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Establishment of Low Cost Production Monitoring Technique

Lei WANG, Ching Yuen CHAN

***Abstract*—This paper presents a new technique to monitor a production plant by observing the characteristics of component movements in the plant. Most modern monitoring systems rely on various sensory devices to capture production information but the proposed methodology only requires simple counters in association with a mathematical model. In the proposed technique, the plant will be segmented into Regions Of Interest (ROIs) and the blocking in a plant can be observed by watching on each ROI. More importantly, the algorithm to deploy counters subjected to a defined maximum response time has also been worked out for the system design purpose.**

***Index Terms*— production monitoring, automated transfer system monitoring, material handling**

I. Introduction

Enhancement of automation degree in modern manufacturing has put more emphasis on the aspect of plant monitoring and fault diagnosis. Most plants rely on heterogeneous sensors to collect signals and it is based on the integration of these signals that the holistic picture of the plant can be supervised. Despite the wide applications of this type of methods, the disadvantages are also obvious: high cost, lack of interoperability, difficult in maintenance, and poor adaptability [1]. Besides, from the management viewpoint, the major problem in terms of decision making nowadays is not information insufficiency but the contrary, information overload [2]. In other words, management in production would appreciate a straightforward but effective method to oversee the whole plant rather than being lost in the supervision of trivial routine operations. Traditionally, production monitoring methods emphasize on the healthiness of work-stations (machines) as well as the potential impact on systematic efficiency and little attention is put on the material transportation. However, over one quarter of system shutdowns were due to the abnormities of material handling mechanism like mechanical failures or conveyor jam [3].

In this paper, a new approach to monitor a production plant especially the material handling by means of watching the characteristics of flowing components with counters will be presented. Additionally, the response time of the proposed method is analyzed and an appropriate algorithm has been developed to deploy the monitoring counters subjected to the constraint of a defined maximum response time.

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Lei Wang is with the Department of Industrial and Systems Engineering of The Hong Kong Polytechnic University (corresponding author, phone: +852 2766 5594; fax: +852 2362 5267; e-mail: lei.wang@connect.polyu.hk).

C. Y. Chan is with the Department of Industrial and Systems Engineering of The Hong Kong Polytechnic University (e-mail: mfcychan@inet.polyu.edu.hk).

II. Literature review

Majority of modern production systems rely on certain monitoring techniques to tell the operating conditions. Based on the difference in goals, these monitoring techniques can be roughly classified into two distinct types: Single Machine-Oriented Monitoring (SMOM) methods and Process-Oriented Monitoring (POM) methods. SMOM aims to watch the status of a single machine by means of measuring downtime, temperature, vibration, etc. and the ultimate purpose is to enhance performance [4, 5]. POM, as the name suggests, stresses on the monitoring of holistic process healthiness. Various types of POM approaches have been reviewed in literature [6]. It is obvious that the success of both POM and SMOM demands numerous efforts in not only the hardware deployment but also the integration of collected information, which is also the bottleneck of the traditional centralized framework.

Thanks to the great development of computer technology, agent-based distributed monitoring frameworks are introduced into manufacturing systems to address these problems [7]-[9]. In spite of the promising advantages of an agent-based distributed manufacturing system such as modularity, decentralization, and autonomy; the high implementation cost as well as the complexity of the system scares off many potential users [7]. Besides, lack of a standard platform in supporting communications among separate devices leads to either poor interoperability or time-consuming development.

III. Algorithm description

A manufacturing system can be represented as connections of branches with components moving in different branches as in Fig. 1; along each branch a series of work-stations are connected by material transportation mechanisms (like conveyors). For a branch in such a system, the following hypotheses are assumed:

1. Production rate is constant under healthy situation.
2. Components flowing in a branch comply with the First-In-First-Out (FIFO) principle and overtaking is not allowed.
3. There is no scrap or rework in a branch.

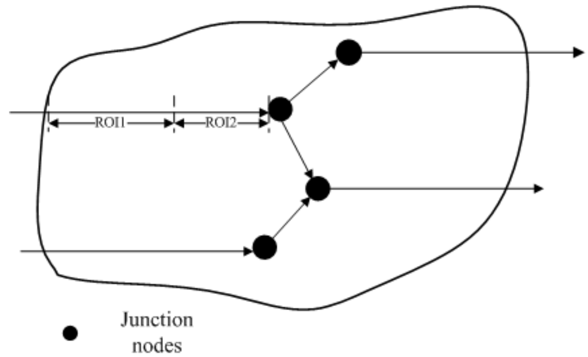

Fig 1 Modeling of a manufacturing system

From the management point of view, most concerns are on the whole system smoothness rather than that of a certain single workstation or a transportation mechanism. Starting on this, the basic concept is to detect the healthiness of the system by watching the situation of every branch, and this can be done by obtaining features on how components moving in a branch such as the time span variation between components, Work In Progress (WIP) and so on. To collect this information, the only required devices are a pair counters installed at the Inlet and the Outlet of a branch, and it is named as a Region Of Interest (ROI) in this paper.

One of the most sensitive criteria to evaluate a monitoring method is the maximum response time that is the time from a fault happened to telling a fault detected. Regarding the difference in response times, monitoring and diagnosis tasks for a given manufacturing system can be classified into immediate response, intermediate response, and slow response [9]. In other words, there is always an essential concern on the maximum response time in the design of a monitoring technique. In fact, to meet a specified allowable response time, the branch can be further segmented into several ROIs such as the case of ROI1 and ROI2 in Fig. 1, and details on how to deploy counters subject to tolerable maximum response time when a blocking occurs will be presented in following sections.

A. *Single ROI Modeling*

Time series are important factors in this study. To steer clear of possible confusions between a *time interval* and a *clock time*, capital letter "T" is employed to symbolize a time interval and small letter "t" stands for a clock time. Fig. 2 shows the schematic view of an ROI and the circles represent workstations with processing time of $\mathrm{T}_{\mathrm{p},k}(0 \leq k \leq \mathrm{n})$, among which the 0^{th} and the n^{th} circles are counter locations with no processing time. With the given parameters of an ROI such as the ideal transfer time (T_k) from the $(\mathrm{k}-1)^{th}$ work-station to the k^{th} work-station, ideal inter-arrival time (T_e) of components, the minimum time gap (T_g) between two adjacent components, the clock time when the α^{th} component arrives at the inlet is denoted by $t_{i,\alpha}$ and it reaches the outlet at $t_{o,\alpha}$.

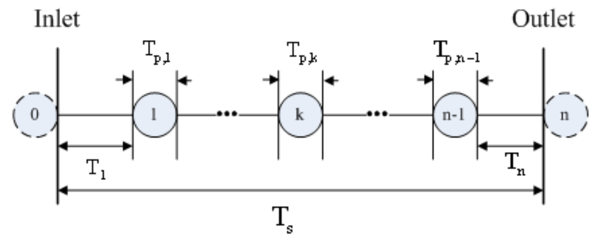

Fig 2 Schematic view of an ROI

The original concept is that when a defect occurs, the Inter-Arrival Time (IAT), Inter-Leaving Time (ILT), and WIP within the ROI would have some changes. Based on these clues, the production plant can be monitored in some ways and even be diagnosed timely. The aim of this paper is to tackle this issue and as a monitoring system, the response time will be an indispensable concern so this will also be a necessary piece to be addressed here. The proposed methodology is good for an automated system. One general type of abnormality is blocking, and in the following sections, how to apply the proposed methodology in blocking detection will be illustrated.

B. *Maximum Response Time Analysis*

Blocking herein means stoppage at a certain position within an ROI in the production system. When a blocking occurs components will congregate between the Inlet and Blocking Point (BP) while components in the downstream of the BP will keep flowing out through the Outlet until exhausted. Assume that after $\mathrm{T_i}$ upstream components are queuing up to the inlet and after $\mathrm{T_o}$ all downstream components have just flowed out through the outlet, then the response time equals to the smaller one of the two values $\mathrm{T_i}$ and $\mathrm{T_o}$. The point at which possesses the equivalent value of $\mathrm{T_i}$ and $\mathrm{T_o}$ is called Balanced Blocking Point (BBP) here and blocking occurring at the BBP can be detected at both the Inlet and the Outlet simultaneously. For a blocking occurring before the BBP, it can be detected in the first instance at the Inlet; vice versa, it would be signified at the Outlet first if after the BBP, also see Fig. 3 for various blocking situations [10].

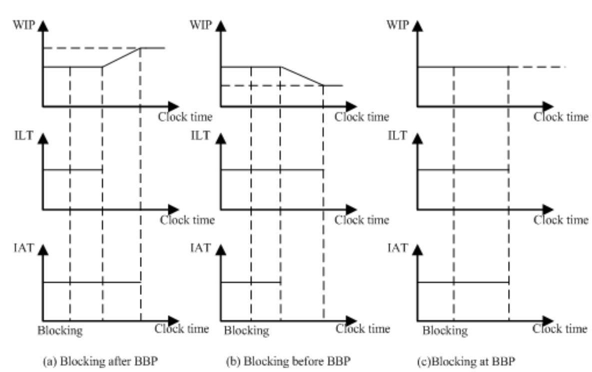

Fig 3 Phenomena of blocking at different locations [10]

Once the BBP has been identified in the ROI, the maximum response time of the ROI can also be obtained as:

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$$\mathrm{T_{r,max}} = \left(1 - \frac{\mathrm{T_g}}{\mathrm{T_e}}\right) * \mathrm{T_s} + \mathrm{K_{BBP}} * \mathrm{T_g} - \sum_{k=1}^{\mathrm{K_{BBP}}} \mathrm{T}_{\mathrm{p},k} \tag{1}$$

Where $\mathrm{T_s}$ refers to the ideal throughput time from the Inlet to the Outlet and the first term is to determine the space on the transfer line to accommodate products; in the second term $\mathrm{K_{BBP}}$ is the work-station index before the BBP that is used to tell the number of upstream work-stations and here, we assume that one work-station has one product on it; the final is the summation of $\mathrm{T}_{\mathrm{p},k}$ that is to remove the work-station processing times.

C. Algorithms to Segment ROIs

For a given branch to meet the requirement of a specified maximum response time ($\mathrm{T_{r,c}}$), the most straightforward solution is to segment it into separates smaller ROIs such that the maximum response time of each of which is equal to or less than $\mathrm{T_{r,c}}$. Therefore, the problem of designing the monitoring framework becomes the issue of segmenting an ROI to smaller ROIs. This operation can be achieved by using the following three steps.

Step 1: Estimate the time length of the ROI from Inlet to Outlet ($\widetilde{\mathrm{T}}_\mathrm{s}$) that equals to maximum response time ($\mathrm{T_{r,c}}$).

In steady state, it is expected that the inter-arrival time (T_e) is larger than processing time of any work-station involved. Therefore, work-stations can also be regarded as part of the transfer mechanism and the whole ROI is simplified as in Fig. 4.

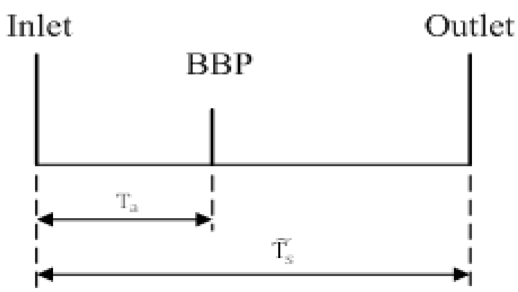

Fig 4 Simplified model of ROI

From the definition of BBP mentioned, a blocking occurs here will experience maximum response time and in which $\mathrm{T_o}$ equals $\mathrm{T_i}$, so:

$$\mathrm{T_o} = \widetilde{\mathrm{T}}_\mathrm{s} - \mathrm{T_a} \tag{2-1}$$

$$\mathrm{T_i} = \left(\frac{\mathrm{T_a}}{\mathrm{T_g}} - \frac{\mathrm{T_a}}{\mathrm{T_e}}\right) * \mathrm{T_e} \tag{2-2}$$

$$\mathrm{T_{r,c}} = \mathrm{T_i} = \mathrm{T_o} \tag{3}$$

By substituting (2-1) and (2-2) into (3), we can deduce that:

$$\widetilde{\mathrm{T}}_\mathrm{s} = \frac{\mathrm{T_{r,c}}}{(1-\frac{\mathrm{T_g}}{\mathrm{T_e}})} = \frac{\mathrm{T_e}}{(\mathrm{T_e}-\mathrm{T_g})} * \mathrm{T_{r,c}} \tag{4}$$

That is to say, once we have defined the maximum response time ($\mathrm{T_{r,c}}$) that the system can be tolerated, then the maximum time length ($\widetilde{\mathrm{T}}_\mathrm{s}$) of every ROI with reference to its Inlet can be calculated.

Step 2: Error analysis of the maximum response time obtained in Step 1.

It is time to reconsider the impact of work-stations on the response time estimation in before. Once the $\widetilde{\mathrm{T}}_\mathrm{s}$ has been obtained, a physical branch can successively be divided into smaller ROIs with time lengths equal to or smaller than $\widetilde{\mathrm{T}}_\mathrm{s}$ from the inlet to the outlet. Subsequently, the actual BBP of each segmented ROI can be found as well. To signify the difference, the index of the work-station just before BBP becomes $\widetilde{K}_{BBP}$ and the actual maximum response time of the ROI can be obtained through (1). By substitutions, it is:

$$\widetilde{\mathrm{T}}_\mathrm{r,max} = \mathrm{T_{r,c}} + \widetilde{\mathrm{K}}_\mathrm{BBP} * \mathrm{T_g} - \sum_{k=1}^{\widetilde{\mathrm{K}}_\mathrm{BBP}} \mathrm{T}_{\mathrm{p},k}$$

In other words, for a segmented ROI the error between the tolerant maximum response time $\mathrm{T_{r,c}}$ and the actual maximum response time $\widetilde{\mathrm{T}}_\mathrm{r,max}$ can be worked out as:

$$\mathrm{T_{r,c}} - \widetilde{\mathrm{T}}_\mathrm{r,max} = \sum_{k=1}^{\widetilde{\mathrm{K}}_\mathrm{BBP}} \mathrm{T}_{\mathrm{p},k} - \widetilde{\mathrm{K}}_\mathrm{BBP} * \mathrm{T_g} \tag{5}$$

To meet the design requirement of a maximum response time, $\widetilde{\mathrm{T}}_\mathrm{r,max}$ should always be equal to or less than $\mathrm{T_{r,c}}$. That means, for the preliminarily segmented ROIs after Step 1, summation of work-stations processing times before BBP ($\sum_{k=1}^{\widetilde{\mathrm{K}}_\mathrm{BBP}} \mathrm{T}_{\mathrm{p},k}$) should never be less than $\widetilde{\mathrm{K}}_\mathrm{BBP} * \mathrm{T_g}$; otherwise the requirement on maximum response time cannot be met and the process should go into Step 3 as follows.

Step 3: Adjustment of $\widetilde{\mathrm{T}}_\mathrm{s}$ if $\sum_{k=1}^{\widetilde{\mathrm{K}}_\mathrm{BBP}} \mathrm{T}_{\mathrm{p},k}$ is less than $\widetilde{\mathrm{K}}_\mathrm{BBP} * \mathrm{T_g}$

Considering the impact on maximum response time from work-stations both upstream and downstream of the BBP, the new time length of an ROI should be shortened according to (6) as:

$$\widetilde{\mathrm{T}}_\mathrm{s} = \widetilde{\mathrm{T}}_\mathrm{s}{}' - 2 * (\widetilde{\mathrm{K}}_\mathrm{BBP} * \mathrm{T_g} - \sum_{k=1}^{\widetilde{\mathrm{K}}_\mathrm{BBP}} \mathrm{T}_{\mathrm{p},k}) \tag{6}$$

Where $\widetilde{\mathrm{T}}_\mathrm{s}{}'$ is the old value. It is anticipated that based on these three steps given, one can determine the suitable arrangement of ROIs on a manufacturing system so that the response time on a blocking symptom can be detected within a specified time.

IV. Discussion and Conclusion

This research paper presents a method to monitor the production plant with simpler counters only. It has been illustrated how blocking, one of the common faults in the plant, can be detected. Besides, the method for deploying these counters subjected to the constraint of a maximum response time has also been established. The key advantages of this method lie in the convenient implementation with simple hardware and good adaptability. In addition to blocking, there are other abnormalities concerned in a manufacturing plant like slowdown of efficiency, which will be studied in further

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researches.

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