Human integration and participation in time constraint workshops with limiting transportation resources

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Abstract

The aim of this communication is to demonstrate that, a design using robustness at each level of the control systems allows us to integrate non deterministic behaviours, represented by a time delay, without control recalculation. Our interest focuses on workshops with staying time constraints. A real case study of a baker's workshop is presented.

Keywords

Performance Evaluation, Periodic Functioning, Robust control, Time Petri Nets

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1 INTRODUCTION

A design approach using robustness at the organisational or operational level of the control systems allows us to integrate non deterministic behaviours which can represent the participation of human agents in a production entity. In this context, we focus on workshops with staying times constraints (such as no-wait in process workshop, useful in electroplating industries, food distribution companies, etc...). In such cases, product quality depends on careful respect of processing times. The presence of humans in such production lines, especially if the functioning mode is a cyclic one, can introduce variations due to inaccuracies in behaviour. These can lead to temporal specification violation. Our contribution is to demonstrate that a control policy can be robust to such variations.

In the second section the robustness concepts for a production workshop are reviewed. In the third section, a modeling approach based on Time Petri nets with time on places is proposed. In the fourth section, robustness of the control model to the variation at the entry of the workshop is demonstrated. Finally, a real case study of a baker's workshop is presented.

2 ROBUSTNESS APPROACH

System robustness is the capacity of a system to maintain its feasibility and goal constraints in acceptable boundaries, faced with some predictable or unpredictable perturbations (CORINE, 1997). For each system there are two types of perturbations:

- The internal one is a variation within the process (e.g. change in task duration)
- The external one is a variation in the input or the outputs of the process (e.g. change in the production rate).

We focus on robustness to the external perturbation. The respective modeling we develop for this type allows us to integrate human inaccuracy without changing the control policy.

3 MODELING

T-time PN (Berthomieu, 1991) have been developed to model time-out constraints in network area, but the staying time of tokens in the input places of a synchronization transition are not taken into account. Therefore P-time PN will be used to take into account staying time constraints. Let us note that P-time PN include the timed PN specification ability. Khansa W. has proposed a P-time PN with compulsory firing restrictions (Khansa, 1997). This model can guarantee the specified range of staying time in all places of the net. A P-time PN is a pair $\langle R, I \rangle$ where R is a Marked PN and I is defined as in follows:

$$I0: P \rightarrow (Q^+ \cup 0) \times (Q^+ \cup \infty)$$

$$p_i \rightarrow I_i = [a_i, b_i] \text{ with } 0 \leq a_i \leq b_i, \forall i, 1 \leq i \leq m, m = \text{Card}(P).$$

I_i defines the interval of staying time of a mark in the place p_i (Q^+ is the set of positive rational numbers). A mark in the place p_i is taken into account in transition validations when it has stayed in p_i more than a duration a_i and no longer than b_i (after the b_i duration, the mark is said to be dead). A P-time PN has a live token sequence if there is a sequence where: $\forall p_i, \exists q_i / a_i \leq q_i \leq b_i$, q_i is the staying time of a mark in the place p_i .

3.1 Modeling Flow-shops with P-time PN

At first, the sequence of a product describes the process constraints. The carrying of the products by the robot is contained in these specifications. For a three machine line the model of the routing is given in Figure 1 (a).

Figure 1. Product routing model and model of a particular control.

A maximum and a minimum duration is associated with each place. For particular operations the upper bound may be infinite. The empty robot shifts are still not modeled in Figure 1 (a). An example of a particular control for a three-machine line is given in Figure 1 (b). Each empty hoist shift has a lower bound associated duration. This corresponds to the physical limitation of the speed (the upper-bound is infinite). The robot must be ready to carry a product as soon as its processing ends. Violation of these restrictions directly affects product quality.

3.2 Modeling A Flexible Manufacturing System

We consider an FMS as a set of machines connected via conveyors and buffers. Let $M = \{m_i\}$ with i as a non negative integer, be the set of machines. There are several kinds of products but the ratio between them is given as in (Hillion and Proth, 1989). The resource class is divided in to two subclasses:

- The going with resources: they come with the products during its fabrication.
- The visited resources: they are used by the product at a given production step.

The plant is assumed to contain no assembly workshop.

Let us denote R an instance of a class called sequential process (Ezpellata and Martinez, 1993). R is a marked P-time PN, where $R = P_e \cup P_{gwr} \cup P_{vr}$. P_e is the set of product places representing the product states, P_{gwr} the going with resource place and P_{vr} the set of visited resources: $P_e \cap P_{gwr} = \emptyset$, $P_e \cap P_{vr} = \emptyset$ and $P_{gwr} \cap P_{vr} = \emptyset$.

Now, a system of i sequential process can be introduced: it is the combination of several sequential processes, where $P_{gwr} = \bigcup_i P_{gwr}$, $P_{vr} = \bigcup_i P_{vr}$ and $P_e = \bigcup_i P_e$.

This decomposition also allows us to model a workshop dealing with several kinds of products. It is well known that every manufacturing process in the periodic repetitive mode can be modeled by Strongly Connected Event Graphs (for short SCEG) (Laftit, 1991). Consequently, the model of the FMS and its control is a SCEG. Let us consider the routing of a given kind of product. The corresponding model may be considered as a flow-shop model with limited resource constraints. The limitation comes from the number of resources used in the considered routing and their use by the rest of the plant.

3.3 Performance evaluation

The upper-bound and the lower-bound of the functioning cycle can be computed with a polynomial algorithm: this provides a sufficient condition of liveness (Khansa, 1997). Consequently, mono-periodic functioning with P-time PN offers the same advantages as with timed PN. The next section will focus on the possibility of changing the production rate. In the case of an FMS, there may be several kinds of product. A production cycle contains several different products each produced with its own specific ratio.

4 ROBUSTNESS WITH RESPECT TO THE FUNCTIONING RATE

Let G be a P-time SCEG and $[Cmin, Cmax]$ is its interval of valid time cycle. Let us demonstrate that introducing a product in a time $[Cmin, Cmax]$ is supported: there will be no constraint violation. Let ${}^o p$ be the input transition of the place p and p^o its output transition, $S^o p_n$ is the n^{th} firing of ${}^o p$ and Sp^o_n the instant of the n^{th} firing of p^o , C is the effective functioning time cycle and q_p is the staying time of a mark in the place p .

$$S^o p_1 + q_p \leq Sp^o_1 + M_o(p)C. \quad (1)$$

As there is no margin in the routing model, concerning the place p_k ; it may be written:

$$S^{\circ}p_k - S^{\circ}p_l = \sum_{i=1}^{i=k} q_i - \sum_{i=1}^{i=k} M_o(p_i)C \quad (2)$$

The origin instant is considered to be the n^{th} firing instant of the transition t_1 . Let us consider two transitions of the routing model whose firings are consecutive. Let a_{ij} be the minimum duration of the hoist transfer between i and j . This lower-bound models some physical restrictions (its speed for example). $At(p)$ denote the amount of time during which a token remains available in the place p without being used. Considering our assumption on the routing model, such a waiting may only occur on a empty hoist travel.

$$S^{\circ}p_j - S^{\circ}p_i = \sum_{k=i}^{k=j} q_k - \sum_{k=i}^{k=j} M_o(p_k)C. \quad (3)$$

A similar equation may be established for an FMS without assembly workshop. The difference between the firing instants of transitions belonging to two different routings indexed by e and f , can be computed as follows:

$$\begin{cases} S^{\circ}p_{je} - S^{\circ}p_{le} = \sum_{k=le}^{k=je} q_k - \sum_{k=le}^{k=je} M_o(p_k)C \\ S^{\circ}p_{jr} - S^{\circ}p_{lr} = \sum_{k=lr}^{k=jr} q_k - \sum_{k=lr}^{k=jr} M_o(p_k)C \end{cases}$$

$$\Rightarrow S^{\circ}p_{jr} - S^{\circ}p_{je} = S^{\circ}p_{lr} - S^{\circ}p_{le} + \sum_{k=lr}^{k=jr} q_k - \quad (4)$$

$$\sum_{k=le}^{k=je} q_k + \sum_{k=le}^{k=je} M_o(p_k)C - \sum_{k=lr}^{k=jr} M_o(p_k)C$$

In this case, the expression is more complicated. Nevertheless, in the presence of input variations, sensitivity depends on the difference between the number of tokens in the routing e and f . The influence of the number of tokens is also the same for the computation of C . Consequently, a simple change in index name allows us to use Equation 3 for an FMS model. Of course, the Equation 3 formalism will be used below, in order to simplify the mathematical expressions.

Transitions i and j are connected via a single empty hoisted travel:

$$S^{\circ}p_i + At(p) + a_{ij} = S^{\circ}p_j. \quad (5)$$

$$At(p) + a_{ij} = \sum_{k=i}^{k=j} q_k - \sum_{k=i}^{k=j} M_o(p_k)C, \text{ with } At(p) \geq 0 \quad (6)$$

$$\sum_i^j M_o(p_i) = n, \text{ avec } n \geq 1, \quad At(p) \geq n(C_{\max} - C). \quad (7)$$

Let us consider a variation occurring on the period C . The functioning period for the input is also $C + V(C)$ instead of C ($V(C) \geq 0$). At each firing of the input transition, a delay of $V(C)$ is introduced with regard to the C period functioning. Let P_m be the set of marked places at the initial instant. This set will be exactly

the same at the instant $C+V(C)$. In fact, each token will replace the nearest token down in the routing model. Nevertheless, considering the Relations 6 and 7, we can write:

$$At(p) \geq \sum_{k=i}^{k=j} M_o(p_k)(C_{\max} - C) \geq \sum_{k=i}^{k=j} M_o(p_k)V(C) . \quad (8)$$

The latter relation proves that the time shift between the two functionings continues to be smaller than the hoist margin. A dual demonstration can give the same conclusion for functioning with the period $C-V(C)$ (where $C - V(C) \geq C_{\min}$). A consequence of the latter results is the possibility of changing the rate: the only assumption is that the period must remain in the interval $[C_{\min}, C_{\max}]$. It should be noticed that the control does not need to be modified. Moreover, with a flow-shop, a single variation of an input instant would produce no violation if the distance with the last input is in $[C_{\min}, C_{\max}]$ (Collart Dutilleul and al. 1994).

5 MODELING AND STUDY OF THE BAKER'S WORKSHOP

In this kind of production, quality control is an important task to perform. In fact, this process is sensitive to the variations of a large number of parameters difficult to control (humidity, quality of used raw materials, etc...). The presence of a human operator is appreciated because of his ability to evaluate these complex inter-dependent variations: bread's colour, taste, shape of bread, etc...

Figure 2. Baker's workshop with three parallel furnaces

The workshop considered is represented in Figure 2. It contains one robot and three furnaces. The robot transports plateaux which are loaded by a human operator. We show that the variations in loading times are totally tolerable by the process. Naturally, this is a simplification of the real workshop, but the qualitative results remain the same.

5.1 The Time Petri Net Model

The three furnaces can be considered as one furnace with capacity 3. The human agent loads the robot by one plateau from the loading station, the robot travels to the parallel furnace station, and unloads the product into one of the empty furnaces. There are now three possibilities: the robot can wait in the furnace station, return to

the loading station or proceed to the unloading station. These are represented by the Time PN model in Figure 3.

Figure 3. P-Time PN workshop model

Figure 4. SCEG model of a scheduling

The robot sequencing allows the three furnaces to be used together. This P-time PN model is obviously a SCEG shown in Figure 4. The performance evaluation of the SCEG gives: $C \in [22, 24]$. The settings of the workshop input instance have to be fixed. In Table 1 the setting values are chosen for the minimum cycle functioning (C_{min}). If the input rate has to be changed, settings of $At(p_i)$ must be recomputed. For the maximal time cycle (C_{max}) the values are represented in Table 1. The parameter Δ is defined as: $\Delta_{jk} = S^o p_j - S^o p_k$ for $j, k \in \{a, e, i\}$. Switching from the maximum functioning rate to the minimum will take place in a time cycle without any constraint violation. In fact, the input rate may be defined with an accuracy of 8.3%. This margin allows variation in worker speed. Nevertheless, this variation is desirable when there is a product quality problem. In this case, the worker must perform a more accurate control.

Table 1. Settings of the workshop input instance.

	$At(p_d)$	$At(p_h)$	$At(p_o)$	$At(p_n)$	$At(p_m)$	$At(p_i)$	Δea	Δie	Δai
Cmin	2/3	2/3	2/3	2/3	2/3	2/3	11/3	11/3	11/3
Cmax	4/3	4/3	4/3	4/3	4/3	4/3	13/3	13/3	13/3

6 CONCLUSION

Based upon robustness properties, this paper has shown that some non deterministic behaviour may be taken into account by several kinds of workshops with staying time constraints. These formal results may be used at the design step. Moreover, they may be useful for information management (Collart Dutilleul and al., 1997). In this presentation, we focus on robustness evaluation in order to synthesise a control which takes human participation into account. This approach has been presented in order to deal with processes where human expertise is needed. It tries as far as possible to keep the workmen on the line so as to preserve company know-how. An application example is given on an industrial baker workshop. Nevertheless, formal properties still have to be developed and the applications of control robustness for information management have still not really been studied.

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