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Utilization vs. Throughput: Bottleneck Detection in AGV Systems

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ABSTRACT

It is commonly believed, that improving the machine or AGV with the largest utilization improves the throughput. Unfortunately, this is not always the case, as the utilization is a rather imprecise measure of the bottleneck. This paper presents an AGV system, where improving the machine with the largest utilization does not improve the overall system. Rather, the AGV's with a smaller overall utilization are the bottleneck. The paper applies a bottleneck detection method based on the active periods of the machines and AGV's, which is able to detect the bottlenecks reliable and accurate.

INTRODUCTION

Every logistic or manufacturing system has one or more bottleneck. To improve the throughput of the system, it is necessary to improve the bottlenecks. (Blackstone 2001; Goldratt 1992). The problem is to find these bottlenecks. There are currently a number of conventional methods in use to detect the bottlenecks, based on either the utilization or the queue statistic as for example waiting time or queue length. Unfortunately, these methods have a number of shortcomings. Queue statistics require the existence of a separate queue for every machine, with an ideally infinite capacity. Unfortunately, this is rarely the case. Even if this requirement is satisfied, the method is very dependent on outside influences as for example the control logic or batch sizes. In any case, it is often difficult to detect the primary bottleneck, let alone secondary bottlenecks or non-bottlenecks.

Using the utilization to detect the bottleneck has the small advantage that it is measured directly at the machine or AGV and can be used in any system. Yet, as it will be demonstrated below, the utilization is an imprecise measure of the bottleneck, and improving the machine or AGV with the largest utilization does not necessarily improve the overall system, and the resources invested in the improvements will not return an improved system performance. Even if the system is simple enough such that the maximum utilization represents the largest bottleneck, it is difficult to detect secondary or non-bottlenecks. Furthermore, the large sets of data required to determine the utilization accurately does not allow the detection of short-term bottlenecks or the analysis of non-steady-state systems.

The following section will describe a AVG system in detail, where the utilization is an incorrect measure of the bottleneck. The effects of different improvements onto the system will be described in detail. The second section describes the use of the active period bottleneck detection method to reliably detect the bottlenecks and to measure the effect of improving the system. The paper will close with a summary.

AGV SYSTEM

The presented system consists of three machines and three AGV's as shown in Figure 1. The three AGV's bring parts from the "in" station to the first machine M1, then to the second machine M2, to the third machine M3 and then to the "out" station. The AGV's only proceed to the next stop if the next stop is free, i.e. not blocked by the previous AGV. Each machine also has two buffers of capacity one for unprocessed and processed parts. There is an infinite supply and demand of parts at the "in" and "out" stations.

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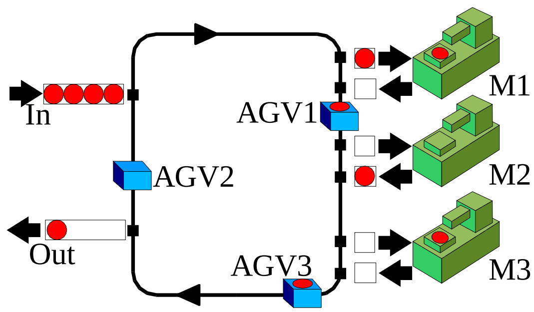

Figure 1: AGV System

Table 1 shows the machine parameters. Besides the deterministic cycle time, each machine has randomly occurring failures, with an exponential distributed mean time between failures (MTBF) of 10,000s and an exponential distributed mean time to repair (MTTR) of 500s. Table 2 shows the distances the AGV has to travel between the stations and the time for a speed of 500mm/s. Loading and unloading is instantaneous. The distance from M3 to the “in” station includes the stop at the “out” station.

Machine	Cycle Time (s)	MTBF (s)	MTTR (s)
M1	55	10,000	500
M2	60	10,000	500
M3	40	10,000	500

Table 1: Machine Parameters

From	To	Distance (mm)	Time (s)
In	M1	34,650	69.3
M1	M2	6,050	12.1
M2	M3	6,050	12.1
M3	In	32,700	65.4

Table 2: AGV Travel

The simulation was implemented using the GAROPS simulation software (Nakano et al. 1994). The simulation was run for 400 hours. The measured utilization of the system is shown in Figure 2, including the confidence intervals with a confidence level of 95%. It can be seen clearly, that according to the measured data, machine M2 has the largest utilization of 80% (including both work and repair times), and therefore would be according to conventional wisdom the main bottleneck. Second would be M1 with an utilization of 73%, followed by the three identical AGV’s with 66% and M3 with 55%. The measured production rate was one part every 80.5s.

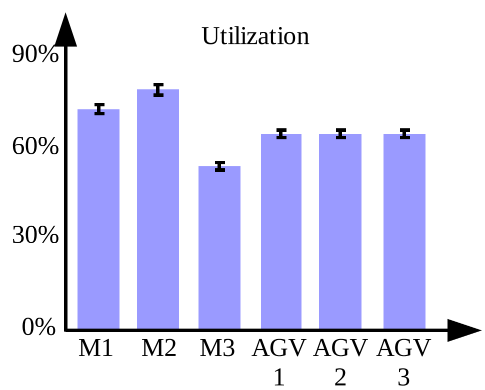

Figure 2: Utilization

According to the utilization, M2 is presumed to be the bottleneck. Subsequently, improving M2 would improve the overall production rate. To test this theory, the cycle time of M2 has been improved significantly from 60s to 40s, a reduction of 33%. Surely, if M2 would be the bottleneck, this would improve the system.

However, after simulating and analyzing the data, the production rate was virtually unchanged at 79.5s per part, compared to 80.5s for the initial simulation. Furthermore, with a confidence interval of ±1.5s, it cannot be said with any certainty if the production rate has changed at all. Subsequently, an improvement of M2 did NOT improve the system, and therefore M2 is NOT the bottleneck, and the utilization can NOT be used to detect the bottlenecks reliably. Figure 3 further below gives an overview of the production rates of all compared systems.

However, if M2 is not the bottleneck, then which machine or AGV is the bottleneck? To find the bottleneck, different machines and AGV’s have been improved independently, and the resulting production rate has been analyzed. The three machines have all been changed with respect to the cycle time, and the failure rate, and the AGV’s have been tested for an improved speed, comparing altogether seven different systems to the initial system. Table 3 and Figure 3 shows the results of the different improvements, where the original and improved columns show the cycle time, the MTTR/MTBF, and the speed for the cycle time, repair and AGV improvements respectively. Surprisingly, the improvement of the AGV’s had the largest impact on the production rate, reducing it from 80.5s to 69.5s per part, and therefore the AGV’s are the bottleneck, despite the fact that they have a rather low utilization of only 66%. Therefore, the utilization cannot be used to determine the bottlenecks or non-bottlenecks. The next section will present the active period bottleneck detection method for a reliable and accurate bottleneck detection.

Machine	Original	Improved	Production Rate (s)
M1 Cycle	55s	30s	79.6s
M2 Cycle	60s	40s	79.5s
M3 Cycle	40s	20s	80.3s
M1 Repair	500/10,000s	100/50,000s	
M2 Repair	500/10,000s	100/50,000s	75.8s
M3 Repair	500/10,000s	100/50,000s	75.3s
AGV’s	500mm/s	1000mm/s	69.5s

Table 3: Improved Systems

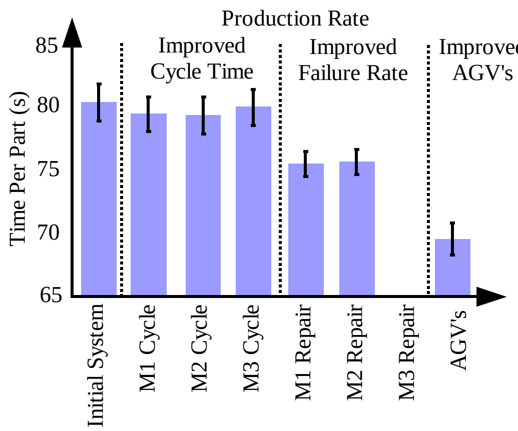

Figure 3: Production Rates

ACTIVE PERIOD BOTTLENECK DETECTION

The active period bottleneck detection method uses the same data as the utilization in determining the bottlenecks, by investigating when a machine is active or not. However, while the utilization determines the **percentage** of time a machine is active, the active period method determines the **duration** a machine is active without interruption. This gives a much better understanding of the constraints within the system, and therefore allows for a much more reliable bottleneck detection. Initially, the average active duration (Roser, Nakano, and Tanaka 2001) has been measured, yet the method has been improved to determine the bottleneck at any given point in time by finding the machine or AGV with the longest active period at that time. This method has been proven to work reliably for non-AGV systems (Roser 2001; Roser, and Nakano 2002; Roser, Nakano, and Tanaka 2002), and this paper will demonstrate the usefulness for AGV systems.

As the method is described in more detail in the above references, the following description will be brief. The active period bottleneck detection method determines the periods during which a machine or AGV is active without interruption. The term “Active” includes not only machines working or AGV’s transporting, but also breakdown periods, tool changes, or recharging times, i.e. any time a machine or AGV cannot process or transport a part right away. The active periods are occasionally interrupted by inactive periods, where the machine or AGV has to wait for the completion of a process by another machine or AGV. This would for include starved or blocked machines or AGV’s.

The underlying idea of the method is that at any given time, the machine with the longest active period is the bottleneck, and the system is constrained by this machine. The method further distinguishes between shifting bottlenecks, where the active period of one bottleneck overlaps with the active period of the next bottleneck, and sole bottlenecks, where the current bottleneck does not overlap with previous or subsequent bottlenecks. Figure 4 shows an example of a two-machine system, where at the beginning machine M1 has the longest active period, and therefore is the bottleneck. Later, the bottleneck shifts from machine M1 to M2, and then M2 is the sole bottleneck. The likelihood of a machine being the bottleneck can be measured easily by determining the percentage of the time a machine is a sole or shifting bottleneck.

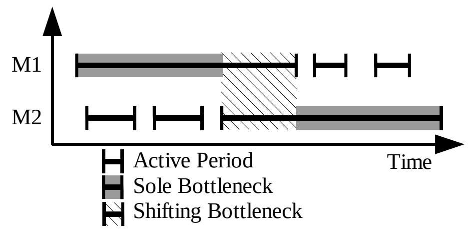

Figure 4: Shifting Bottlenecks

Analyzing the AGV system using the active period method gives a very different bottleneck than the utilization in Figure 2. According to the active period method, the main bottleneck is the AGV system, with each AGV having a bottleneck probability between 25% and 50%, whereas the machines all have a bottleneck probability of less than 10%.

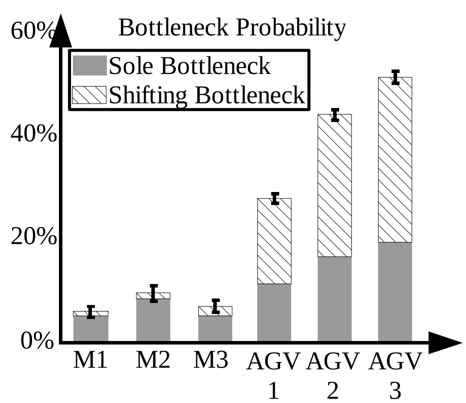

Figure 5: Active Period Bottleneck Probability

A detailed analysis of the shifting bottlenecks confirm that the failure rates have more impact on the throughput as the cycle time, as analyzed in Table 3 and Figure 3. Figure 6 shows a graph of the sole and shifting bottlenecks for the original system, and the times of the failures of different machines. It can be seen clearly, that every time a machine became a bottleneck, a machine failure has happened at the beginning of the bottleneck period. While Figure 6 shows only a brief period of simulation time, the results are similar throughout the simulation.

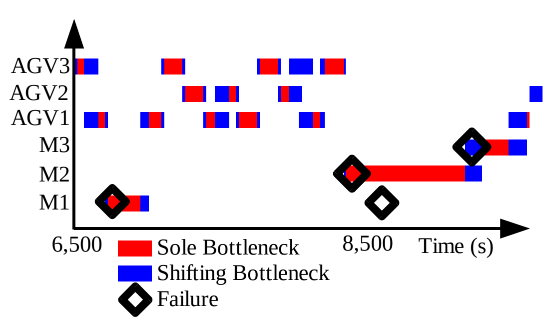

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Figure 6: Bottlenecks and Machine Failures

Therefore, if there would be no machine failures, the machines would not become the bottleneck at all. The shifting bottleneck analysis using the active period bottleneck detection method therefore not only detects the bottlenecks reliable, but also allows a deeper understanding of the underlying causes of the bottlenecks.

SUMMARY

It has been shown, that the conventional bottleneck detection methods as for example the measurement of the utilization, the waiting time or the queue length occasionally fail to detect the primary bottleneck reliably, and are usually unable to detect secondary bottlenecks or non-bottlenecks. Furthermore, queue based methods require an infinite queue in front of every machine, and utilization based methods require a large amount of data to accurately measure the utilization.

On the other hand, the shifting bottleneck detection method based on the active periods within the system is able to measure the likelihood of a machine being the bottleneck reliably for all machines and AGV’s. Thus, it is easy to determine which machine is the primary bottleneck, which machines are the secondary bottleneck, and which machines are no bottlenecks at all.

The analysis does not require large amounts of data, but can also be performed for small sets of data where conventional methods fail. This allows the use of the shifting bottleneck detection method not only for steady state systems, but also for variable systems, where the system changes over time, as for example due to a change in the production program.

Finally, the method allows the monitoring of the bottlenecks, giving insights about the underlying behavior of the system and the cause of the delays in the throughput.

The method has been implemented in a software tool Garops Analyzer, automatically analyzing the data of the GAROPS simulation and detection the bottleneck, showing the results in an easy to understand MS EXCEL spreadsheet.

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