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Holistic Manufacturing System Analysis

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ABSTRACT

The Toyota Central Research Laboratories have recently developed a number of simulation based methods to understand and predict the behavior of a manufacturing system. The novel idea of these methods is a holistic view of the manufacturing system, i.e. understanding the system by analyzing the relations between the machines instead of analyzing machines independently. This paper provides a framework of the holistic manufacturing analysis and a summary of the developed methods.

ATOMISTIC VS. HOLISTIC ANALYSIS

The understanding and optimization of manufacturing systems is a frequently researched subject in discrete event simulation. Yet, most methods analyze the system in an atomistic view, and study each machine separately. However, if the correlated manufacturing system is broken into its independent machines before analysis, it is difficult to later combine the analysis of the machines into a understanding of the entire system. The holistic methods, however, analyze not only independent machines, but the interaction between machines. The Merriam-Webster online dictionary defines holistic and atomistic as follows:

> ***holistic****: relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into parts*
>
> ***atomistic****: characterized by or resulting from division into unconnected or antagonistic fragments*

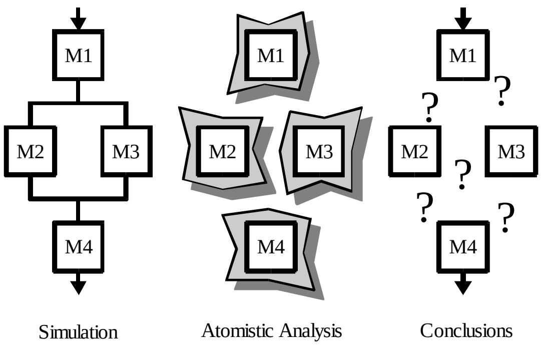

Figure 1: Atomistic Analysis Process

The current status quo of manufacturing simulation analysis is usually an atomistic analysis, completely ignoring the dependencies and interactions and achieving only a fraction of the possible conclusions which are hidden in the simulation data. For example, in a standard analysis the working times of a machine is summed up to calculate the utilization, with utter disregard of the relation of the individual working times to the other machines. This approach is visualized in Figure 1, where the manufacturing system is broken into its individual elements for an atomistic analysis. Therefore it is very difficult to determine valid conclusions for the correlated system. (Roser 2004b)

The holistic analysis approach is fundamentally different from the standard output analysis. The holistic analysis analyzes the interactions between the machines and statistically represents the correlations between the machines in order to understand the system. This results in a much better understanding of the system, and also allows for a prediction of the system performance based on the changes in the different entities as shown in Figure 2, where the complex interactions of the system are analyzed to obtain a holistic understanding of the system. Subsequently, valuable information about the system is obtained and it is easy to make valid conclusions for the correlated system.

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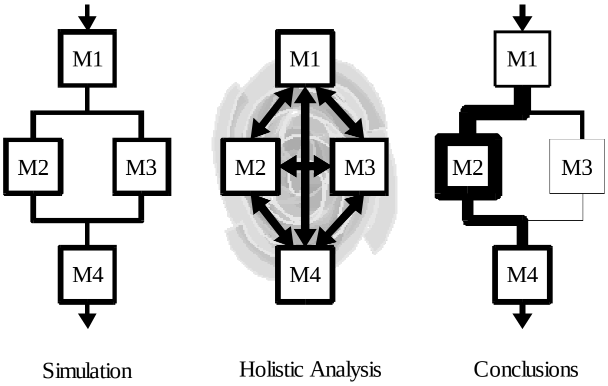

Figure 2: Holistic Analysis Process

SHIFTING BOTTLENECK DETECTION METHOD

For example the shifting bottleneck detection method compares the uninterrupted active (working) times of the different machines, and at any given time the machine with the longest uninterrupted active period is the bottleneck for this time. Thus the system is analyzed from a holistic point of view by comparing the different machines at different times. Subsequently, it is possible to measure the level of constrains of the machines and to make a valid prediction of the effect of a change in the machines onto the entire system.

It is also possible to show the percentage of time a machine is the sole bottleneck and the percentage of the time a machine is part of a shifting bottleneck is measured for the selected period of time as shown in Figure 3.

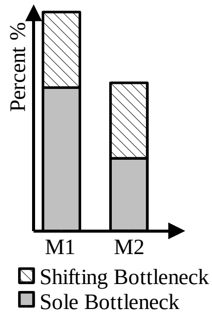

Figure 3: Average Bottleneck over Period of Time

This method has been tested and documented extensively. (Roser 2002; Roser 2003b)

BUFFER ALLOCATION MODEL

Buffers improve the system throughput by reducing the idle time (blocking and starving) of the machines. Therefore, to understand the buffers it is crucial to understand the blocking and starving of the machines, the causes thereof, and, most important the path to the causes and the buffer locations in between. The blocking and starving analysis analyzes every starving or blocking occurrence of every machine in the simulation, and finds the cause of the starving and blocking, and, more important, the buffer locations on the path between the idle machine and the cause thereof. This allows a good estimation of the effect of a buffer onto the entire system.

An example system with 7 machines has been analyzed, and the causes of the blocking and starving of the machines has been established as shown in Figure 4 for machines M3 and M5, showing the path of the starves (cross-hatched) and blocks (diagonal-hatched) from machine M3 and machine M5 to the machine causing the starve or block. The width of the path represents the fraction of the starves/blocks following this path.

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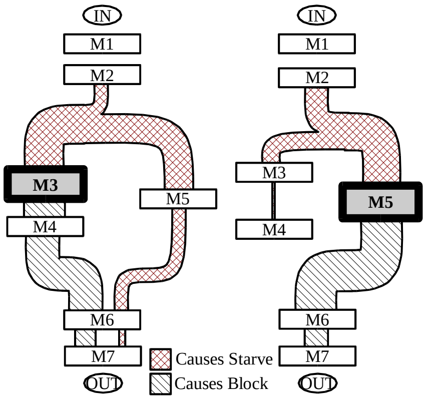

Figure 4: Causes of Blocking and Starving of Machines M3 and M5

The path between the idle machines and the cause thereof allows an estimation of the effect of buffers. Only buffers in these path affect the machines.

The buffer prediction model can also easily be used to optimize a manufacturing system, for example using a multi step optimization, where the prediction model is used for a local area optimization, after which a new simulation verifies the results. The results of the new simulation are then used for a subsequent optimization step. This is repeated until no further improvement is possible. Figure 5 shows a multi step optimization for a system similar to Figure 4, where the step size is limited to 15 buffer spaces per buffer. The simulation quickly reached an optimal plateau after 4 steps, and no further improvement was possible after step 13. (Roser 2003a; Roser 2004a; Roser 2004c)

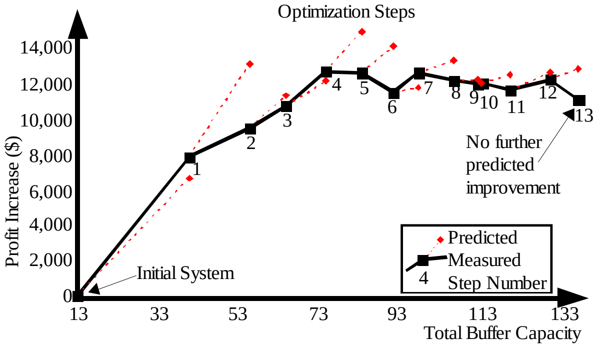

Figure 5: Multi Step Buffer Optimization

CONCLUSIONS

The presented holistic approach of analyzing not only the entities of the manufacturing system but also the interactions between these entities greatly enhances the understanding of the system by statistically analyzing the interactions in a manufacturing system. Subsequently a much deeper understanding of the system can be obtained. If the relations between the system entities is understood, the effect of changes in one entity can be estimated, greatly benefiting the industry by predicting the behavior of the system.

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