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INTELLIGENT MODELING AND SIMULATION OF FLEXIBLE ASSEMBLY SYSTEMS

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ABSTRACT

A combination of product mix and production volume is analyzed using a reconfigurable simulation model aiming to improve the performance and optimal designing requirements. The performance under different production scenarios is developed to find the optimal combination of product mix to meet future customer demands. This research provides a re-configurable assembly system modeling by adding flexibility and evaluates alternative designs. The best satisfaction of the production requirements under dynamic production is validated with real application.

1 INTRODUCTION

In lean manufacturing environments of advanced manufacturing systems, the flexible production line is designed to manufacture a variety of products in timely manner with minimal inventories. Such a system is composed of number of workstations linked together by an automated transfer line. Furthermore, a computer program carries out the function of production scheduling, operation monitoring and production control. A large number of factors are critical in the effective operations of such flexible production lines including number of product options, manufacturing operation of each, product type, workstation capacity, processing time of the operations at each station, material handling capacity at each work station, and overall material handling capacity.

The realistic simulation model development becomes very essential and effective for designing and managing assembly line, which needs to be highly flexible, being of increased complexity day by day. Simulation has been commonly used to study behavior of real world manufacturing system to gain better understanding of underlying problems and to provide recommendations to improve the systems. The re-configurable assembly line can provide flexibility for high mix low volume manufacturing systems, which is a growing customer's demand. Azadeh (2000) develops an integrated simulation model, which generates a set of optimizing alternatives for a heavy continuous rolling mill system in a full-scale steel-making factory and generates a set of optimum production alternatives. It is designed to integrate with other workshops of the factory, locates the optimum solutions by a rule-based methodology and is capable of answering all production and inventory issues. Patel (2002) discusses the methodology of modeling and studying the Final Process System of the automobile manufacturing process in order to develop an effective and efficient process to ensure the system throughput. Choi (2002) discusses the initial efforts to implement simulation modeling as a visual management and analysis tool at an automotive foundry plant manufacturing engine blocks. The optimum performances were identified through the use of scenarios by varying the number of assembly machines and processing time. Potoradi (2002) describes how a large number of products are scheduled by a simulation engine to run in parallel on a pool of wire-bond machines to meet weekly demand. The frequently updated schedule redirects the line towards maximum demand fulfillment based on the latest status of the line. Kibira (2002) presents virtual-reality simulation to the design of a production line for a mechanically assembled product. Altiparmak (2002) uses simulation metamodels to improve the analysis and understanding of decision-making processes of an asynchronous assembly system to optimize the buffer sizes in the system. Wiendahl (1991) uses the simulation tools in the field of assembly planning and due to different objectives of the different efforts, the tools are divided into the four-hierarchy classes assembly shop, cell, station and component.

To observe real manufacturing systems is very expensive and sometimes cumbersome. Therefore, a simulation model is an easier way to build up models for representing real-life scenarios to identify bottlenecks, to enhance system performance in terms of productivity, queues, resources utilization and cycle times as well as lead times are important areas for today's manufacturing. The modeling environment can be used to observe the operation of the production line under a number of different situations including different levels of demand, changes in product mix, and variation in operations times. The simulation study provides a clear picture of the performance of the drive production line under different possible production scenarios including variations in demand, product mix, number of operators, operations of workstations, number of shifts and other production factors deemed important. The scenario analysis in simulation modeling is done by changing the line configuration to accommodate expected future demands. The proposed intelligent simulation model can be analyzed easily in terms of throughput, resource utilization, queuing length and work in process to understand the line behavior and to compare the behavior difference between various models. The objective of this study is to give an environment where the user can build up more realistic model to analyze the assembly line to enhance system performance.

2 PROBLEM STATEMENT

The proposed simulation modeling research is done based on how to build a reconfigurable simulation model to meet the customer requirements as well as improve system performances. The fuzzy rule based machine and labor dynamics are considered to capture manufacturing dynamics in simulation environment. A power drive assembly system is considered for the proposed modeling and simulation analysis. Power drives are capable of delivering varying levels of power to multiple sizes of electric motors. The horsepower of the motor defines these categories. There are many different horsepower-handling levels offered, each of which uses a different frame to house its drive. Four of the horsepower handling levels are considered, and, therefore, four different frame sizes will be considered. These frame sizes are categorized as frame 0, 1, 2, and 3. Each of these frame sizes comes in four different models (A, B, C, and D) that vary only in the complexity of control that they can provide. Based on the frame sizes and models, the product mix is considered. These sixteen different products are assembled through a complex series of operations that are distributed across eight workstations; and all sixteen products are also assembled on the same assembly line. The assembly starts at one of two starting points. Frames 0 and 1 begin the assembly process at Workstation 1, and frames 2 and 3 start the assembly process at Workstation 2. The product group ‘0’ and ‘1’ goes through 1A-1B-Hipot-4-5-Test-Pack, whereas the product group ‘2’ and ‘3’ goes through 2A-2B-Hipot-4-5-Test-Pack, which is shown in Figure 1. After that, all drives go through all of the remaining workstations regardless of the frame size. Workstation 3 is a primary testing station to make sure that all connections have been made before the unit is powered up. This workstation is fully automated. Workstations 4 and 5 add the various components that make the difference between models A, B, C, and D. Each product is then put through a functional test and is powered up under the load of an electric motor. Four parallel workstations are available for functional test. The final workstation is packaging, where finishing touches are made to the assembly and the product is packaged.

The assembly line is semi-automated, meaning that some of the processes are done manually (the actual assembly) and others (testing) are fully automated. Also, the system is equipped with a smart conveyor system that knows what is being built, where that part came from, and what the destination of the part is. The conveyor is responsible for routing the part to the correct workstation. The assembly line consists of two loops (1, 2) and each loop consists of two workstations (A, B). Then there is an automated testing station, Station 3, named Highpot (Hi-pot). The third loop consists of two different workstations (4, 5), and that is followed by a fail station and four semi-automated testing stations. Material handling is automated at the assembly line, and sensors keep track of each pallet and direct it accordingly. There are nine workstations and eight full-time operators that produce product, as Hi-pot is an automated station. Currently the assembly line is able to accommodate current demand. In the future, however, demand is expected to rise, and it is expected that the assembly line should be able to meet the expected increase in production. The problem that arises from that expectation is that with the current layout, balance, and material management system.

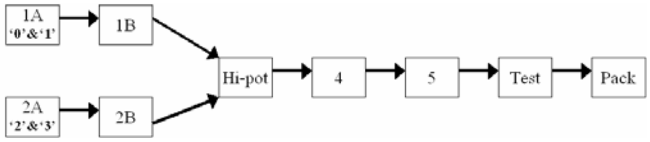

Figure 1: Power Drive Manufacturing Process Outline

The assembly line flows well and was designed with a great deal of forethought. It is capable of meeting the current demand and has very nice features, such as fixturing, and it is highly automated. However, the line has two major problems that affect its optimal performance. First, the line is not balanced. Some drives are produced much faster than others, and the workstations are not balanced to accommodate this. Also, there are two starting points that funnel into a single assembly line. This is a source for bottlenecks at Workstation 3 and Workstation 4. The second major problem has to do with wasted time. There are many repetitive tasks, such as reaching, searching, and walking that can be reduced. These can be reduced in part by removing excess forward stock from near the workstation and developing a material management system. In addition to the material management system, there are procedural techniques that could be taught to operators to reduce unnecessary motions.

3 SIMULATION MODEL DEVELOPMENT

The simulation study is done in Rockwell Automation’s power drive assembly process to improve their existing problems in the assembly line and identify the capacity of the assembly line through the discrete event simulation program *ARENA* under a combination of product mix and product volume. The goal is to analyze the current assembly process and determine how the client can achieve future production goals. Some of the ways to achieve the goal are by improving the efficiency of the assembly line, determining the maximum operational capacity of the line, and assisting in developing an accurate and intelligent simulation model. The power drive assembly process is studied with different scenario.

The simulation model is developed and used to determine cycle time, production capacity, manpower requirements, number of shifts, workstation utilization, workload distribution among workstations and operator utilization under a different number of production scenarios. The simulation model is developed in such a way, it demonstrate the production capacity and performance of the production line for the combination of four different frames and product families under at least three possible demands per year. The simulation results can be used for the redistribution of operations between workstations, determination of bottlenecks, assignment of operators to production line, decision about number of shifts, and decision about the degree of synchronization of production of different models.

3.1 Base Simulation Modeling

The model is developed using Arena, a flexible and powerful simulation software tool from Rockwell Software Corp. that allows analysts to create animated simulation models that accurately represent virtually any system. Designed modules are available to construct the model, and custom modules can be created for specific user needs. The simulation study is done for Rockwell Automation's power drive assembly process to improve its existing problems in the assembly line and identify the capacity of the assembly line through the discrete event simulation program Arena under a combination of product mix and product volume. The goal of the project is to analyze the current assembly process and determine how it can achieve future production goals. Some of the ways to achieve the goals are by improving the efficiency of the assembly line, determining the maximum operational capacity of the line, and assisting in developing an accurate and intelligent simulation model. The power drive assembly process is studied with different scenarios.

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The simulation model for the power drive assembly system is developed for thirteen categories of the product as shown in Table 1. Before the actual construction of the simulation model, all assumptions were explicitly identified and listed. The downtimes and repair times are well approximated by triangular distributions. Operators are always available for machine repair, without reference to shift patterns. Finished parts always leave the main line without hindrance or blockage. Raw material is infinitely available (no starvation at the upstream system-environment interface point). There is no downtime involving workstation-to-workstation transfer, i.e., material-handling equipment experiences no downtime. The schedule module is used for defining break time, lunch time, and unexpected delay time such as failure, machine downtime, and preventive/ scheduled maintenance time, etc. The rejection rate in the hi-pot and rework time is also included as necessary.

Category	Distribution	Category	Distribution
0-A	0.37	2-C	0.02
0-C	0.07	2-D	0.01
1-A	0.14	3-A	0.14
1-C	0.03	3-B	0.02
1-D	0.03	3-C	0.03
2-A	0.1	3-D	0.02
2-B	0.01		

Table 1: Power Drive Product Category Distribution

The sequence is used to determine the route of the different categories of products. The simulation model used two shifts' operating hours, with each shift incorporating a 30-minute break for coffee break, lunch, or dinner. The weekly meeting and discussion took about one hour. 92% of yielding is considered for Hipot and testing station. The processing time, failure history, and other parameters are collected (Ali 2003). The overall base simulation model for the drive assembly system is represented in Figure 2.

Utilization of resources is a key factor in keeping production cost low. If the utilization of resources is high, the production cost will be low. Otherwise, production costs will be higher because the company has to pay for the resources whether used or not. The purpose of the simulation is to establish the parameters for optimal utilization of the production resources given the production variables and the throughput. Comparing utilizations, it is obvious the Station 2B utilization is much higher than that of the other stations. So the production is controlled by workstation 2B. It is

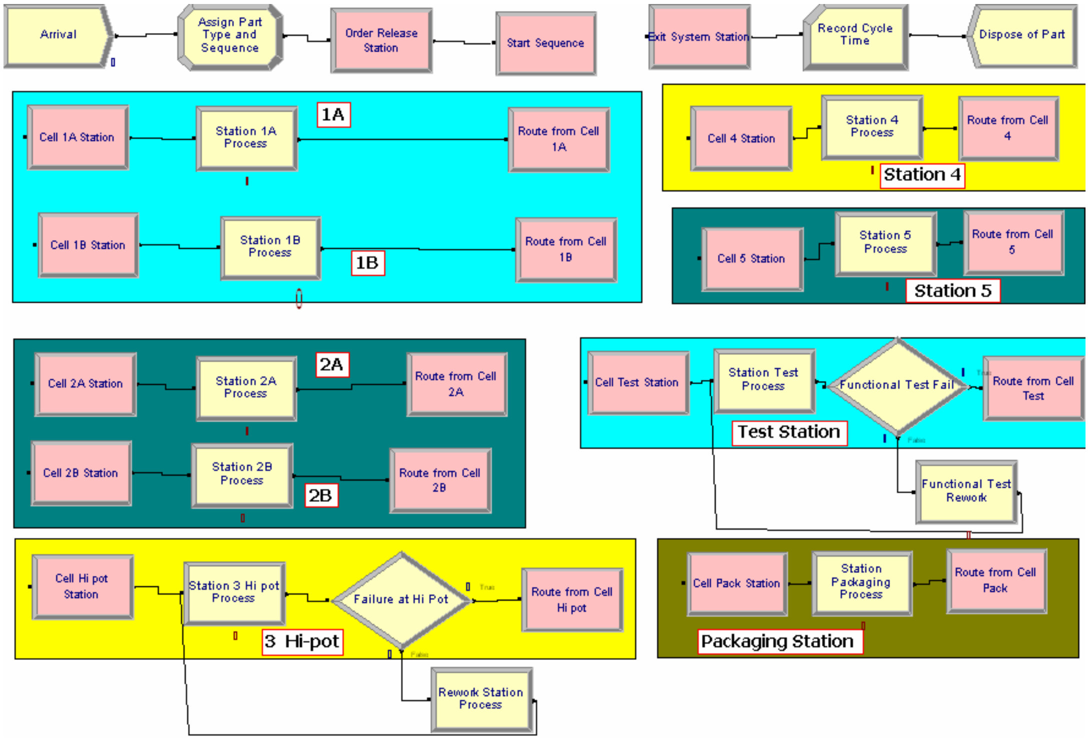

Figure 2: Base Simulation Model

found that the bottleneck workstation (workstation with highest utilization) is Workstation 2B. This is because the process time of those resources is greater than process time of the others. A different utilization scenario is shown in Figure 3.

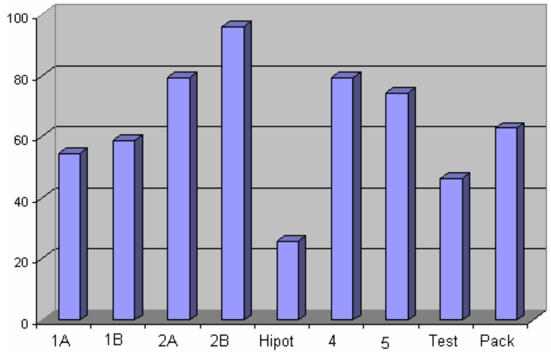

Figure 3: Utilization Comparison of Base Model

The Longest queue is found in bottleneck stations. As the buffer size is limited and different for different stations in the power drive assembly systems, the queue may not provide regular accurate information on the bottleneck station. From the utilization as well as queuing systems without limiting buffer size, we can easily deduce that Workstation 2B is the bottleneck machine. So to identify the bottleneck in the power drive assembly line, the queuing length and the utilization of each resource have been observed. It is found that the queue length was long before those resources, which had maximum utilization. The bottleneck occurs when the queue length becomes long before any resource. Normally the arrival of the frame is considered available all the time, and the type of product is selected based on the order issued. A different scenario analysis will be done later to reduce the bottleneck.

3.2 Reconfigured/Redesigned Assembly Line

To make the assembly line flexible, the workstations are allowed to mirror each other. The purpose of making the assembly line flexible is to meet current demand. If more Frame 2 and 3 drives are ordered, it may be necessary to simply produce more of that drive on that given day. By building this flexibility into the assembly line, it would be able to handle fluctuations in product demand. This flexibility is more of a short-term solution and will work best if the assembly line can handle the predicted production volumes. To add flexibility in the assembly line, the following two scenarios are added into the model: adding the capability to run Frame 2 drives at Workstations 1A and 1B, and adding the capability to run Frame 2 and 3 drives at Workstations 1A and 1B.

To create this flexibility, it would be simple to make the materials for Frames 2 and 3 available at Workstations 1A and 1B and likewise for Frames 0 and 1 at Workstations 2A and 2B. Workstations 1A and 1B perform very similar tasks to Workstations 2A and 2B. Workstations 2A and 2B are responsible for building Frame 2 and 3 drives, and Workstations 1A and 1B are responsible for building Frame 0 and 1 drives. It would not be feasible to store materials for all drives at all workstations, though. This would be counterproductive to the efforts to reduce excess material. This flexibility could be a great asset to the assembly line if the production volumes ever shift.

As customer orders are estimated to double existing production and require more varieties, it is necessary to make the line more flexible to meet future demands. The utilization comparison is done for scenarios 1, 2 and 3, shown in Figure 4. From the figure, it is easily seen that the bottleneck station is Station 2B.

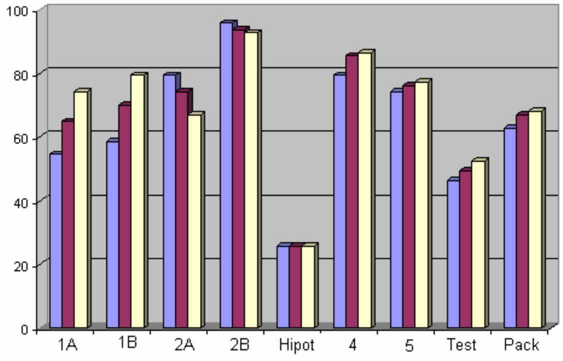

Figure 4: Utilization Comparison of Scenario 1, 2, and 3

3.3 Reconfigured/Redesigned Simulation Model with Additional Station

The bottleneck Station is 2B, which can be observed from utilization and queue comparison. To eliminate this bottleneck, the most obvious improvement is to add a pre-assembly station between Stations 2A and 2B, which will result in a reduction in cycle time. Also, the assemblies done at Station 2B need to be revised to insure elimination of repetitive reaches and searches that can cut down on the cycle times. Moreover, flexibility has been added to the assembly line by adding the capability to run Frame 2 drives at Workstations 1A and 1B, and adding the capability to run Frame 2 and 3 drives at Workstations 1A and 1B.

Adding an additional workstation to the assembly line will create a more substantial impact on the product cycle time. The two-station operation time is distributed with logical break into three stations. The easiest and most effective way to reduce the time in the operation is to remove some of the steps that the operator must go through. While we cannot simplify the product and remove steps from the assembly process, we can move some of the steps to an additional workstation. Workstation 2A takes less time than the Workstation 2B, on average. Dividing the time between three workstations gives us approximate processing time per workstation. The goal is to come close to that by dividing the operations into three parts instead of the two they are currently in. Based on the TAKT times, this will be necessary to meet future production.

There are four large parts to the plan that will increase the production of the operation, improve its efficiency, and provide flexibility for changes in demand. These four parts all each other when brought together. By improving the layout of the material, the operator will spend more time building drives and less time walking to retrieve the parts s/he needs to build a drive. Eliminating the need for that same operator to search for components to replenish his stock by bringing in a person whose entire job is to make sure that everyone has all of the components needed also greatly improves operator efficiency. Creating carts that the parts runner will replenish will improve the parts runner's efficiency as well as give the assembly line an added degree of flexibility. Finally, adding an additional workstation will remove the bottleneck from Workstations 2A and 2B. Together all of these things will play a huge role in the ability of the assembly line to achieve its projected production goals.

The base simulation model is reconfigured and redesigned with an additional station and the model also measures the performance of the systems. From the utilization comparison in Figure 5, we can easily see that after adding Station 2C, the bottleneck has shifted from Station 2B to Station 4 and 5, and to the packing station. As we improve the bottleneck station and produce more parts, Stations 4 and 5 are getting more frames, so utilization has increased. The flexible line is used as well as the unique line scenario by adding Station 2C with a flexible line. This shows that production increases significantly because of eliminating the bottleneck, organizing the materials placement, and balancing the line. Still production does not meet the required capacity. Now the focus shifts to how to eliminate the bottleneck stations: 4, 5, and packaging.

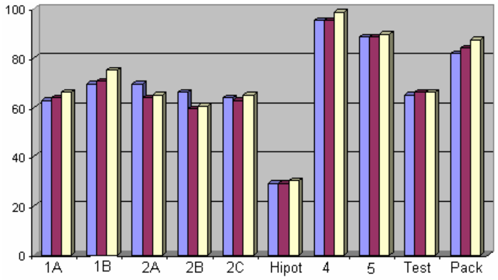

Figure 5: Utilization Comparisons of Scenarios 4, 5 and 6

3.4 Reconfigured/Redesigned Simulation Model with Revised Improved Processing Time

The bottleneck stations are Stations 4, 5, and packaging, one more station is added parallel to operation 5 to minimize the setup time. If we add three stations in series, it will be necessary to have three different setup times. In scenario 7, the additional station is added and uses existing processing time. Scenario 8 proposes reduced processing time at Station 4 and 5 with the existing system, and adds a packaging station. The recommended processing time (PT) is used for Station 4 with 15% reduction in processing time and for Station 5 with a 10% reduction in processing time.

In scenario 9, Station 6 is added to the series with the recommended distributed processing time of 4, 5, and 6. Scenario 10 adds the additional Station 6 parallel to 5 with the distributed proposed time of Stations 4, 5, and 6 where Stations 5 and 6 are identical operations (Figure 6). In scenario 11, the processing time of Stations 1A and 1B is reduced by 10% and 5%, respectively by having pre-assembled parts as well as adding fixtures. The utilization comparison has been done for scenarios 8, 9, and 10, which are shown in Figure 7. From the utilization we can easily see that the assembly line is much more balanced than in previous scenarios.

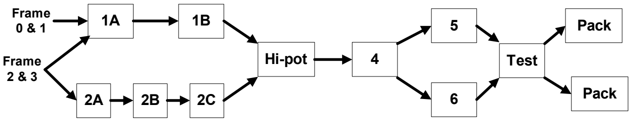

Figure 6: Assembly System with Parallel Station and Revised Process Time

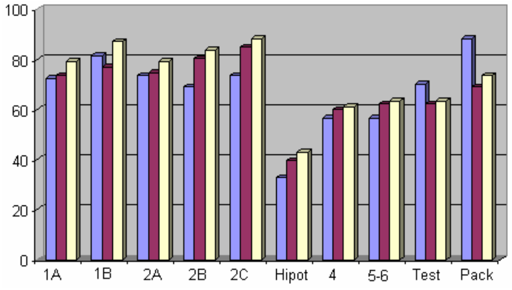

Figure 7: Utilization Comparison of Scenario 8, 9, and 10

3.5 Intelligent Simulation Model

A fuzzy knowledge based intelligent simulation model is developed to incorporate a prototype system design in power drive assembly systems; the model is capable of including manufacturing dynamics using machine and labor modules. As knowledge acquisition and representation are important steps in the modeling process, this knowledge-based simulation makes it easy for the system to acquire knowledge for better representation of the manufacturing scenario. The modules are developed in such a way that the model can capture dynamic behaviors to represent more realistic scenarios of manufacturing systems. The performance analysis that has been done shows that the intelligent model represents better scenarios. Utilization, queue, work in process, productivity, and cycle time are considered for the comparison. Intelligent modeling for manufacturing system decision-making can be used for controlling production to meet future customer demands. The intelligent simulation model in Arena is shown in Figure 8 where fuzzy rule based labor and machine dynamics are considered.

4 RESULTS AND DISCUSSIONS

4.1 Capacity Comparison

Because the operation sequence of each product is different and operation time is different, the production capacity of the system varies. Thus the capacity of each product is identified first for product mix and production volume. We assume four different types of power drive products and consider a typical sequence for those products, and identify each capacity per day. A steady-state system is identified first to eliminate initial bias. All replications are run for an equivalent of 80 hours of production. The data from the simulation model is gathered from the consecutive 10 replications of 16 hours (double shift), 80 hours (weekly, double shift) and 500 hours (yearly, double shift). The replications can be identified to obtain a satisfactory confidence interval for the power drive cases.

Figure 9 presents the throughput of the different scenarios of power drive assembly systems. The output has improved significantly from scenario 1 to scenario 6, since the bottleneck station has been identified and balanced by adding one station and reorganized material management systems. By improving material management systems, the non-value-added time is reduced, which leads to improvement in the operation time. The improvement of throughput is found after using the proposed model strategy, which represents a more realistic scenario, and eliminating the bottleneck of the systems. The capacity of the production line is set into a database. If the environment of the assembly systems changed, the model could be run to get new or modified capacity and revise the production scheduling. In this way, we can get real-time capacity status for the power drive assembly. If any new product comes, it can be identified from the flow sequence, then it can easily be modeled from the proposed power drive modeling systems to analyze the system to get better performance and identify how to fit into the existing assembly line to identify the capacity level for that particular product.

4.2 Validation of the Proposed Intelligent Simulation Modeling

Validation is necessary to show that the proposed model has the acceptable level of confidence in the performances. Validation is also concerned with whether the proposed model is indeed an accurate representation of the real system. There are several ways to validate the model. Balci (1989) shows how to assess the acceptability and credibility of simulation results. If the interval is too large, the model might not show real representation. Statistical methods are

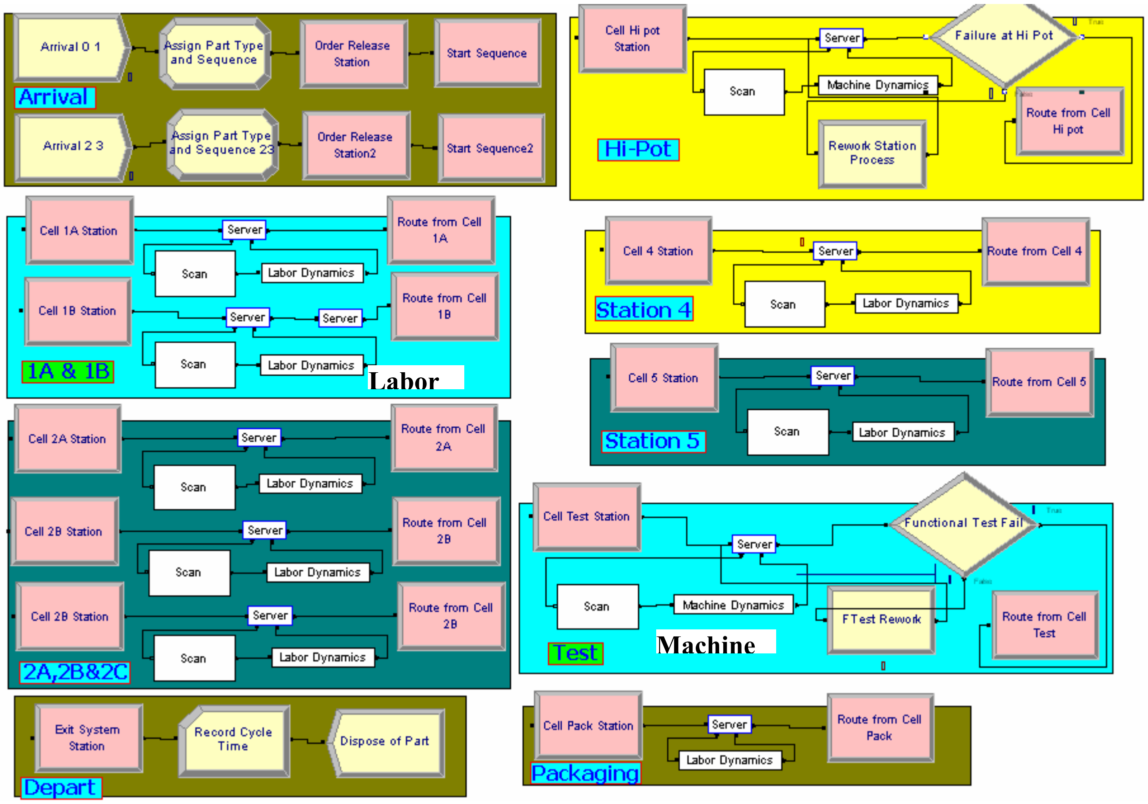

Figure 8: Simulation Model with Dynamics

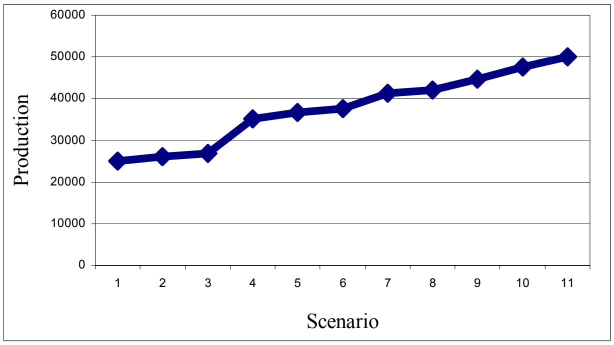

Figure 9: Annual Production Comparison

used to check for accuracy of results. There are a few goodness-of-fit tests, such as the chi-square test or the Kolmogrov-Smirnov test, which could be applied to fit distribution. A t-test validation technique is used to see whether the proposed simulation model shows significant improvement or not. Comparison between the actual throughput and the simulated one is used for the proposed model validation. The cycle time comparison is done, which also proves the validity of the intelligent simulation model. Initially we have found that the simulated results validated the real systems, while the later part shows the dynamic model is a closer representation of the actual systems.

4.3 Cycle Time Validation

The cycle time comparison is done both with dynamics and without dynamics in the model scenario. It is found that balancing the line and dynamics consideration significantly impacts the cycle time scenario. Figure 10 represents the cycle time variation without dynamics and line balancing. Figure 11 depicts the cycle time scenario with the consideration of dynamics and line balancing. It can be easily identified from the figures that the cycle time variation in Figure 10 is much higher than in Figure 11. After line balancing and dynamic consideration, cycle time becomes more stable.

5 CONCLUSIONS

The base model was a replication of the existing system without variation. The reconfigured/redesigned model, representing potential modifications to the productions system mentioned earlier, was likewise developed to include stochastic variability and to allow ease of experimentation. The intelligent model added stochastic variation, consisting of unscheduled downtime, and buffer sizes, machine and labor dynamics. The proposed modeling environment in simulation can improve simulation accuracy for power drive assembly systems. These assembly models can be applied in a real system to analyze the system performance more efficiently and effectively. The modeling environ-

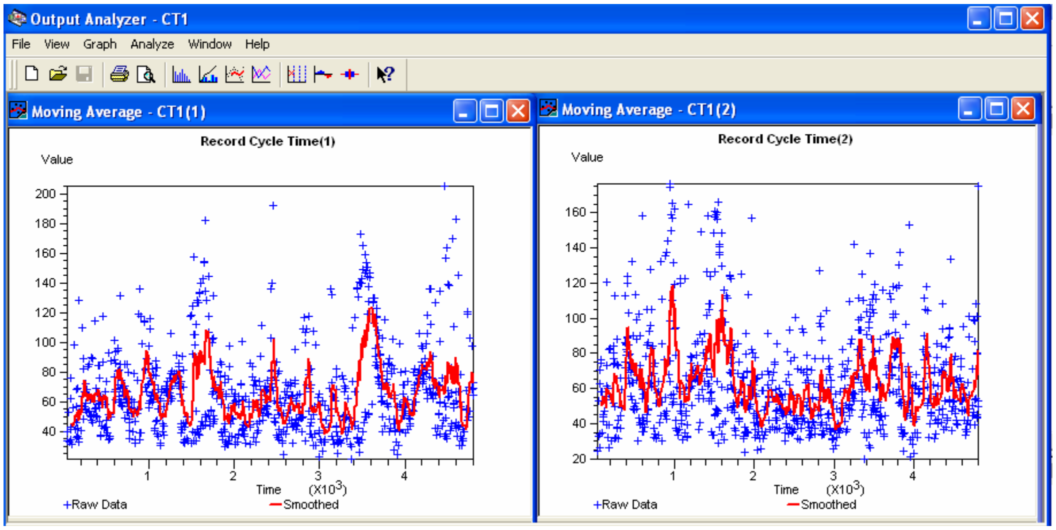

Figure 10: Cycle Time Variation without Dynamics and Line Balancing

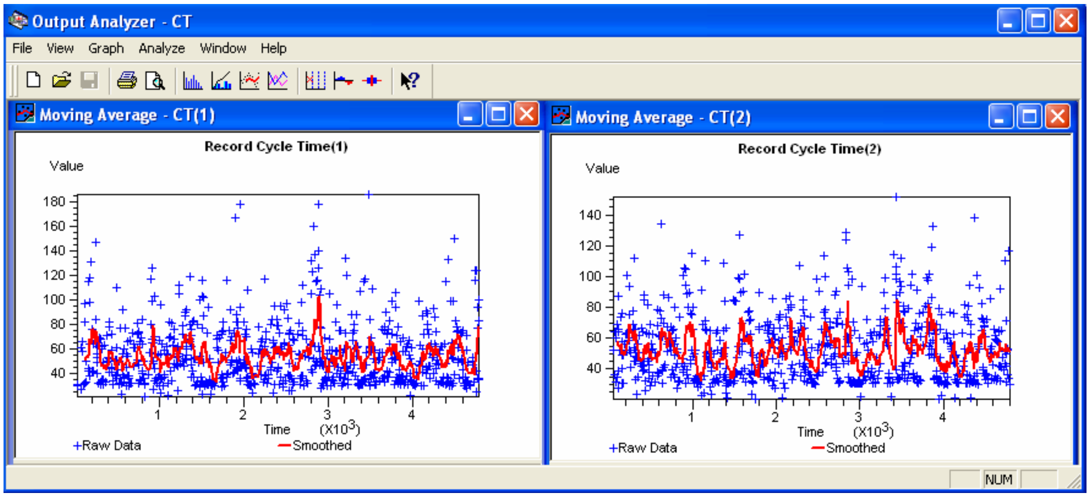

Figure 11: Cycle Time Scenario with Dynamics and Line Balancing

ments can be easily used for line balance and the behavior of the line. Management can prevent any unexpected situations by analyzing the performances through the simulation model. In order to improve modeling accuracy, simulation resources need to include both dynamic and static characteristics of the real scenario. The proposed modeling systems can improve the modeling accuracy in terms of more realistic presentation of all activities. Knowledge acquisition representation is used to acquire the knowledge for better representation of the manufacturing scenario in the model.

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