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Bottleneck In Flexible Manufacturing System

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ABSTRACT
Flexible Manufacturing System is a dominant system that allow companies to have good productivity and high variety in products. It is restricted by the existence of one or more bottleneck that affect on process flexibility. Locating bottleneck is a way to improve the system and make it work efficiently. In this paper, a review was done on flexible manufacturing system and bottleneck. Previous attempts to explore solutions for bottleneck were explained. Moreover, advantages and limitations of these works were shown in a table.

Keywords: Flexible Manufacturing System, Bottleneck, Detection

1. Introduction

The competition of companies in marketplace require to be an efficient and fast in production. These companies try to have suitable manufacturing systems that can be flexible to any circumstance as product life cycles are reduced in the continuously changing market. To respond to these demands, the use of a flexible manufacturing system (FMS) has been widely applied in order to attain high productivity and production flexibility (Kaschel C. & Bernal, 2006). FMS is a system that has capability to react to any changed condition happen in process. It includes numerically controlled machines with the aid of value-added, automatic and material handling facilities. Industrial companies use FMS to fulfil the demands for making different kinds of products from small to medium quantity in production (Qiao, Lu, & Mclean, 2006).

Flexible manufacturing systems have obtained many researchers concern. Some researches dealt with identifying FMS, its merits in scheduling, control, cost, operation time, etc. These studies were based on presumption that the quality related issues have minimal impact. However, flexibility in any process have a big relation to quality. For example, in machining operations, when the quality level of product is usually determined by the location error of the flexible fixtures and product change, it may result in reducing quality due to reallocating the fixtures. One of the major issues that face industries is bottleneck. It usually happens due to failure in production line (Wang, Li, Arinez, & Biller, 2010).

Several attempts were done to study bottleneck in flexible manufacturing system and methods to determine and avoid it. In this paper, these methods will be shown with mentioning their advantages and limitations in each if there is any. This paper is organized in the following manner; Section I is the Introduction; section II is the Literature Review; section III is Related Works; section IV is Advantages and Limitations; section V will be Conclusion and Future Work followed by section VI which is Acknowledgments, and the final section will be the list of References which have been cited accordingly.

2. Literature Review

Manufacturing companies look for ways to compete and become order-winners especially where the current market faces rapid changes of the customer requirement and product specification. To deal with these changes, it is necessary for a manufacturing system to conform to these changes as quickly as possible in order to remain competitor in the market. This development leads to a conflict for a manufacturing system due to the decrease in productivity while variety increases. So, the flexible manufacturing system is a good method that can combine between variety and productivity (El-Tamimi, Abidi, Mian, & Aalam, 2012).

A flexible manufacturing system is an integrated arrangement that consists of automated workstations like computer numerically controlled (CNC) machines which have ability of tool change, a storage system, hardware handling system and a computer control system that organizes the processes of the production system. The important factors in the design of FMS are having high investment and decisions made in planning for the system must ensure compatibility between the automated manufacturing system and the demands of the market that can be changed at any time (Park, 2005).

Flexible manufacturing system is recognized to have ten types. First type is machine flexibility where several processes are performed without changing setup. The second one is material handling flexibility in which it use possible paths for transportation of parts between machines. The third type is operation flexibility which contains different processing plans for manufacturing part. Another kind is process flexibility that has capability to make number of part types without need to do major changes in operation setup. The next type is product flexibility which helps to make it simple for manufacturers to introduce products into current product mix at good time and cost. Routing Flexibility is also a sort of FMS which provide alternative routes for a part to be processed through the system in a specific plan. The following type is volume flexibility which is capable of manufacturing products at different volumes profitably in accordance to capacity of production. The eighth type is expansion flexibility has advantage of building manufacturing system and expand it by applying some changes in it. Control program flexibility is the ninth kind which has intelligent machines a software to control the system to make it runs for a long time without any stop. The last type is production flexibility that produces a number of product sorts without requiring to add big investment in the capital equipment (ElMaraghy, 2006).

FMS is useful to implement in the area of both flow shop and job shop industries, despite the complexity that may exist when it is applied in the production due to level of flexibility than can be accepted. Some of gained benefits from an FMS are: increase in the use of machine, fewer machines to be utilized in process, less space needed in the factory, fit any change, decline in inventory demands, less manufacturing lead time, improve company's productivity and great chance to have automated production. (Abazari, Solimanpur, & Sattari, 2012).

One of the major issues that may happen in manufacturing system is bottleneck. A bottleneck is defined as the failure of machine to work well which affects on the performance of the manufacturing system. It can be also described as the one that is the most sensitive in the production line. It causes the process to be slow, reduce the productivity and delay in project, hence it will make loss to the company (Gingu, Zapciu, & Sindile, 2014).

In manufacturing system, a bottleneck can happen when there is a task achieved faster than it is supposed to be in production line. This may lead to several problems such as inventory that is more than required and increase in process lead time. Bottleneck doesn't happen by only a machine, but another factors can play the role to create a bottleneck like automated guided vehicle, labors and conveyor (Leporis & Králová, 2010).

Bottlenecks can be classified in two categories based on duration. The first one is short term bottleneck in which the equipment make the process performance slow for short period. The second one is long term bottleneck where the machine reduces the performance for long period (Yang, Chung, & Park, 2014).

Types of bottleneck can be also classified into three kinds which are simple bottleneck, multiple Bottleneck and shifting bottleneck. In simple bottleneck, one machine is the cause of bottleneck within the process. In multiple bottleneck, several machines lead to several bottlenecks which are fixed during the process. For shifting bottleneck, the bottleneck is at once shifting from one machine to another. No single bottleneck happens in shifting type (Lima, Chwif, & Barreto, 2008).

3. Related Works On Bottleneck In FMS

Bottleneck is a fault in the system that slows down the whole operation. In order to develop any manufacturing system, it is important to solve the issue of bottleneck to ensure the flexibility in the production system. There were many researches that have concern about detection of bottleneck in flexible manufacturing system (Li & Meerkov, 2000).

Wang, Li, Arinez, & Biller (2010) developed identification method for quality performance in FMS using markov chain model with data obtained from a factory floor. First thing was doing some assumptions for factors which are FMS, products sorts and their quality properties. A FMS can be improved if there is any sequence in it that gives higher quality, so the quality bottleneck sequence will be the one which lower the quality more than any other sequence. Transitions indicators were made to determine quality bottleneck in the system by looking for the transition that has highest effect on quality. The next step was testing 10,000 cases through conducing numerical experiments to check the indicators used in the model. The results show that the indicators are well precise in locating any bottleneck and thus it is a good method to be used to enhance quality.

Wang, Zhao, & Zheng (2005) indicated that bottleneck can be determined by evaluating system performance by measuring average waiting time and average utilization. Average waiting time can be calculated using the folowing equation:

$B = \{i|W_i \max (W_1, W_2, \dots, W_n)\}$ ………………………………………………………….. (1)

Where:

B: Bottleneck

W_i: Products mean waiting time in ith machine

The machine that has the longest value represents bottleneck in the system. This method is suitable for systems with unlimited buffers and when there is only one machine with highest waiting time value. If average utilization (capacity workload) is used to define bottleneck, then the following equation can be used:

$B = \{i|\rho_i = \max(\rho_1, \rho_2, \dots, \rho_n)\}$ ……………………………………………………………… (2)

Where:

P_i: utilization of the ith machine

Using average utilization is not that efficient way as there might be more than one machine has the same workload which means the difference in this average is small.

Active Period Method is another method introduced by Roser, Nakano, & Tanaka (2001). It is used for detecting the bottleneck in a discrete event system by examining the average duration of a machine being active for all machines and calculates the average active period for each station. The machine with the longest average uninterrupted active period is considered the bottleneck.

The first thing in this method is to put all states into two group: active and inactive. If the machine is in waiting status for a part to be arrived or removed then it is in inactive group, otherwise it is grouped with the active one. Then set of durations A_i and average time for a machine are calculated using equation 3 and 4. The machine with highest average active time is the bottleneck as this has least interruption and can affect on the whole system if it becomes inactive.

$A_i = \{a_{i,1}, a_{i,2}, \dots, a_{i,j}, \dots . a_{i,n}\}$ ………………………………………………………….. (3)

Where:

i: Machine

A_i: Set of durations for each machine i

a_i: Duration

$\bar{a}_i = \frac{\sum_{j=i}^{n} a_{i,j}}{n}$ …………………………………………………………………………... (4)

Some researchers tried not only detect bottleneck but also prevent it. Hoshino, Hiroya, Naka, & Ota (2010) made an approach to solve the problem of use many robots in FMS with the aim to increase productivity. Material- handling robots (MHRs) and material-processing robots (MPRs) were used in this system. Testing was done by simulation to look for the best approach to be used that integrates all operational techniques that help to find bottleneck and then improve the system to avoid it. Dynamic routing was used for MHR after shortest path was first found so that MHR can plans and define a path to the next step after MPR finish from it at a specific station. In addition, operation dispatching rule was applied to reduce the total distance that robot moves during the process. The cost in each operation was remained low which make this method more efficient to be applied.

In high flexible manufacturing system where changes in product or process flow may happen, a bottleneck will shift from one station to another. In order to deal with this problem, Yan, An, & Shi (2010) proposed net-like model for knowlegable manufacturing system. In this model, manufacturing cells are assigned with differenct process tasks. Each one has its own buffer at the begnning and at the end of the production line. Some algorithms were conducted in this model. First one was to make the model understand the structure and the mechanism of the current system. Then another algortihm was made to to keep analyze the situation of the start buffer and localize any bottleneck to store it for improvement of system later on. The advantage of this model is that it allows for shifting of bottleneck between stations till efficiency meets requirement.

Sengupta, Das, & VanTil (2008) proposed a framework to define and rank the bottleneck in the production system. The method consists of four steps. The first one was to obtain from each machine involved in the process the data of inter-departure time. The information included time that machine accomplishes the task. The next step was the place where each machine fail or breakdown as the next machine to continue the process may be busy with another part. Then, the data gathered in first step must be arranged to get rid of the failure times. The last step was to calculate the total cycle time that machine need to for doing its task successfully and waiting till next task or part to reach it. Then the machine with the highest time value was considered as the bottleneck in the process.

Li, Chang, Ni, Xiao, & Biller (2007) developed data driven method for bottleneck detection in order to increase productivity and decrease cost. First, the bottleneck in this system was determined as the machine with highest ratio of total system in a specific time. Turning point then was defined based on two points: upstream machines will be disrupted and downstream one will be under starvation status by bottleneck machine. After that, verification was performed using analytical way based on four situations that the machine might be in. These conditions are whether the machine is working or disrupted or starved or not operating. Simulation was also conducted to validate that a bottleneck in complex manufacturing process is turning point.

4. Advantages And Disadvantages Of Previous Works

Bottleneck detection is important to improve FMS and prevent it if it is possible. Table 1 summarizes the merits and the demerits of methods discussed in the previous section for future work.

Table 1: Review of previous researchers

Author	Approach	Strengths	Limitations
Wang, Zhao, & Zheng, 2005	**Mathematical Detection method**	❖ Good for real-time performance. ❖ Simple and easy to be	❖ Not suitable for complex FMS.

		used.	
Wang, Li, Arinez, & Biller, 2010	**Markov Chain Model**	❖ Provide Mathematical Model to detect bottleneck. ❖ Show details about the process steps.	❖ Many equations are shown for derivation which make it difficult to see the final equations to be used.
Roser, Nakano, & Tanaka, 2001	**Active Period Method**	❖ Good Literature to explain some concepts. ❖ No need for much knowledge about the system to apply the method.	❖ nly Applicable for discrete status.
Hoshino, Hiroya, Naka, & Ota, 2010	**Active Period Method**	❖ Good method for any system with different layout. ❖ Low cost without affecting the system plan.	❖ No validation was provided for this approach.
Yan, An, & Shi, 2010	**Net-like Model**	❖ Can be applied with a random manufacturing capacity. ❖ Ability to detect several bottleneck at the same time.	❖ Lack of quantitative information for algorithm 3.
Sengupta, Das, & VanTil, 2008	**Conceptual Framework**	❖ An easy approach to collect bottleneck places. ❖ Failure, repair and other issues of machines were analysed.	❖ Limited to constant cycle time.
Li, Chang, Ni, Xiao, & Biller, 2007	**Data Driven Method**	❖ Applicable for both long and short term. ❖ Combine between analytical and simulation methods.	❖ Can't define critical bottleneck in the system.

5. Conclusion And Future Work

In conclusion there are several approaches that provide the way to detect bottleneck in FMS. Most researches concentrate on conducting methods for bottleneck detection rather than suggest ways to prevent bottleneck to happen or reduce it. These studies used mathematical and simulation without use real time information. Some of these models were done without testing them to be used in industry. In the future, the hope is to propose new ways to prevent or solve bottleneck issue in FMS.

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