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MODELING PRODUCTION OF AUDIO SYSTEMS USING SIMULATION

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ABSTRACT

The manufacturing sector has become an essential sector in Malaysia. This sector needs to be efficient and sound in facing great competition. Reducing costs will ensure that manufacturing companies remain competitive in the market. This study was conducted in a manufacturing company that produces audio systems by using simulation technique. Simulation technique can help the management team in making the right decisions. The objectives of the study are to identify the problems arising in the system and to forecast the throughput based on several scenarios. The aim of these scenarios is to see the system performance. System performance is determined by looking at total output and cycle time. The percentage of resource utilization, waiting time and queue time is also taken into consideration. Three scenarios were built in order to see the performance of the system after the throughputs were increased. ARENA® software was used in modeling the system.

Keywords: *Simulation, manufacturing systems, system performance, assembly line*

ABSTRAK

Peralihan daripada ekonomi berasaskan pertanian kepada perindustrian di Malaysia telah menyebabkan perkembangan yang pesat dalam bidang perindustrian. Proses untuk menyiapkan sesuatu produk dalam perindustrian yang pelbagai dan kompleks menyebabkan teknik simulasi amat sesuai untuk digunakan. Kajian ini dijalankan untuk membina model simulasi yang menggambarkan keadaan sebenar di sebuah kilang membuat sistem audio. Kajian ditumpukan ke atas operasi di 'assembly line'. Hanya sejenis model sahaja yang diambil kira iaitu set hifi. Perisian simulasi ARENA® digunakan. Model yang dibina disahkan telah mewakili sistem yang sebenar melalui dua proses iaitu verifikasi dan pengsahihan model. Eksperimen dijalankan untuk melakukan perubahan ke atas model yang dibina. Oleh itu, eksperimen dapat *dijalankan tanpa mengganggu sistem yang sebenar. Kecekapan sistem ditentukan dengan melihat kepada nilai hasil dan 'cycle time'. Di samping itu, peratusan penggunaan sumber, masa menunggu dan bilangan menunggu juga diambil kira. Didapati bahawa terdapat lima proses dalam kajian yang sumbernya tidak digunakan sepenuhnya. Kemudian, tiga keadaan atau senario telah dibina untuk mencapai objektif. Senario dibina berdasarkan kepada perubahan yang ingin dilakukan.*

Kata kunci: *Simulasi, manufacturing systems, assembly line*

INTRODUCTION

Malaysia, once known as an agricultural country has now been transformed into an industrialized country, with more than one-third of its Gross Domestic Product (GDP) emanating from the manufacturing sector. Since 1987, manufacturing has overtaken agriculture as the leading growth sector of the economy. In terms of exports, manufacturing provides about 80% of Malaysia's total trading, and is now the engine of growth for the economy. It has become the main agenda of the manufacturing sector to produce cost effective products so as to stay competitive in business. One of the action taken is to increase efficiency at production lines and encourage greater productivity. Computer simulation is a technology that could lead to the achievement of this aim. A simulation model can be an effective tool in the design, analysis, and operation of manufacturing and other complex systems (Balci, 1990).

Computer simulation is the discipline of designing a model of an actual or theoretical physical system and conducting experiments with this model for the purpose of understanding the behavior of the system and /or evaluating various strategies for the operation of the system (Banks, 1999). It is one of the most powerful tools available to decision-makers responsible for the design and operation of complex processes and systems. As manufacturing of goods normally involves complex processes, the use of a simulation technique has a huge potential to be a useful tool in this sector. It makes possible the study, analysis and evaluation of circumstances that would otherwise not be possible. In an increasingly competitive world, simulation has become an essential problem solving method for engineers, designers and managers.

Simulation models of business processes can assist overcome the inherent complexities of studying and analyzing businesses, and therefore contribute to a higher level of understanding which can be used to improve processes (Harrel & Tumay, 1995).

The purpose of this study is to demonstrate the use of simulation technique as a decision support tool in the manufacturing sector to increase plant performance. The focus of the study is on the process of producing audio systems at the assembly line. The assembly line is where all the parts are combined to produce a complete product.

APPLICATION OF SIMULATION IN MANUFACTURING

One of the largest application areas for simulation modeling is that of manufacturing systems, with the first use dating back to at least the early 1960's (Law & McComas, 1991). As the manufacturing system becomes more complex, making effective decisions for these systems are becoming increasingly difficult as well. Applying guesswork to find the best possible solution will not be practical to the management as it involves high risks. An effective analysis tool is therefore required to assist the management to experiment changes within the system and to seek more options for improving performance and reducing system costs.

It has become a common scenario for engineers and planners to focus more effort on improving processes, equipment, and methods with the goal of getting new manufacturing systems. They are frequently concentrating less on overall coordination, integration and scheduling issues of the plant. As a consequence, manufacturing systems are implemented poorly and often perform below anticipated levels.

There are many reasons contributing to the difficulties engineers and planners face in carrying out these system analysis activities. Among them are the increasing size and complexity of systems, changes in the demand for system services, availability of more options in configuring systems and greater expectations for improved performance by customers (Schwetman, 1998).

Schwetman (1998) suggested that system analysis projects were initiated for the following reasons:

- a new system is being designed and implemented (or acquired); there are questions about component tradeoffs, and the best choices are often difficult to determine.

- an existing system is delivering unsatisfactory performance; in many cases, the unsatisfactory performance is evidenced by customer complaints, slow response times and low levels of service; in many cases, the result can be reduced revenues, higher operating costs and lost business.

- the workload for an existing system is predicted to change; the managers of the system need to provide the best possible estimates of the impacts on system performance that will result from these changes.

Model-based system analysis is the technique often used to address the need to predict performance in these situations. Increasing competition has compelled manufacturing sectors to find ways to manufacture cost effective products while maintaining customer satisfaction and making continuous improvement to both products and processes. A corresponding range of methods and tools have been exploited to assist in accomplishing these objectives. Simulation is a technology that is powerful enough to evaluate and analyse alternative strategies in designing manufacturing and business systems.

There are many ways in which simulation technology has benefited manufacturing sectors. Simulation can be used to evaluate the performance of a system, existing or proposed, under various configurations of interest and over long periods of real time. The management needs to have control of their systems to reduce the chances of failure to meet specifications, eliminate unforeseen bottlenecks, prevent under or over-utilization of resources, and optimize system performance.

In the manufacturing sector, the management needs to consider issues such as the requirement of resources at the plant. This requires the management to evaluate the different alternatives that benefit the company the most. The decision may involve capital investment such as buying different types of machines, changing plant configuration, labor requirement planning and changing workers' shift.

RESEARCH OBJECTIVES

The aim of the study is to develop a simulation model of a manufacturing plant producing audio systems. In order to achieve the stated aim, the following objectives were identified and pursued:

- to develop simulation models that are capable of imitating the plant operations.

- to investigate the bottleneck points, utilization of resources and other performance measures, which can help increase the plant's efficiency.

- to increase the plant's throughput by reducing cycle time.

- to propose an alternative operating policy in order to decrease bottleneck and to increase the performance of the plant.

PRODUCTION PROCESS FLOW DESCRIPTION

Figure 1 shows all the processes at an assembly line in the plant. It consists of seven major processes with altogether thirty-two processes. The major processes begin with the combining front followed by bottom chassis combine, general inspection, final combining, final inspection, finishing and ends with packing activities, all of which are shown in Figure 1. The description of activities at each process are described below.

Combining Front (CF)

The first process is the combining front. This process is at the beginning of the conveyor. There are three sub-processes in the combining front. However, the combining front processes are led by a line leader. The processes are cassette mecha assembly, fixing cassette mecha to front cab and pass CD changer, top cab, side cab for both left and right. Therefore, there are four persons involved in the process, comprising three workers and one Line Leader. The operators are labeled as CF1, CF2 and CF3 as illustrated in Figure 1.

Bottom Chassis Combine (BC)

The second process is the bottom chassis combine. This is the most important process and the biggest process, which covers almost half of the overall process. Normally, this process uses up to thirteen workers as it has thirteen sub-processes. Some parts come via a conveyor. This process is done outside of the conveyor. The sub processes are called breaking PWB (printed wiring board), combine display PWB, screw display PWB, button click sound, screw bottom chassis, power PWB preparation, PT soldering, screw PT, fix AC cord bush, fan unit

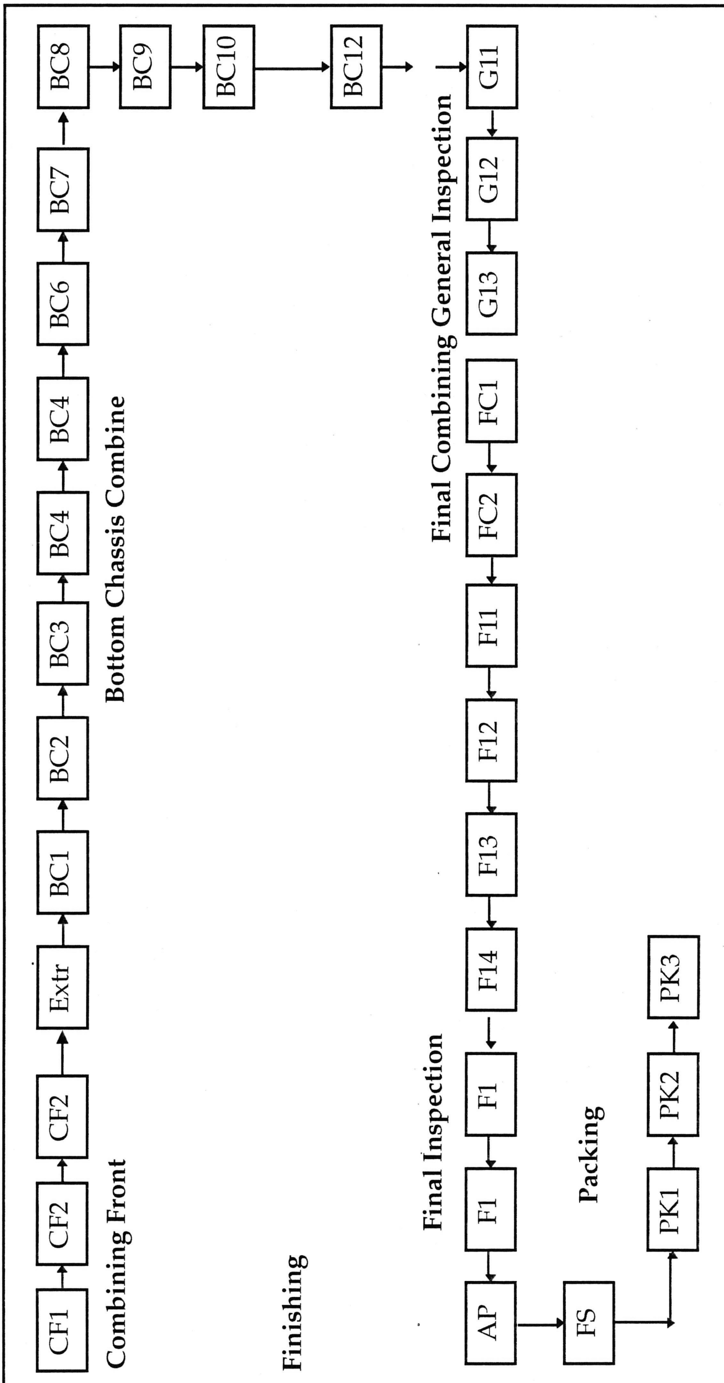

Figure 1
Plant Layout

preparation, screw fan to bottom chassis, screw back plate and combine CD changer. Figure 1 shows that the operators at the bottom chassis combine are labeled as Extra, BC1, BC2 and so on until BC12.

General Inspection (GI)

The next process is the general inspection. Three things are inspected by three workers here, which are tuner to tape record, CD spring to tape record and MP3 inspection. In the model, they are named as GI1, GI2 and GI3 as shown in Figure 1. If the parts are rejected here, the possible cause would be electrical. The rejected parts will be taken out of the conveyor and technicians will be responsible for overcoming the problems.

Final Combining (FC)

The fourth process is final combining. After the parts have been inspected at general inspection, the next sub process is the side cab combine (left and right). Then, it goes to the second sub process namely, top cab combine. With two sub processes involved, therefore two workers are working at this stage and they are labeled as FC1 and FC2.

Final Inspection (FI)

Then, the parts go through the second inspection that is, the final inspection. There are six workers doing six sub-processes here. The first worker on final inspection checks the hipot test or tape inspection. The next sub process is tuner inspection, CD inspection, T1 to T2 record (tape1 & tape2), karaoke inspection and VCD inspection. The last sub process in the final inspection is the appearance check. Normally, the failure cause is appearance cause and therefore the line leader will take over to repair it. FI1, FI2 and so on until FI6 are the operators doing activities in the final inspection processes as described in Figure 1.

Finishing (FS)

The entities enter the finishing phase through the conveyor. After this process, a worker fixes all accessories part to polybag and puts them together with the parts. The accessories preparation process is done outside of the conveyor and the worker puts them into the parts moving on the conveyor. The two operators are called FS and AP and they are shown in Figure 1.

Packing (PK)

The entities enter the final process at the packing stage. Three workers will perform three steps in packing. The first sub process is to fix the polybag or polyform. Then, a worker does a p/case preparation and fixes the speaker box. Next, the last worker in packing fixes the complete set and accessories to p/case and closes the p/case and sticks a back code to the p/case. In the model, these three operators are labeled as PK1, PK2 and PK3 as described in Figure 1. Then, the entities reach the end of conveyor and are sent to storage.

SIMULATION APPROACH

In any simulation study there is a structured approach to conduct. This approach is not necessarily unique but in general it has some common elements (Centeno, 1996). Figure 2 presents the general simulation process as proposed by many simulation modelers (Gogg & Mott, 1993). A similar approach has been applied in developing the simulation model at the manufacturing plant under study. As presented, the simulation modeling flow is very easy to comprehend, useful and handy in guiding modelers with a simulation modeling project.

Understanding the problem clearly will make the modeling task easier. An accurate definition of the problem formulation can dictate the level of details required in the model and may indicate specific areas where special care must be taken (Sadowski, 1991). The aims and objectives will determine how the model will be defined, what aspects of the system will be simulated, and what assumptions that can be adopted to simplify the building of the model (Shannon, 1998). 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.

After the system has been flow-charted and organized, pertinent information about the system's operation and control logic is collected. Operation characteristics, such as operation time and set-up time, are collected for each element in the system. The modeler must be knowledgeable about programming and/or a simulation package. Model verification ensures that the model behaves in the way it is intended. Therefore the input data must be correct. Model validation ensures that the model has successfully captured the operational characteristics of the system and behaves the same as the actual system.

Operational assumptions are also established for system elements when actual data are in short supply or non-existent. System elements are assumed to operate in a certain manner for the purposes of the simulation model. Simulation experiments are expensive in terms of time, the labor of experimenter, and cost of computer time. The DOE methodology provides a structure for the modeler's learning process (Kelton *et al.*, 1998). Using the DOE methodology can also determine how system parameters can be compared in order to analyze the system.

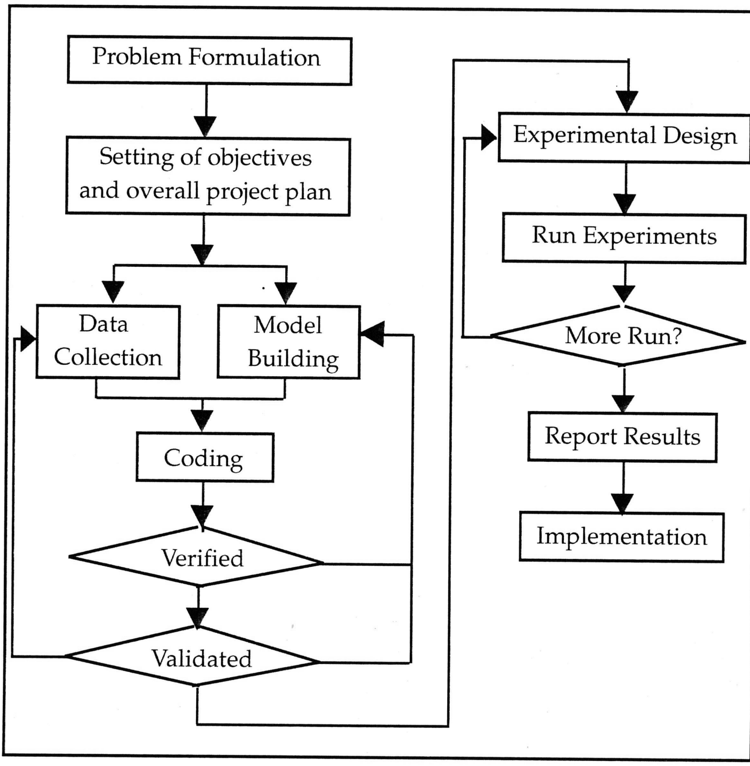

Figure 2
Simulation Modeling Processes

Simulation has to be done with many replications. Law and McComas (1991) recommended that the simulation runs should be done between three to five times and the averages of these runs are recorded. The focus of the output analysis should be on the performance measures. The performance measure is actually the input for decision-making and it gives insight to the understanding of the system behavior. The model document should describe a data structure, the key elements of the model, the general flow of logic, and all variables, and queues. The ultimate reward from developing a simulation model is to gain information that can be used to improve decision making with the system. The success of the implementation phase depends on how well the previous steps have been performed. It is also contingent upon how thoroughly the analyst has involved the ultimate model user during the entire simulation process.

DEVELOPMENT OF SIMULATION MODEL

The model is developed using ARENA simulation software. In the model, the audio parts represent the entity that moves throughout the system. In the ARENA software, the Input Analyzer is used to fit the appropriate distribution to the empirical data collected. Most of the data were directly available, via operation or equipment specification documents. The simulation model presents an animated display of the production system. This animation can be run concurrently during simulation. The modeler can also include animation in a real-time display of model statistics, such as dynamic plots, histograms, and time clocks, during the simulation in order to illustrate system performance. Statistics such as cycle time, resources utilization, queue time, and throughput can also be computed from the simulation output.

Input Analysis

Data analysis provides the driving force for any simulation model. Without input data, the simulation model itself is incapable of generating any data about the behavior of the system it represents (Bank & Carson, 1990).

Most discrete-event simulation models require the replication of randomly occurring events. These events are more conveniently characterized by statistical distribution. In the software used, ARENA, the Input Analyzer is used to fit the appropriate distribution to the empirical data. The initial task is to create data files for the inter-arrival time, service time, and delays.

Once a data file has been selected, the data can then be displayed in the form of a histogram. The class interval is determined automatically, but the user may change that. The minimum intervals allowed are 5 intervals and the maximum is 100 intervals. The numerical information, such as number of data points, type of data, number of intervals and the interval range associated with the histogram, is also displayed for the user. Other information, such as the mean, standard deviation, minimum and maximum values are also shown. The modeler may fit the distribution to the data simply by using the FIT option, and then select a particular distribution from the resulting drop-down menu. The FIT option also includes the best-fit selection. The best fit will then be displayed on the screen. After completion of input data, the user can then run the model. The simulation output can be saved into a file where it can be analyzed later, by using either the Output Analyzer in ARENA or other statistical software.

The input data are collected from the manufacturing company itself. In this model the important data needed are the process times taken in each process. There are seven main processes involved. The appropriate distributions are fitted to the empirical data by using Input Analyzer that is already built in ARENA® software. This tool can be used to determine the quality of fit of probability distribution functions to input data. In addition, the Input Analyzer can generate sets of random data that can then be analyzed using the software's distribution-fitting features.

Model Verification

Verification is the process of ensuring that the model designed (conceptual model) has been transformed into a computer model with sufficient accuracy. In simple words, model verification is building the model correctly. It consists of checking the code, inspecting output reports and checking that the modeled elements work the way real world elements do.

SIMULATION RESULTS

The statistics collected from the simulation model include plant throughput, cycle time, resources utilization, queue length and time spent in the queue.

Plant Throughput

The average of daily plant throughput for the model is 578 units of hi-fi set. The historical data at the plant is 590 units. The difference between simulation output and historical data is 2.1%. The small difference shows that they are in good agreement.

Cycle Time

The cycle time is the average of process time taken to complete the production of a unit of hi-fi set. The simulation output shows the average cycle time is 43.9 minutes. The historical data on the other hand shows the cycle time is 40.6 minutes. The difference between these values is 8.13%. The small difference between these values indicates that the model is acceptable.

Resource Utilization

From the simulation output, the most utilized resources are at the combining front and bottom chassis combine. At the combining front, the utilization is from 91.0% to 94.6%. For the bottom chassis, the utilization is 80.8% to 94.6%. These values indicate that the resources are busy. The high value is due to the conveyor speed that has been programmed.

The output shows that the packing section has the lowest utilization with an extreme value of 69.1%. It is also clear that the bottlenecks exist at the location where inspection sections take place. These inspection activities took place at GI1 (General Inspection 1) and FI1 (Final Inspection 1). The utilization of GI1 is 95.3% and FI1 is 93.3%.

Waiting Time and Queue Length

From the simulation output, the longest waiting time occurs at GI1 and FI1. The average values of waiting times at GI1 and FI1 are 2.5 minutes and 2.6 minutes, respectively. At other processes, the waiting time is minimum. The results of waiting time agree with the queue length. The length of queue occurs at the same processes namely GI1 and FI1. At GI1, the queue length is 3.2 and at FI1 is 3.4.

MODEL EXPERIMENTATION

Once the model has been verified and validated, the experimentation of model phase or 'what if' analysis can commence. The user can now begin to experiment with various scenarios. Each scenario represents the case that is of interest to the user. The number of scenarios to be experimented depend on the circumstances that need to be investigated.

Scenario 1

For scenario 1, the management would like to examine the impact to the system if throughput was increased by 10% as forecasted to happen in a year's time. They were interested in studying the impact this increase would have on the system. If the increase caused serious bottlenecks to the system then they would want to know how to overcome this problem. The output model for scenario 1 includes resource utilization, waiting time, queue length, plant throughput, and cycle time. The model was run for five replications and the average output was recorded.

The results show the bottlenecks present in a few stations with an increase of 10% throughput. Bottlenecks were noticed at CF1, CF2, Extra, BC1, BC6, BC12, GI1 and FI1. The system could cope with the new scenario because so many bottlenecks were present. The highest value of waiting time and queue length exists at CF1, CF2, BC6 and GI1. The waiting time for CF1 increased from 0.03 minutes to 4.05 minutes and the queue length increased from 0.01 units in queue to 5.61 units. The maximum waiting time and queue length occurs at CF2 with 7.9 minutes and 10.8 units respectively. For BC6, the waiting time and queue length rose from 0.24 minutes to 4.40 minutes and 0.29 units and 5.63 units of hi-fi set respectively. At GI1, the waiting time and queue length are 2.47 minutes and 3.20 units and they increased to 5.76 minutes and 7.56 units of hi-fi set.

Table 1 shows the resource utilization, waiting time and queue length for selected stations, where bottlenecks exist. Scenario 1 generated an output of 581 units of hi-fi set. There is only a slight increase as compared to the actual output of 578 units of hi-fi set. The cycle time also increased to 67.9 minutes.

Table 1
Resource Utilization, Waiting Time and Queue Length for Scenario 1

Process	ResourceUtilization	Waiting Time	Queue Length
CF1	99.89	4.0474	5.6069
CF2	99.73	7.8496	10.8290
Extra	99.26	1.8544	2.4335
BC1	98.71	1.3079	1.7004
BC6	97.74	4.4041	5.6252
BC12	95.90	1.8613	2.3329
GI1	95.50	5.7641	7.5474
FI1	93.77	1.5357	2.0161

The differences in cycle times were quite high. Therefore an increase in throughput of 10% will have a negative impact on the current system. The current system cannot cope with the increase. Therefore the next scenario will examine how to improve the system with the increase in throughput.

Scenario 2

In scenario 2, capacity is increased at selected stations where bottlenecks seem to occur. The stations identified are CF1, CF2, Extra, BC1, BC6, BC12, GI1 and FI1. Capacity is increased from 1 operator to 2 operators.

At stations CF1, CF2, Extra, BC1, BC6, BC12, GI1 and FI1, where capacity has been increased, the value of waiting time and queue length is reduced significantly. However, bottlenecks are present at other stations, which are CF3 and BC2. Therefore, capacity was also increased at these two stations. As a result of this increase, the throughput increased to 643 units, an increase of 65 units of hi-fi set as compared to the actual output. The cycle time also increased as compared to the value of actual cycle time, which is 44.8 minutes.

The resource utilization, waiting time and queue time for this scenario can be viewed in Table 2 below. For the stations with increased capacity, the utilization is very low since the job process is shared between two operators. For these stations, waiting time and queue length are almost zero. Small bottlenecks exist at BC10 and FI5 and the system appears to be able to cope with this situation.

Table 2
Resource Utilization, Waiting Time and Queue Length for Scenario 2

Process	Resource Utilization	Waiting Time	Queue Length
BC10	96.52	2.8634	3.8133
FI5	93.46	2.6278	3.2582

In scenario 2, the total number of operators was increased to 10 operators. However, a rough calculation on the overhead and revenue showed that it seems worthwhile to increase the number of operators. The increase in output is 65 units per day and the selling price of a single hi-fi set is more than RM1,000. Revenue could be increased by at least RM65,000 per day. The salary of an operator is estimated approximately RM650. The monthly of salary of 10 operators is RM6,500.

Scenario 3

Scenario 3 is then tested based on the same criterion of scenario 2. In this scenario, with the capacity maintained as in the previous scenario, we wanted to examine the maximum level that the system could handle. Capacity is two operators at stations CF1, CF2, CF3, Extra, BC1, BC2, BC6, BC12, GI1 and FI1. At other stations, the capacity is only one.

The throughput increased 15% and the output generated also increased to 658 units of hi-fi sets and the cycle time taken was 44.3 minutes. The system can only cope to a 15% increase in throughput. This is the ideal increase in throughput for this system. With a bigger increase, the system would become worse. The resource utilization for the stations with two operators are low. Some bottlenecks exist due to increase in waiting time and queue time. However, the system can cope with this situation since the bottlenecks are fewer. The maximum waiting time and queue length occur at station BC3 with 3.95 minutes of waiting time and 3.56 units of queue length. Other stations, where bottlenecks exist are BC4, BC5, BC9, BC10, and FI5. Most of the stations generated a waiting time of one minute and a queue length of one unit of hi-fi set. At BC4, the waiting time is 2.51 minutes and the queue length is 2.75 units of hi-fi set; while at FI5, they are 3.74 minutes and 2.85 units respectively. These values are described in Table 3.

Table 3
Resource Utilization, Waiting Time and Queue Length for Scenario 3

Process	Resource Utilization	Waiting Time	Queue Length
BC3	97.67	3.9570	3.5605
BC4	95.40	2.5147	2.7535
BC5	93.54	1.5947	1.2643
BC9	93.26	1.4182	1.0577
BC10	94.75	1.4101	1.0624
FI5	93.53	3.7404	2.8499

CONCLUSION AND RECOMMENDATION

This paper presents the results of a case study, which involved the use of computer simulation technique for production planning of an audio system. 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 the ability to deliver quality products to customers.

Many manufacturing sectors give priority to produce cost effective products to stay competitive in business. One of the action taken is to increase the efficiency at the production line. Simulation is a technology that can achieve this purpose. In this study, a simulation model was developed for a case study in the manufacturing sector. Statistical output from the designed model ascertained that an improvement over the current scenario exists. From the model it is obvious that bottlenecks were present at certain stages of the production. Bottlenecks limit the production capacity of the plant.

The model can also be used as a tool for making decisions of a production plant. Investigations on planning and changes can be tried on the model without disturbing the existing operations. 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 have given as insights into the different operational characteristics at the plant. This 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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