Using Simulation to Determine the Batch Size for I/O Drawer Test Process in a High-End Server Manufacturing Environment

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ABSTRACT

In this research, discrete-event simulation is used to study the I/O drawer test process in a high-end server manufacturing environment in order to identify the optimal batch size of the I/O drawers to be tested per driver. High-end server manufacturing environment is characterized by fast lead time and lengthy build process. Therefore, main components of the server, such as I/O drawers, are tested ahead of time (fabrication test) and stored in inventory as tested parts to be ready for prompt fulfilment of the customer orders. In this research, a simulation model is developed for the I/O drawer test process with a focus on batching the I/O drawers on testing. Different scenarios for the batch size are considered and a statistical comparison is performed against the current scenario used by the I/O drawer Fab test operators. Unlike the "one-piece flow" lean concept which encourages small batch size (even one), the results show significant savings in cycle time and energy consumption when the batch size is increased. This is attributed to the lengthy setup time of the I/O drawer testing process as using small batch sizes requires very short set-up time. The optimal batch size scenario results in cycle time savings by 20% which is equivalent to 8116 hours per year. Other savings include: electrical energy and less consumption of chilled water for the cooling units.

1. INTRODUCTION

High-end server environments are characterized by the lengthy testing processes of servers and server components, short lead time, and stochastic nature of production processes and order arrivals. Every customer order for a high-end server can be unique. Moreover, before an order is shipped, the customer may alter the server configuration or even cancel the order. The lead time requested by the customer is much less than the time required for building a server. Hence, there is a need to adopt the build-to-plan strategy (push system) in order to be ready for any customer orders. When a customer order is received, tested parts are pulled from the inventory and assembled to the customer order (pull system). One of the main components of the high-end servers is the I/O drawer which is tested before being assembled into the final product to guarantee the quality of the finished product, decrease the number of defects that occur during the assembly processes, and reduce the subsequent quality control tests. The I/O drawer assembly and test consist of three major processes: (1) I/O drawer assembly, (2) Fab test for I/O drawers, and (3) dekiting of tested I/O drawer.

I/O drawers are assembled then batched in a frame for the fabrication test. The number of I/O drawers in the batch varies from 2 to 8 depending on the availability of the I/O drawers and the personal decision of the assembly operator. Usually, the operators assemble six or less I/O drawers per frame since batching more than six requires arm extension for the 7th and the 8th I/O drawer's positions at the top of the driver. Currently, there is no recommended batch size for the operators to follow. Therefore, the operators batch different number of I/O drawers per frame depending on their availability.

Fab test process is characterized by high energy consumption due to the prolonged test durations. Furthermore, the test process requires lengthy set-up time even for one I/O drawer. The test time consists of a set-up time of 24 hours and about 7% extra hours for any further I/O drawers. Figure 1 represents a high level flow chart of the Fab test process, which shows the main operations of the Fab test and the number of operators and test cells for each operation. Fab test of I/O drawers is performed in batches in order to save the time of testing per unit I/O drawer. In this study, simulation modeling is used to analyze the I/O drawer assembly and test process with the focus on batching the I/O drawers on

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testing. Different scenarios for the batch size are considered and a statistical comparison is performed against the current random scenario of batching. The case of batching seven or eight I/O drawers presents some ergonomic difficulties, which can be harmful to the operators due to the "over-the-shoulders" arm extension. Therefore, batching seven or eight will be excluded from feasible batching alternatives.

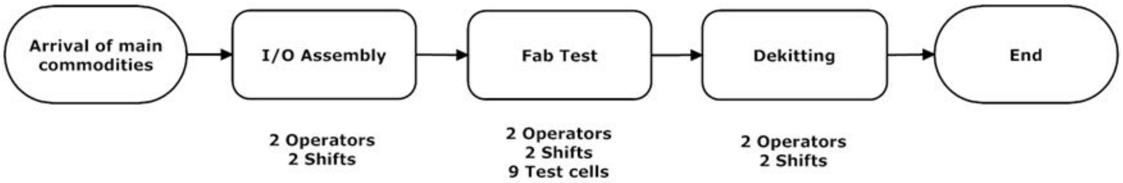

Figure 1. High level BNC fabrication flow chart.

2. LITERATURE REVIEW

The U.S Environmental Protection Agency [1] published a practical guide for "lean and green" which suggests a decision-making framework to identify the environmental harmful and hazardous materials and the opportunities for environmental improvement. This framework can be viewed as twofold objective: (1) reduce the environmental impact of the origination processes and (2) save costs. Fab test in high-end server manufacturing environments can be a source of lean and environmental wastes if not managed properly. Unlike the "one-piece flow" lean concept that suggests testing one component at a time to reduce WIP and improve quality [2], testing components in batches is found to be more effective due to the lengthy set up times. Testing one component at a time can increase the energy waste and the waiting times. To reduce the waste, an optimal batch size can be determined using simulation and mathematical models. Several studies in the literature have discussed the selection of batch size in manufacturing environments. For example, Yan *et al*. [3] analyzed the simultaneous batch splitting and scheduling problem for identical parallel production lines. The problem is mathematically formulated and a proposed heuristic method based on genetic algorithm was used to find the solution. Yu [3] developed a framework to study product variety and batch size in a monopolist firm. Prasad and Maravelias [5] developed a mixed-integer linear programming model that involves three levels of discrete decisions: selection of batches, assignment of batches to units, and sequencing of batches in each unit.

Simulation modeling can be used to reduce waiting times and eliminate environmental wastes. Discrete Event Simulation (DES) is widely used to analyze the complex behavior and interactions of complex systems with less effort when compared to analytical models. DES has been used for many applications in manufacturing environments including (1) assessment of scheduling policies and work order release [6], (2) performance evaluation of manufacturing systems based on cycle time, throughput, and Work-in-Process (WIP) [7], (3) capacity analysis of assembly lines [8], (4) study of production design changes [9], and (5) evaluation of design alternatives [10]. The use of DES for determining the batch size in manufacturing systems has been discussed in some studies. For example, Enns [11] evaluated the effect of fixed batch size setting in Material Requirements Planning (MRP) systems. Simulation results showed that the batch size settings can affect inventory band delivery performance. Rulkens *et al*. [12] used dynamic simulation to determine the optimal batch size of a furnace and pre-clean area of a wafer fab. Alexander [13] used discrete-event simulation to study the batch processing of a transactional-based process.

3. SYSTEM MODELING

Discrete-event simulation is used to study and analyze the I/O drawer test assembly and test process in order to identify the optimal batch size. The simulation models were developed using Arena® software, version 14.0 (www.arenasimulation.com). The methodology of this research is as follows.

1. Study the I/O drawer fabrication process in the server manufacturing environment
2. Develop the baseline simulation model, which accurately reflects the current process
3. Validate the baseline scenario by comparing simulation results to real data
4. Develop and study the "what-if" scenarios
5. Provide results of comparison between the current scenario and the newly suggested "what-if" scenarios

3.1. ASSUMPTIONS FOR MODEL DEVELOPMENT

The main characteristic of the simulation model is summarized in Table 1. The following assumptions were made during the development of the simulation model:

1. Two operators per shift, for two shifts work at I/O drawer assembly process.
2. Two operators per shift, for two shifts at Fab test with nine testing cells.
3. Two operators in the first shift and one in the second shift at dekitting station working 80% of the time at dekitting I/O drawers.
4. The Fab test time includes fixing problems time.
5. Transportation time is implied within processes except between assembly and Fab test.

Table 1. Simulation model characteristics.

Model Characteristic	***Description***
Entity	BNC build Order
System Type	Steady State
Attributes	Product type
Resources	Assembly stations and operators Test cells and operators Dekitting stations and operators
Inputs	Arrival times of orders First pass yields
Outputs	Throughput Cycle times Resource utilizations Energy costs
Replication Length	92 Days
Number of Replications	60
Warm up period	12 Days

3.2. DATA COLLECTION

The data was collected from different sources including manufacturing floor system (MFS) and time studies. MFS was used to collect data related to the Fab test time. A time study was conducted to determine the I/O drawer configuration, transportation, and dekitting times. Historical data was collected for one quarter (three months) for a period that was characterized by high volume production since more data points were available to be used in fitting the statistical distributions for the different operations and arrival patterns. Table 2 shows the main component arrivals distributions.

Table 2. Statistical distributions for the collected data.

Entity Type	**Time between arrivals (Days)**	**Entities per arrival**
Part 1	EXPO(2.13)	Disc(.2,20,.4,30,1,45)
Part 2	0.5+ EXPO(1.34)	TRIA(30,45,110)
Part 3	0.73* EXPO(1.43)	72
Part 4	EXPO(2.17)	TRIA(60,90,220)
Part 5	EXPO(0.999 + EXPO(1.5))	72
Part 6	0.999 + WEIB(2.13, 0.428)	180

3.3. MODEL VALIDATION AND VERIFICATION

The model was verified and validated by comparing the results of the key performance indicators (KPIs) obtained from simulation with different data sets that were collected from the real system. The animation in Arena was used to check the logic and ensure the accuracy of the model. The key performance measures studied include throughput, total number of Fab tests required to test all I/O Drawers and cycle time. The number of tests represents the number of times the test cell is run to test the drawers and it decreases with increasing the batch size. As explained above, the testing time is a function of the number of tests needed to Fab test all I/O drawers. Therefore, number of tests is the foremost measure of performance and is used in calculating the savings in testing time for any proposed scenario. In addition to number tests, the cycle time and the throughput are used to validate the model. Using a level of significance of 0.05, a p-value that is less than 0.05 would imply that the simulation results are statistically different from the actual throughput, cycle time, and number of tests. Table 3 shows that the simulation model was statistically indifferent from the historical data.

Table 3. Baseline Simulation Model Results.

	Simulation	**Actual**	**% Difference**	***P-Value***
Throughput (Units)	1126	1085	3.78	0.77
Cycle Time (Hours)	56.13	56.4	-0.48	0.21
Num. of Tests	256	242	5.79	0.56

4. SIMULATION RESULTS

Simulation experiments were conducted to study the effect of changing the batch size on the performance measures of the process including cycle time, throughput, and number of tests. Batch size values were varied between 1 and 8. Batch size values of 7 and 8 were not considered since these scenarios can present ergonomic hazards to the operators. However, if a lifting tool is designed to help the operators lift and place the I/O drawers in the driver without any ergonomic risks, 7 or 8 batch sizes can be selected. The batch size simulation results are shown in Table 4. It can be found that the batch size value of 6 given the current restriction on batch sizes of 7 and 8. It should also be noted that there is no specific value of the current batch size used by the operators. It can be found that batch size of 6 will result in the minimum possible cycle time. Furthermore, excluding batch sizes of 7 and 8, batch size of 6 will result in the minimum number of tests. Once the drawers become available for test, operators put them into the driver and run the test.

Table 4. Simulation results for batch size.

Batch Size	*Throughput*	*Cycle Time*	*Number of Tests*	*Best Choice*
1	611.97	504.17	504.17	
2	1018.20	152.94	509.17	
3	995.67	70.76	331.77	
4	1066.87	60.03	266.70	
5	1041.77	55.75	208.28	
6	1050.87	50.26	175.10	√
7	1100.70	53.95	157.18	
8	1112.78	53.48	138.97	

A paired t-test was conducted to check whether there was a significant difference between the current scenario and the optimal scenario (see Table 5). The results show a significant difference in the cycle time of the I/O drawers test process within the same period using 95% confidence interval (C.I.). It can be found that applying the alternative scenario will reduce the cycle time by approximately 5-20%. Furthermore, applying the alternative scenario will reduce the number of tests required to produce the same number of I/O drawers by 19-37%. Consequently, reducing number of tests will save 2,029 testing hours, which will save enough power to run the Fab test (nine cells) for 9.5 days, 24 hours a day. However, it is also shown that the difference between the throughput values for before and after scenarios is not statistically significant which means that the alternative scenario will not affect the throughput. Table 6 shows the conversion process of the saved testing hours into dollar values.

Table 5. Paired T-Test Comparison between Baseline and the optimal Scenario.

Output	*Average*	*95% C.I.*
Cycle time (hours)	-7.43	(-11.88, -2.98)
Number of tests	-67.30	(-88.80, -45.80)
Throughput	13.80	(-121.80, 94.20)

In addition to the power savings, there is a saving in energy required to remove the heat generated during these extra hours of testing time. Applying the new scenario will make the Fab test processes more "green and lean" in terms of saving wastes in energy, motion, and transportation associated with the extra tests required to test the same number of I/O drawers.

Finally, even though the concept of reducing the batch size is widely used in Lean manufacturing ("one-piece flow") with demonstrated benefits; application of this concept requires short set-up time which is not applicable in the case of Fab test. Therefore, this research shows that batching could be preferred in case of lengthy setup time.

Table 6. Savings Due to the Saved Testing Time.

	Value	***Units***	***Dollar per Quarter***
A. Electric Rate	\$ 0.12	per kWh	
B. Cooling water Rate	\$ 0.05	per ton-hr	
C. Testing System Power	20	kW	
D. Saved Testing Hours	2,029	hrs/qtr	
E. Saved Electrical Energy (C x D)	40,580	kWh	4,870
F. Thermal Energy (E x 3.412*)	13,8459	kBTU	
G. Cooling Unit Engine Power	5.6	kWh	
H. Cooling Unit Capacity	276	kBTU/hr	
I. Cooling Unit Run Time (F / H)	502	hrs	
J. Cooling Unit Energy (G x I)	2,807	kWh	
K. Cooling Unit Energy Cost (J x A)			337
L. Cooling Water Savings (B x F)			577
Quarterly Savings			5,783
Total Annual Savings = \$ 23,123			

* CONVERSIONS: KWH = 3.412 KBTU, 1 TON REFRIGERATION = 12 KBTU/HR, 1 HP = 0.746 KW, 1 KBTU = 0.0833 TON-HR

5. CONCLUSIONS

The I/O drawer assembly and fabrication test process in a high-end server manufacturing environment was investigated using simulation modeling. The main focus was to determine the best batch size of the I/O drawers to be tested per driver. Simulation modeling was used to account for randomness in the system that is resulted from inconsistency in main component arrivals and continually changing first pass yield and test process design. The baseline scenario was modeled, verified, and validated. Several scenarios for batch size were considered by changing the batch size value between 1 and 8. A Batch size of 6 was found to be the best choice. The results show significant savings in the cycle time, test required to test the same number of I/O drawers which is reflected in the energy consumption and the associated costs.

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