT_{att}/T_{att})*100	87	75

4.1.10 Comparison of the results of the existing model studied with the test results of the proposed model

In accordance with the production technical team, we studied the lost time T_{att} according to the variations of the periods of the initial level 0, at the fourth level of decision-making. For this, we varied the periods P0 and P4 by a respective increment of 10 minutes and 30 minutes.

The Figures 10 and 11 show the experimental variations in time lost depending on P0 and P4. The results of the experiment are compared to the theoretical results with the study team. The maximum value of the level 0 and level 4 period has been set by the Director after consulting his team. Values were estimated at 79 minutes to the initial level and 249 minutes to level 4 (see figure 10 and 11).

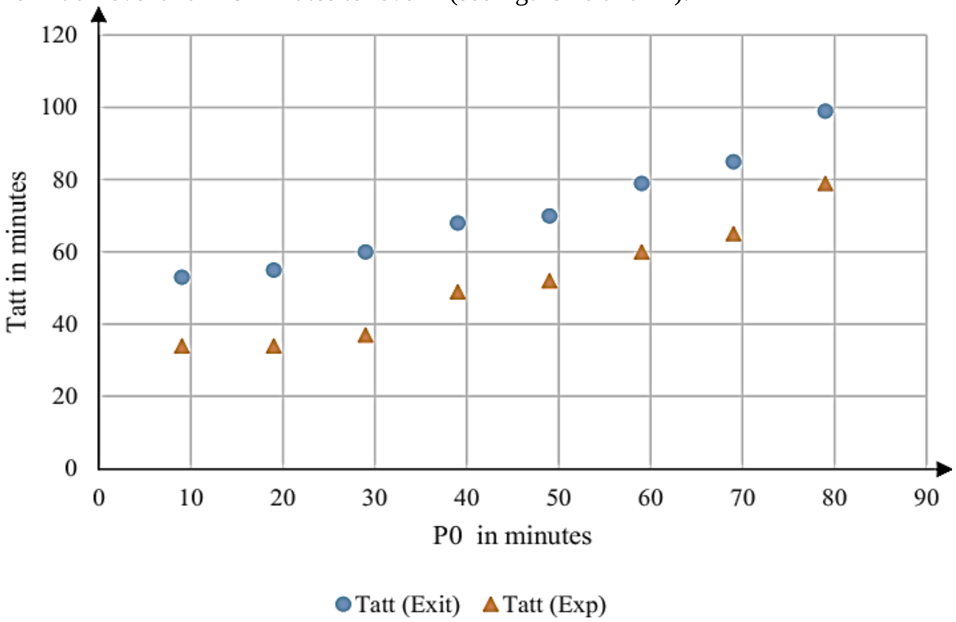

Figure 10: Evolution of the waiting time between the existing model and the theoretical model experimented according to P0

The evolution of the waiting times for these two experiments is close to a polynomial function of degree 2 with respect to the variation of the parameter P0.

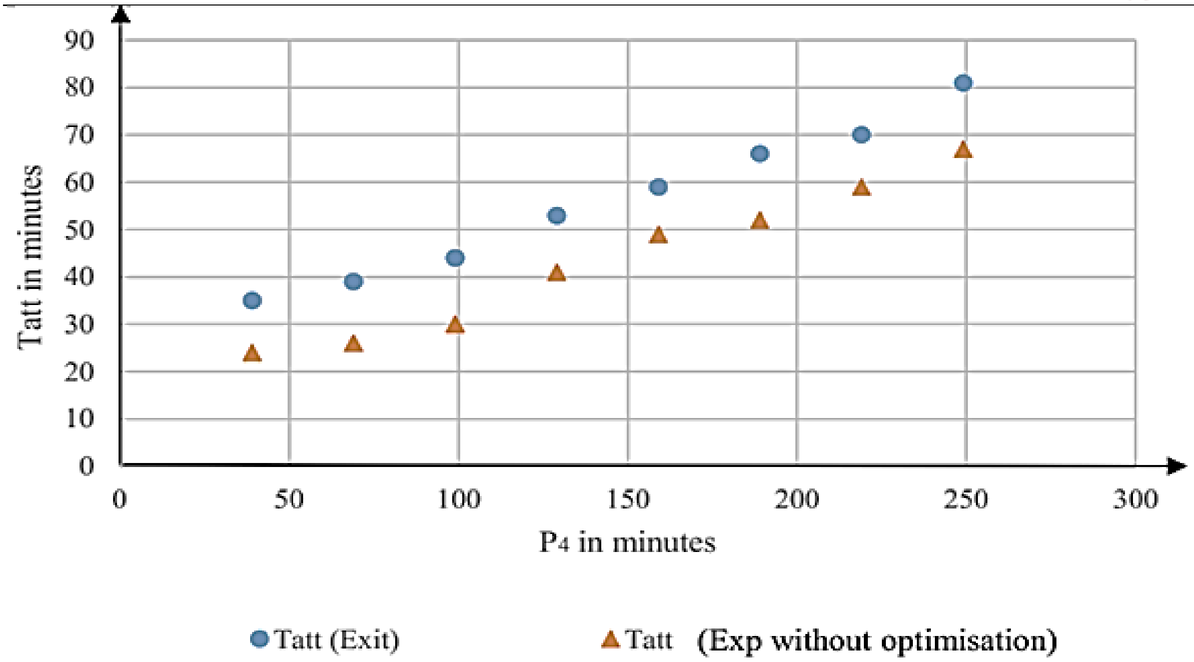

Figure 11: Evolution of the waiting time between the existing model and the theoretical model experimented according to P4

The evolution of the waiting times for these two experiments is close to a linear function with respect to the variation of the parameter P4. The curves of evolution of waiting times between the theoretical model experimented and that it exists keep the same tendency when we leave from one period to another. For smaller mesh combs, Tall evolution changes from a polynomial function to a linear function.

4.1.11 Evaluation of the errors committed between the theoretical model and the existing model

Figures 12 and 13 show the evolution of absolute errors between the theoretical model and the existing model results for k = 0 (Figure 12) and k = 5 (Figure 13).

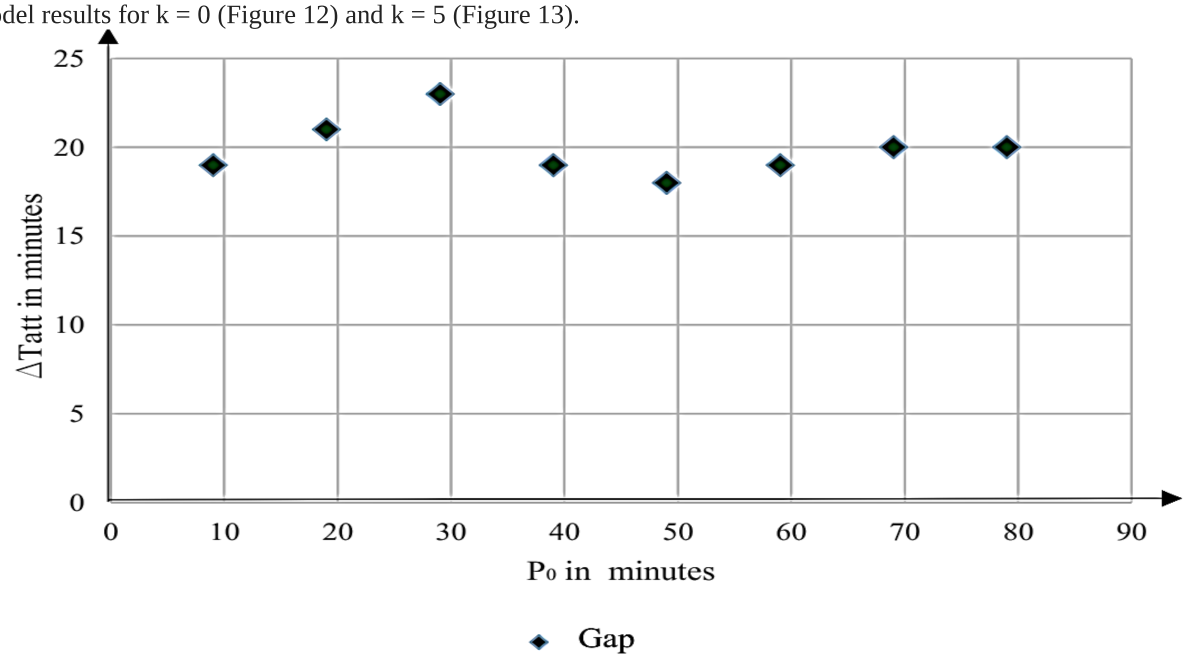

Figure 12: Evolution of the absolute error made on waiting times between the existing model and the theoretical model experimented with P0

The evolution of the absolute error committed on the waiting times between these two models is close to a polynomial function of degree 6 with respect to the variable parameter P0

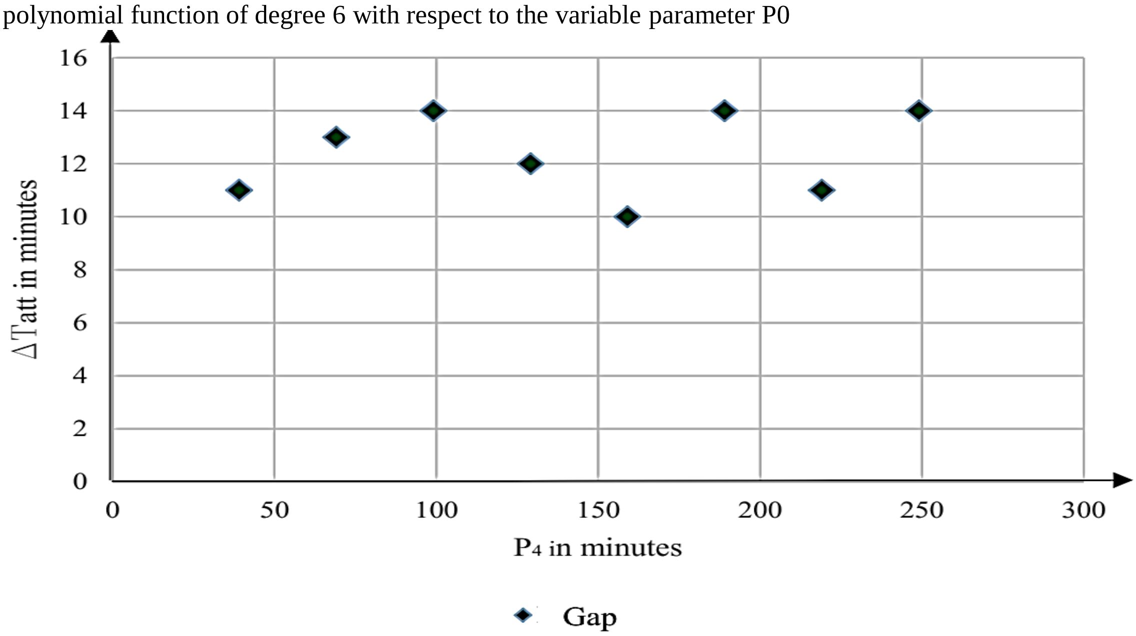

Figure 13: Evolution of the absolute error committed on the waiting times between the existing model and the theoretical model experimented according to P4

The evolution of the absolute error committed on the waiting times between these two models is close to a polynomial function of degree 6 with respect to the variable parameter P4.

For the two parameters considered, the trend remains the same for the evolution of errors made on the waiting time.

V. CONCLUSION

This article has identified an indicator, lost time and studied it in a hierarchical system subject to periodic event management. On the basis of certain assumptions, the lost times have been modeled and it has been shown that they depend solely on the parameters of the system, in particular the start dates of the reference period of the different levels involved in the processing and the date of appearance of the event.

An experimental study was conducted in an Technical team. The results obtained were compared with those of the existing model. Errors in the selected levels were acceptable. An algorithm to reduce the lost time, applied to the sugar production unit, gave an experimental gain of about 75%.

These encouraging results are the subject of a more precise study, concerning the measurements of different times. The margin of error can be significant, which is explained by the fact that the Technical team who occupy their professional workload is also the one who takes the measurements of time. For reasons of professional confidentiality, it is difficult to employ a stranger to make time measurements for the different levels of decision-making.

Future work is needed to refine the experimental results before obtaining, possibly after repeated measurements, an algebraic expression of the time variations lost as a function of the period. The difficulty lies in the quality of the measured values and their validation taking into account the uniqueness of an event.

REFERENCES

[1]. Crawford K.M., Cox J.F "Designing performance measurement systems for just in time operations", *International Journal of Productions Research, Vol. 28 (11), pp. 2025-2036, (1990).*

[2]. Bonds T.C., «The role of performance measurement in continuous improvement «International *Journal of Operations Production Management, Vol 19 (12), pp. 1318-1334*

[3]. Bititci U.S., (2000). "Dynamics of performance measurement systems", International Journal of Operations & Production Management", Vol. 20 (6), pp. 692-704.

[4]. Bitton M., (1990). "ECOGRAI: méthode de conception et d'implantation des systèmes de mesure des performances pour organisations industrielles », Thèse de Doctorat en Automatique, Université de Bordeaux I., (1990).

[5]. Le Dain A.M., Ndao P.I., (1997). “Sur un système d’indicateurs de performance pour l’évaluation d’une automatisation dans une entreprise papetière », 2ème Congrès International Franco-Québécois, Le Génie Industriel dans un monde sans frontière, 3-5 septembre Albi.
[6]. Berrah L., Mauris G., Foulloy L., Haurat A., (2000). ” Global vision and performance indicators for an industrial improvement approach”, *Computers in Industry, vol. 43, p. 211-225.*
[7]. Letouzey A., Geneste B., Grabot B., (2001). “Production and Planning Forecasting under uncertainty using possibility theory”, CASYS (2001), 5th International Conference on Computing Anticipatory Systems, Liège, Belgique, 13-18
[8]. Berrah L., Haurat A., les "Une stratégie de mises en performance d'indicateurs de la place versent le pilotage des processus de production", MISMO 97, 1ère Conférence Francophone sur la Modélisation et la Simulation, Rouen, France, 5-6 juins, (1997),.
[9]. Ceruti O., Gattino B.", Indicateurs et tableaux de bord ", gestion AFNOR, (1992).
[10]. Berrah L., L'indicateur de performance concepts et applications, Cepadues, 171 p., (2002).
[11]. Bititci U.S., (1995). « Modelling of performance measurement systems in manufacturing enterprises » *International Journal of Producion Economics, Vol. 42, pp. 137-147.*
[12]. Hernandez-Silva J. Mercé C. Fontan G., (2007). “A multilevel approach for scheduling and capacity management “, International Conference on Industrial Engineering and Systems Management, Beijing
[13]. Sperandino S.", « Usage de la modélisation multi-vue d’entreprise pour la conduction des systèmes de production », Thèse de Doctorat en Productique, Université de Bordeaux I. (2005)
[14]. Massotte P., Bataille R., (2000). “Future production systems: Influence of self-organization on approaches to quality engineering”, *International Journal of Production Economics, Vol. 64 (1), pp. 359-377.*
[15]. Regnier P., *Conduite réactive des systèmes de production,: intégration des régimes périodique et évènement*. Thèse Doctorat en sciences. D'Université Bordeaux je, 1998,
[16]. Menye J.B., *Etude de la promptitude d'un système de production travaillant en périodique du régime*. De DEA Productique. D'Université Bordeaux je, (2003).
[17]. Humez V., *Proposition d’un outil d’aide à la décision pour la gestion des commandes en cas de pénuries: une approche par la performance*. De Thèse Doctorat. D'INP Toulouse, (2008).
[18]. Meva'a L., Danwe R., Nganhou J., (2011). “Modeling the wait time of a hierarchical system: Case study of an Internal Medicine Unit”, *International Journal of Engineering and Technology, vol. 3, (1), pp 6-12.*
[19]. Meva'a L., Danwe R., Nganhou J., "Modeler le temps de l'attente d'un système hiérarchique,: Étude du cas d'une Unité de la Médecine Interne", Journal International de Construire et Technologie, vol. 3, (1), pp 6-12, 2011.
[20]. SOSUCAM : service entretien et suivi des équipements de production, 2017