Model and Reduction of Inactive Times in a Maintenance Workshop Following a Diagnostic Error

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Abstract — **The majority of maintenance workshops in manufacturing factories are hierarchical. This arrangement permits quick response in advent of a breakdown. Reaction of the maintenance workshop is done by evaluating the characteristics of the breakdown. In effect, a diagnostic error at a given level of the process of decision making delays the restoration of normal operating state. The consequences are not just financial loses, but loss in customers' satisfaction as well. The goal of this paper is to model the inactive time of a maintenance workshop in case that an unpredicted catalectic breakdown has occurred and a diagnostic error has also occurred at a certain level of decision-making, during the treatment process of the breakdown. We show that the expression for the inactive times obtained, is depended only on the characteristics of the workshop. Next, we propose a method to reduce the inactive times.**

Keyword: hierachical system; catalectic breakdown; diagnostic error; model, inactive time.

I. INTRODUCTION

Competing environment put companies under a lot of pressure. They have to meet up with production goals and also gain a portion of the market. In this context, error are reduced and unforeseen breakdowns [1, 2] that may occur in production tools can prove disruptive. It is the responsibility of the maintenance workshop to resolve such events in the shortest time possible. Restoration to the normal state can be considered as an indicator of the workshop's performance. Various works have been dedicated to systems' performance (e.g. [3, 4]), having the same objective: the amelioration of system performance.

Regnier first approached the topic of the reactivity of systems that faced a disruptive event [5]. He was followed by Humez [6]. Both proposed a model of systems based on a multi-leveled structure, the decision making model GRAI [7, 8]. Recently, a model was developed by the authors, in order to express the reaction of a medical unit in relation to different parameters, notably the reference periods of the different levels at which the decision were made [9]. The same model is employed in this paper. We have considered the multi-leveled structure for the organization of maintenance workshops. Regarding the return to normal state, the general objective is divided into sub objectives having acceptable dimensions and complexity. The difficulties in aggregating heterogeneous information and the loss of communication between decision levels can be removed. In the case of a diagnostic error, the error can have repercussions right up to the peak of the structure.

In the first part of the paper, we present the hypotheses of our work, and then, in the second part, we propose a model of the inactive time following a diagnostic error. Next, we propose a method to reduce the inactive times. We end with a numerical application of the approach.

II. HYPOTHESES OF THE STUDY

We consider that the maintenance workshop is hierarchical and multi-leveled. Therefore, several levels of decision making exists, some of which are shown in Figure 1.

The treatment of a catalectic breakdown, which makes production tools unavailable, follows a precise process which is based on the following hypotheses:

- We consider the arrival of an unexpected breakdown at a post to be a disruptive event for the maintenance workshop.
- We consider the most unfavorable case of the disruption, to be that it appears at level 0, is not treated and has repercussions right up to the Nth level where it's finally treated.
- Regarding the propagation of the event, we consider that the disturbance appears at a level, where it's not treated and has repercussions at higher levels. This repercussion moves from one level to the next until it gets to the level where it's treated.
- We consider the functioning to be periodic: repercussion from one level to the next has two phases, an upstream phase which is the ascending phase (from lower levels to higher levels), and a downstream phase, which corresponds to repercussions from a level that elaborates it to a lower level, which applies it. In both phases, the repercussion from one level to the next is

done at the end of the period. This conduct is said to be periodic.

- Transmission of the event or response from one level to next is not instantaneous. There is a non-zero transmission delay upstream and downstream between two consecutive levels.
- At each level, there is a shift (which could be zero) between the reference date, time origin t(0) and the start date of the reference period of level k considered as $x_k(0)$. This shift is not necessarily the same for all levels.
- A diagnostic error occurs only at level 0 of the upstream phase and it is only noticed at higher levels right up to the level N (the last level).
- Once a diagnostic error is discovered at a given level, the management is no longer periodic, from the level where it's discovered to the level 0 until it returns to this same level.

III. MODEL OF THE INACTIVE TIME

A. Model of the delay in reaction.

The objective presented in Figure 2 is to express the reaction delay of the system as a function of the occurrence date of an unwanted even and the system parameters, notably the start date of the reference period of the different levels involved in the treatment.

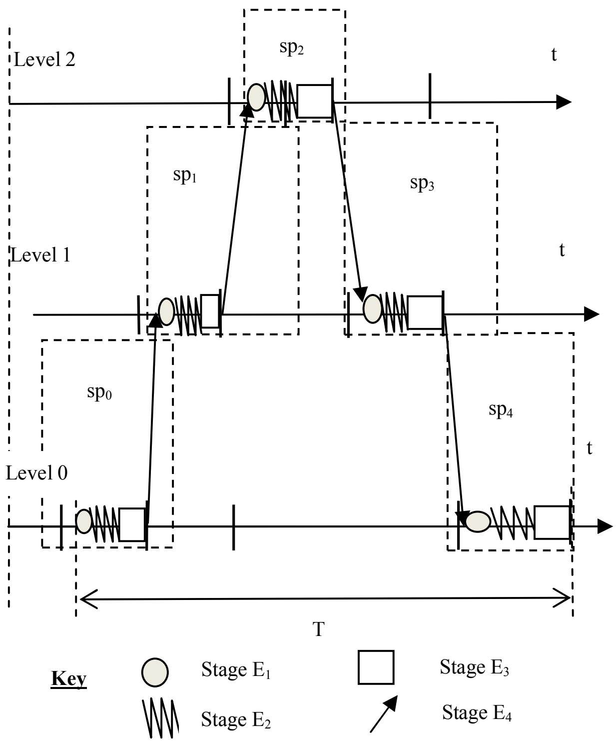

Fig. 1. Example of the proccess on two levels

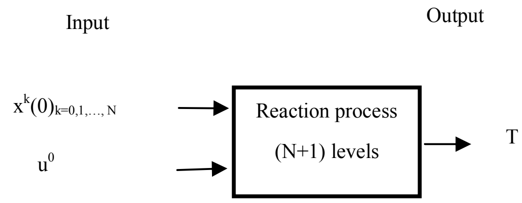

Fig. 2. . Objective of the model

where $x^k(0)$:Initialization date of the reference period.
u^0: Occurrence date of the event.
T : Reaction time of the maintenance workshop.

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

We designate a sub process to every passage of an event in a level. Therefore, every level k, except for the highest level (k=N), has two sub processes sp_k and sp_{2N-k} which treats the upstream and downstream events respectively as shown in Figure 3. The level N which treats the event has only a single sub process: sp_N

Therefore, the process has in total 2N+1 sub processes (0,1,……,2N). In every sub process sp_i , except for the last one, the event in the upstream phase passes through four successive states and the reaction in the downstream phase also passes through four successive states as presented in Table 1. The last sub process sp_{2N}, has just the three first stages.

TABLE I. DIFFERENTS STATES OF TREATMENT

State	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	Waiting for the end of the period	Waiting for the end of the period	$T_{i,3}$
E_4	Transfer to a higher level	Transfer to a lower level	$T_{i,4}$

The appreciation of the gravity of the event in the state E_1 in the upstream phase determines the mode of periodic or factual treatment.

We define below the parameters of the model:

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 the period order
N : level at which the event is treated
sp_i : sub process i of the system
E_l : state l of the treatment of the event
P_k : duration of a period of the level k
j_i :synchronization period for which the event is treated in sp_i;
$x^k(0)$: start date of the reference period for the level k
x^i_0 : arrival date of the event in the sub process sp_i

$T_{i,l}$: duration of the state l of sp_i
S : execution date of the reaction;
T : reaction delay of the system to the event
u^i : entrance date into sp_i, of the event
$x^k(j)$: finish date of the period j of the level k
x^i_l : finish date of the state E_l for the event sp_i ;
s^i : exit date of the event (end of the last stage) of sp_i ;

For any sub process, the treatment sequence is the same. Figure 3 presents the dates for which the perturbation in the sub process changes state.

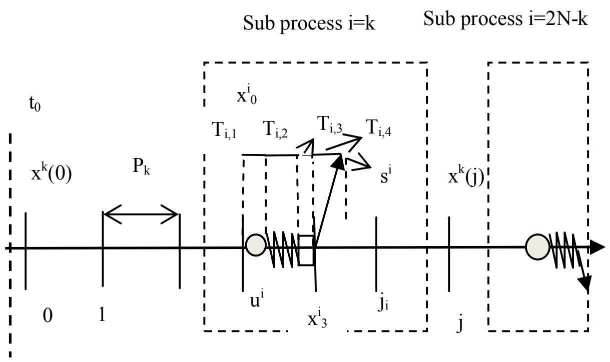

Fig. 3. Duration and change of state in a sub process sp_i

There exists two distinct dynamics in the treatment process. One part is the dynamic of the event (its change of states) which is made at irregular instances and is a function of the duration of the different states which are intrinsic characteristics of the system in relation to a given event. The other is the dynamic of decision making which is regular, since it is periodic at each level.

However, the two dynamics have to be synchronized so that the event can pass from the state E_3 to the state E_4, as shown in Figure 3, before a decision relative to its treatment is finally taken. One of the two dynamics has to adapt itself to the other. This is what makes the difference between the periodic conduct and factual conduct. In factual conduct, it is the dynamic of decision making that adapts itself to that of the event, and given that it's irregular, the factual conduct is therefore forced to be irregular. On the contrary, in periodic conduct, it's the dynamic of the event which adapts to that of decision making. This is what will involve the wait times before the treatment of the event. In reality, the two modes coexist in the designation of mixed conduct, which means that it operates on a periodic conduct, but for critical events, decision is taken without waiting for the end of the period.

The passage from a period j to the next j+1, on a given level k, effects itself at finish date of the period k, $x^k(j)$, which is given by:

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

or :

$$x^k(j)=jP_k+x^k(0)$$

In periodic conduct, the event is treated in a sub process sp_i, at a period j_i, of the level k (where the sub process appears), which we determine as follows:

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

where E represents the real part of x.

The dates for change of states of the event (passage from the state E_l to the state E_{l+1}), for each of the four states in the sub process sp_i, x_l^i, are given by:

$$\begin{cases} x^i_l=x^i_{l-1}+T_{i,l} \quad \forall l\in\{1,2,4\} \\ x^i_3=x^k(j_i) \quad l=3 \end{cases}$$

For l=3, the equation which we have, shows clearly the synchronization between the two dynamics. It permits us to determine the date for which transfer decision for the event is taken. This date coincide with the end of the synchronization period j_i, of the sub process sp_i.

The entrance u^i and the exit s^i of sp_i in the upstream phase of the process are such that:

$$\begin{cases} u^i=x^i_0 \\ s^i=x^i_4 \end{cases}$$

We thus obtain:

$$\begin{cases} x^i_1=x^i_0+T_{i,1} \\ x^i_2=x^i_1+T_{i,2} \\ x^i_3=x^k(0)+j_i.P_k \\ x^i_4=x^i_3+T_{i,4} \end{cases}$$

What proceeds the exit date is therefore:

$$S^i=x^k(0)+j_iP_k+T_{i,4}$$

This result is true for all the sub processes i, except for the last one, i=2N, for which reason the state E_4 does not exist, (consequently $T_{2N,4}$=0).

For i =2N we have to consider a diagnostic error at level 0 in the upstream phase only, which is noticed only at higher levels until it gets to the highest level N. In the case where an error is noticed at level 0, correction is done immediately and does not affect the maintenance process. On the contrary, if the error is only noticed at higher levels, the diagnostic error causes a delay ΔT which increases the treatment time of the breakdown as shown in Figure 4. We then have:

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

The entrance date of an event in a sub process is equal to its exit date from the proceeding sub process.

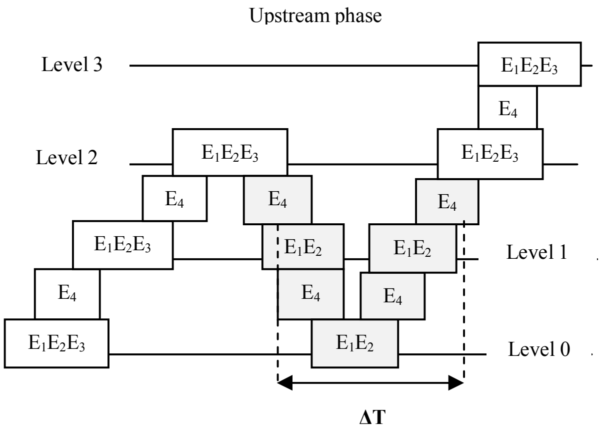

Fig. 4. Delay in a diagnostic error detected at level 2

Parameters at entrance:

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

Parameters:

$$\begin{cases} P_k \quad \forall k = 0,1,\dots,\ N \\ T_{i,l} \quad \forall l \in \{1,2,4\} \text{ et } i = 0,1,\dots 2N \end{cases}$$

, except T2N,4 which does not exit.

Calculation:

For i=0,1,…,2N-1

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

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

The expression of ΔT is given by:

$$\Delta T = T_{0,1} + T_{0,2} + 2\sum_{i=2}^{N}\left(T_{i\text{-}1,1} + T_{i\text{-}1,2}\right) + \sum_{i=1}^{N} T_{i\rightarrow i\text{-}1,4} + T_{i\text{-}1\rightarrow i,4}$$

where:

$T_{i\rightarrow i\text{-}1,4}$: Transition time from sub process i to sub process i-1.

$T_{i\text{-}1\rightarrow i,4}$: Transition time from sub process i-1 to sub process i.

We apply a realistic hypothesis that: $T_{i\rightarrow i\text{-}1,4} = T_{i\text{-}1\rightarrow i,4} = T_{i,4}$

Consequently:

$$\Delta T = T_{0,1} + T_{0,2} + 2\sum_{i=2}^{N}\left(T_{i\text{-}1,i} + T_{i\text{-}1,2}\right) + 2\sum_{i=1}^{N} T_{i,4}$$

Reaction delay represents the time that elapses between the occurrence and execution of the response. In reference to our model, difference has to be made between the exit date of the process event (exit date of the last sub process sp_{2N}) and the occurrence date of the event at the first level 0. This is written as:

$$T = S^{2N} - u^0$$

Or:

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

We therefore have an expression for the reaction delay as a function of the system parameters.

B. Calculating inactive time

At each level k of decision making, the state E_3 in the upstream phase and downstream phase represents the wait for the end of the period. For this reason we are going to establish another expression for the delay in the previous reaction. It's gotten by uniquely expressing as a sum, on the entire process, the duration of the events in all the different states of every sub process.

Equally at this stage, effects of diagnostic errors detected at a level other than level 0 in the upstream phase should be integrated:

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

Which is of the form: (1)+(2)

with:

$$\left(\sum_{i=0}^{2N} T_{i,3}\right) \quad (1)$$

and

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

This expression illustrates that reaction delay is made of part (1) which constitutes the inactive time, and part (2) which constitutes the actual time for the process, therefore has an incompressible priority.

Approaching this expression for the reaction time using that which has been obtained previously, the inactive time (1) is written:

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

Or:

$$\sum_{i=0}^{2N} T_{i,3} = \left(j_{2N}P_0\right) - \left(u^0 - x^0(0) + \sum_{i=0}^{2N}\sum_{l=1}^{2} T_{i,l} + \sum_{i=0}^{2N\text{-}1} T_{i,4}\right)$$

We realize that delay in diagnostic error does not influence the calculation of inactive times; this is explained by the factual treatment of error before moving to the periodic treatment.

In this equation, for a given system and event, only j_{2N} varies as a function of the start dates of the reference period for the levels. All the other terms are constants.

In order to reduce the reactivity delay, it is imperative to reduce the inactive times, $T_{k,3}$ and $T_{2N-k,3}$ (duration of the stage E_3), of the two sub processes upstream and downstream, appearing at the level k by adjusting the start date $x^k(0)$, of the reference period of the level, in a manner to cancel one of the two inactive times. The adjustment on a level is carried out in the following manner:

if $\min(T_{k,3}, T_{2N-k,3}) \le x^k(0)$, then

$x^k(0)=x^k(0) - \min(T_{k,3}, T_{2N-k,3})$

if not

$x^k(0)=P_k + [x^k(0) - \min(T_{k,3}, T_{2N-k,3})]$

The result is the elimination of the shorter of the two wait times. We obtain a new start date for the reference period and a new wait time which is smaller.

For the entire treatment process, we successively apply the same principle to all levels of the process starting with the lowest preference. The algorithm below permits us to effect this calculation:

$x^k(0)=0 \quad \forall\ k=0,1 ;\ldots,N$

for k ranging from 0 to N, Do :

if $\min(T_{k,3}, T_{2N-k,3})=0$, then

k=k+1

If not, if $\min(T_{k,3}, T_{2N-k,3}) \le x^k(0)$

$x^k(0)= x^k(0) - \min(T_{k,3}, T_{2N-k,3})$

If not

$x^k(0)=P_k + [x^k(0) - \min(T_{k,3}, T_{2N-k,3})]$

End if

k=k+1

End if

End

IV. APPLICATION

The data for the example are as follows:

- Time unit is the minute.
- The reference date is any minute considered to be the time origin.
- The occurrence date of the event after the reference minute is u^0=3min.
- The periods of the levels are: P_0=6 min, P_1=4 min and P_2=2 min.
- We initialize the reference period of all the levels to the reference date t_0=0. That's to say: $x^1(0)=x^2(0)=x^3(0)=0$.

The duration of the dates of the different stages of each sub process are given in Table 2 below:

TABLE II. DURATION OF THE STAGES

Sub process i	Duration $T_{i,1}$	Duration $T_{i,2}$	Duration $T_{i,4}$
0	2	2	5
1	3	3	5
2	2	3	4
3	2	2	2
4	3	2	

We also consider that there is an error of diagnostic made in level zero that we realize at level 1. We obtained the following results which we've regrouped in Table 3:

TABLE III. SIMULATION RESULTS

Calculated data			
u^i	$T_{i,3}$	j_i	s^i
3	5	2	17
17	1	6	29
29	0	17	38
38	2	11	46
46	11	9	70

The exit date of the event is s^4=70 min. The reaction delay is T=67 min. The total wait time is 19 min.

Next we apply the algorithm to reduce the wait times at the different levels. We obtain the following results per level:

A. *For the level 0, sub processes sp_0 and sp_4*

None of the wait times is zero, we proceed to the adjustment. The smallest wait time is $T_{0,3}$=5 min in sp_0. It is superior to $x^0(0)=0$. The new value of $x^0(0)$ is:

$x^0(0)=P_0+[x^0(0)-\min(T_{0,3},T_{4,3})]=6+(0-5)=1$

We obtain the following results:

Parameters			Results							
$x^0(0)$	$x^1(0)$	$x^2(0)$	$T_{0,3}$	$T_{1,3}$	$T_{2,3}$	$T_{3,3}$	$T_{4,3}$	s	T
1	0	0	0	2	0	2	10	65	62

The new wait times are 14min

B. *For the level 1, sub process sp_1 and sp_3*

We have the same value of inactive time $T_{1,3}= T_{4,3}$ =2 min. The new value of $x^1(0)$ is:

$x^1(0)=P_1+[x^1(0)-\min(T_{1,3},T_{3,3})]=4+(0-2)=2$

The wait times are 14 min and we obtain the following results

Parameters			Results						
$x^0(0)$	$x^1(0)$	$x^2(0)$	$T_{0,3}$	$T_{1,3}$	$T_{2,3}$	$T_{3,3}$	$T_{4,3}$	s	T
1	2	0	0	0	0	2	12	65	62

C. *For the level 2, sub process sp_2*

The wait times $T_{2,3}$ is zero. We do not adjust the start date of the reference period for this level. We conserve $x^2(0)=0$.

The results are the same to those previously obtained.

Parameters			**Results**						
$x^0(0)$	$x^1(0)$	$x^2(0)$	$T_{0,3}$	$T_{1,3}$	$T_{2,3}$	$T_{3,3}$	$T_{4,3}$	s	T
1	2	0	0	0	0	2	12	65	62

At the exit of level 2, we obtain a total inactive time of 14 min instead of the initial 19 min. Bringing back the time unit of the previous example which was the minute, the reduction of 5 min obtained on the reaction delay which brings it back to 62 min is important for the maintenance workshop.

We think on the other part that the inactive time of 14min to the end of the process are incompressible in the measure or, after the principle of the method, one of the two inactive times at a level is zero.

V. CONCLUSION AND PERSPECTIVES

In this article we modeled the inactive times in a maintenance workshop following an unforeseen breakdown. We have established that this breakdown depends on system characteristics. After characterizing a diagnostic error at level 0 which is only noticed in higher levels in the upstream phase, we've showed that this error does not influence the inactive times of a maintenance workshop faced with a breakdown. We have realized an application which models and reduces inactive times. The data that we used as input come from a maintenance workshop and a study is currently performed in order to compare the results with what we have on the field. The first results are globally satisfactory. A study is also conducted for the analysis of error estimation compared with the inactive time accuracy as well as for an analysis of model limitations. As an added perspective, we will extend our model of inactive times, using a mix conduct which gives a better representation of systems functioning.

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