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MODELING AND SIMULATION OF HARD DISK DIVE FINAL ASSEMBLY USING A HDD TEMPLATE

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ABSTRACT

A HDD template is designed and developed for modeling and simulation for final assembly of hard disk drive (HDD) manufacturing using Arena. The designed HDD template is a high flexibility and good performance at an internal supply chain level and self-development and improves the system performance significantly. It is developed the intelligent based dynamic machine knowledge, which can capture dynamic based activities with fuzzy system. The study shows how modeling and simulation tools can be used and integrated to implement highly automated systems for industrial processes and deal with flexible products. In such context we designed and developed a prototype for the final assembly of hard disk drive with dynamic and static behavior.

1 INTRODUCTION

Due to dynamic and uncertainty, the final assembly process is an important sector in the manufacturing of hard disk drive. To manage and control the assembly line effectively, as well as reduce the piling up inventory, the highly automated computer control manufacturing systems sometimes fail during operation due to unexpected breakdowns of machine, and major mismatches in capacities between different parts of process and production target. As production system is characterized by short production life cycle with high production diversity and customer demand, it is necessary to analyze the production system to get optimize outcome. The more realistic simulation representation becomes more essential and effective for designing and testing of large scale engineering system which being increased complexity day by day (Xue 1997). Simulation has been commonly used to study behavior of real world manufacturing system to gain better understanding of underlying problems. However simulation model cannot completely encompass the dynamic and uncertain characteristics of the real-life system due to conventional modeling approach. Jadhav and Smith (2005) describes a methodology developed for simulation modeling and analysis of printed circuit board (PCB) manufacturing lines, capturing the complex interactions between its components using a custom-developed PCB assembly template. Hasgül and Büyüksünetçi (2005) used simulation modeling to analyze a new mixed model production line. Robinson (2006) discussed issues and research requirements for conceptual modeling for simulation. Guru and Savory (2004) presents a template-based conceptual modeling infrastructure for simulation of physical security systems. The internal and external dynamics are considered for designing the simulation template in Arena for HDD assembly system, which can give more opportunity to develop more realistic model. Internal dynamic represents such as machine break down, absentee rate, defect ratio, while external dynamic describe changes out of management control such as sales schedule, defect ratio of incoming parts, marketing effects and delay of parts delivery. In real life application internal dynamics usually depend on the enterprise policy and management skill and external dynamics require much coordination effort with other departments and usually involve decision-making at higher management level.

In modern environment of discrete part manufacturing, for conducting a simulation study, the scenario of interest needs to be constructed in logical form (Lefrancois et. al. 1996). In this paper, a hard disk drive final assembly process is being studied by a HDD template and logic be added to capture activities effectively. The proposed final assembly process simulation model can be analyzed effectively in terms of throughput, utilization of resources, queuing length and work in process to understand the line behavior and compare the different behaviors. The objective of the study is to give an environment where users can build up more realistic models to analyze the assembly line in terms of enhance system-level performance. The proposed modeling environment n can be improved simulation accuracy for internal supply chains at electronics manufacturing.

2 HDD PRODUCTION PROCESS SCENARIO

A hard disk drive company consists of a series of process to produce HDD from raw material to finish goods. The hard disk drive is produced by the components of the printed circuit board assembly, rotor assembly and head disk assembly, which are shown in Figure 1. The printed circuit board (PCB) assembly, rotor assembly and head disk assembly (HDA) areas draw out the raw material from the material warehouse base on the daily going rate schedule by the production control section. The completed rotor arm will be transferred to head disk assembly area to install to the motor base casting, together with the disk to become HDA. All PCB must be tested before using at final assembly section. The head disk assemblies and completed PCB will be mounted in the final assembly and all drives go through a self-scan test and passed before they can be packed and shipped to finished goods warehouse.

Final assembly is an important section in the hard disk drive manufacturing process. It is the final stage of operation where the head disk assembly and main printed circuit board are being mounted together, media written with the firmware code, going through a series of functional test before packaging for shipment. The production capacity is very much dependent on available parts in warehouse. As final assembly depends upon complex steps, together with various uncertainties such as the supply of HDA cannot cope up sometimes with schedule. Excessive inventory of PCBA is carried when HDA is shortage. The large work-in-process (WIP) causes short transport vehicle such as tote box, trolley or cart and slow operations in transporting the parts and also high functional fallout at disk ware, self-scan and final test stations (Ying and de Souza 1998).

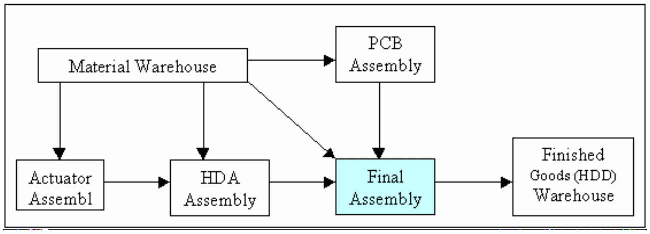


Figure 1: Final assembly system

3 HDD TEMPLATE

Computer simulation has increasingly become the most popular and frequently employed tool for problem solving and decision-making in the manufacturing and production environment. It has been commonly used to study behavior of real world manufacturing system to gain better understanding of underlying problems. Simulation is also very effective in comparing different alternatives for area of improvement on an existing system. The advance simulation tool Arena is used to analyze the production line with the aim to improving the system performance in the internal supply chain level. As each company has own real system, the modeling will be effective after knowing the existing resources and depends upon design the module.

To design the hard disk drive assembly template, first define the various resources and then develop all resources depend upon actual activities in the internal supply chain. For module develop, the logic has been supplied with the basic Arena module that can capture all necessary activities in shop floor level. It can provide capability to represent model close to real-world. Many modules have been developed for hard disk drive industry to meet the various purposes of many resources such as HDA damper, mount, auto-screw, disk-ware, labor, self-scan, plug connector, labeling and others resources. The user interface of each module has data-entry dialog where users can easily enter necessary information. All building modules are collected and referred to a template named as HDD template, which is shown in Figure 2. Users can develop any hard disk drive assembly model and change their various parameters as required to identify their behavior and performance of internal supply chains in electronics manufacturing.

Figure 2: HDD template

3.1 Intelligent Machine Knowledge

As manufacturing system becomes more complex, more and more activities and behavior can not properly described by simply using fixed delay or random statistical distribution. That's need various type of knowledge for realization to represent (Widman et al. 1989 and Nielsen 1991). System dynamics with in production scenario regardless the change is time depend or time independent. Conventionally dynamics are represented as random variables. The dynamics qualitative relation tendency to upper and lower bound are known but the quantitative relations are unknown. These types of dynamic are called fuzzy dynamics. The machine dynamic behavior is considered with respect to machine lifetime, breakdown condition etc. in order to improve accuracy of simulation resources. It must take into account not only static characteristics such as delay time etc. but also fuzzy dynamics. In order to represent all changes in simulation resources, we define resources as a feature set relating to an attribute set. Features such as past processing time, part rework rate, machine down time and machine maintenance period (de Souza and Ying 1997).

Machine may exist in different forms but their key behavior and characteristics from a simulation stand point, can be described by those features. A feature may be time varying, state varying or invariant parameter. The attribute set is a collection of all-important information of a resource such as working environment, machine lifetime and skill. The machine knowledge defined maximum machine life, maximum and minimum reject number, maximum minimum fault time, working state and maintenance technician skill level. Machine fault times at different life span are considered for machine fuzzy knowledge and the machine working state and maintenance technician skill level are also consider for non fuzzy knowledge to design the intelligent machine. The fuzzy relationship is defined and designed and fuzzification is added in the logic window of Arena simulation. The fuzzy structure is represented in the operand window to define all parameters for any resources. An operand window for machine-level intelligence is developed and tested for validation and verification which is depicted in Figure 3.

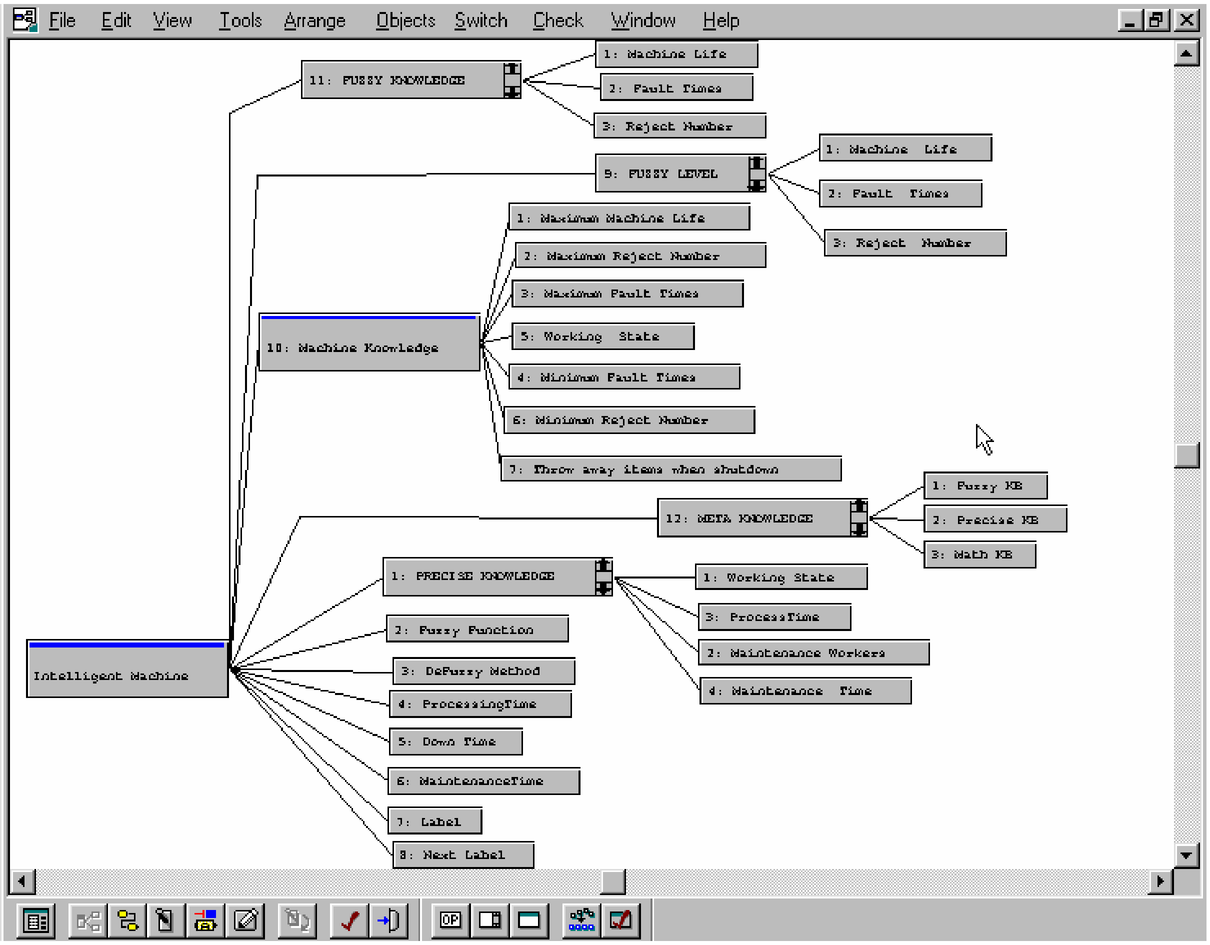
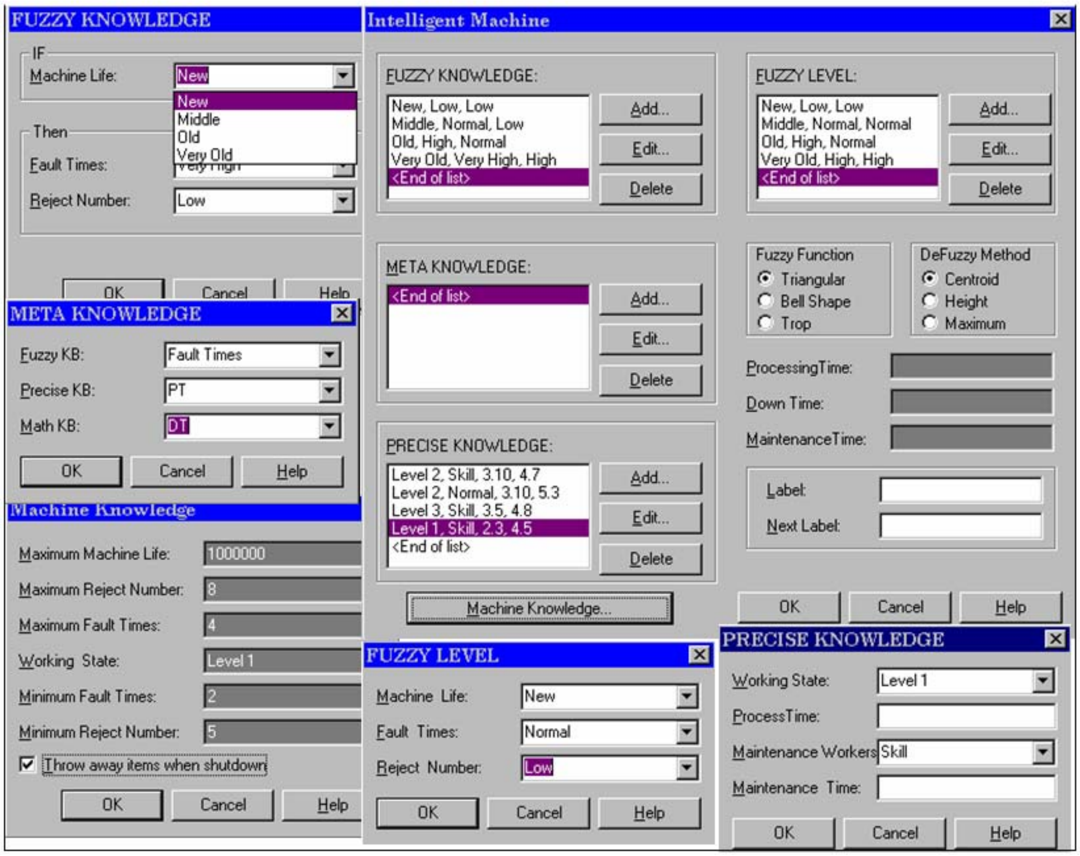


Figure 3: Operand window of machine intelligent design



FUZZY KNOWLEDGE

IF

Machine Life: New

Then

Fault Times: Very High

Reject Number: Low

Intelligent Machine

FUZZY KNOWLEDGE:
New, Low, Low
Middle, Normal, Low
Old, High, Normal
Very Old, Very High, High
<End of list>

FUZZY LEVEL:
New, Low, Low
Middle, Normal, Normal
Old, High, Normal
Very Old, High, High
<End of list>

META KNOWLEDGE:
<End of list>

PRECISE KNOWLEDGE:
Level 2, Skill, 3.10, 4.7
Level 2, Normal, 3.10, 5.3
Level 3, Skill, 3.5, 4.8
Level 1, Skill, 2.3, 4.5
<End of list>

Fuzzy Function: ● Triangular ○ Bell Shape ○ Trop

DeFuzzy Method: ● Centroid ○ Height ○ Maximum

ProcessingTime:
Down Time:
MaintenanceTime:
Label:
Next Label:

META KNOWLEDGE

Fuzzy KB: Fault Times
Precise KB: PT
Math KB: DT

Machine Knowledge

Maximum Machine Life: 1000000
Maximum Reject Number: 8
Maximum Fault Times: 4
Working State: Level 1
Minimum Fault Times: 2
Minimum Reject Number: 5
☑ Throw away items when shutdown

FUZZY LEVEL

Machine Life: New
Fault Times: Normal
Reject Number: Low

PRECISE KNOWLEDGE

Working State: Level 1
ProcessTime:
Maintenance Workers: Skill
Maintenance Time:

Figure 4: Input dialog of machine intelligent

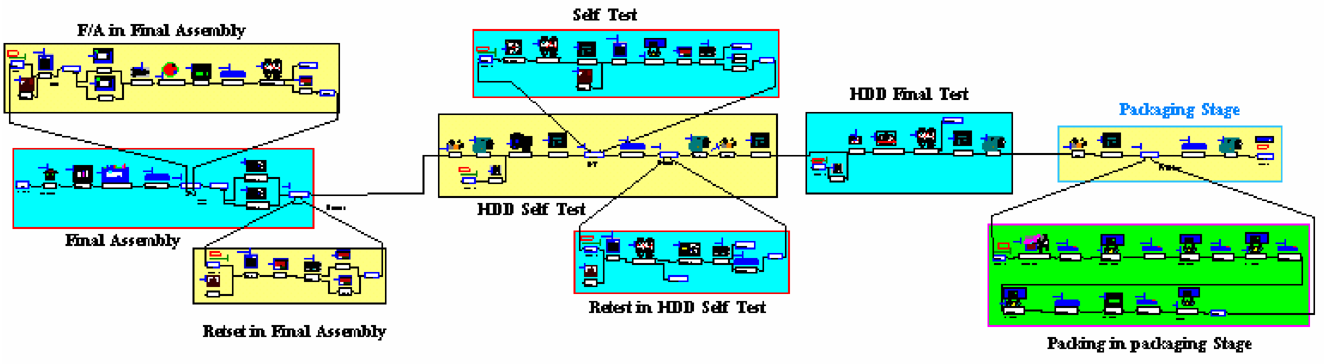


Figure 5: Hard disk drive final assembly model

Based on the fuzzy structure in operand window and the relationship in logic window, different data dialogs are generated where users can enter necessary information for simulation. A data dialog for machine intelligence is shown in Figure 4.

Down time is the non-operating period when machine idle or under maintenance. Reject rate refers to the number of defects occurred in every hundred units. Change over time depends upon the complexity of the product. Some products may require changes on the entire software program and fixtures while others may only be required to make modification on program configuration. Maintenance period is the times spend for preventive maintenance activities. Technician classified as skill and normal. The machine operating performance data is collected by supplying the maintenance personnel. The relation between lifetime, fault time, and reject number are considered in the following order:

Life time	Fault time	Reject Number
Very new	Very low	Very low
New	Low	Low
Normal new	Low	Normal
Normal	Normal	Normal
Normal old	High	Normal
Old	High	High
Very old	Very high	Very high

Maintenance has two possibilities: good or poor. If maintenance is good then fault time and reject number will be low. Otherwise, maintenance is poor resulting into normal fault time and reject number. Further, maintenance time will depend upon the worker's skilled level. The above factors are considered to get more realistic presentation of the model that can help in simulation to get more accurate result.

4 MODEL DESIGN AND DEVELOPMENT

The assembly system for hard disk drive generally consists of four categories. It can be final assembly stage, self scan stage, final test stage and packaging stage. The HDD template and assembly models are constructed in such a way that each model investigates dynamic performance of the overall system or a predefined section with in the internal supply chain. Overall final assembly model for HDD is shown in Figure 5 in Arena simulation (Ali 2000). Each modeling system has been described in the following sections.

4.1 Final Assembly Stage

Figure 6 represents the model of final assembly stage. The arrive module receives the HDA and get mounted to the PCBA. The final assembly consists of a number of operators and an automatic screw machine. The incoming materials also identify defect ratio caused by auto screw machine module. Good and bad parts are separated in the visual mechanical checking. Two operators in parallel mount the main PCB onto the HDA. There may be several disk-ware machines and each machine consists of several targets. Each target is capable of writing the frame ware code onto one drive at a time and all targets can simultaneously perform the disk-ware process. HDDs are loaded onto the targets by robot. Upon completion, the robot unloads the drive and then puts back to the conveyor or awaits for next operation. The concurrent activity of disk ware process is modeled by the disk-ware module, which was designed specifically for that purposes. D/W status consists of several logics to identify the drive status and segregate the pass and fail ones. If the drive fails first time, it gets loop back to re-test in the disk-ware station. If it passes the retest, it can proceed to the next station. If the drives fail twice, it will be rejected to the reject bin.

4.2 Self-Scan Stage

Figure 7 is shown as a self-scan process model. In Self-Scan, the trolleys first get loaded by the operator until it is full. The labor modules pull the trolley. Each trolley has its present capacity. The number of the operator is set in the labor module dialog. The operator gets one empty and loads the drives until it reaches the specified capacity. When the trolley is fully loaded, it will be pushed to a Self-Scan test area to perform the self-test. A transporter module represents the movement of fully loaded trolley being transported from disk ware area to Self-Scan test area. The operator returns after that and awaits for the next task. The trolley of drives is then undergoing self-test for the required test time. The testing process is represents by Self-

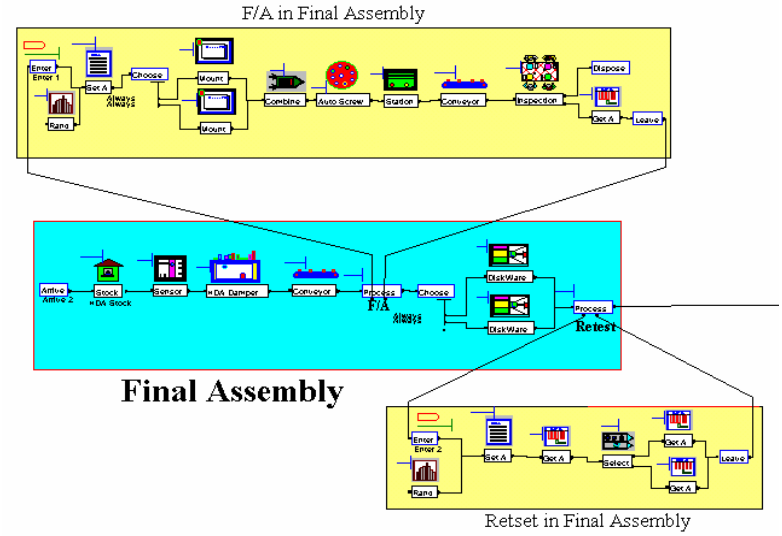


Figure 6: Final assembly stage model

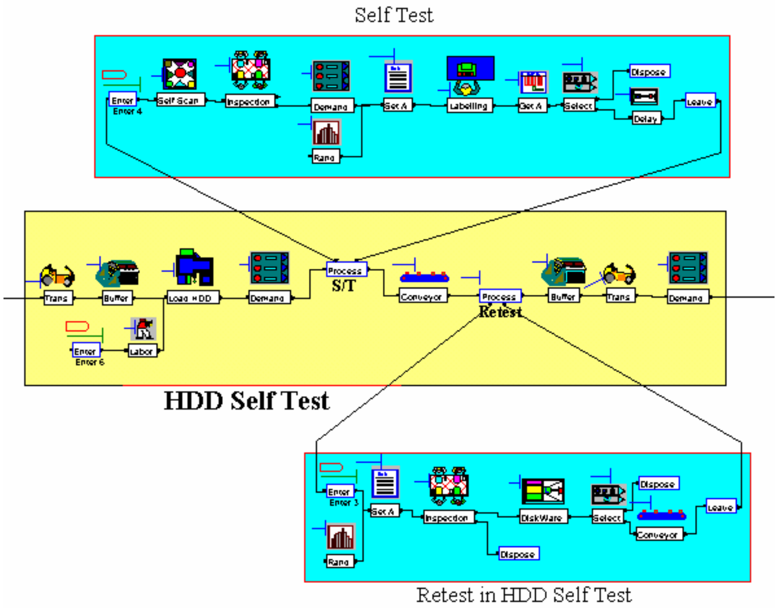


Figure 7. Self-Scan stage model

Scan, labeling modules. Upon the completion of self-test the full trolley is unbatched and a pass or fail status is labeled on the drives. The pass drives remain on the Self-Scan trolley and batch together before moving to the final test area. The drives will get unbatched in the final test area. For the first time failure, it will be tested one time through the Self-Scan process and if the drives fail again it will be rejected.

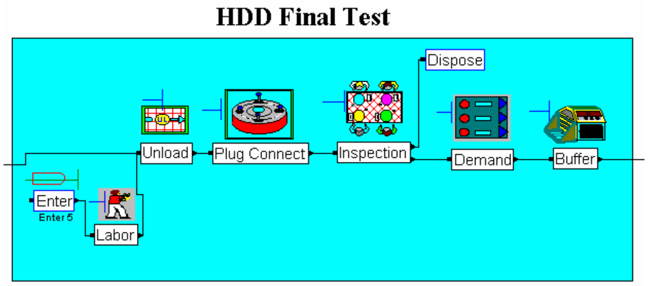


Figure 8. Final test stage model

4.3 Final Test Stage

Figure 8 shows the final test model. The Final test station consists of host and several targets. The host downloads the test software to the targets. The drives are being connected to the targets and all targets can test simultaneously. Each time the final test operator unloads three drives from the Self-Scan trolley. The arrangement is to ensure a smooth flow of process. To start final test, the operator first connects the drives to targets. Next three drives are unloaded and connected them to the target again. Six drives testing at the same time. Upon test completion the operator unloads the drives from the target by disconnecting the power and interface connectors. The drives are then placed on the final test cart which is capable of carrying hundreds drives. Once the capacity is full, the final test cart will be transferred to the packaging area, where the drives are labeled according to the required specification and ready for shipment. Similar to Self-Scan the transporter module represents the movement of final test cart from final test area to packaging line.

4.4 Packaging Stage

Packaging is the last stage of the final assembly process. The operators working in the packing line are evenly spaced out and sitting in front of conveyor. The conveyor speed is fixed. It is modeled by the conveyor module and is placed in between the operators. The labeling module with necessary process time input to each station represents the operator. The packaging stage is shown in Figure 9.

4.5 Typical HDD Model

A typical simulation model of the HDD in Arena environment is shown in Figure 10, which can be used to analyze the performance in terms of productivity, queue, work in process, and the material handling process to improve the manufacturing support for different models to meet the production schedule. This model is developed for a particular product. The model correctness mostly depends on the module construction function being exactly to the logic as designed. As the module is designed by defining the parameters from the real system, it may give a more real world system. If the model represents the real world system more closely, the analysis results will be more accurate. It is concluded that through simulation, the effect of time variant dynamics such as time in queue on the throughput can be obtained. This will be difficult if an analytical tool is used since it will involve the complex queuing theory. Thus the hard disk drive assembly models are representing more realistic scenario of internal chain.

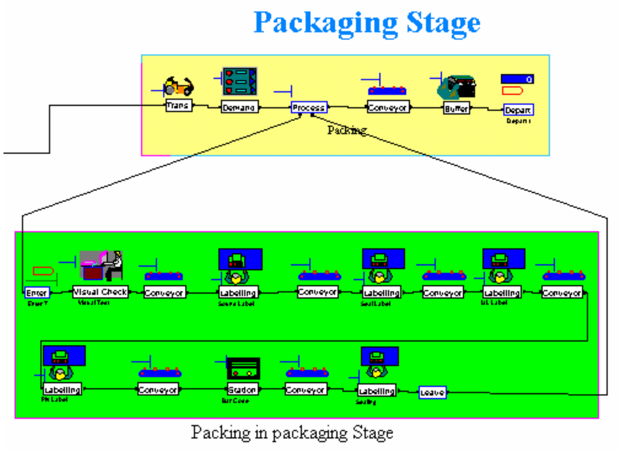


Figure 9. Packaging stage model

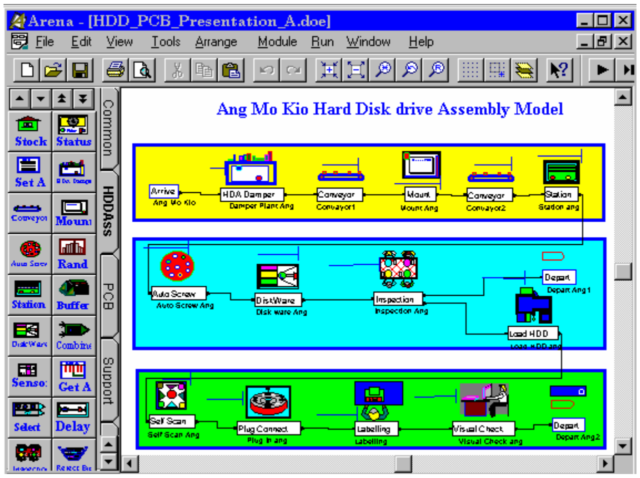


Figure 10. Typical HDD model in Arena simulation

5 VALIDATION OF HDD MODEL

Sargent (2004) discussed detailed about validation and verification of simulation models. Balci (2001) provides a methodology for certification of modeling and simulation applications. Validation of HDD models is done through comparing the actual throughput with the simulated one, which is analyzed through statistical analysis. The model is validated with a degree of confidence between the output and actual results. A 95% confidence interval for the expected average throughput in the real system is selected. This is to check if the expected real system falls into this distribution to claim model as valid. The test statistic and t-distribution is selected to validate HDD models. A paired t-test is considered to test the difference between of the real life throughput and simulated throughput. The simulated throughput and real life throughput for hard disk drive assembly is shown in Table 1.

From the t-test, the calculated value of the test statistic is t = 2.038 and t-distribution critical value $t_{7,\,0.975} = 2.365$. As the calculated value of the test statistic is less than the t-distribution critical value ($t < t_{7,\,0.975}$), the result falls within 95% confidence interval. Since the calculated value of the test statistic does not fall in the rejection region, we do not reject the result (Ali 2000). Thus data does not present sufficient evidence to indicate that the results can be rejected. The t-test for simulated output and actual output falls within the confidence interval. This implies that the model is accurate provided that more sampling data are collected from more replications. Thus the model does have an accuracy level to indicate itself being valid.

Table 1: Simulated and actual throughput comparison

No.	Simulated throughput	Actual throughput	Difference
1	2696	2745	-49
2	2455	2336	119
3	2895	2743	152
4	2776	2558	218
5	2455	2570	-115
6	2785	2595	190
7	2698	2610	88
8	2802	2741	61
Total	*21562*	*20898*	*664*
Average	*2695.25*	*2612.25*	*83*

6 ANALYSIS OF SIMULATION RESULTS

Simulations are run in order to gain an understanding of the behavior of the system. This understanding of the behavior is an important input to decision-making concerning the system. To improve any system, we must integrate factory floor information with upper level decision system. Simulation might play a bigger role to provide those information. In such context, we have focused on developing a specialized template for effective modeling and simulation. HDD assembly models are constructed using designed template. in such a way that each model investigates the dynamic performance of the overall system or a predefined section within the internal supply chain. The output performance to be analyzed includes time in the assembly system, throughput, queuing time and length and resources utilization.

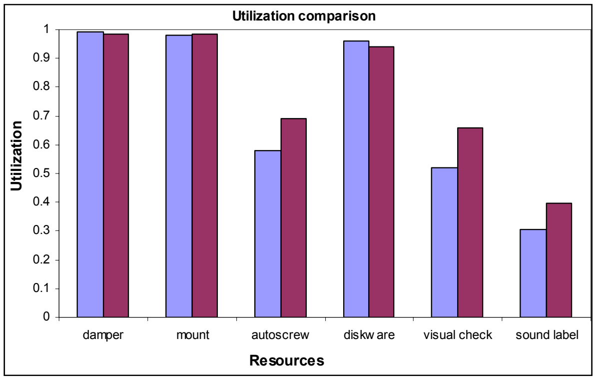


Figure 11: Utilization comparison

6.1 Utilization Comparison

The utilization of the resources is a key factor to keep production cost low. If utilization of the resources is high, the production cost will be low, otherwise production cost will be higher because it has to pay for the resources if used or not. The purpose of the intelligent simulation is to establish the parameters for optimal utilization of the production resources given the production variables and the throughput. The comparison of some resource utilization of conventional model is found that some resource utilization is higher and some resources utilization is lower. It is also found that the bottleneck workstations (workstations with highest utilization) are sensor, damper, mount, disk-ware and labor. This is due to higher process time of those resources. Moreover, the buffer utilization is higher, which are placed before the bottleneck resources. The comparison between the conventional scenario and intelligent scenario of resource utilization is depicted in Figure 11. It illustrates that the utilization of the intelligent model is better for most of the resources. Product mix affects the system performance because of the variation of operation sequence and processing time of different job systems. It should consider the utilization factor to make more realistic decisions.

6.2 Queuing Analysis

As it is very difficult to solve a complex queuing problem in manufacturing through analytical tools, the dynamic simulation tool can solve this problem and easily observe realistic scenario. The comparison of the average waiting time in queue between the proposed and conventional modeling is illustrated in Figure 12. It shows that the disk-ware and labor station queue time is longer i.e. bottleneck in those resources. Figure 13 depicts the average queue sizes of the proposed model are lower than the conventional one. It also proved similar result as waiting time in queue. Result shows improvement than the conventional due to use fuzzy logic at the time of the module design. It is concluded that through simulation, the effect of time variant dynamics such as time in queue on the throughput can be obtained.

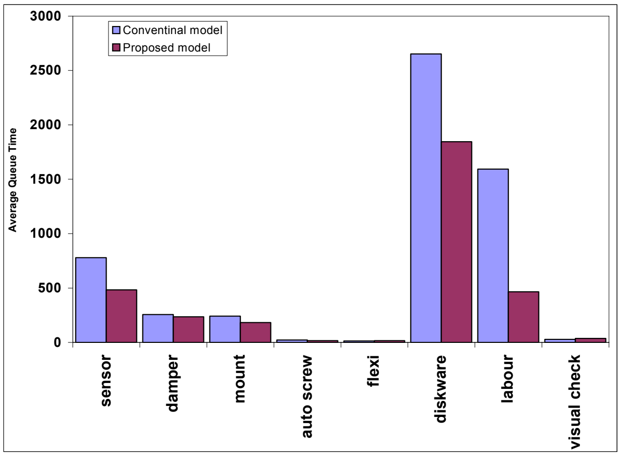


Figure 12: Average queue time comparison

6.3 Identified Bottleneck

A machine or work center having jobs arriving at a rate faster than they leave. A work center with the longest queues impedes smooth production. But all these essentially mean that the production system is not able to meet its objectives such as delivery dates, production quantities and product cost. The first step for the solution is to identify or better predict bottlenecks. It can be solved by one or more of the following methods such as modifying product mix (product target), changing lot sizes or batch size. The production smoothing (machine loading), changing priority, changing the dispatch rules (the order in which the waiting jobs should be processed) at a work center. Evaluating alternate process routes and redesigning the affected parts or systems also can be solved. If the problem can still not be solved, it needs to add extra resources where bottleneck appears.

Production personnel have to evaluate many different options and coordinate with the design and process engineering departments to get a good solution. Due to lack of tools and time, generally a thorough analysis is not carried out. We concentrate on the design of the component assembly process, which is the system bottleneck. It is found that the bottleneck workstation (workstation with the highest utilization) is the disk-ware and labor. As the process time in disk-ware and manual labor takes a longer time than other resources, the bottleneck resources are those. After identifying the bottleneck, the product mix is modified and the batch sizes are changed to get better results. It is concluded that through intelligent simulation, more realistic bottlenecks can be found and then minimized to improve the productivity.

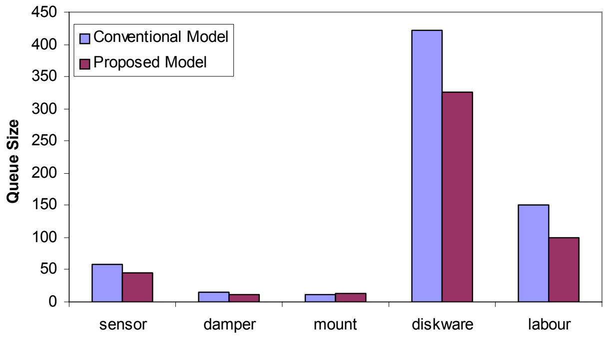


Figure 13: Average queue size comparison

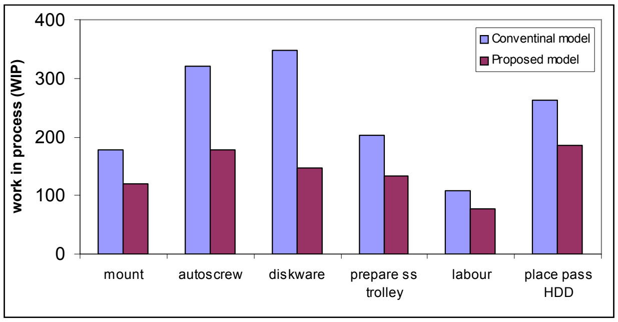


Figure 14: WIP comparison

6.4 WIP Analysis

Each part type follows hundreds of operations where machines are subject to random failure, set up changes are needed for different part types and also maintenance and rework must be considered. Another factor is skilled workers and sometimes they are absent at random manner. These factors result in long throughput time, large work-in-process (WIP) inventory and significant lateness. If the actual product is behind the demand (positive lateness), customers are unsatisfied, and sales may be lost. WIP is the number of unfinished parts in the system, which consists of the material in buffers and the piece being processed on machines. The less the WIP is the shorter the throughput time. However, too little inventory will reduce the system capacity, which will increase tardiness. WIP can be reduced through intelligent simulation. But one key question is that what is the minimal necessary WIP and how should it is allocated in a manufacturing system to make the production effective? As some WIP is required in case of a machine break down or blocked, it should keep the optimal WIP inventory to improve the productivity. The comparison of WIP between conventional and proposed model is shown in Figure 14 and the WIP reduced significantly compared with the conventional model. The systems are also tested for various batch sizes of 20, 50, 100 and 200. Among those, 50-batch size is found to be the best one, which is the lowest WIP shown in Table 2.

Table 2: WIP variation with various batch sizes

Batch size	Conventional model	Proposed model
20	3402	3124
50	3260	2897
100	3358	3012
200	3427	3155

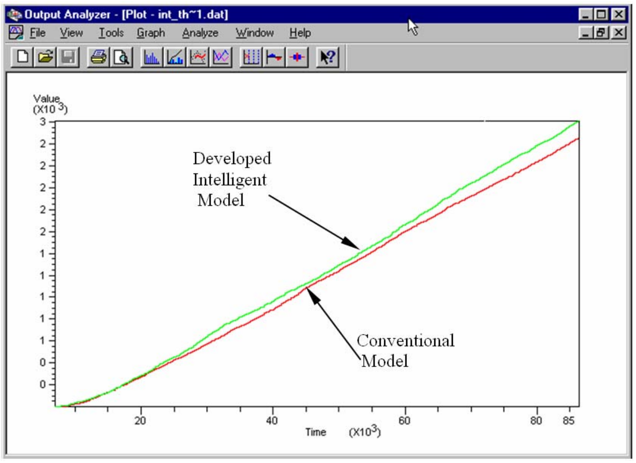


Figure 15: Throughput variation between conventional and proposed modeling

6.5 Throughput Analysis

The average throughput of the hard disk drive final assembly for the conventional and proposed modeling for various batch sizes. It is found that 50 batch sizes throughput is better than others batches. The throughput comparison between the conventional and the proposed intelligent model is depicted in Figure 15. The improvement of throughput is found after using the proposed conventional model as the model represents more realistic scenario. The throughput finding shows that the entire production is not in steady condition. Sometimes by representing more close to real-world, the performance might be decease as we use abstract information for modeling. Still it is necessary to do more in depth representation of complex manufacturing scenario in modeling and simulation. It can be easily identified throughput of the specific line or product to give a response to customers about with the existing shop floor status.

7 CONCLUSIONS

A HDD template is developed to improve simulation accuracy for the internal supply chain in electronics manufacturing. It would provide a platform to represent activities in modeling and simulation more close to real-world scenario. Based on HHD template, a final assembly model for hard disk drive is developed and validated with real world applications to analyze the system performance more efficiently and effectively. The modeling environment can be easily used for line balance and the behavior of the line using HDD template and extend to other applications. Dynamic and static characteristics of the real life scenario are addressed in this studying for modeling and simulation improvement. Any unexpected situation can be prevented by analyzing through this intelligent simulation model. In future research, this modeling environment can be integrated with real shop floor for performance analysis and predicting production target.

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