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Research Issues In Detection Of Bottlenecks In Discrete Manufacturing System - A Review

V.S.Jorapur, Research Scholar, Basaveshwar Engineering College Bagalkot, India

V.S.Puranik, Professor, Department of Industrial Production , Basaveshwar Engineering College Bagalkot, India

A.S.Deshpande, Professor, Department of Mechanical Engineering, Gogte Institute. Of Technology, Belgaum, India

Abstract:

Performance of any discrete manufacturing system is solely governed by its throughput. The throughput in turn depends upon many factors such as capacity of machines, labor, raw material quality, scheduling of jobs etc. Bottleneck is one such phenomenon, which affects the throughput predominantly, if not detected and reduced.

This paper essentially discusses the various approaches provided by different authors to detect bottleneck/s, in a discrete manufacturing system, its elimination and to improve the performance of the system. Numerous studies on detecting and overcoming bottlenecks show that it is not a trivial task to provide a unique method to detect and reduce the bottleneck in a discrete manufacturing system. Therefore, the objective of present work is to review the methods provided in the last decade and list their shortcomings in one or the other areas of application. The paper also attempts to suggest a conceptual approach which attempts to address these research issues.

Key Words: bottlenecks, discrete manufacturing system

Organization of the paper is like this: In **Introduction is divided into three sections** I describe all the definitions of bottlenecks available in the literature. Section II explains the bottleneck detection methods available so far in the literature.

INTRODUCTION:

From the manufacturing system point of view, bottlenecks are the congestion points of the system, which slow down the whole operation chain. It is necessary to recognize the bottlenecks and eliminate to improve the performance of the system. . Many factors of a manufacturing system contribute to the bottlenecks such as machine capacity, number of operators, their skills, and so on. In few cases, it may be worthwhile" to directly ask the knowledgeable" employees as suggested by Cox and Spencer (1997) but in majority of the cases, we have to depend on numerous floor data or log data to recognize bottlenecks and to improve them. The iterative method of improving bottlenecks as suggested by Yong-Cai Wang and others *et.al*.(2006) leads to definitions of bottlenecks followed by their detection methods and analysis, so that performance estimates are carried out .This is a vital input to application demands. Bottleneck of a system may be different from different perspective and different for different class of customers. Different detection methods, approximation methods, and asymptotic results have been presented. However, there is no commonly accepted definition or detection technique.

This paper aims at reviewing the entire research carried until so far and on careful observation, we can conclude that few suggested methods aim at estimating system performance and few suggest how to measure and improve upon the bottlenecks. Various methods suggested so far can be grouped as: 1) Bottleneck detection and its reduction after collecting the data for one cycle. 2) Bottleneck detection and its reduction prior to the start of production itself.

Kuo,Lim and Meerkov (1996) and Chang, Kuo and Meerkov (1998) introduced the definitions of bottlenecks for Bernoulli and Markovian serial production lines. According to Kuo,Lim, and Meerkov , in case of Bernoulli lines, a machine was referred to as bottleneck (BN) if partial derivative of system production rate with respect to machines isolation production rate was the largest. This definition captures system parameters like performance, reliability, buffer etc.

According to Chang,Kuo, and Meerkov the above definition is not applicable to Markovian production lines as Bernoulli line depends on single parameter where as Markovian line depends on two independent variables-Up and Down time. A machine $\mathbf{m_i}$ is up-time bottleneck (UT-BN) if

$$\frac{\partial PR}{\partial T_{up_i}} \geq \left| \frac{\partial PR}{\partial T_{down\,j}} \right| \quad , \; j \neq I,$$

Similarly, it is down-time (DT-BN) bottleneck machine if,

$$\left| \frac{\partial PR}{\partial T_{down_i}} \right| \geq \left| \frac{\partial PR}{\partial T_{down_j}} \right|, \quad j \neq I$$

And a machine $\mathbf{m_i}$ i is bottleneck (BN) if it is both UT-BN and DT-BN, Similarly up-time preventive maintenance and down-time preventive maintenance bottlenecks are defined as

$$\frac{\partial PR}{\partial T_{up_i}} \geq \left| \frac{\partial PR}{\partial T_{down\,j}} \right|$$

------ respectively .In balanced two machines lines(machine with identical efficiency) the machine with smaller downtime is BN and in unbalanced two machines , DT-BN is the machine with smallest value of v.T_{up}. T_{down} , where v is the probability of blockage for first machine and probability of starvation for the second machine.

*bottleneck detection methods can be grouped into two categories: Analytical and Simulation based. Analytical methods are suitable for long-term prediction and not for short-term bottleneck detection. Shifting Bottleneck Procedure as suggested by Adams et.al.(1988), decomposes the job shop problem into a number single machine sub problems. At each iteration a critical or bottleneck machine is identified and scheduled with scheduling decisions at subsequent iterations being subordinated to those scheduled earlier. S.Nakajima (1988) provided Overall Equipment Effectiveness (OEE) to measure the productivity and performs diagnostics at equipment level. However such metrics are lacking at the factory level, as indicated by a literature review. To address this gap , overall factory effectiveness is proposed (OFE) by Scott and Pisa (1998), which is about combining activities and relationships between different machines and processes and integrating information ,decisions, and actions across many independent systems, subsystems. Operations research based methods (i.e. optimization and network computation) and control theoretical methods are based on rigorous mathematical modeling. System analysis based methods (i.e. IDEF, Petri net) for productivity improvement are driven by information systems. The performance metrics based methods indicate that quantitative metrics for measuring factory level diagnostics and productivity are lacking. Hence OTE (Overall Throughput Effectiveness) METRICS were proposed by Muthaih and Huang(2007) to address the gap mentioned in performance metric based methods. However this method highlights its ability of bottleneck detection in a Just-In Time environment. And nothing is mentioned about its application in other manufacturing environments. Arne Ingemansson (2004) suggested a methodology of identifying bottleneck machine and its reduction by using a combination of automatic data collection and discrete event simulation for a manufacturing system. However this method finds its application with industries having data acquisition setup. It is useful in that analysis can be done offline without disturbing the actual manufacturing system and with real time data.

Collecting Inter-Departure time and failure cycle data to identify and rank bottlenecks in a manufacturing system was proposed by Sengupta and Das(2008) . It assists in replacing collection of cycle time data with inter departure time .This method is applicable to identify both momentary and average bottlenecks. However, this method uses only deterministic cycle times.

Shifting bottleneck method was proposed by Roser, Nakano(WSC,2002) which captures active duration of a machine . Active duration includes actual processing time, repair time, as well as tool change time. The active duration also includes machine being blocked or starved. This method divides bottleneck into sole bottleneck or shifting bottleneck machines. It also enables us to find out momentary and average bottlenecks. At any instant of time, a machine with longest active duration is sole bottleneck and shifting of bottleneck from previous to current machine happens during overlap. Without the knowledge of machine sequence, active period algorithm can be used for bottleneck detection. This method can be used for a wide range of entities ,for example, machines, AGVs, factory workers, computer networks, and demand logistics. This method fails to identify the primary bottleneck machine when active durations of few machines are same in the network.

A data driven bottleneck detection method proposed in Li.et.al (2007) detects bottlenecks using the term “Turning Point “. A turning point is defined as the machine where the trend of blockage and starvation changes from blockage being higher than starvation to starvation being higher than blockage. Further the sum of a “turning point “machines blockage and starvation is smaller than its neighboring machines. Hence such machine has highest percentage of sum of operating time and down time compared to the other machines in the segment. It has been proved (Li.et.al. 2007) that this method can provide quick bottleneck detection.

A method based on the concept of Kuo.et.al. (1996, 2008), who proposed an indirect method of bottleneck detection for open serial lines, was proposed by Biller .et. al. (2008). This method popularly known as “ Arrow based method “ detects bottlenecks in longer lines by arranging the probabilities of starvations (ST) and blockages(BL) for each machine and placing the arrows directed from one machine to another according to whether BLi > ST_{i+1} or ST_{i+1} > BLi ,wherein in former case arrow in forward direction and backward in latter case. Then a single machine with no emanating arrows is the bottleneck.

A method of evaluating “criticality indicator “for each workplace and comparing the values to detect the critical place, was proposed by Kralova, Bielak (2004).Criticality indicator for I th workplace is calculated as the difference of the individual rates for this workplace (the average rates of utilization, starvation, blocking, waiting for labor) with respect to whole system average of this rate. Mathematically,

$$KR_i = \frac{\sum_{i=1}^{n} Bi}{n} - B + I_i - \frac{\sum_{i=1}^{n} I_i}{n} + BL_i - \frac{\sum_{i=1}^{n} BLi}{n} + L_i - \frac{\sum_{i=1}^{n} Li}{n}$$

Where, KR_i = criticality indicator for i th workplace

B_i = average utilization rate for ith machine, (idle, %)

Ii = average starvation rate for ith machine (idle %)

L_i = average waiting rate for labors (labor, %)

BL_i = average blocking rate for ith machine (blocked, %)

The workplace with minimal value of KR is regarded as bottleneck and with maximal value as a maximal capacity reserve.

Jinasha Lu, SHEN, and LAN(2006,IEEE) studied some possible causes for shifting bottlenecks and provided solutions. According to them sudden change of market demand leading to change of product mix, leads to shifting bottlenecks. Production batch size also has influence on shifting bottlenecks, load balanced level also a cause for this. They applied TOC principles for product mix related problem and DBR method for unavoidable bottleneck shiftness.

Zgai, Sun and Wang (2010) proposed an Orthogonal experiment (BD-OE) for job shop . A finite number of experiments by combining different dispatching rules, which has greatest effect on system index, a factor introduced to determine the bottleneck

The research gaps identified from this review is as under.

1. In shifting bottleneck detection method , active duration of each machine is taken into account for primary and secondary bottleneck machines identification. But its drawback lies in the fact that it fails to identify the primary bottleneck machine in case of tie in the active duration of machines.
2. Since no method is completely able to identify the bottlenecks in different scenarios , it is worthwhile to use a combinatorial approach to resolve this issue.

PROPOSED CONCEPTUAL APPROACH

The method suggested by Roser is limited to a network consisting of non-identical active durations. Our work aims at improving the method suggested by Roser such that the method is robust and can be used in any situations. We are using a combinatorial approach to resolve this issue.

CONCLUDING REMARKS

From the above literature review it is clear that still a large gap exists in the improvement of performance of discrete manufacturing system by suggesting new / modified methods to detect and reduce bottlenecks .

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