PERFORMANCE EVALUATION OF MANUFACTURING SYSTEM USING SIMULATION

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Abstract: One of the largest application areas for simulation is that of manufacturing systems, with the first uses dating back to at least the early 1960's. Simulation is an analytical tool attractive to managers and engineers seeking to design, understand, and improve a business process. Simulation permits study and improvement of the process design, via use of a model, without having to build, disturb, or disable the actual process. This paper discusses how simulation is used to improve the performance of the local manufacturing plant that manufactures aircraft composite parts. In this study, simulation technique is applied to model the existing system and then used to simulate the design and operational policies of the plant production process. The model covers the operations at Primary Manufacturing Area (PMA) and Secondary Manufacturing Area (SMA). The model is built in modular form and then later integrated. The paper concludes with some material highlighting how easy the tool is to apply to this kind of problem and also presents some thoughts on how the tool might be enhanced to improve its value.

Keywords: Simulation, Manufacturing, Performance

INTRODUCTION

Manufacturing sector is one of the country's priority growth engines in order to achieve the national aspiration of being a fully developed nation as aspirated by the Prime Minister's Vision 2020. In year 2003, the sector continued to be a major contributor to Malaysia economy, accounting 31 per cent (2002:30.1%) of Gross Domestic Product (GDP) and 81.1 per cent (2002:84.4%) of total exports [1].

It has been the main agenda of the manufacturing sector worldwide to produce a cost effective products so to stay competitive in the business of globalisation era. Consequently, the manufacturers need to improve their productivity and increase the efficiency at production processes. To achieve this purpose, computer simulation is a technology that could offer. Implementation of simulation is considered as a new technology in this country's manufacturing sector, but has become a norm in many manufacturing sectors in developed countries.

Simulation is defined as the use of a computer model to mimic the behaviour of a complicated system, and thereby gain insight into the performance under a variety of circumstances [4]. Simulation has many applications, from space flight and aircraft to ships and cars, and from nuclear power to manufacturing industry. The technique of simulation is preferable to real system assessments, because of its ability to experiment with the real system without actually incurring any direct capital investments. Such a technique can be used for modelling a complex process and model, which are difficult to solve mathematically [3]. The opportunities to cut costs and to improve service levels are tremendous by applying this technology. The design of new manufacturing systems or improving the existing system can be immensely supported by simulation as the designer is given an opportunity to assess the proposed system via properly designed experiments without the cost and time associated with physically building the system.

According to Kelton et al. [2], the main reason for simulation's popularity is its ability to deal with very complicated models of correspondingly complicated systems. This makes it a versatile and powerful tool. Besides, the obvious reduction in cost of computers and simulation software, emergence of more user-friendly and powerful simulation software, increase in the speed of model building and delivery, and acceptance of an established set of guidelines of simulation model building [5].

This study focuses on applying a simulation technology to a manufacturing system of an aerospace industry in Malaysia. The manufacturing plant under study is a joint venture between two Malaysian companies and two American companies. The plant involves in the production of advanced composites materials, i.e. producing fixed trailing edge parts for the wings of an aircraft. Simulation study at this plant is initiated because the workload for an existing system is predicted to change. The managers need to understand the impact of such changes on system performance. The simulation model offers practical information to the management to make informed decision on the performance of this system.

The main objective of the study is to model and simulate the design and operational policies of the production process, which can be used to improve the performance of the different activities at the plant. The study also intends to evaluate the performance of existing operations and capability of the plant resources. It can then be used to find an alternative design of optimum production system. The study was to provide information on machine utilization, part flow time, and information on bottlenecks. The simulation was also used to test "what if" scenarios such as increased production requirements, resources utilization and other effects of operating variables on production.

MATERIALS AND METHODS

A series of factory visits and meetings with the company key-personnel were conducted for a period of three months. Information on the plant layout and process flow was gathered to describe the system. Data on arrival rates, process times, failure rates, number of resources (workers, machines, conveyors and transporters), and distances between stations were recorded via machines auto-records, process observation and interview. Figure 1 shows the general flow of the production processes at the plant under study. Current production rate of the plant is 110 parts per day. In this study, the process begin when a semi-finish product flow in a single part order along moving lines in lay-up cells through autoclave, water-jet trim, test, paint, inspection and finally to shipping. Batch processing is also applied at a few workstations.

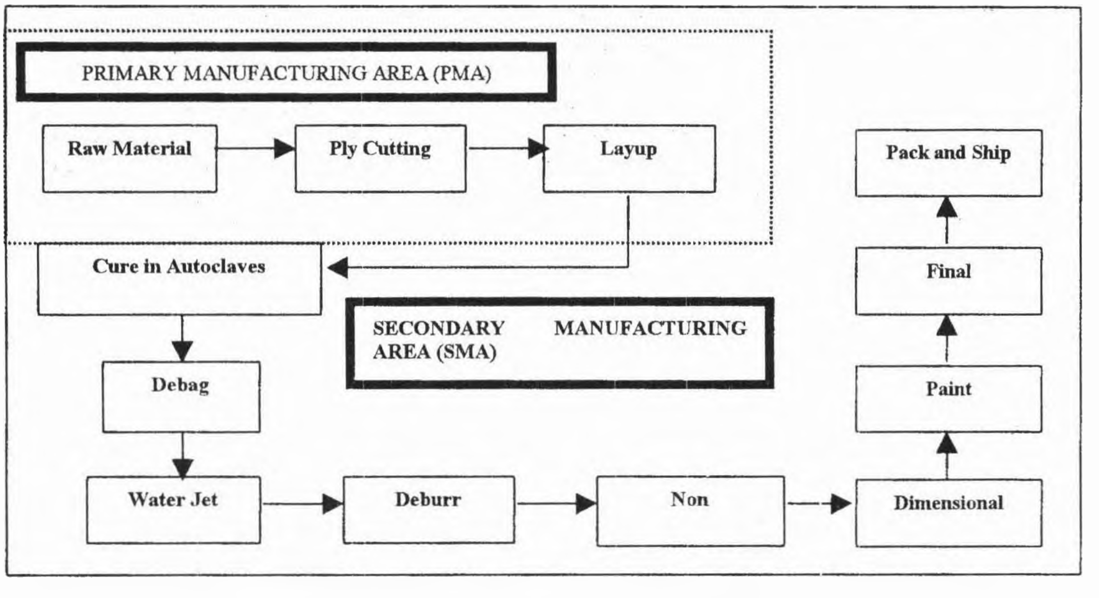

Figure 1. General flow of production process.

Input Data. Input data provide the driving force for any simulation model. Without input data, the simulation model itself is incapable of generating any data about the behaviour of the system it represents. Table 1 exhibits the distributions of process times at five PMA stations (one ply cutting machines and 4 layup stations) were fitted, using 100 samples of actual data (for each of the process) and the Arena Input Analyzer. The distributions of process times at eight SMA stations were also fitted, using 50 samples of actual data (for each of the process except for dimensional inspection process with 100 samples of data).

Table 1: Distribution of Process Times (in minutes)

Sub-model	Process	Distribution	Expression
1	Ply Cutting	Beta	6 + 3.94 * BETA(2.28, 2.38)
	Layup W	Triangular	TRIA(13, 13.9, 15)
	Layup X	Weibull	13 + WEIB(1.05, 2.46)
	Layup Y	Weibull	13 + WEIB(3.38, 2.84)
	Layup Z	Weibull	14 + WEIB(2.11, 2.61)
2	Debag	Triangular	TRIA(3.07, 3.52, 3.98)
3	Water Jet Trim	Beta	4.9 + 1.04 * BETA(1.83, 2.38)
	Deburr	Beta	15.1 + 4.75 * BETA(1.87, 2.11)
	NDT	Normal	NORM(90, 0.784)
	Dimensional Inspection	Weibull	10 + WEIB(5.27, 2.6)
4	Paint	Beta	7 + 1.89 * BETA(1.86, 2.28)
	Final Inspection	Triangular	TRIA(8.01, 8.49, 8.98)
5	Rework	Uniform	UNIF(40, 50)

Model Development. The actual production process was studied and modelled into computer simulation programme. The first step of the project was to define and formulate the problem. Understanding the problem clearly will make the modelling task become much easier. The second step was the model development. The model development is the most visible part of the simulation study. The model development will adhere to the goals and objectives and will be completed in phases of increasing complexity. The model will first capture the basic logic of the system and the logic flow. Part movement and elements will be added and verified as the model is developed. As soon as basic model function has been encoded, more detail can be added for each location until the desired function is achieved. The last step was doing the experimentation and presenting the analysis results. The software chosen for this case study was ARENA by Rockwell Software. It is a menu driven package and run on an IBM compatible PC. The resulting layout was animated when the simulation was run, showing the movement of parts and resources with elapsed time. The simulation can be interrupted at any stage and a comprehensive reporting system can be viewed. A modular approach was taken to develop the model. Five individual models, one model represents PMA, and four models represent four sections at SMA. Each one was developed to study the capacity of each area in isolation. After the models were verified and validated individually, they were integrated in order to study the performance of the entire system.

RESULTS AND DISCUSSION

Output Analysis

The statistics collected from the simulation model include parts throughput, parts flow times, resources utilisation, and work-in-process quantity (WIP). The simulation model was run for 5 replications and the average were recorded.

Parts throughput represents the number of parts for the period of one-week study. Table 2 shows the output of the throughput using simulation compared with the actual plant data and it seem that they are in good agreement.

Table 2. Number of Predicted Parts Compared With Historical Data.

Part Type	Average Simulation	Historical Data	% Difference
W	117.8	118.8	0.84
X	96.2	99.4	3.22
Y	115	118.8	3.20
Z	96.8	99.4	2.62

Part cycle time is the total time that a part spends in the system to complete all the activities from cutting to packing. The flow time should be kept to a minimum to reduce work-in-process inventories, which carry hidden cost. The average parts flow time is compared with the actual data together with calculated error is given in Table 3.

Table 3. Flow Time of Parts.

Part Type	Average Simulation (hr)	Actual Data (hr)	% Difference
W	27.8858	30	7.05
X	28.8001	30	4.00
Y	27.7921	30	7.36
Z	28.2961	30	5.68

Resource utilisation is the ratio of the average resource number busy to the average resource number scheduled. Resource utilisation is a common indicator of measuring how busy is the machines and operators. Table 4 exhibits the average of five replications scheduled utilisation for all resources. The output data indicate that the resource utilisations range from 81% to 98%.

Table 4. Scheduled Utilisation Values for Resources

Resource	Average	Resource	Average	Resource	Average
Ply Cutter 1	0.91	Operator X5	0.84	Operator Z5	0.84
Ply Cutter 2	0.91	Operator X6	0.84	Operator Z6	0.83
Operator W1	0.87	Operator Y1	0.86	Deburr Operator	0.98
Operator W2	0.87	Operator Y2	0.86	Dimensional Inspector	0.86
Operator W3	0.87	Operator Y3	0.86	Inspector 1	0.98
Operator W4	0.87	Operator Y4	0.87	Inspector 2	0.97
Operator W5	0.87	Operator Y5	0.87	NDT Technician	0.98
Operator W6	0.87	Operator Y6	0.87	Debag Operator	0.81
Operator X1	0.84	Operator Z1	0.83	Painter 1	0.89
Operator X2	0.84	Operator Z2	0.83	Painter 2	0.88
Operator X3	0.84	Operator Z3	0.83	Rework Operator	0.85
Operator X4	0.84	Operator Z4	0.83	Waterjet Machine	0.97

Work-in-process (WIP) quantity for each type of part was also computed from the model. The output from the simulation model is then compared with the historical data The results are shown in Table 5.

Table 5: WIP For Each Type of Parts.

Part Type	Average Simulation (min)
W	52.96
X	45.77
Y	52.88
Z	44.92
Total	196.54
Actual Data	197
% Difference	0.23

Model Experimentation

In line with the plan of company to expand its business by producing more parts, an increase of 20% of production capacity was experimented. The number of daily arrival was increased from 110 parts to 132 parts to investigate whether the present resource capacity can tolerate. Besides, additional two alternative scenarios were also experimented. One of the scenarios is by an increase of water jet trim machine operation time by 2 hours (20% increase) and 1.5 hours (18.75% increase) extra times for other resources. The other scenario is by an increase of 2 hours extra time for resource with high utilisation (>95%) i.e. deburr operators, final inspectors, NDT machine and waterjet machine, and 1.5 hour for other resources (ply cutters, layup operators, painters, dimensional inspectors, rework operator, and debag operator). The simulation model was run for 5 replications and the average was recorded for each of the scenarios.

Table 6 shows and explains that present resource capacity (Scenario 1) was unable to cater the production increase. However, Scenario 2 and 3 seem that they are in good agreement with 20% expected increase of throughput.

Table 6: Number of Predicted Parts Throughput.

Production throughput	Simulation Output	Scenario 1	Different	Scenario 2	Different	Scenario 3	Different
W	117.8	119.2	1%	140	19%	141.4	20%
X	96.2	99.8	4%	119.4	24%	118.2	23%
Y	115	120.2	5%	141.6	23%	140	22%
Z	96.8	103.6	7%	117.4	21%	117.2	21%
Total Throughput	425.8	442.8	4%	518.4	22%	516.8	21%

Parts flow time of the three scenarios is given in Table 7. Scenario 1 shows that the parts will spend about 30% extra time compared to other scenarios, where the parts will spend less time in the system.

Table 7: Flow Time of Parts.

Part Type	Simulation Output	Scenario 1	Different	Scenario 2	Different	Scenario 3	Different
W	27.8858	37.4852	34%	26.6088	-5%	26.0064	-7%
X	28.8001	37.516	30%	26.6815	-7%	26.6476	-7%
Y	27.7921	37.3099	34%	26.2804	-5%	25.7439	-7%
Z	28.2961	36.594	29%	26.0743	-8%	26.174	-7%

Table 8 exhibits the resource utilisation for the three cases. Deburr operator, final inspector 2, NDT technician and waterjet machine seem to be fully utilised in Scenario 1. However, for the other two scenarios, resource utilisations in Scenario 2 are higher than in Scenario 3.

Table 8: Resources Utilisation for Each Scenario

Resource Utilisation	Simulation Output	Scenario 1	Scenario 2	Scenario 3
Ply Cutter 1	0.91	1.00	0.92	0.92
Ply Cutter 2	0.91	1.00	0.92	0.92
Operator W1	0.87	0.90	0.88	0.89
Operator W2	0.87	0.90	0.88	0.88
Operator W3	0.87	0.90	0.88	0.89
Operator W4	0.87	0.90	0.89	0.88
Operator W5	0.87	0.90	0.88	0.88
Operator W6	0.87	0.90	0.88	0.89
Operator Y1	0.84	0.87	0.84	0.83
Operator Y2	0.84	0.87	0.84	0.84
Operator Y3	0.84	0.87	0.84	0.84
Operator Y4	0.84	0.87	0.84	0.83
Operator Y5	0.84	0.87	0.84	0.83
Operator Y6	0.84	0.87	0.83	0.84
Operator Y1	0.86	0.90	0.88	0.88
Operator Y2	0.86	0.90	0.88	0.89
Operator Y3	0.86	0.90	0.88	0.89
Operator Y4	0.87	0.90	0.88	0.89
Operator Y5	0.87	0.90	0.89	0.88
Operator Y6	0.87	0.90	0.88	0.89
Operator Z1	0.83	0.88	0.83	0.81
Operator Z2	0.83	0.89	0.83	0.81
Operator Z3	0.83	0.89	0.83	0.81
Operator Z4	0.83	0.89	0.83	0.81
Operator Z5	0.84	0.89	0.83	0.81
Operator Z6	0.83	0.89	0.83	0.81
Deburr Operator	0.98	1.00	1.00	0.95
Dimension Inspector	0.86	0.90	0.89	0.87
Inspector 1	0.98	1.00	1.00	0.95
Inspector 2	0.97	1.00	0.99	0.93
NDT Technician	0.98	1.00	0.99	0.97
Operator Debag	0.81	0.84	0.82	0.81
Painter 1	0.89	0.91	0.91	0.91
Painter 2	0.88	0.92	0.90	0.90
Rework Operator	0.85	0.83	0.86	0.75
Water Jet Machine	0.97	1.00	0.98	0.98

Parts work-in-process (WIP) of the three scenarios are given in Table 9. Scenario 1 shows that WIP value is much higher compared to other scenarios.

Table 9: WIP for Each of Scenario

Work-in-process (WIP)	Simulation Output	Scenario 1	Different	Scenario 2	Different	Scenario 3	Different
W	52.96	85.8284	62%	60.8769	15%	59.37	12%
X	45.77	71.8447	57%	50.4458	10%	50.72	11%
Y	52.88	85.5136	62%	60.0425	14%	58.91	11%
Z	44.92	69.4871	55%	49.5122	10%	49.92	11%
Total	196.53	312.674	59%	220.877	12%	218.91	11%

CONCLUSION

This paper presents the results of a case study, which involved the use of computer simulation technique for production planning process of aerospace industry. The model built is used to investigate a variety of issues, for example to determine the impact of a proposed change, without affecting production. The model is also able to determine the plant capacity under various situations. This enhances the ability to manage the system, control its capacity, and make better decisions regarding its operation, which in turn improves ability to deliver quality product to customers.

When production rate was increased by 20% to investigate the current plant capacity, the current resources capacity was unable to tolerate with this increment as experimented in Scenario 1. Obviously, the parts flow time and WIP increase tremendously with the 20% increase of parts demand. Scenario 2 deals with the 20% production rate increase with an increase of water jet trim machine operation time by 2 hours (20% increase) and 1.5 hours (18.75% increase) extra time for other resources. However, the utilisation of deburr operators, final inspectors, NDT machine and waterjet machine found to be very high.

The last experiment, Scenario 3 is by an increase of 2 hours extra time for resource with high utilisation (>95%) i.e. deburr operators, final inspectors, NDT machine and waterjet machine, and 1.5 hour for other resources (ply cutters, layup operators, painters, dimensional inspectors, rework operator, and debag operator). Clearly from the simulation outputs, the result is the best design to meet the expected production throughput with acceptable resources utilisation.

The research and the simulation model developed have improved understanding of the inter-relationship of the several physical components of the plant. The process of constructing the simulation models and reviewing the interaction of these components has given an insight into the different operational characteristics at the plant. The approach of system analysis is not only beneficial to the modeller, but it is also useful to the planner since it gives a thorough understanding how the plant behaves and not how one thinks it behaves.

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