Process Flow Simulation to Reduce WIP Built-up and to Maximize Throughput in a Multi-part Multi-operation Process – A Case Study

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Abstract

The need to study the behavior of complex manufacturing processes with multiple machines, job mix and variable batch sizes to establish production schedules to meet specific demands and to identify bottlenecks in the system, cannot be over emphasized. Unfortunately direct analytical formulations of the behavior of these systems are not feasible. Since direct solutions are not possible, simulation of the manufacturing process using process simulation software packages is the next best alternative. In this paper the findings of a case study that was carried out for a large manufacturing system have been presented. The focus of the simulation study was to a) identify areas of potential bottlenecks like build-up of WIP, loss of throughput and loss of time due to cross-loading of parts at various workstations, b) establish optimum batch sizes to reduce excessive WIP built-up, c) study the feasibility of adding a new machine to eliminate a cross-loaded operation with a high changeover time, and d) run the simulation model with known production requirements for planning daily production schedules (to decide optimum batch sizes) to meet the assembly requirements for a group of parts. In this paper, first the modeling process is described, then the simulation run results are presented and finally the effectiveness, limitations, and computational issues associated with these types of simulation studies are discussed.

Introduction

Simulation of manufacturing systems to study the behavior of the manufacturing process, schedule production activities and optimize job mixing/batch sizing has been established a very reliable tool. Since analytical modeling of the behavior of these discrete-event processes is not feasible, computerized simulation models have been frequently used for simulating manufacturing processes [1-3]. Object-oriented techniques have also been used for simulating manufacturing systems [4]. Some authors have applied formal methods to verify manufacturing simulation models [5]. There are many commercial general purpose simulation software packages available in the market that allows realistic simulation of the behavior of manufacturing systems. There have been studies to decide which specific software is suitable for a specific simulation requirement [6, 7].

For the simulation study reported in this paper, the software package Witness 2001 [8] was used due to two factors: 1) The Witness software has been in use in the organization for some time and the process planning personnel were accustomed to use it and 2) Witness had a good object-oriented programming capability to control the behavior of majority of the elements in a manufacturing system. These simulation studies were conducted to analyze the behavior of the process line for two intermediate shafts (hereinafter referred to as SH-1 and SH-2) for a large manufacturing company producing transfer gears for four wheel drives. The objectives were to establish optimum batch sizes to reduce excessive WIP (Work-In-Progress) build-up in the production process and to study the feasibility of adding a new machine to eliminate a cross-loaded operation with a high changeover time of about six hours.

Objectives

The simulation package Witness 2001 was used for developing various models to study the behavior of the production line for two intermediate shafts. The goal of the simulation study was to:

a. Identify areas of potential bottlenecks like build-up of WIP, loss of throughput and loss of time due to cross-loading of parts at various workstations
b. Explore alternatives to improve the production system performance by optimizing process parameters like batch sizes, job sequencing, etc.
c. Study if a new machine could be added to streamline a cross-loaded operation that was creating WIP pileup.
d. Run the simulation models with known production requirements for planning daily production schedules to decide the optimum batch size to meet production/assembly requirements for a group of parts.

Methodology

Simulation of production process using Witness 2001 is carried out in two steps:

a. Building a suitable model by connecting prototype elements from the element library and fine-tuning the parameters to reflect actual behavior. This last part may need some programming work. Witness provides a set of pre-defined base primitives that can be instantiated to create elements for representing real-life production elements like machines, parts, labors, conveyor, vehicle, track, etc. Parameters of each of these items could be fine-tuned to represent actual behavior as far as feasible.
b. Running the model for stipulated conditions. Depending on the scenario being simulated, several trial runs may be necessary with varying parameters.

In order to develop realistic simulation models, following steps are needed:

1. Establish model parameters so that the model resembles the plant situation as far as possible. This step involves both verification and validation of the respective models.

2. Establish procedures to operate the model for various machine and operation configurations:
    a. Run the model for a specified number of days to establish the production figures.
    b. Run the model long-enough to produce a specified quantity of each of the parts.

c. Set up an optimization run for establishing batch sizes that could meet production requirement with minimum WIP.

The simulation models were tuned to perform following four scenario analyses:

1. Purpose: Run until the model reaches a steady-state and track WIP and Finished Quantity
Batch Size: Specified
Time of run: Not set
# of Batches to run: Not set
Cross-loading pattern: Wait / Next

2. Purpose: Run for specified time (# of days/ shifts, etc) to find Finished Quantity
Batch Size: Specified
Time of run: Specified
# of Batches to run: Not set
Cross-loading pattern: Wait / Next

3. Purpose: Run to produce specified output: Find time required and WIP build-up
Batch Size: Specified
Time of run: Not set
# of Batches to run: Specified
Cross-loading pattern: Wait / Next

4. Purpose: Run for specified time: to optimize batch size, etc., using the optimizer plug-in
Batch Size: Not set (but a range has to be specified for the controlling parameters)
Time of run: Specified
# of Batches to run: Not set
Cross-loading pattern: Wait / Next

In the cross-loading pattern "Wait" sequence means a strict sequence of operations, say, run 100 quantity of part1, then 150 of part2, then 200 of part3, etc. and wait indefinitely for arrival of a part if that part is not in the queue. The "Next" sequence means that when a scheduled part is not available, the next part in the schedule will be processed. This is like a somewhat restricted FIFO. These two sequences are in-built in Witness and could be used as required to simulate a process. However, it is also possible to generate more complex sequences programmatically. However, major problem is to decide the criteria for such sequences.

For the 4th run (Optimization), optimality criteria (cost function) and constraints have to be specified. For the case study the optimality criteria was “optimum batch size to produce specified daily requirement”. In this effort an objective function was established as a minimization of Cost of carrying WIP and Incentive for producing the specified quantity, so that a minimization of this function would give low WIP cost and high yield. While the WIP cost could be established accurately, there was no method to establish exact factor for the finished quantity. The cost minimization function that was adopted for this study was: C1*WIP + C2/Yield, where C1 and C2 are positive constants.

Details of Case Studies

Intermediate Shaft Process Flow: In this process, machining operations are performed on four parts (intermediate shafts: SH-1: Parts 1&2, SH-2: Parts 3&4) starting with green (raw material) input from the inventory to the final de-hick operation. Figure-1 shows the flow diagram (actual plant layout has been used to develop the schematic diagram*). One of the major bottlenecks in the process flow was the WIP build-up at the clipper which was serving the four parts and the changeover time was about six hours. The Witness model for the existing condition (Figure-2) was run for various operating conditions (batch sizes based on actual requirements) and the results confirmed the observation of large WIP build-up. An alternate arrangement was proposed to reduce the WIP built-up by introducing a new clipper machine so that the cross-loading could be eliminated by separating the process into two independent processes. The proposed alternate scheme is shown in Figure-3. One of the operations in this process was heat treatment (HT), which was at a separate common facility and it was established from the heat treatment logs that each batch of shafts take between 14 to 24 hours for completion of the HT operation. This heat treatment process was simulated in the model using a uniform random distribution between 14 to 20 hours.

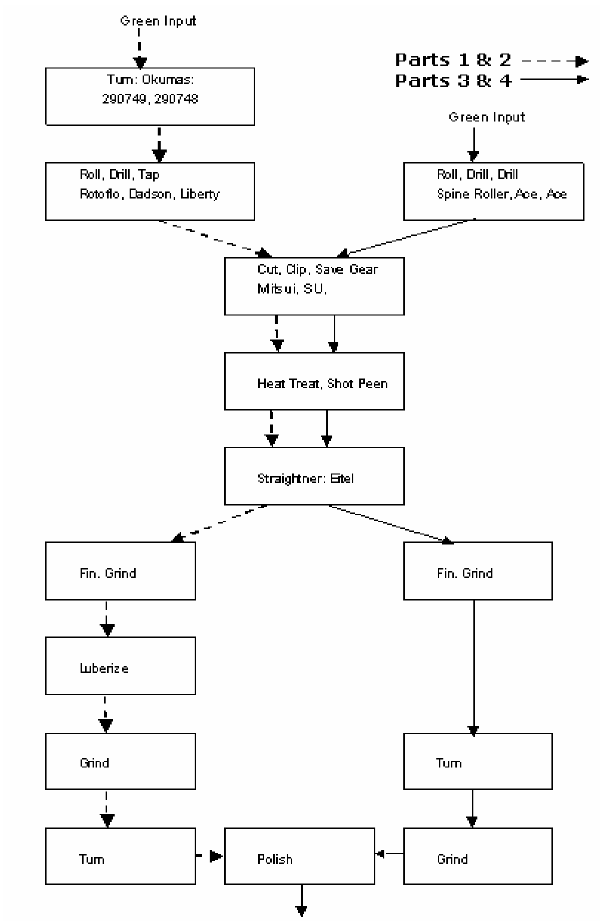

Figure-1: Intermediate Shaft Process Flow Diagram

* Although the study has been conducted using actual machine/operation data, plant layout and process parameters, those data are not shown in this paper.

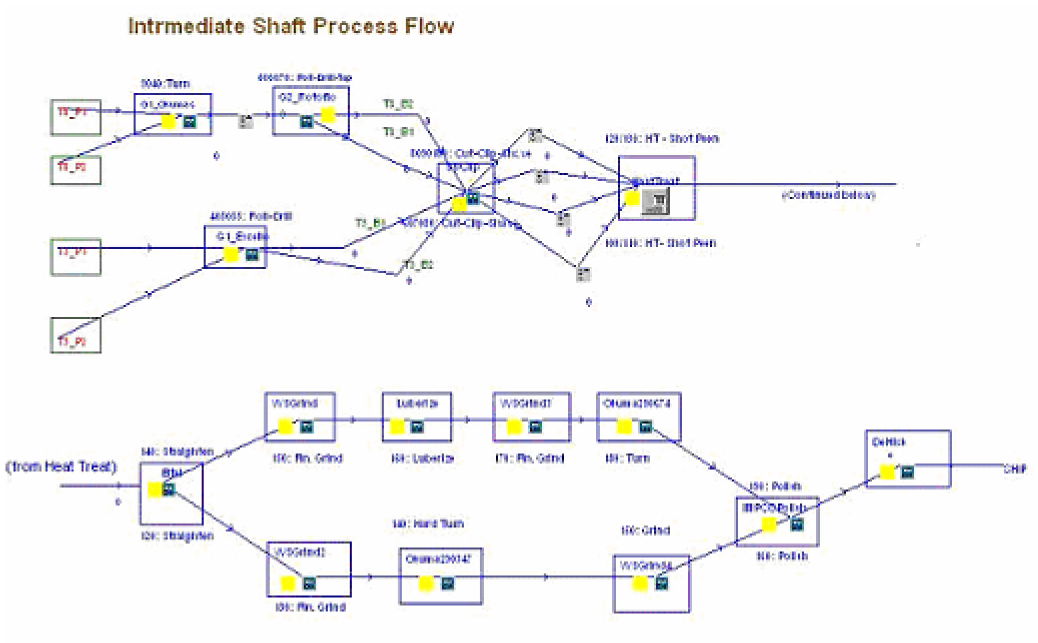

Figure-2: Witness Model - Intermediate Shaft Process Flow

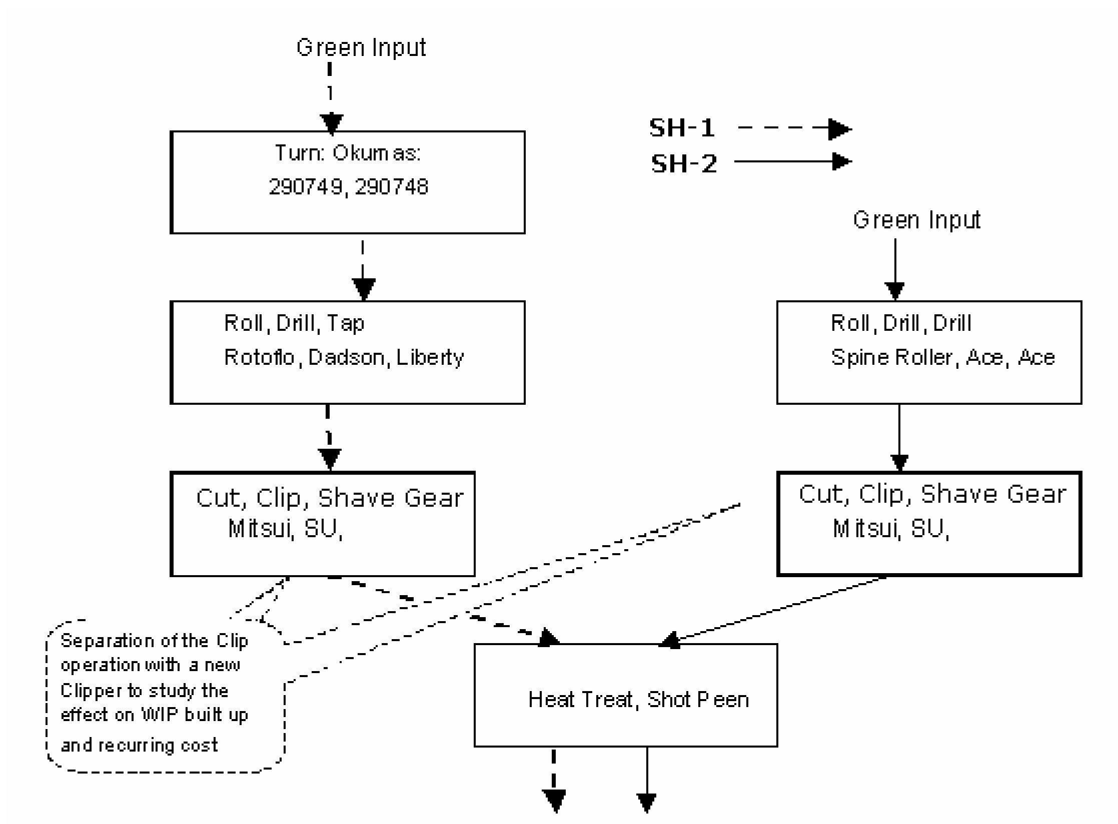

Figure-3: Separation of the Clipper Operation - Intermediate Shaft Process Flow

First and Second Speed Gear Process Flow

This system is almost similar in configuration to the intermediate shafts. The Witness model for this process is shown in Figure-4.

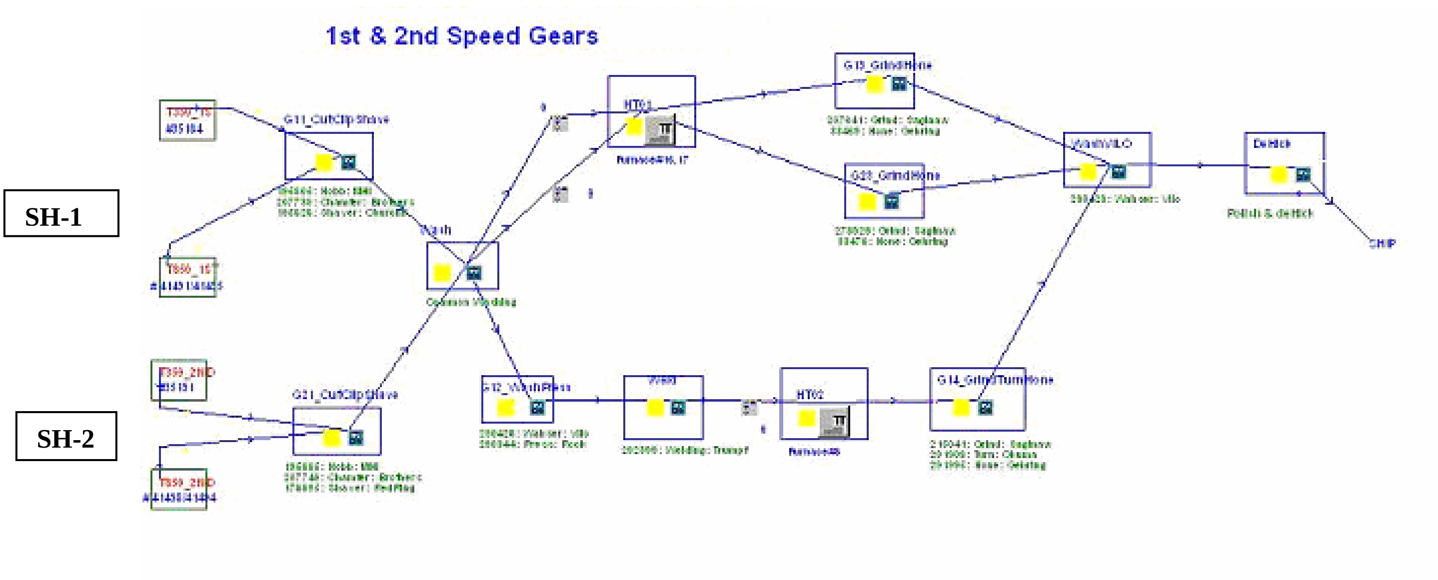

Figure-4: Witness Model – 1st and 2nd Speed Gear Process Flow

Discussion of Results, Limitations and Constraints

Simulation and optimization runs were carried out at various conditions for the above two models to arrive at optimum batch sizes to meet specified production schedules with minimum WIP. Progress of a typical batch optimization run has been shown in Figure-5 and the final results from a typical batch size optimization run has been shown in Figure-6.

The decision to add a new clipper machine to streamline the process needed financial justification. The simulation study results were used to show the extent of WIP reduction and improvement in throughput. Based on the results the management decided to go for a new clipper machine.

Another option that was studied was to see if the simulation models could be run on a daily basis to do job scheduling based on daily requirements. It was proposed that each morning a new set of actual production requirements would be used to run the simulation models to arrive at optimum batch sizing for that day's production.

In general simulation studies give estimates of the actual situation, which are stochastic processes. Accuracy of the results depends on how accurate each modeling element is and how closely the model represent the actual process. This has two aspects: nature of in-built elements in the software - how flexible and accurate they are in simulating the physical behavior of a machine or process and how realistically the parameters could be established by work-study.

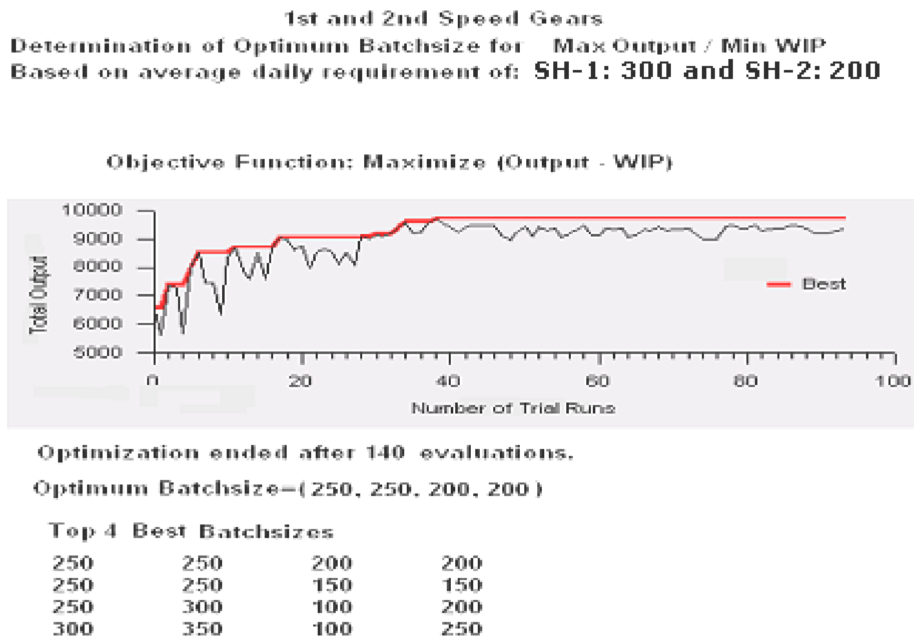

Figure-5: Witness Optimization Run Results - 1st and 2nd Speed Gear Process Flow

Because the software imposes fixed rules/behavior of the base elements, the accuracy of a simulation study depends on how accurately the process parameters (such as cycle time, setup time, etc) may be estimated and how accurately the pre-defined elements may be connected through logical/ programmed links.

In this study, the process parameters were taken from actual recorded JPH (jobs per hour) data that were collected and compiled during Sept-Oct, 2001, for incorporation in the master JPH database. These parameters were quite accurate and hence the results of the simulation studies were representative of actual situations. The models were run several times with known scenarios to fine-tune and to validate the model and then postulated future operation scenarios were simulated.

One major constraint for running large simulation models is the run time (depends heavily on hardware resources). In the present case, Witness was installed on a relatively older Pentium machine running under Windows operating system. For some simulations scenarios Witness estimated that some of the optimizations would require running the computer for several days at a stretch. Those scenarios could not be studied. So, for running these simulation studies on a regular basis to assist the production planning for day-to-day activities, more computing power would be required.

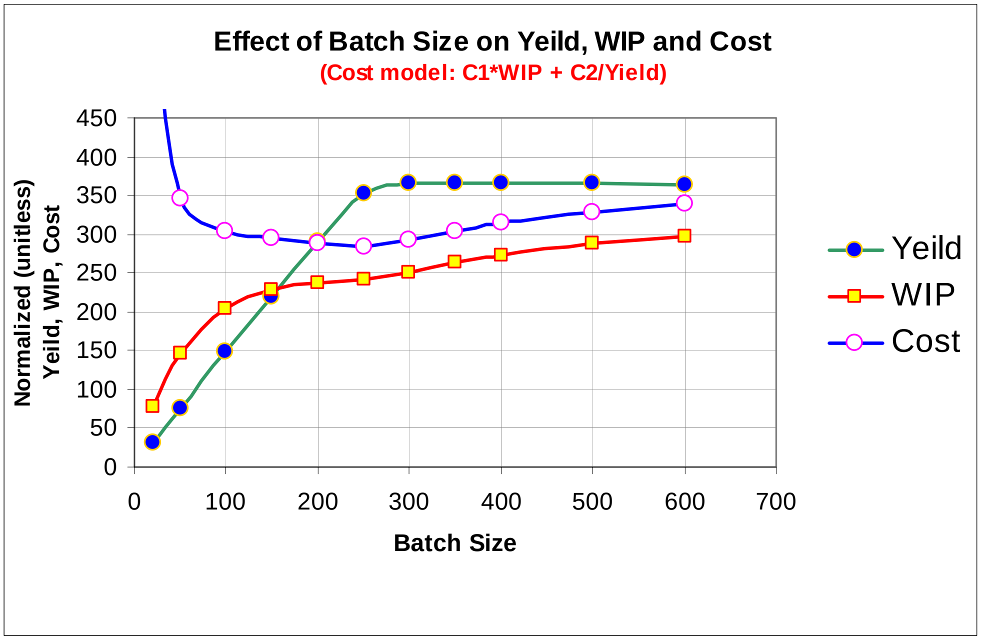

Figure-6: Witness Run Results - Effect of Batch Size on WIP, Yield and Cost

Conclusion and Future Extension Possibilities

The simulations models developed in this study showed that the existing bottlenecks in the manufacturing process could be identified and alternate solutions could be effectively studied by using suitable simulation tools. Since these simulation models have the potential to accurately predict behavior of the process flow, these models could be run on a regular basis for establishing daily production schedule by determining optimum batch sizes to meet the desired output with minimum WIP. However, one major constraint that was observed in using these simulation techniques for daily planning was the computing resource requirement. Specifically for optimizing the batch sizes in a multi-part multi-machining process, the run times were very high. Faster machines with larger memory as well as storage capacities would be needed to reduce the simulation run times.

These simulation studies could be extended to other areas of the plant where many parts/items go through common operations Suitable modeling and optimization studies could be carried out to streamline the process and reduce running costs.

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