MODELING, SIMULATION AND ANALYSIS OF AN AUTOMOTIVE MANUFACTURING SYSTEM USING ARENA SOFTWARE

By
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CERTIFICATION OF APPROVAL

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Electrical & Electronics Engineering Programme
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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AZWIN AZHAR

ABSTRACT

The objective of this project is to develop a model, simulate and analysis a manufacturing system using ARENA. The scope of study is focusing on an automotive manufacturer, specifically on the automotive part component stamping line. The aim is to provide the best method to improve the workstation process efficiency and to ascertain its limitations and problems to achieve production target. The procedures include data gathering, model building, simulation, verification, and validation and performance analysis. To improve understanding about ARENA, a case study is carried out to make a simple simulation model. Then the model is simulated using the actual stamping productions data gathered which include the production index daily, process specification, parameters, production schedule and machine breakdown. The output of the simulation is generated in a form of report. The report is organized into sections which summarized across all replications. The results show that the percentage error of ARENA model is less than 5% as targeted. This model would be used as a decision support system for the investigation of improving the process by implementing several decisions like line balancing and simplifying operation. "What-if" analysis is applied to give a review on the decision is presented. The findings confirm the qualitative behaviour of the manufacturing system in response to the different decision options.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of study

Due to rising manufacturing costs and the globalisation of market economics, increasing attention has been placed on improving the manufacturing lines. The need to simulate and redesign manufacturing processes to allow decision makers to explore various options and scenarios are important. Simulation has been identified as one of the best means to analyze a manufacturing process. In Malaysia, although many companies are involved in analysis of the manufacturing processes, still in most cases the analysis is performed based on experience and intuition and not many analytical models and design tools have been used. The main objective of this project is to develop a model of an automotive part assembly line using ARENA. The main is to improve the process in term of its efficiency and to ascertain its limitations and problems to achieve a production target.

1.2 Simulation in manufacturing system

ARENA, the world's leading simulation software has been used successfully by organisations the world over to advance the efficiency and productivity of their business [5]. ARENA is designed to provide the power required for successful simulation within an easy-to-use modelling environment. Automotive manufacturers and their suppliers have persistent process requirements throughout their facilities from corporate functions to shipping completed assemblies [3]. ARENA can be applied through the whole scale area of automotive manufacturing system including:

- Press Room

Automotive manufacturer must meet the demanding and growing requirements involved in stamping, forming and fabricating of metals [8]. For over 60 years, ARENA has been helping automotive manufacturers with their metal forming automation control needs, including a complete line of standard and custom press and automation control solutions for the pressroom including:

i. Press controls and Clutch/Brake
ii. Robotic automation part handling
iii. Tandem line controls
iv. Sheet metal feed motion control
v. In die servo transfer motion technology

- Body Shop

Through ARENA a quality solutions to automotive body shop can be achieve to problems such as:

i. Reduction of wiring (and associated costs) via single network connections to robots and welders and safety networks
ii. Usable process data from robots and welders
iii. PDS (Upload/Download, Programming and Configuration) for robots and welders
iv. Process Data/System Health (cycle time, idle time, blocked/starved)
v. Material Call and Andon systems
vi. Part Tracking and Build Scheduling
vii. Flexible manufacturing systems
viii. De-coupled Conveyor Systems
ix. Safety Systems as productivity tools
x. Control System Performance — every millisecond counts!
xi. Scalable Solutions to leverage Engineering Resources and Common Programming tools across product families
xii. Life Cycle Cost Reduction

xiii. Integration into Plant IT Systems

xiv. IP 65/67 IO and Motor Control

- Paint Shop

Today's automotive paint shop is a key focus area within the assembly process. Understanding the complexities and interrelationship of the process parameters is critical to developing an efficient and cost-effective environment. Humidity and temperature control, paint flow, viscosity, body temperature is just a few of the areas that factor into a smoothly-run facility [8]. ARENA enable automotive manufacturers to receive best-practice knowledge and technology regarding

i. Addressing the new Clean Air Act regulations

ii. Understanding and incorporating the latest paint technologies

iii. Reducing Total Life Cycle costs

iv. Relieving competitive pressure to improve quality at less cost

In the midst of a fiercely competitive market, profitability depends upon how well resources are managed from supply chain to shipping at every step along the way. And survival means improving efficiencies faster than models and part numbers change [1]. ARENA can improves bottom line manufacturing by optimizing paint shop performance. This Solution integrates manufacturing, plant floor systems and materials linking the supply chain directly to the production and finishing processes.

Arena's proven simulation results can help automotive manufacturer in all areas of

i. Process Equipment

ii. Application Equipment

iii. Conveyors

iv. Monitoring, Scheduling, Routing and Tracking

- Powertrain

Manufacturers of Powertrain components, such as foundries, engines, transmissions, axles, brakes and steering gears, utilize ARENA to provide automation solutions that maximize their operating efficiencies. ARENA provides solution for the application sectors that are typically found within a Powertrain facility, namely:

i. Machining
ii. Assembly
iii. Test
iv. Material Handling
v. Safety and Information Systems

1.2.1 Advantages of simulation

i. Normal analytical techniques make use of extensive mathematical models which require assumptions and restrictions to be placed on the model. This can result in an avoidable inaccuracy in the output data. Simulations avoid placing restrictions on the system and also take random processes into account; in fact in some cases simulation is the only practical modeling technique applicable [2]
ii. Analysts can study the relationships between components in detail and can simulate the projected consequences of multiple design options before having to implement the outcome in the real-world [2]
iii. It is possible to easily compare alternative designs so as to select the optimal system.
iv. The actual process of developing the simulation can itself provide valuable insights into the inner workings of the network which can in turn be used at a later stage.

1.3 Problem Statement

In most manufacturing company, production and equipment improvements and development are usually implemented directly onto the system. Rarely the uses of simulation techniques are applied. Therefore, the manufacturing is done 24 hours within two or four shifts in a day. Technicians and operators especially have to work overtime in order to reach targeted production rate in case if the output is rather low or the defects are high. Normally, manual analyses are developed, and lots of statistical experiments are conducted. It is very costly to change to an experimental layout that might not work out anyway. This technique is time consuming and practically is not the best method to solve defects issues.

The automobile industry is under enormous competitive pressure to enhance productivity while reducing production cost. Doing so requires efficient management and control of complex, large-scale processes. Vast amounts of information about production, material handling, and quality must be effectively transferred and shared across the entire plant [3]. To increase productivity, production line downtime must be minimized. The typical automotive assembly line consists of 40 to 60 workstations aligned in sequence. If a failure occurs at any workstation for example, running out of materials, having the wrong or poor quality parts, performing the process incorrectly or out of sequence, the operator must shut down the entire production line [11]. To improve daily output, these errors need to be resolved immediately and kept to a minimum. However, supervisors often have difficulty identifying what caused the problem and where it originated.

Material logistics must also be managed carefully. Any materials handling system must be able to support multiple vehicle models and minimize material shortage that can cause line stoppage. To ensure the production line runs smoothly, clear communication must exist between the material centre and production shops. The material status at each work station must be continually monitored to ensure quick response to any shortages.

To reduce costs, quality must be closely monitored and controlled. Product quality data must be gathered throughout the production process. This ensures quality issues are resolved upstream, eliminating the costly waste and rework to fix and reassemble a finished product. However, the main target is to lower production costs while improving product quality. To come out with a solution, they need to collect and analyze production data so they could better manage the production process, clarify responsibilities, and continuously improve performance [7].

With an animated ARENA simulation model, the aim is to design the facility and make changes to the model and "test drive" it before the changes are implemented onto the actual system. Then purpose of modelling and simulate is to compare operational strategies and confidently select the best one from the simulation results and crystal report. This is a useful tool where we can communicate to all concerned with the success of the project (from the management team who sign off on the decision, through to the people on the shop floor who will "drive" it) exactly how it will function and what implications specific variations might have [3]. Therefore, data gathering and parameter identification process is required for the model to be build. The data must be valid which so that the model is a mimic of the actual manufacturing system.

1.4 Objectives and Scope of Study

The objectives of the study are:

i. To design and build a model of manufacturing system
ii. To simulate the model of manufacturing system
iii. To generate the optimum changes in performance measures of manufacturing process

The typical performance objectives are:

i. Increase productivity
ii. Reduce cycle time
iii. Reduce cost
iv. Eliminate waste

The scope of study is to generate a manufacturing system simulation mathematically, to study its properties and operating characteristics and finally to draw conclusion and propose a decision based on the results of the simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There are about seven types of simulation. There are the discrete distributions, continuous distributions, probabilistic simulation via Monte Carlo technique, and time dependent versus time independent simulation, simulation software, Visual simulation and object-oriented simulation. Visual Interactive simulation use computer graphics to present the impact of different management decisions. It can be integrated with GIS and users perform sensitivity analysis with static or a dynamic (animation) system. It gives the decision makers interact with the simulated model and watch the results over time [10].

2.2 Simulation Language for Manufacturing System

Research also covered about other commercial simulation software which has quite similar functions and application with ARENA. The purpose of this research is just to see how wide is the application of simulation software had been used globally and the varieties of available simulation software that we could purchase from other company.

Flexsim Software Products has been in the simulation software and consulting business since 1993. Taking twelve years of experience with simulation and using the latest advances in software technology they have developed a completely new, object-oriented, simulation-modeling tool called Flexsim [6]. It allows total customization of modeling objects, views, guis, and pretty much anything else you can think of.

ShowFlow Simulation is developed from the renowned Taylor II system. T2 models are fully compatible with ShowFlow which has ALL the capability of T2.

ShowFlow can be linked to Microsoft® Excel® to store simulation input and output data. ShowFlow are using optimised Simulation Algorithm Technology (OSAT) and the model can run in 2D full animation, 2D statistics animation, 3D wire animation, 3D solid animation and 2D scalable bitmaps [12].

SIMUL8 was first used in industry in 1995. It is now used by thousands of engineers in enterprises and many smaller organizations too to make hundreds of important decisions year on year. The SIMUL8 customers are from around the world such as Ford, Hewlett Packard, Intel, Honda, Johnson & Johnson and many more. Until now, SIMUL8 has given almost 800 licenses to organizations and company throughout the globe.

2.3 Modeling Using ARENA

A review of the 2006 WSC *Proceedings,* the proceedings of the world's leading conference on discrete-event simulation—the Winter Simulation Conference shows that over 300 papers were submitted for this year's conference [6]. The search numbers of papers that discuss the various simulation packages, those numbers are quite revealing. The numbers aren't even close. Clearly, ARENA is the undisputed tool of choice among serious users of business process simulation. This comparison from the 2006 WSC Proceedings included the following products: ARENA, AutoMod, ProModel, Extend, Simul8, Any Logic, Enterprise Dynamics, Flexsim, CSIM, Micro Saint, eM-Plant, SIMSCRIPT, Witness, and iGrafx. The result shows that ARENA has been the most simulation products presented at WSC 2006 by 48% [6]. This empirical evidence means ARENA is the world leading simulation software.

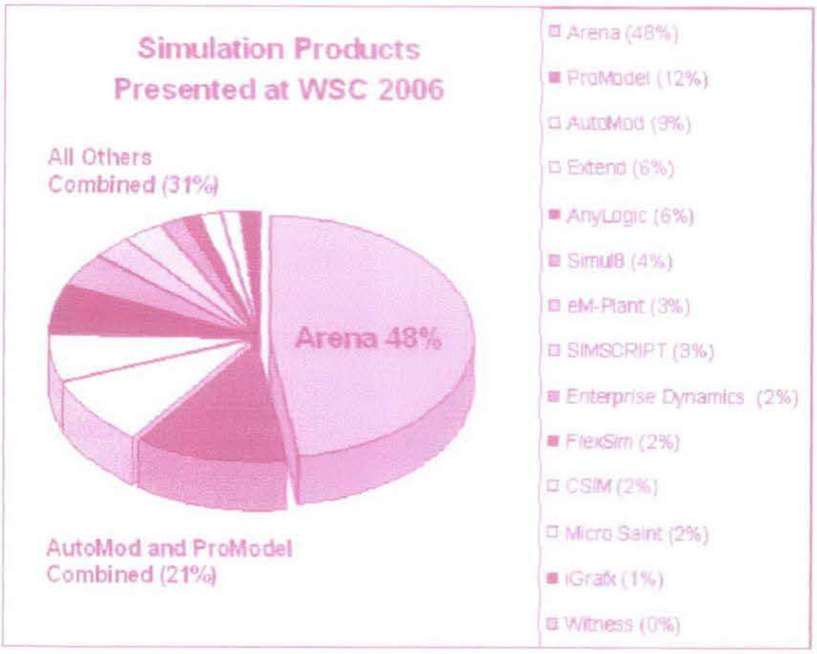


Figure 2.1: Pie chart of simulation products presented at WSC 2006

As an example, the Company Ford Automotive Corporation which is one of the largest automobile manufacturers in the world, wanted to achieve greater market share in South America, and decided to build a new plant dedicated to the production of Ford's Endura engine. The engine was to be produced in Brazil specifically for Ford's Fiesta compact car model, which was soon to be introduced to the South American market [5].

In order to achieve the desired high-volume goal, the manufacturing engineering team of Brazilian and European engineers asked several questions during the plant design phase: What is the optimal plant layout? What equipment will be needed? Where will we locate the needed resources? What will be the impact of future plant expansion? Since the Endura plant was a new facility in a new market, there was no precedent that would help to answer these questions [3]. Due to great capital investment and the considerable risk involved in the project, the team turned to Systems Modelling ARENA simulation software to help determine the best outcome.

Many aspects of the plant were included in the ARENA model: Different floor layouts using various machine resources were compared; likely bottlenecks were located; the efficiency and effectiveness of the plants processes, such as material handling, were assessed; and the impact of future plant expansion was determined.

The team was able to test drive the plant with multiple concepts and alternatives in the model, before investing in capital. Additionally, several members of the engineering team were trained in ARENA so they would possess the knowledge needed to address future modifications to the original engine plant simulation project.

ARENA succeeded in helping the Ford engineering team design the Endura engine plant from the ground up, using simulation to lay out the plant floor and its corresponding processes and determine how to use equipment and labour [5]. The simulation assured substantial savings on equipment and provided precise performance statistics and reports on machine utilization, labour utilization, throughput, WIP and other measures for available choices and production levels. After the team ended this project, it continued to work with the original ARENA model, adding deeper detail of each manufacturing process. Concurrently, Ford Brazil adopted simulation widely throughout Ford's Power train Operations, using ARENA on many other projects.

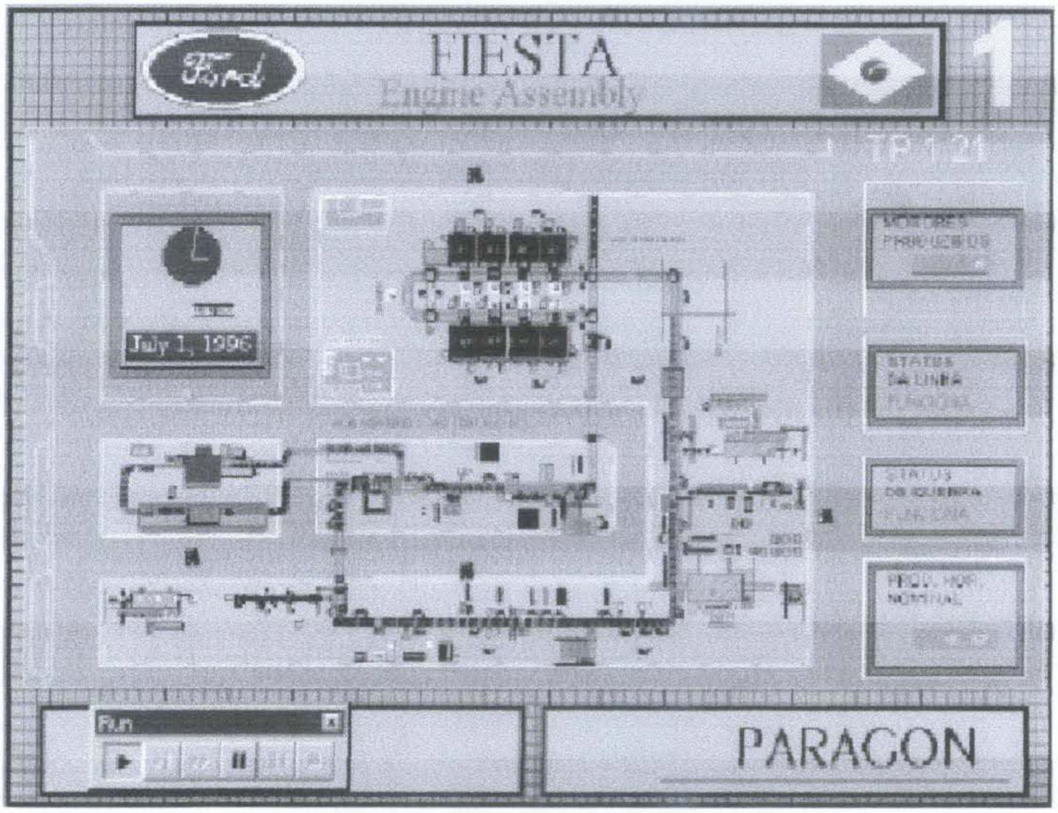


Figure 2.2: Endura engine assembly plant simulation model

RSConsulting Application Services was asked to provide a workable and affordable solution. RSConsulting developed a user-friendly simulation model using Rockwell Software's Arena® simulation software. The highly-detailed model evaluated the dynamic flows of products through the system, evaluating material handling as well as production operations. The high level of detail was required to capture the system sensitivities. A major manufacturer of household appliances wanted to redesign a significant portion of its refrigerator-liner final assembly process, as well as create and implement an effective and appropriate production schedule for that process.

The system under evaluation produces various sizes of refrigerator liners; transfers those whole liners to an area where they are cut, taped, and pressed; then transfers them to an insertion area. Limited resources require that the appropriate mix of liners enter the "press" area to maximize system equipment since changeovers require significant time. A buffer area prior to the press area provides the space to "bank" liners for later use during off-shift or slow production due to upstream failures or bottlenecks. More buffer space was needed for overflow storage and additional floor space had to be located for new equipment purchases. The company was willing to invest a significant amount of equipment and manpower staffing to a plant redesign; however, the amount of equipment and manpower was not known for the production operations in the system. The analysis clearly showed the amount of buffer space that was required for various production scenarios and for multiple equipment layouts. A detailed animation of the system provided validation of the model by displaying each liner as it traversed the system (and system bottlenecks), as well as the dynamic status of the buffers.

By running an anticipated production schedule, RSConsulting was able to find a design with the minimum system resources necessary to meet production goals. Various cost tradeoffs were calculated with the model, balancing equipment and conveyor costs versus production throughput and volume.

With the successful stories on simulation and modelling to improve system and productivity, it is expected that in this project, the system could be improved to achieve an optimum production capacity. This may lead to possibilities of downsizing the man power and increasing efficiency of equipment performance and cycle time [11]. The overall goal is to boost productivity within the economical ways as possible.

CHAPTER 3

METHODOLOGY

3.1 Methodology/Project Work

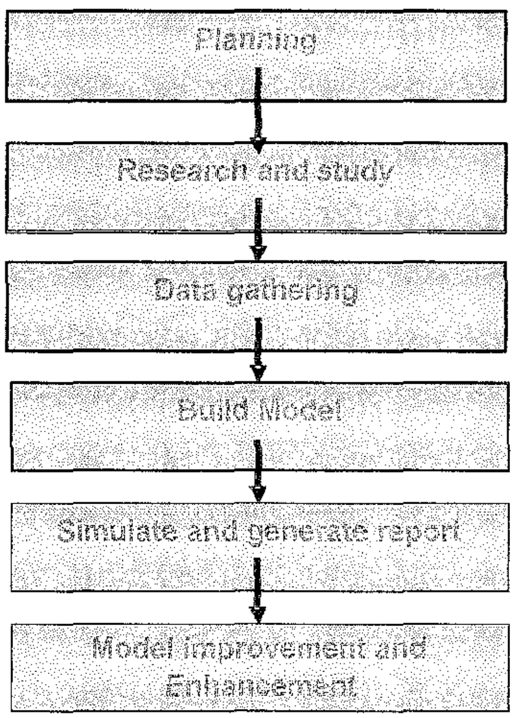


Figure 3.1: Flow chart of project work

Data gathering is the main tasks in this project. This step ensures the correct model is build. It involves meetings and discussions with the engineers and technicians of the manufacturing plant to understand the behaviour of the manufacturing processes. Then, system faults and problems can be referred and pointed out. More particular details also need to be included such as the cycle time, machine downtimes, assembly times, process time and other specification parameters are needed to build the exact imitation of the actual system.

Then the model is build and must be verify using the current production data as comparison. The verified model is then validated by the manufacturing plant expertise such as simulation analysts or engineers. During validation steps, changes are made to the manufacturing system and modelled again. After the model is valid, it is then improve using ARENA simulation tools to give a variety of alternatives to improve productivity and reduce cycle time but mostly a beneficial outcome. Finally, the project's data is documented for records and references.

3.2 Methodology for System Simulation

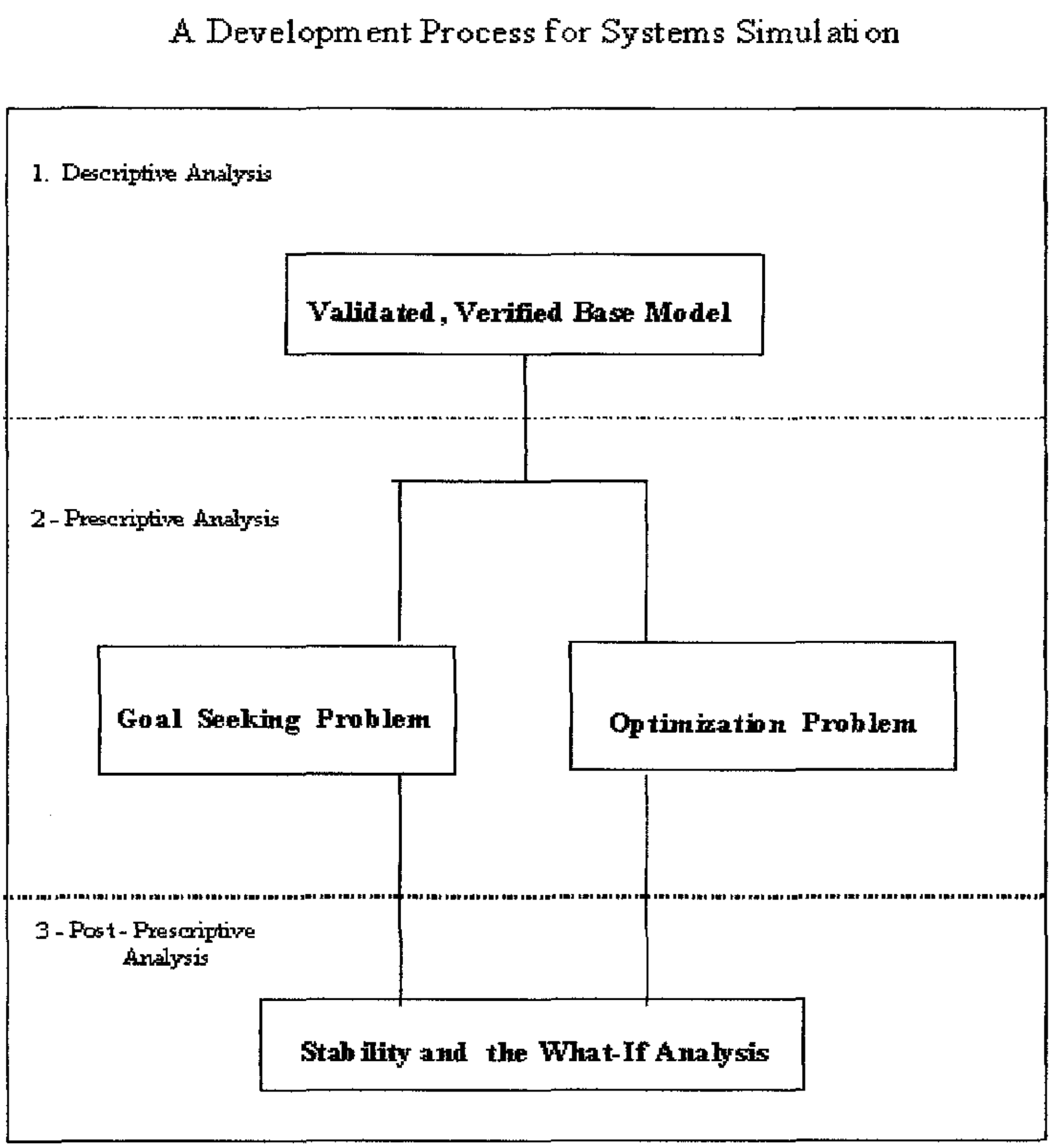


Figure 3.2: A Development Process for System Simulation

ARENA is a discrete event system (DES) and a dynamic system which evolve in time by the occurrence of events at possibly irregular time intervals. ARENA abounds in real-world applications. Examples include traffic systems, flexible manufacturing systems, computer-communications systems, production lines, coherent lifetime systems, and flow networks. Most of these systems can be modelled in terms of discrete events whose occurrence causes the system to change from one state to another. In designing, analyzing and operating such complex systems, one is interested not only in performance evaluation but also in optimization [12]. There are two types of analysis:

a) **Descriptive Analysis**: Problem Identification & Formulation, Data Collection and Analysis, Computer Simulation Model Development, Validation and Calibration, and finally Performance Evaluation.

b) **Prescriptive Analysis**: Optimization or Goal Seeking. These are necessary components for Post-prescriptive Analysis: Sensitivity, or What-If Analysis. The prescriptive simulation attempts to use simulation to prescribe decisions required to obtain specified results. It is subdivided into two topics- Goal Seeking and Optimization [12].

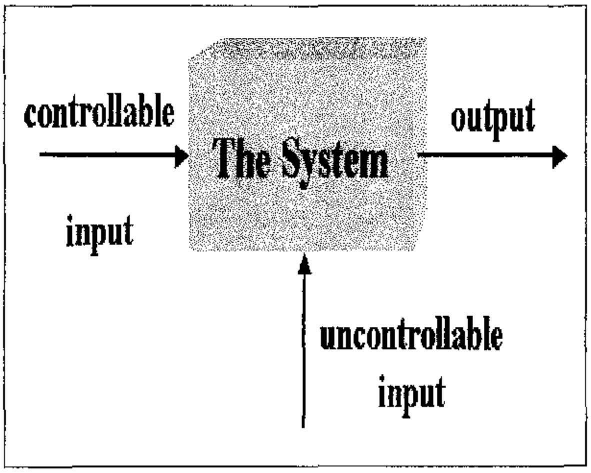


Figure 3.3: Block diagram of general system

Problem Formulation: Identify controllable and uncontrollable inputs. Identify constraints on the decision variables. Define measure of system performance and an objective function. Develop a preliminary model structure to interrelate the inputs and the measure of performance.

Data Collection and Analysis: Regardless of the method used to collect the data, the decision of how much to collect is a trade-off between cost and accuracy [12]. In addition to discussing the proposed processes to build the desired components, the visits also helped to understand each resources capabilities, product range, and capacity availability. These site visits added quite a bit of time to the project. The visits had to be set up at mutually convenient times for the engineers and hence had to be done over two months during the semester break.

Simulation Model Development: Acquiring sufficient understanding of the system to develop an appropriate conceptual, logical and then simulation model is one of the most difficult tasks in simulation analysis.

Model Validation, Verification and Calibration: In general, verification focuses on the internal consistency of a model, while validation is concerned with the correspondence between the model and the reality. The term validation is applied to those processes which seek to determine whether or not a simulation is correct with respect to the "real" system [12]. More prosaically, validation is concerned with the question "Are we building the right system?" Verification, on the other hand, seeks to answer the question "Are we building the system right?" Verification checks that the implementation of the simulation model (program) corresponds to the model. Validation checks that the model corresponds to reality. Calibration checks that the data generated by the simulation matches real (observed) data. A high accuracy of validation, verification and calibration will leads to very low model error. Thus the acceptable ARENA model error used by the certified analyst from Rockwell Automation is ±5%.

Validation: The process of comparing the model's output with the behavior of the phenomenon. In other words: comparing model execution to reality (physical or otherwise).

Verification: The process of comparing the computer code with the model to ensure that the code is a correct implementation of the model [13].

Calibration: The process of parameter estimation for a model. Calibration is a tweaking/tuning of existing parameters and usually does not involve the introduction of new ones, changing the model structure [13]. In the context of optimization, calibration is an optimization procedure involved in system identification or during experimental design.

Input and Output Analysis: ARENA models typically have stochastic components that mimic the probabilistic nature of the system under consideration. Successful input modeling requires a close match between the input model and the true underlying probabilistic mechanism associated with the system [12]. The input data analysis is to model an element (e.g., arrival process, cycle times) in a discrete-event simulation given a data set collected on the element of interest. This stage performs intensive error checking on the input data, including external, policy, random and deterministic variables. System simulation experiment is to learn about its behavior. Careful planning, or designing, of simulation experiments is generally a great help, saving time and effort by providing efficient ways to estimate the effects of changes in the model's inputs on its outputs. For this project, statistical experimental-design methods are used in the context of simulation experiments and an input analyzer to analyze the distribution data to generate the fittest distribution.

Performance Evaluation and What-If Analysis: The 'what-if' analysis is at the very heart of simulation models.

Optimization: Traditional optimization techniques require gradient estimation. As with sensitivity analysis, the current approach for optimization requires intensive simulation to construct an approximate surface response function.

Gradient Estimation Applications: There are a number of applications which measure sensitivity information, (i.e., the gradient, Hessian, etc.), Local information, Structural properties, Response surface generation, Goal-seeking problem, Optimization, What-if Problem, and Meta-modeling [13]. For this project, the "What-if" Problem is applied.

Report Generating: Report generation is a critical link in the communication process between the model and the analyst. ARENA generates the recorded statistic in a crystal repot with .pdf as its extension. The report can be exported to the pdf file. The crystal report covered all statistics through at least a minimum of five replications for accuracy purposes. Therefore for every simulation, five replications are used for every simulation.

3.3 Basic skills of ARENA software building and simulation model

For a beginning, it is important to create an understanding of how a model is described and it concepts basically. Process build in ARENA are called *modules*. Modules are the flowchart and data objects that define the process to be simulated. All information required to simulate a process is stored in a modules. The basic process of any modules is CREATE, PROCESS and DISPOSE. CREATE module is the initial point for flowchart modules which define the entities that will generate by modules. Entities then leave the module to begin processing through the system. PROCESS module describes the main processing method of the modules. There are two types of PROCESS module which are the standard and the Submodel processing. Standard processing signifies that all logic will be stored within the Process module and defined by a specific action while Submodel signifies that the logic will be hierarchically defined in a "Submodel" that consists of unlimited number of logic modules. This module simplifies modules within a process which simplifies the simulation model. The ending point for entities in a simulation model is represented by the DISPOSE module where entity statistics may be recorded before the entity is disposed.

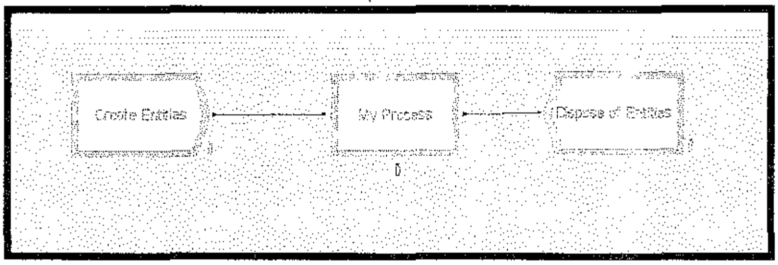


Figure 3.4: The basic process of modules

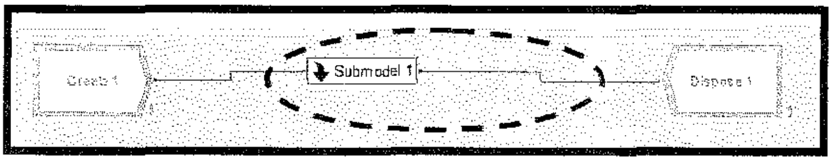


Figure 3.5: Nested-Submodel example

Submodel views can be accessed in different ways. The Navigate panel is one method. When using the Navigate panel, ARENA allows direct access to each Submodel view. This means that in a situation where there are nested sub models, we can directly moves to a Submodel that is many levels deep in the hierarchy. Double clicking on a Submodel object in the model window is another method of accessing a Submodel view. In the case of nested sub models, we need to double-click on each successive Submodel object to get that far into the hierarchy. A third way to access a Submodel view is to right-click on the Submodel object in the model window, and selects "Open Submodel" from the menu.

From the ARENA's online help and the topic of "Automating ARENA", there is a complete listing of the ARENA Object Model. It shows that ARENA offers the ability to automate certain functions using Microsoft Visual Basic for Applications (VBA). This is an advantage for users who are familiar with Visual Basic which allows custom routines to be inserted into a model. Thus it allows user interaction with the model, allow manipulation of variables or delay times, change the number of replications, and many other useful functions [9].

At the very end of the simulation model, ARENA will generate statistic reports which summarized across all replications executed accordingly into various sections. The sections are the key performance indicators, activity area, conveyor, entity, process, queue, resource, transporters, station and user specified. From observations, ARENA will mainly generate reports according to the numbers of replications which altogether are referred as the crystal report. Each categories overview report is broken down by replication. Then each statistics for each replication are organized into sections. The summary section provides information per statistic per section. This section lets analysts compare all the statistics value for each replication. Mainly, this crystal report gives great insight on the process performance and behaviour. Then analysts can make useful of this report to analyze system with different entities or replication. From it, analysts can make predictions and then improve on the weakness by spotting the inefficiencies of the system form the statistic generated by viewing at various section or aspect [11].

However, the report is useless if the model itself does not valid or not describing the actual manufacturing system. Thus, most effort must be put into the model building process. Therefore, more tutorials and training are needed to improve software skills so that ARENA simulink and panel tools can be fully use. Then, improvement can be made on the model by including animation. This may create a better understanding by presenting modules with image and picture animation.

3.4 Data Gathering

There are numbers of manufacturing companies around Malaysia especially in Free Industrial Zone. Approval letters need to be submitted to the Human Resource Department for data gathering for modelling and simulate their process system in their manufacturing facilities. An example of approval letters are attach in Appendix II. The challenges faced is that most company did not interested with Arena software itself as it will consists of their most confidential data and manufacturing system truth or falsity of data depends solely on the application [12]. Data represent or "model" aspects of reality as defined in a specification. Like any model, data can never be absolutely correct for all purposes.

There are four basic types of data that support the modeling, development, and validation of a model or simulation [13]:

a) Reference data

-- Descriptive information (metadata) about all the data used by the model, simulation including data characteristics (e.g., resolution, fidelity, accuracy, completeness, relevancy, unit, appropriateness); specifications to which the data were developed or are provided; and factors describing data quality.

b) Hard-wired data

-- Data values implemented as part of the model (e.g., constants, set parameters). Hard-wired data include the data values incorporated in the algorithms used to mathematically articulate the actions/reactions/interactions of the resources in the system. Although data such as constants are included in this category, the resolution/fidelity assumptions of a simulation may require additional "facts" to be treated in this way [12].

c) Instance data

-- Data values comprising the baseline set of conditions (and allowable dynamic updates) under which the simulation is initiated and executed [12]; input data (e.g., reject rates, product ranges, machine limitations, movement rates, conveyor speed); and output data. Instance data, commonly called input and output data, are data values that are stored and accessed separately from the model settings. They are usually found at the intersections of rows and columns in a relational database and are the facts used to initialize a simulation before it starts and to update it dynamically during execution.

d) Validation data

-- Actual measurements from the real world or "'best guess" information provided by subject matter experts that are used to validate that the results of the simulation are specification. Sometimes, the manufacturing facilities itself give an approval but top management will decide whether it is appropriate or not.

Data collecting is the main tasks in this project. This step ensures the correct model is build. It involves meetings and discussions with the engineers and technicians of the manufacturing plant to understand the behaviour of the manufacturing processes. Then, system faults and problems can be referred and pointed out. . Therefore, the following are the needed data to build a complete manufacturing system model:

- Physical Layout
- Production shift schedule
- Number of pallets
- Station; cycle time, breakdown, repair time and set up time.
- Conveyor : capacity, transfer times
- Production rejection
- Layout diagram with flow and logic identified
- Activity cycle diagram
- Flow chart

3.5 Types of Data Used in Models and Simulation

The vast majority of models and simulations are critically dependent on data. The overall usefulness of any modeling and simulation application is limited as much by the quality of the data as by the quality of the model or simulation involved. Whether a model or simulation is used for analysis, training, or acquisition, the data involved in its preparation and execution should be subjected to the same kind of scrutiny as the model or simulation itself [13].

Data are symbolic representations of factual information to be used as a basis for reasoning, discussion, comprehension, communication, prediction, or calculation. However, although "factual" implies truth, "data" merely denotes information: the "correct enough" for the simulation to be useful. Note that validation data do not directly support the model or simulation itself, but are involved in the verification, validation, and calibration. Validation data are the real-world facts used for comparison to validate the results of a simulation. They come from empirical sources such as test ranges, live exercise results, or historical records; from outputs of other, previously validated simulations; or from the production previous month, year or a range of some period.

CHAPTER 4

SIMULATION RESULTS

4.1 Familiarization with ARENA: Case study of a mortgage application process

The objective of this case study is to examine a simple mortgage application process to illustrate how to model, simulate, visualize and analyze with ARENA. First step is to build the flow chart process of receiving and reviewing a home mortgage application. All the entities are defined for each process panel. All process panels are defined by clicking the panel to open the module and enter the entities that were defined under its specific name. Below is the flow chart of the mortgage review clerk.

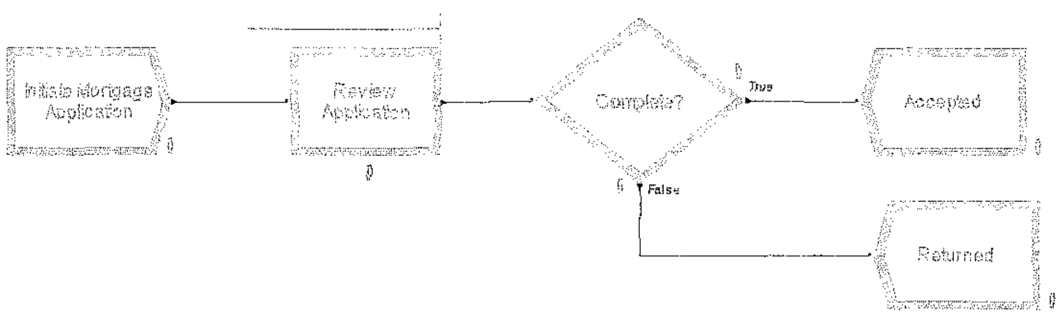


Figure 4.1: Mortgage review flow chart

The flow chart is run for simulation. At the end of the simulation, ARENA will ask whether to view reports or not. By clicking yes, the Category Overview Report will be displayed in a crystal report, as shown in Appendix I.

This report summarizes the result across all replications. The performance of the mortgage review clerk can be analyzed from this crystal report for each replication. Then the most interesting part is to embellish the graphical animation to gain further insight onto the process dynamics [9]. Animation is a great advantage in enticing audience to be interested with the flowchart. For starting, two animation components were added to the mortgage model which is the Mortgage Review Clerk working at a desk, either in busy mode or idle mode and a dynamic plot of the work-in-process (WIP) simulation variable graph. The enhance model are shown as below.

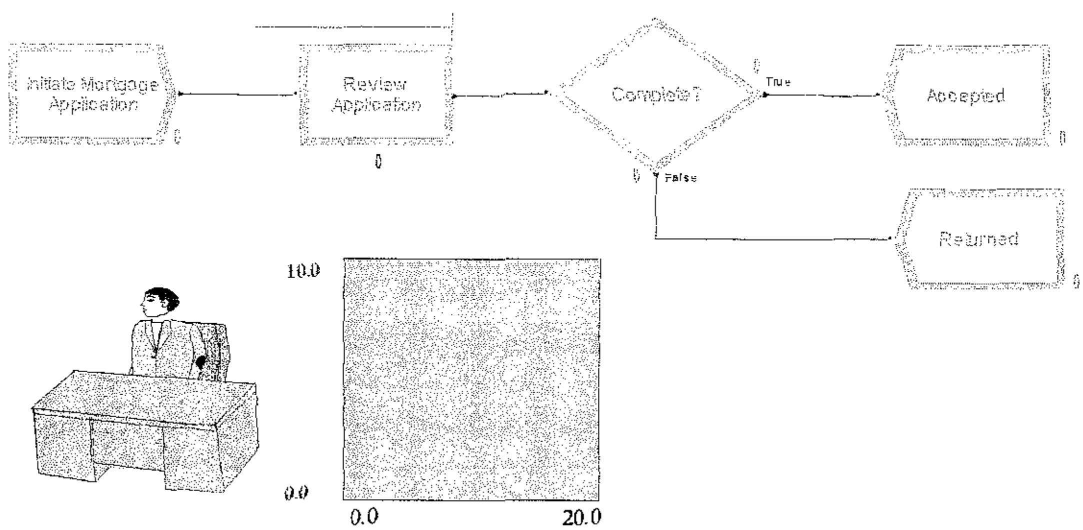


Figure 4.2: Mortgage Review Clerk visualization process enhancement

When modelling the Mortgage Review Clerk as a practice, there are many methods can used to simplify the flowchart into a simple process that audience might understand just by viewing the model. However, the toughest part is to create the Submodel within a process which can downsize the model. The construction of the model is time consuming compare to the simulation process. It needs a lot of experiment and test to create a smooth flow which represents the actual system. All details are analyzed at the end of simulation to be compared to the exact statistic of the real model.

Animation enhancement makes the model more interesting and understandable by audience who does not have any knowledge about what model simulation is all about. Audience tend to focus only at the animation of the clerk. Thus it is important to improve the model by represent complicated process or equipment with a picture or image.

Arena has a lot of advantages especially to the manufacturer if they want to improve their system by visualizing it first using a simulation model. These are the advantages of simulation from the analyst point of view:

1. Theory is straightforward
2. Time compression
3. Descriptive, not normative
5. Model is built from the manager's perspective
6. Manager needs no generalized understanding. Each component represents a real problem component
7. Wide variation in problem types
8. Can experiment with different variables
9. Allows for real-life problem complexities
10. Easy to obtain many performance measures directly
11. Frequently the only DSS modeling tool for no structured problems

4.2 Automotive Manufacturing System

4.2.1 Company and Product Background

UMW Advantech Sdn Bhd (formerly known as UMW Engineering Sdn Bhd), provides innovative engineering solutions for the Auto Component, Transportation, Petrochemical, Oleo chemical and Oil & Gas sectors. Its Auto Component Division supplies OEM and genuine replacement filtration products to Proton, Perodua, Toyota, Honda and other automotive assemblers in Malaysia. It also manufactures domestic and international private label automotive filters. With over 30 years manufacturing experience, proven track record and backed by strong R&D capabilities, it has become the supplier of choice for reliable and high quality products.

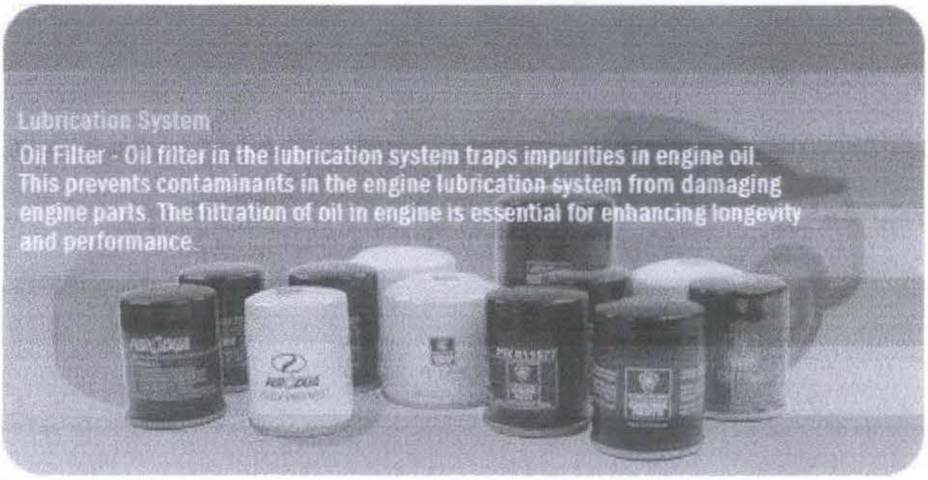


Figure 4.3: Lubrication System – Oil filter

The company's Specialty Equipment Division offers engineering solutions – design, fabrication, installation and commissioning of specialty equipment and structures. It has its own Aircraft Ground Support Equipment line under the Aerex brand, serving various Asian airports. The division also designs and manufactures Process Equipment and Structures for the Oil & Gas, Petrochemical and Oleo chemical sectors. Auto Component Division (ACD) design, manufacture and supply parts and components to the automotive (OEM and Replacement) and industrial sectors. Products include filters, coolants, brake fluids, brake pads, and metal/plastic components.

4.2.2 Problem definition

The company has been involved in the manufacturing of oil filter. The company also produces four out of seven of the oil filter components. To cater for the increasing demand for oil filter, the assembly line throughput has been increased from 800pcs/hour to 1400pcs/hour. However, the problem is the inventory is out of control where they are having more inventory than required. It is proposed to investigate this problem with a simulation model.

4.2.3 UMW Objectives

1. To improve productivity and efficiency through lean technique
2. To evaluate current stamping process (canister) using Arena software
3. To identify an efficient parts supply (canister) schedule

Scope of study:

1. To study current process for stamping line (canister)
2. To apply lean manufacturing technique. Lean manufacturing is a management philosophy focusing on reduction of the nine wastes to improve overall customer value

- Transportation
- Inventory (having more inventory than required)
- Motion (workers moving more than required)
- Waiting time (machine queue or waiting for parts)
- Over-production (making more or earlier than needed)
- Processing Itself (standalone processes)
- Defective Product (Scrap in manufactured products or any type of business.)
- Safety (unsafe work areas creates lost work hours and expenses)
- Information (age of electronic information and enterprise resource planning systems (ERP) requires current / correct master data details)

By eliminating waste, quality is improved; production time and costs are reduced. In this project, the studies will emphasize on canister stamping line which daily run the DC593 4G9 Canister.

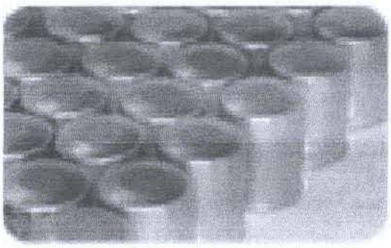


Figure 4.4: DC593 4G9 Canister

4.2.4 Stamping Line Description

There are two production lines for canister stamping line. There are

- APEC 20T
- APEC 30T

Both Apec 20T and Apec 30T have the same process flow with ten process, six machines and one operator operating the machine at the rear end of the stamping line. Even though both lines have same operation, the parameter and machine specification such as cycle time, duration and length is different due to different type of resources. Below is the process detail for APEC 20T and APEC 30T:

Table 4.1: APEC 20T process description

No	Process	Resources	Task	Process time (sec)		
				Min	Value	Max
1	Feeding	Machine	Feeding the metal sheet into the trimming machine	0.90	0.92	0.94
2	Stamping	Machine	Stamp the metal into canister figure	2.88	2.89	2.91
3	Trimming	Machine	Trim the tip of the canister	1.45	1.51	1.66
4	Loading	Machine	Load canister onto the trimming machine	4.33	4.8	4.93
5	Unloading 1	Machine	Unload canister from stamping machine onto the conveyor 1	4.80	4.82	4.90
6	Unloading 2	Machine	Unload canister from trimming machine	2.70	2.77	2.80
7	Quality checking	Operator	Check the canister quality and fill canister into the metal basket	3.35 + 1.65*BETA(0.533, 0.321)		
8	Arrange	Operator	Arrange canister in row by batch	0.213 + LOGN(0.506, 0.31)		
9	Convey 1	Conveyor	Convey canister from stamping machine to trimming machine	18.36		
10	Convey 2	Conveyor	Convey canister from trimming machine to quality station	3.86		

Table 4.2: APEC 30T process description

No	Process	Resources	Task	Process time (sec)		
				Min	Value	Max
1	Feeding	Machine	Feeding the metal sheet into the trimming machine	0.7	0.94	1.2
2	Stamping	Machine	Stamp the metal into canister figure	2.6	2.97	3.4
3	Trimming	Machine	Trim the tip of the canister	1.2	1.52	2.0
4	Loading	Machine	Load canister onto the trimming machine	4.2	4.49	4.8
5	Unloading 1	Machine	Unload canister from stamping machine onto the conveyor 1	4.9	5.1	5.3
6	Unloading 2	Machine	Unload canister from trimming machine	2.6	2.73	2.9
7	Quality checking	Operator	Check the canister quality and fill canister into the metal basket	3.54 + 1.47*BETA(0.628, 0.318)		
8	Arrange	Operator	Arrange canister in row by batch	0.61 + LOGN(0.506, 0.41)		
9	Convey 1	Conveyor	Convey canister from stamping machine to trimming machine	12.56		
10	Convey 2	Conveyor	Convey canister from trimming machine to quality station	5.99		

Below is the process flow for canister stamping line:

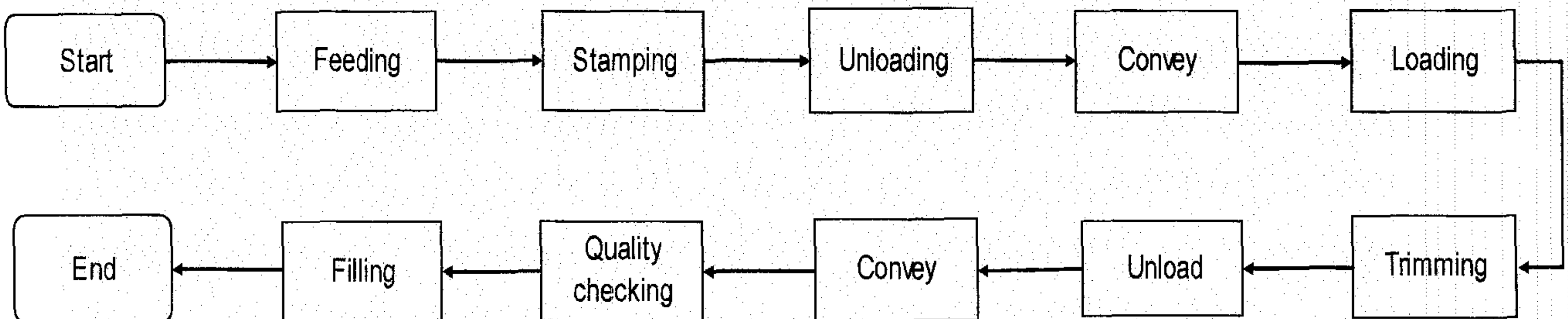


Figure 4.5: Process flow for canister stamping line

4.2.5 Production Schedule

Shift Element: (22days - 24hours Production)

Table 4.3: Production schedule

Working Time	**Rest Time**
8.00-10.00 am	10.00-10.15 am
10.15-1.15 pm	1.15-2.00pm
2.00-3.30 pm	3.30-3.45 pm
3.45-7.50 pm	7.50-8.00 pm (Shift change)

4.2.6 Production Index Daily

The production index daily data for APEC 30T and APEC 20T are attached in Appendix II and Appendix 1V. At least a month of data is needed to design an accurate and precise model. Below is the data that are required for modeling.

Table 4.4: Production index daily data for APEC 20T

Date	Total Production	Reject	Pass	% Yield	Production Time(h)	Actual Time(h)	Productivity per Hour	Breakdown(h)
01/09/2007	6375	5	6370	99.9215686	11.5	11.5	554	0
02/09/2007	4325	3	4322	99.9306358	8.08	7.91	547	0.17
03/09/2007	11460	3	11457	99.973822	21	20.42	561	0.58
04/09/2007	10644	6	10638	99.9436302	20.83	20.08	530	0.75
05/09/2007	11167	7	11160	99.9373153	20.83	20.16	554	0.67
06/09/2007	11609	7	11602	99.939702	20.83	20.41	569	0.42
07/09/2007	7045	7	7038	99.9006388	13	12.5	564	0.5
10/09/2007	7916	0	7916	100	20.67	19.09	415	1.58
11/09/2007	9301	3	9298	99.9677454	21.25	16.75	555	4.5
12/09/2007	4598	3	4595	99.9347542	8.42	8.25	557	0.17
14/09/2007	5281	3	5278	99.9431926	10.25	10.08	524	0.17
19/09/2007	7090	3	7087	99.9576869	12.92	12.59	563	0.33
20/09/2007	9701	8	9693	99.9175343	18.75	18.08	537	0.67
21/09/2007	11493	5	11488	99.9564953	21.25	20.83	552	0.42
22/09/2007	4281	3	4278	99.9299229	8.42	8.25	519	0.17
24/09/2007	11624	6	11618	99.9483827	20.92	20.59	565	0.33
25/09/2007	11171	8	11163	99.928386	20.5	20.08	556	0.42
26/09/2007	11215	8	11207	99.928667	20.17	19.84	565	0.33
27/09/2007	5646	4	5642	99.9291534	10	9.75	579	0.25
28/09/2007	10761	7	10754	99.9349503	20.58	20.33	529	0.25
29/09/2007	4280	3	4277	99.9299065	7.58	7.58	565	0
30/09/2007	4325	3	4322	99.9306358	7.83	7.66	565	0.17
Average	**8241**	**5**	**8237**	**99.9402**	**15.71**	**15.12**	**547**	**0.58**

Table 4.5: Production index daily for APEC 30T

Date	Total Production	Reject	Pass	% yield	Production Time(h)	Actual Time(h)	Productivity per Hour	Breakdown(h)
01/09/2007	10001	10	9991	99.90001	20.67	19.5	513	1.17
02/09/2007	9891	14	9877	99.8584572	21.08	19.58	505	1.50
03/09/2007	9707	12	9695	99.8763779	20.33	19.25	504	1.08
04/09/2007	7020	35	6985	99.5014245	17.58	15.41	456	2.17
05/09/2007	2114	3	2111	99.8580889	4.83	4	529	0.83
06/09/2007	4416	65	4351	98.5280797	14.08	8.5	520	5.58
07/09/2007	4187	10	4177	99.7611655	13.50	8.33	503	5.17
10/09/2007	9526	9	9517	99.9055217	20.08	18.08	527	2.00
11/09/2007	9211	18	9193	99.8045815	19.92	17.75	519	2.17
12/09/2007	14818	17	14801	99.8852747	30.17	28	529	2.17
14/09/2007	8563	11	8552	99.8715403	19.25	16.92	506	2.33
19/09/2007	5505	5	5500	99.9091735	11.58	10.5	524	1.08
20/09/2007	3818	0	3818	100	7.92	7.67	498	0.25
21/09/2007	6078	29	6049	99.5228694	15.17	11.34	536	3.83
22/09/2007	5755	59	5696	98.9748045	13.83	11.33	508	2.50
24/09/2007	11624	6	11618	99.9483827	20.92	20.59	565	0.33
25/09/2007	11171	8	11163	99.928386	20.5	20.08	556	0.42
26/09/2007	11215	8	11207	99.928667	20.17	19.84	565	0.33
27/09/2007	5646	4	5642	99.9291534	10	9.75	579	0.25
28/09/2007	10761	7	10754	99.9349503	20.58	20.33	529	0.25
29/09/2007	4280	3	4277	99.9299065	7.58	7.58	565	0
30/09/2007	4325	3	4322	99.9306358	7.83	7.66	565	0.17
Average	**7374**	**20**	**7354**	**99.6672**	**16.67**	**14.41**	**512**	**2.26**

4.2.7 Input Analyzer

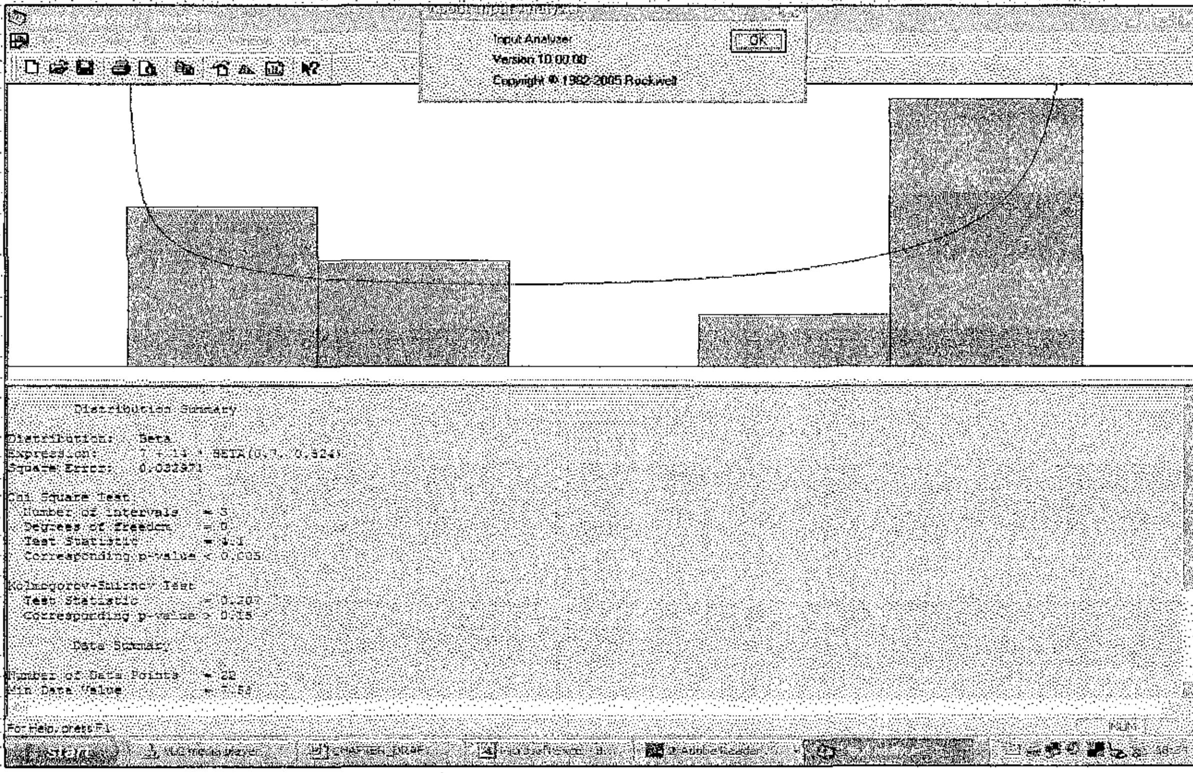


Figure 4.6: Input analyzer tool

The Input Analyzer is provided as a standard component of the ARENA environment. This powerful and versatile tool can be used to determine the quality of fit of probability distribution functions to input data. It may also be used to fit specific distribution functions to a data file to allow you to compare distribution functions or to display the effects of changes in parameters for the same distribution. In addition, the Input Analyzer can generate sets of random data that can then be analyzed using the software's distribution-fitting features.

To run the Input Analyzer, double-click on the Input Analyzer icon or select the Input Analyzer command from the Tools menu in ARENA.

The data files processed by the Input Analyzer typically represent the time intervals associated with a random process. For example, the Input Analyzer might be used to analyze a set of interarrival times, or a set of process times.

4.2.8 Preparing Data Files Manually

To prepare a set of data for use within the Input Analyzer, simply create an ordinary ASCII text file containing the data in free format. For this project, text editor is used for this purpose. The individual data values must be separated by one or more "white space characters". There are no other formatting requirements. ARENA uses a default file extension of .dst for data files.

After the data file has been loaded and displayed as a histogram in a data fit window, the next step is to fit a probability distribution function to the data. To do this, first select the *Fit* menu item. A drop-down menu displays all of the available distribution functions.

The Input Analyzer will then determine the parameters that will fit the distribution function to the data. As soon as the curve-fitting calculations are complete, the resulting probability density function is drawn on top of the histogram. Information characterizing the curve-fit, including an expression that could be included in an ARENA model, is shown in the bottom section of the window.

The quality of a curve fit is based primarily on the square error criterion, which is defined as the sum of $\{ fi - f(xi) \}^2$, summed over all histogram intervals. In this expression fi refers to the relative frequency of the data for the ith interval, and $f(xi)$ refers to the relative frequency for the fitted probability distribution function. This last value is obtained by integrating the probability density across the interval. If the cumulative distribution is known explicitly, then $f(xi)$ is determined as $F(xi) - F(xi\text{-}1)$, where F refers to the cumulative distribution, xi is the right interval boundary and xi-1 is the left interval boundary. If the cumulative distribution is not known explicitly, then $f(xi)$ is determined by numerical integration.

The results of Chi-square and (for non-integer data) Kolmogorov-Smirnov goodness-of-fit tests are also shown. These results are presented in the form of p-values; the p-value is the largest value of the type-I error probability that allows the distribution to fit the data. In general, the higher the p-value, the better the fit. For example, if the p-value is greater than 0.10, then we would not reject the null hypothesis of a good fit at level = 0.10. Below shows the stages of how the input analyzer fit a distribution onto a sets of data:

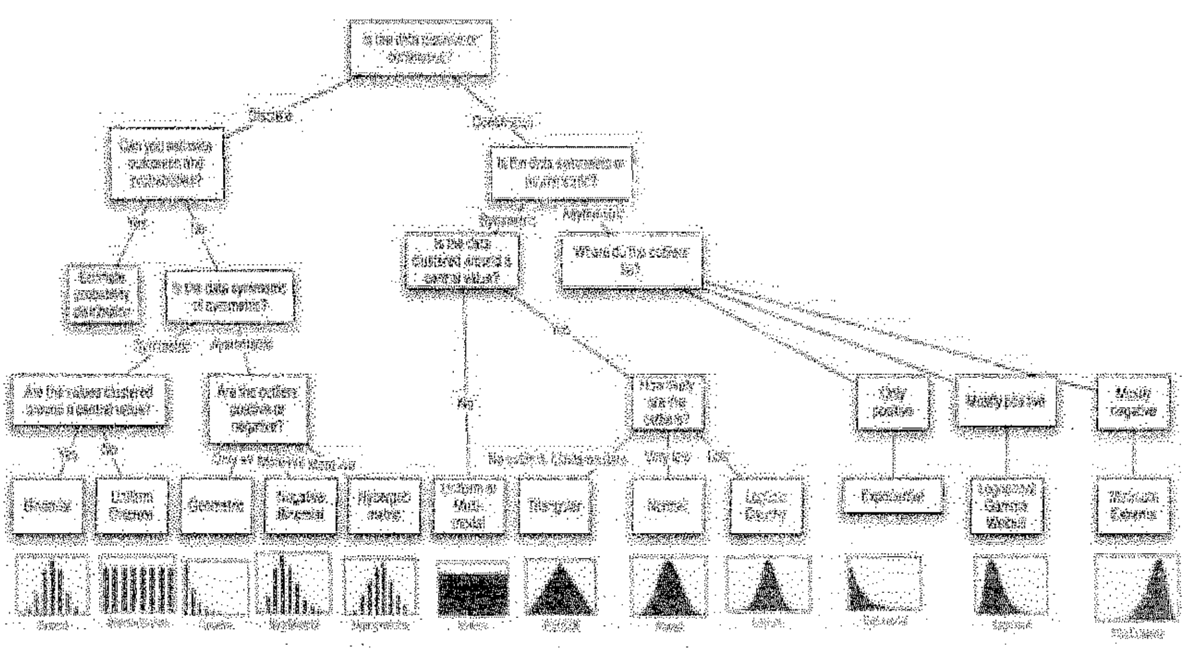


Figure 4.7: Summary of distributional choices

The Kolgomorov-Smirnov test can be used to see if the data fits a normal, lognormal, Weibull, exponential or logistic distribution. Below is the result for data by using the Kolgomorov-Smirnov test:

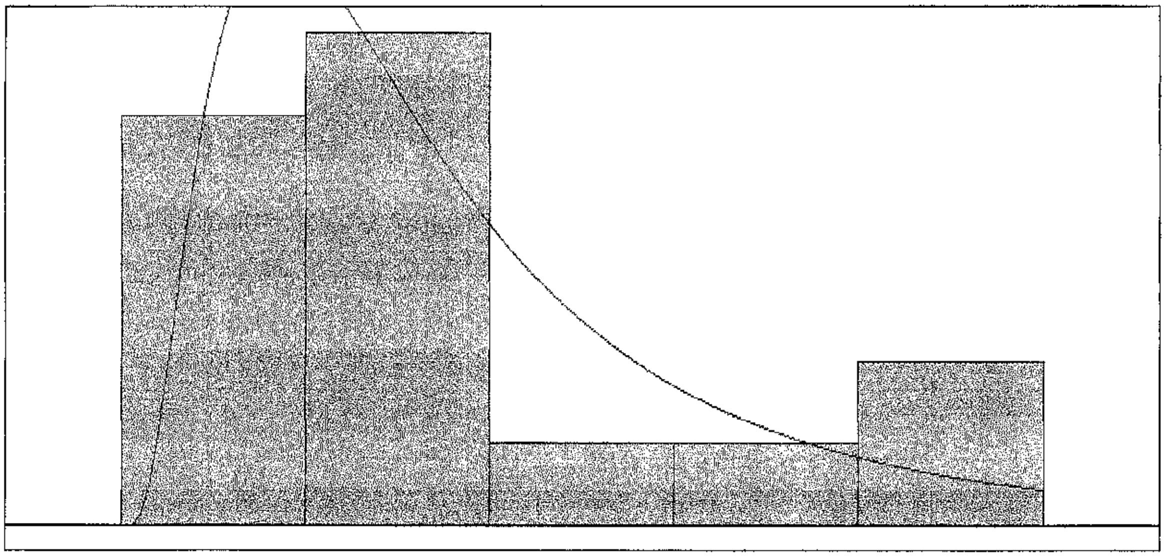


Figure 4.8: APEC20T downtime

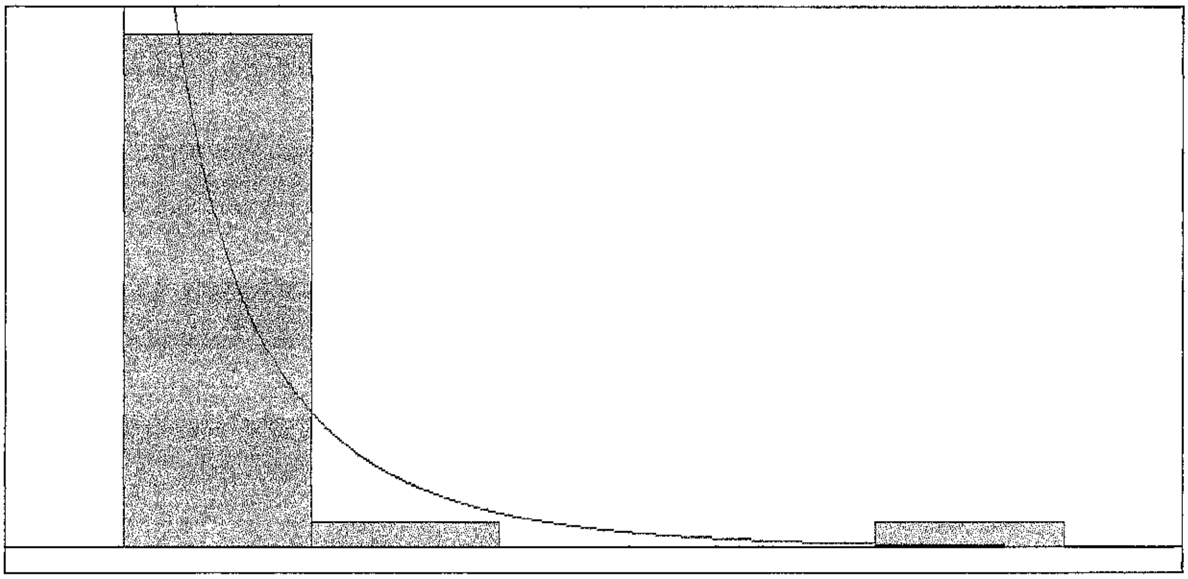


Figure 4.9: APEC30T Downtime

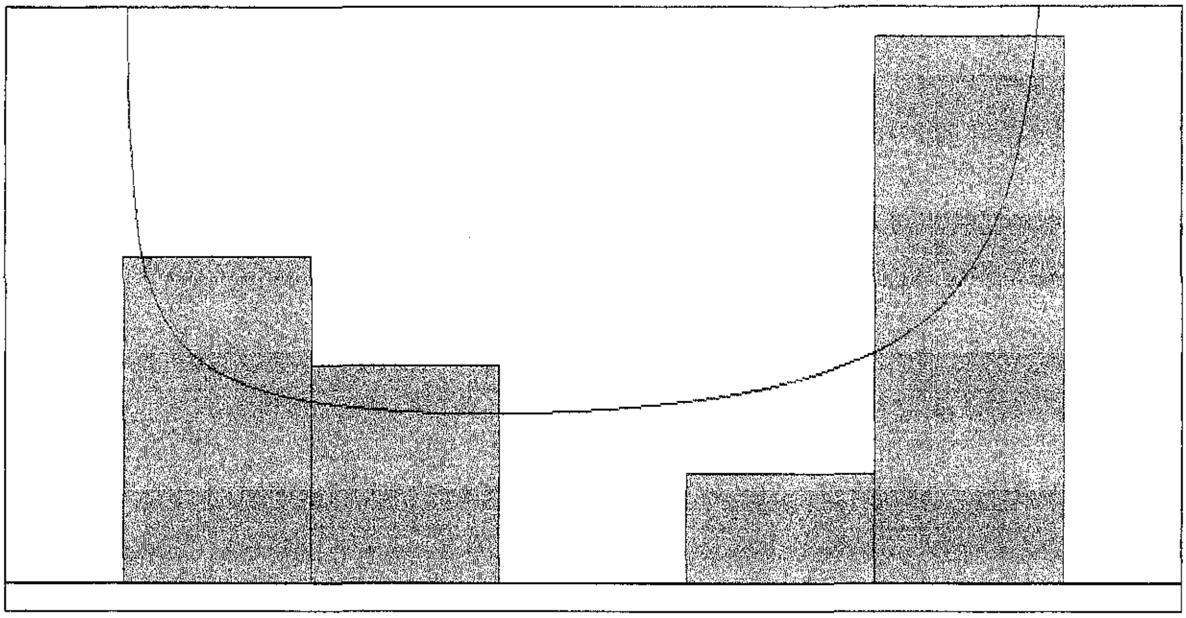


Figure 4.10: APEC20T Uptime

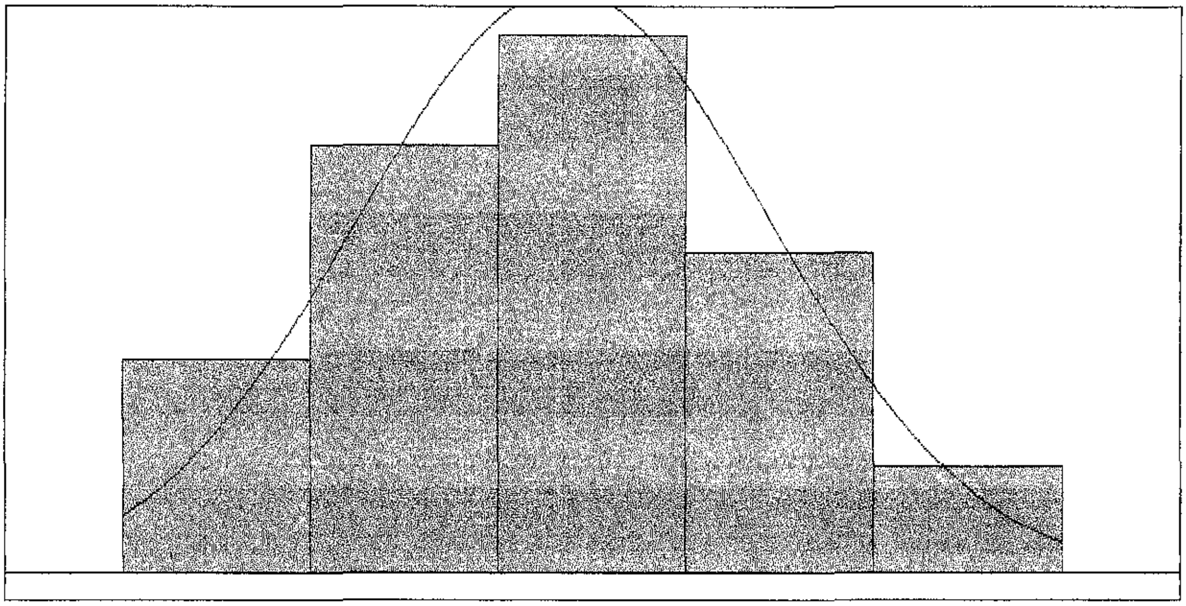


Figure 4.11: APEC30T Uptime

Following are the distribution summary and data summary that best fit for the uptime and downtime of machine resources:

Table 4.6: Distribution summary/data summary for machine uptime and downtime

Distribution/Data Summary				
	Machine Uptime		Machine Downtime	
Statistic	Apec 20T	Apec 30T	Apec 20T	Apec 30T
Distribution:	Beta	Normal	Lognormal	Weibull
Expression:	7 + 14 * BETA(0.7, 0.524)	NORM(16.7, 5.95)	LOGN(2.36, 2.06)	-0.001 + WEIB(0.505, 0.779)
Square Error:	0.032971	0.00187	0.022824	0.01894
Kolmogorov-Smirnov Test				
Test Statistic	0.207	0.169	0.162	0.259
Corresponding p-value	> 0.15	>0.15	>0.15	0.0899
Number of Data Points	22	22	22	22
Min Data Value	7.58	4.83	0.25	0
Max Data Value	20.8	30.2	5.58	4.5
Sample Mean	15.1	16.7	2.26	0.584
Sample Std Dev	5.39	6.16	1.53	0.936
Histogram Range	7 to 21	4 to 31	0 to 6	-0.001 to 4.95'
Number of Intervals	5	5	5	5

Raw data is almost never as well behaved as we would like it to be. Consequently, fitting a statistical distribution to data is part art and part science, requiring compromises along the way. The key to good data analysis is maintaining a balance between getting a good distributional fit and preserving ease of estimation, keeping in mind that the ultimate objective is that the analysis should lead to better decision. In particular, we may decide to settle for a distribution that less completely fits the data over one that more completely fits it, simply because estimating the parameters may be easier to do with the former. This may explain the overwhelming dependence on the normal distribution in practice, notwithstanding the fact that most data do not meet the criteria needed for the distribution to fit.

4.3 Automotive System ARENA Model

The model consists of the Basic Process modules, Advanced Transfer modules and Advanced Process modules. This project consists of application block from all panels.

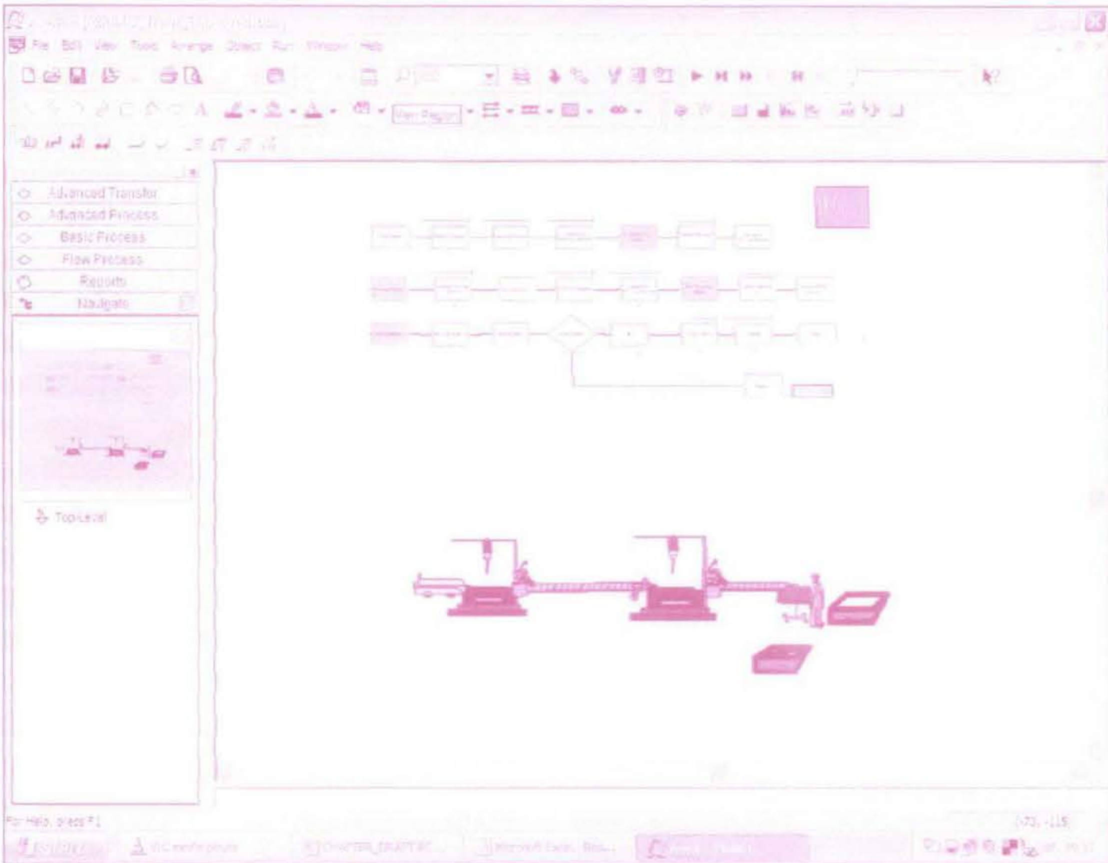


Figure 4.12: ARENA's project bar and workspace

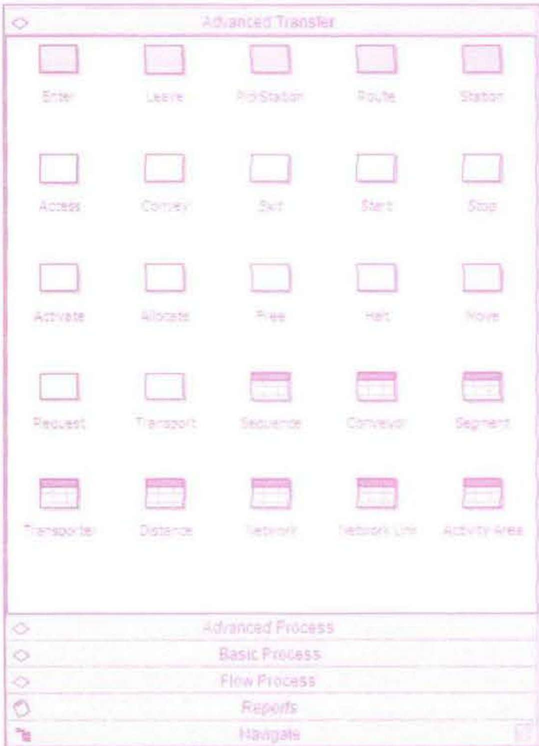


Figure 4.13: Advanced Transfer Panel

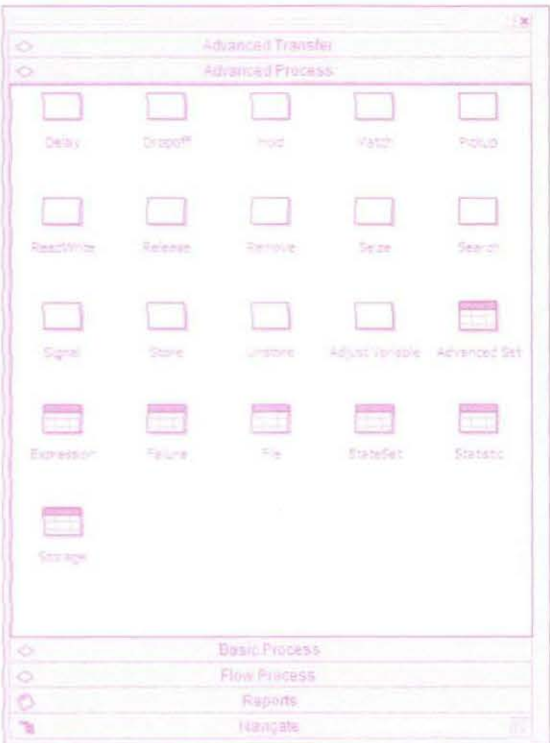


Figure 4.14: Advanced Process Panel

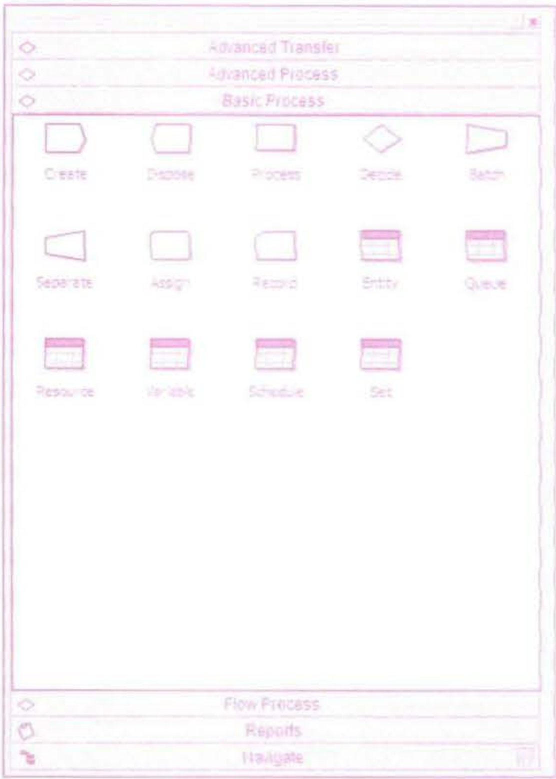


Figure 4.15: Basic Process Panel

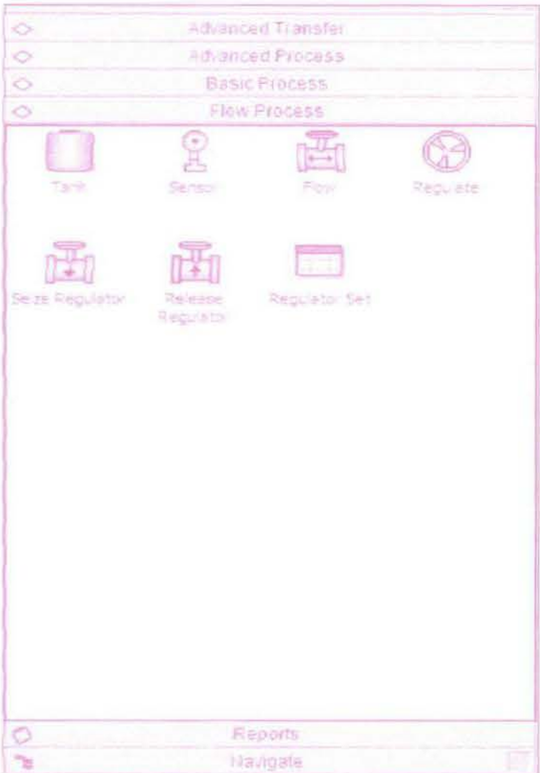


Figure 4.16: Flow Process Panel

Because of both canister stamping line have same process flow, therefore their process module is similar. However the parameter and specification is totally different from one another. Below is the simulation model of APEC 20T and APEC 30T:

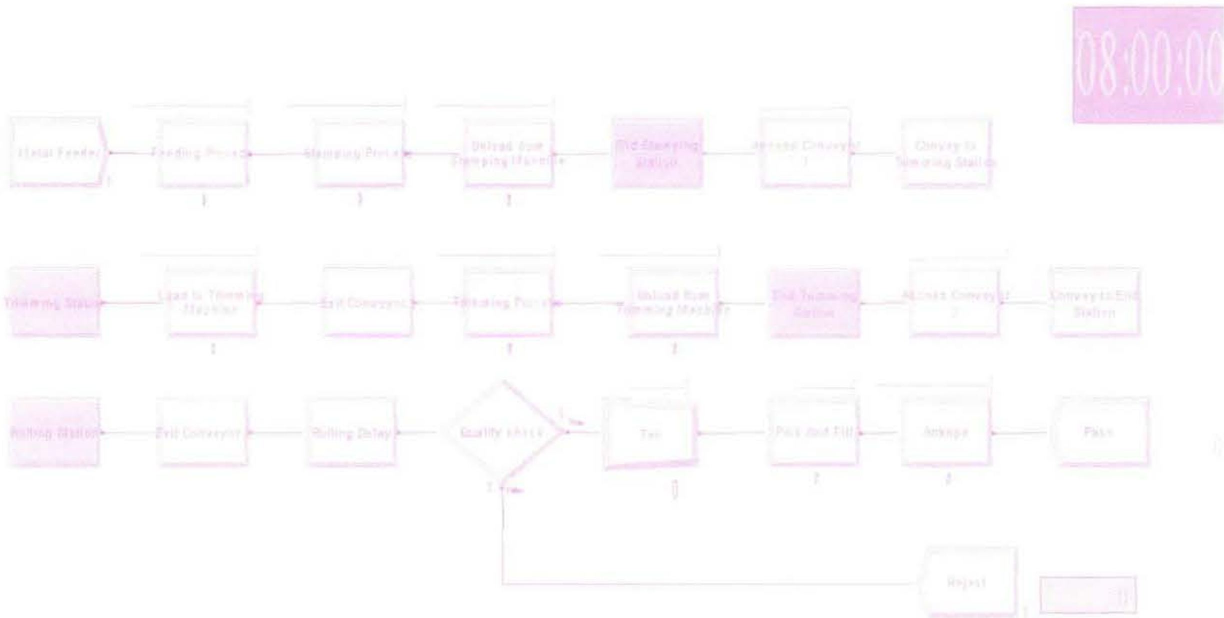
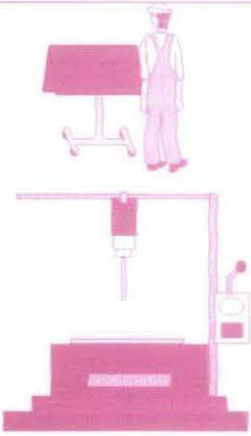


Figure 4.17: APEC 20T and APEC 30T simulation model

Table 4.7: Modules used in ARENA Model

Module	Function
	Create module is intended as the starting point for entities in a simulation model. Entities are created using a schedule or based on a time between arrivals.
	Process module is intended as the main processing method in the simulation. The process time is allocated to the entity and may be considered to be value added, non-value added, transfer, wait or other.
	The Station module defines a station (or a set of stations) corresponding to a physical or logical location where processing occurs.
	The Access module allocates one or more cells of a conveyor to an entity for movement from one station to another. Once the entity has control of the cells on the conveyor, it may then be conveyed to the next station.
	The Convey module moves an entity on a conveyor from its current station location to a specified destination station. The time delay to convey the entity from one station to the next is based on the velocity of the conveyor (specified in the Conveyor module) and the distance between the stations (specified in the Segment module).
	The Exit module releases the entity's cells on the specified conveyor. If another entity is waiting in queue for the conveyor at the same station when the cells are released, it will then access the conveyor.
	The Delay module delays an entity by a specified amount of time.

	Decide module allows for decision-making processes in the system. It includes options to make decisions based on one or more conditions (e.g., if entity type is Gold Card) or based on one or more probabilities (e.g., 75% true; 25% false).
	Entities arriving at the Batch module are placed in a queue until the required number of entities has accumulated. Once accumulated, a new representative entity is created.
	This module is intended as the ending point for entities in a simulation model. Entity statistics may be recorded before the entity is disposed.
	A clock is animated by clicking on the clock button from the Animate toolbar.
	A variable is animated by clicking on the variable button from the Animate toolbar.
	Use the *Identifier* field within the *Picture Placement* dialog to indicate which resource the picture(s) will represent. Since resource animation is such that during the run the resource picture changes based on the state of the resource, a different picture can be associated with each resource state (Idle, Busy, Inactive, Failed, or some user-defined state).
	The characteristics of a segment path object may be specified while adding the segment to the model using the Animate Transfer toolbar, or by double-clicking on the segment after it has been placed.

4.4 Animation in System Simulation

Animation in systems simulation is a useful tool. Most graphically based software packages have default animation. This is quite useful for model debugging, validation, and verification. This type of animation comes with little or no additional effort and gives the modeller additional insight into how the model. This type of animation comes with little or no additional effort and gives the modeller additional insight into how the model works. However, it augments the modelling tools available. The more realistic animation presents qualities which intend to be useful to the decision-maker in implementing the developed simulation model. There are also, good model management tools. Some tools have been developed which combined a database with simulation to store models, data, results, and animations. ARENA provides all of those capabilities. Following figures are the ARENA animation model for developed by using the clip art provided by ARENA tools:

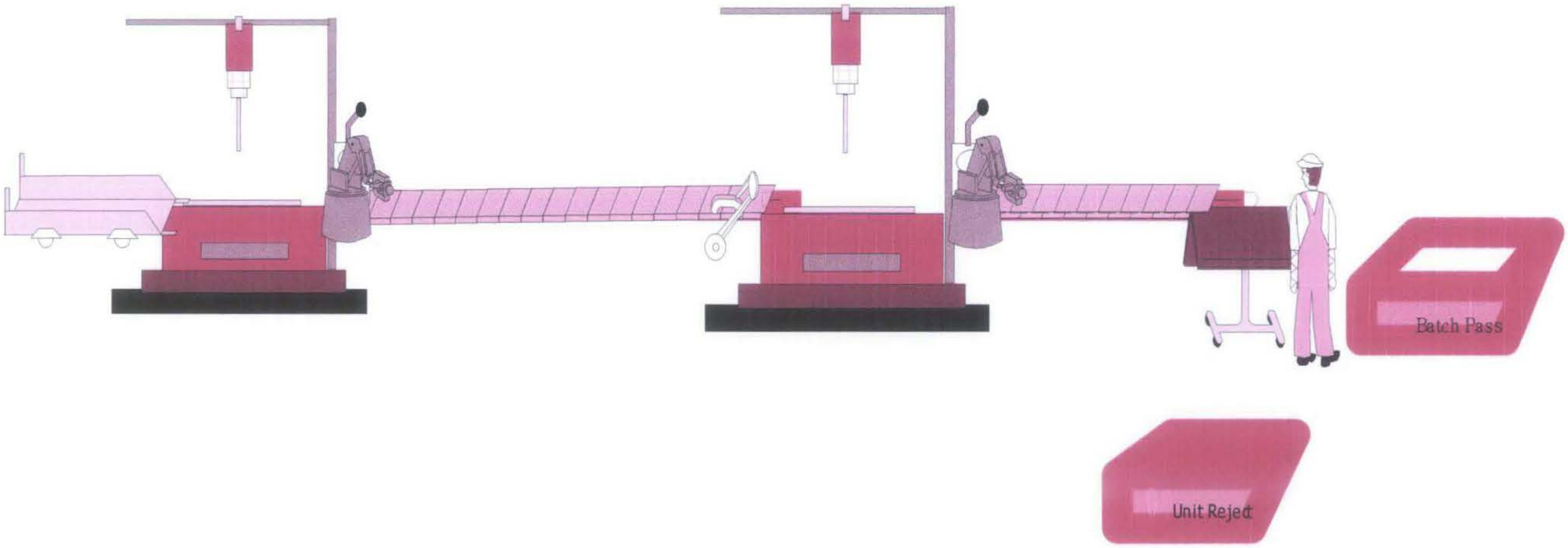


Figure 4.19: ARENA Animation model for APEC20T

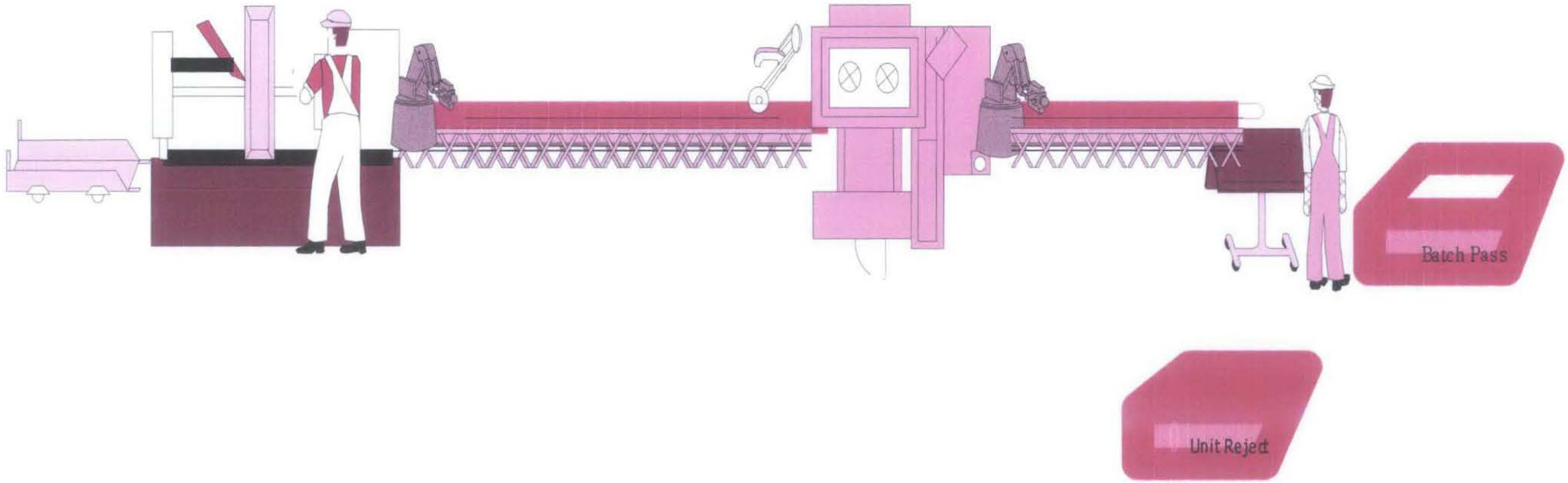


Figure 4.20: ARENA animation model for APEC30T

4.4.1 Validating the Simulation Model

Before the new model could be considered reliable by UMW manufacturers, it had to be validated. The validation process confirms that the model generates results that reflect the actual world of UMW manufacturers. The validation compared the production, and environmental profiles generated by the model to the known data tracked by UMW. Below is the calculation for the model error based on the simulation results:

Formula:

$$\text{Percentage of Model Error (\%)} = \frac{|\text{Simulation Value} - \text{Actual System Value}|}{\text{Actual System Value}} \times 100\%$$

For APEC 20T (Refer to Appendix for crystal report),

Simulation productivity per hour = 55 batch x 10pcs/batch = 550pcs/hour

Actual average productivity per hour = 547pcs/hour

$$\text{\% of Model Error} = \frac{|550 - 547|}{547} \times 100\% = \mathbf{0.5484\%} < \mathbf{5\%}$$

Simulation productivity per day = 822 batch x 10pcs/batch = 8220pcs/day

Actual average productivity per day = 8241pcs/day

$$\text{\% of Model Error} = \frac{|8220 - 8237|}{8237} \times 100\% = \mathbf{0.2064\%} < \mathbf{5\%}$$

For APEC 30T (Refer to Appendix for crystal report),

Simulation productivity per hour = 52batch x 10pcs/batch = 520pcs/hour

Actual average productivity per hour = 512pcs/hour

$$\text{\% of Model Error} = \frac{|520 - 512|}{512} \times 100\% = \mathbf{1.5625\%} < \mathbf{5\%}$$

Simulation productivity per day = 747batch x 10pcs/batch=7470pcs/day

Actual average productivity per day = 7374pcs/day

$$\text{\% of Model Error} = \frac{|7470 - 7374|}{7374} \times 100\% = \mathbf{1.30187\%} < \mathbf{5\%}$$

Table below summarized the simulation result for the average output production over five replication simulation:

Table 4.8: APEC20T Validation Info

APEC 20T	Average output production rate (pcs/hour)	Average output production rate (pcs/day)
Specified production rate	**500**	**8000**
Actual production rate	**547**	**8237**
Model production rate	**550**	**8220**
Actual error (based on target prod rate)	**9.4000%**	**2.9625%**
Model error (based on actual prod rate)	**0.5484%**	**0.2064%**
Status*	Model is validate with error<5%	Model is validate with error<5%

Table 4.9: APEC30T Validation Info

APEC 30T	Average output production rate (pcs/hour)	Average output production rate (pcs/day)
Specified production rate	**500**	**8000**
Actual production rate	**512**	**7354**
Model production rate	**520**	**7470**
Actual error (based on target prod rate)	**2.4000%**	**8.075%**
Model error (based on actual prod rate)	**1.5625%**	**1.5774%**
Status*	Model is validate with error<5%	Model is validate with error<5%

* The acceptable error for ARENA Model used by certified analyst from Rockwell Automation is ±5%.

The specified production rate is the setting for all the machines resources. Based on the simulation result, it is observed that the actual output of production is higher than the specified production rate for both production lines. This may be the main factor that contributes to the problems which UMW is facing which inventory is overflowing. The factors that were identified are:

- The engineers use 500pcs/hr production rate as reference to calculate how many hours they should run the production line but the actual production rate is higher than 500pcs/hr. The simulation model simulates the average production rate over many replications. Thus engineers can simulate the production rate in hours, minutes, days or months. The simulation had proved that the production rate per hour is higher than the specified production rate. Therefore they have inventory overflowing due to inaccurate production rate. Apec20T is running at 550pcs/hr and Apec20T is running at 520pcs/hr.

- Production schedule is calculated without including the machine breakdown. This is due to no proper reference of breakdown history and breakdown patterns for each line. Then they could not estimate the hours they needed to cover up the demand when breakdown occurred accurately. The simulation results is simulate with the breakdown patterns added where the distribution data techniques id applied to estimate the patterns of breakdown time for all machine. Thus it gives a more accurate interpretation on how many hours needed to cover the demand if breakdowns occurred.

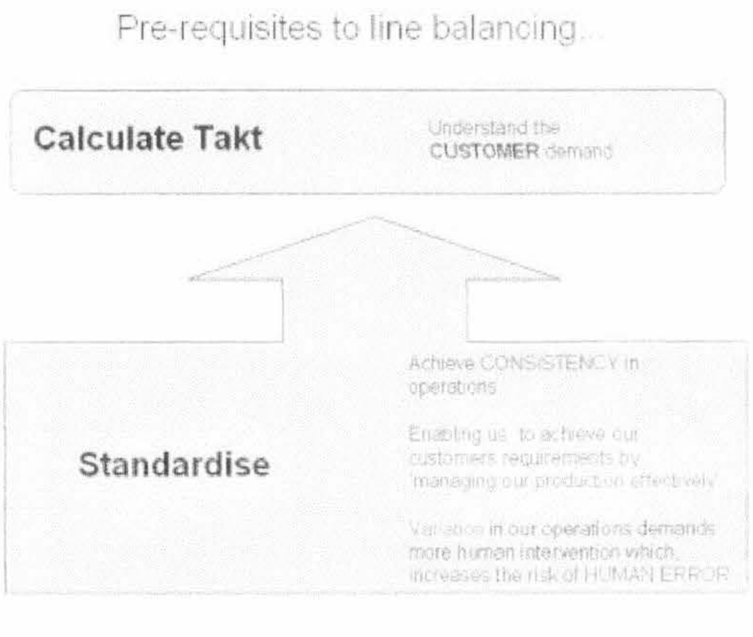
- Estimation and calculation are based on experience which not accurate and precise as they do not have the tools like ARENA to do the interpretation and experiment. The simulation results are based on data history generated by the real system. No estimation is used when modelling the system as statistical and established methodical approach is taken count. Thus it is proven by validating the model with the APEC20T and APEC30T production data up to 30 days.

Using the model, it can tackle the problem because:

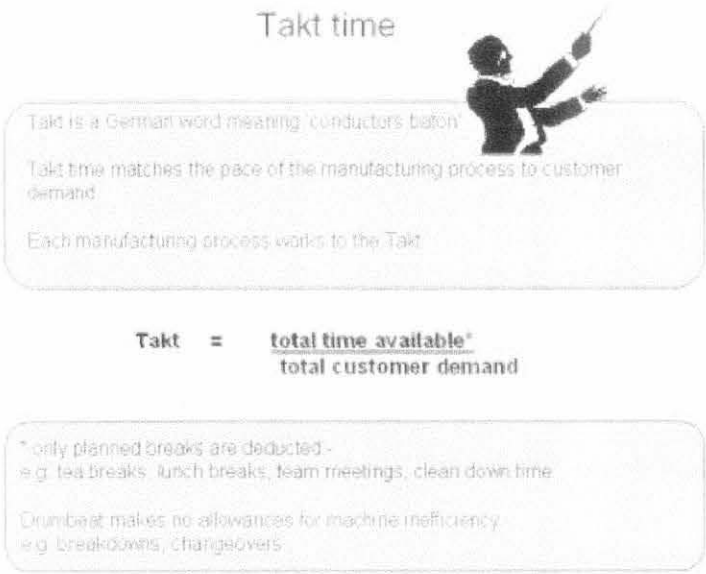
- The simulation results simulate the average output production rate over many replications which identified the output production rate for each production line but also the production rate for each machine. Engineers then can calculate and estimate the production schedule time correctly to produce output according to demand more accurate and precise. Therefore output would meet demand without overflowing. Following is the recommended calculation that can be used for scheduling purposes:

Takt Time & Standard Work

Takt Time



Takt Time is the production "Drumbeat" based on customer demand



- Simulation duplicates production processes on a computer, allowing users to experiment with different scenarios without disrupting production or incurring any of the costs of actual implementation. Since simulation models duplicate production processes, they allow tracking of specific activities that otherwise would be aggregated into over production. These models can be designed to allow the user to try out any number of variables, such as the number and type of operations, the sequence of operations, production volumes, and process times. Engineers can simulate the output for the whole production line or machine when breakdown occurred. By specifying the breakdown time in the model, engineers can simulate the production hour's total time needed to cover the demand rate. The simulation result will recorded the entire statistic in the crystal report. The simulated output production rate is based on the machine behaviour which mimic the current system by modelling using the system parameter setting, breakdown patterns data, rejected output data and etc. which gives the overall operation performance of each resource.

4.5 Line Balancing Method

Assembly Line Balancing, or simply Line Balancing (LB), is the problem of assigning operations to workstations along an assembly line, in such a way that the assignment be optimal in some sense. Ever since Henry Ford's introduction of assembly lines, LB has been an optimization problem of significant industrial importance: the efficiency difference between an optimal and a sub-optimal assignment can yield economies (or waste) reaching millions of dollars per year [14].

4.5.1 Definitions of Line Balancing

The classic OR definition of the line balancing problem, dubbed SALBP (Simple Assembly Line Balancing Problem) by Becker and Scholl (2004), goes as follows [15]. Given a set of tasks of various durations, a set of precedence constraints among the tasks, and a set of workstations, assign each task to exactly one workstation in such a way that no precedence constraint is violated and the assignment is optimal. The optimality criterion gives rise to two variants of the problem: either a cycle time is given that cannot be exceeded by the sum of durations of all tasks assigned to any workstation and the number of workstations is to be minimized, or the number of workstations is fixed and the line cycle time, equal to the largest sum of durations of task assigned to a workstation, is to be minimized where:

- Everyone is doing the same amount of work
- Doing the same amount of work to customer requirement
- Variation is 'smoothed'
- No one overburdened
- No one waiting
- Everyone working together in a BALANCED fashion

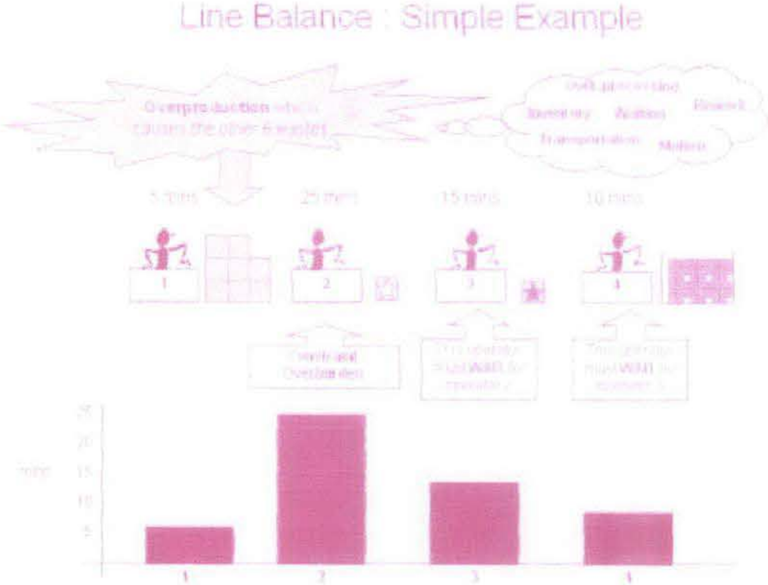


Figure 4.21: Simple example of line balancing

Here we see operator number 1 over-producing, thus creating the other 6 wastes. We simply re-balance the work content (Re distributes some of the work), using a line balancing board or Yamazumi board as it is often known [14].

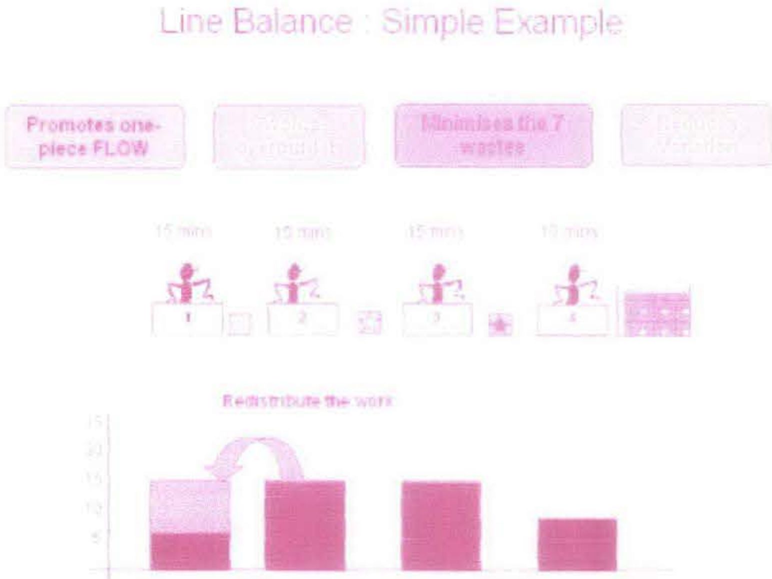


Figure 4.22: Simple example of line after balancing

4.5.2 Do Not Balance but Re-balance

Many of the OR approaches implicitly assume that the problem to be solved involves a new, yet-to-be-built assembly line, possibly housed in a new, yet-to-be-built factory. To our opinion, this is the gravest oversimplification of the classic OR approach, for in practice, this is hardly ever the case [15]. The vast majority of real-world line balancing tasks involve existing lines, housed in existing factories – in fact, the target line typically needs to be rebalanced rather than balanced, the need arising from changes in the product or the mix of models being assembled in the line, the assembly technology, the available workforce, or the production targets. This has some far-reaching implications, outlined below.

- **Workstations Have Identities**

As pointed out above, the vast majority of real-world line balancing tasks involves existing lines housed in existing factories. In practice, this seemingly "uninteresting" observation has one far-reaching consequence, namely that each workstation in the line does have its own identity. This identity is not due to any "incapacity of abstraction" on part of the process engineers, but rather to the fact that the workstations are indeed not identical: each has its own space constraints (e.g. a workstation below a low ceiling cannot elevate the car above the operators' heads), its own heavy equipment that cannot be moved spare huge costs, its own capacity of certain supplies (e.g. compressed air), its own restrictions on the operations that can be carried out there (e.g. do not place welding operations just beside the painting shop), etc [16].

- **Unmovable Operations and Zoning Constraints**

The need to identify workstations by their position along the line (rather than solely by the set of operations that would be carried out there) is illustrated by the typical need of line managers to define unmovable operations and zoning constraints. An operation is marked as unmovable if it must be assigned to a given workstation [15].

This is usually due to some kind of heavy equipment that would be too expensive to move elsewhere in the shop. Zoning constraints are a generalization of unmovable operations: they express the fact that an operation can only be assigned to a given (not necessarily contiguous) subset of the workstations in the line.

- **Cannot Eliminate Workstations**

Since workstations do have their identity (as observed above), it becomes obvious that a real-world LB tool cannot aim at eliminating workstations. Indeed, unless the eliminated workstations were all in the front of the line or its tail, their elimination would create gaping holes in the line, by virtue of the other workstations' retaining of their identities, including their geographical positions in the workshop. Also, it is often the case that many workstations that could possibly be eliminated by the algorithm are in fact necessary because of zoning constraints [16].

- **Need to Equalize Loads**

Since eliminating workstations cannot be the aim of the optimization of the line, as pointed out above, it is the equalization or smoothing (indeed "balancing") of the workload among workstations that should be the practical aim of LB.

It is worth noting that the classic objective of minimization of the cycle time, i.e. minimization of the maximum lead time over all workstations, is not necessarily the same objective as load equalization. The aim of the latter usually translates into minimization of the squared differences between workstation loads, which means that a small increase in the maximum lead time may yield a substantial reduction in load misbalance, i.e. a better equalization of workload.

The important practical point to be made here is that the line's cycle time is almost always given by the company's marketing that sets production targets. The maximum cycle time set by marketing cannot of course be exceeded by the line (otherwise the production target would not be met), but it is typically useless to reduce the line's cycle time below that value. In this context then, minimizing the cycle time is only required as long as it exceeds the target – once that objective is met, equalization of the workload should be pursued instead.

- **Multiple Operators**

In many industries, in particular automotive, the product being assembled is sufficiently voluminous to allow several operators to work on the product at the same time. Since that possibility does exist, not exploiting it would lead to unnecessarily long assembly lead times, implying a reduced productivity [15]. It is therefore often the case that several operators are active on the product simultaneously.

Once a workstation features more than one operator, the workstation's lead time ceases to be a simple sum of durations of all operations assigned to it. First of all, the workstation as a whole will need the time equal to the lead time of its "slowest" operator to complete all operations assigned to the workstation [15]. Needless to say, since operations are indivisible chunks of work, this is certainly not equal to the sum of durations divided by the number of operators.

More importantly though, the precedence constraints that nearly always exist among the operations assigned to a workstation, may introduce gaps of idle (waiting) time between operations, whenever an operator needs to wait for another one to finish a task. These gaps significantly reduce the efficiency of the workstation and must obviously be reduced as much as possible. This transforms the initially trivial computation of a workstation's lead-time (i.e., a simple sum of operation durations) into a full-fledged scheduling problem [16].

4.6 Line Balancing Results

Key outputs from the simulated performance were tracked to understand the behaviour of the production line. From the simulation, it can be seen that we have a bottleneck in some station. By observing the crystal report at the parts waiting time, the station that has the most parts waiting can be determined for line balancing. The bottlenecks in the flow were identified and the associated capacities adjusted in consultation with the engineers until a smooth flow was achieved. For APEC 20T, stations conveyor 2 and unloader have the most number of canister waiting or in other terms bottleneck are occurring while for APEC 30T, stations Conveyor 1, stamping and unloader have the most number of canister waiting. This line jam can affect the rate of production. Thus line balancing has to be carried out to smoother the production.

The number of parts waiting at the unloader and trimming machine is dramatically reduced. Number of throughput is very high and we can lower it down to get a clean operation without waiting parts at any station. After line balancing exercise was conducted, the parts waiting have been reduced in numbers to be less than 10 parts waiting at every station. This is an example of a smooth production. Below is the number waiting for APEC20T and APEC30T:

Table 4.10: APEC20T, before line balancing

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	4.6369	12.02	0.2947	21.9637	0.00	360.00
Access Conveyor 2.Queue	175.38	169.76	61.4050	402.97	0.00	1519.00
Arrange.Queue	0.00466704	0.01	0.00	0.02111926	0.00	31.0000
Feeding Process.Queue	14.7745	29.89	0.00	55.3833	0.00	916.00
Load to Trimming Machine. Queue	0.8001	2.10	0.02337434	3.8234	0.00	68.0000
Pick And Fill.Queue	0.3428	0.87	0.00	1.5882	0.00	32.0000
Stamping Process.Queue	18.2620	19.98	0.00	33.2762	0.00	729.00
Ten.Queue	4.4328	0.14	4.2890	4.5942	0.00	10.0000
Trimming Process.Queue	24.0643	66.80	0.00	120.32	0.00	1393.00
Unload from Stamping Machine. Queue	29.1398	38.08	0.00	73.7175	0.00	668.00
Unload from Trimming Machine. Queue	32.1870	34.36	0.00	62.5472	0.00	906.00

Table 4.11: Apec20T, after line balancing

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.1651	0.05	0.1244	0.2593	0.00	1.0000
Access Conveyor 2.Queue	0.1588	0.01	0.1514	0.1675	0.00	1.0000
Arrange.Queue	0.00519042	0.01	0.00	0.02266751	0.00	34.0000
Feeding Process.Queue	7.8215	14.04	0.00	39.8496	0.00	459.00
Load to Trimming Machine. Queue	0.00621026	0.02	0.00	0.04347179	0.00	20.0000
Pick And Fill.Queue	0.1762	0.25	0.00	0.7229	0.00	34.0000
Stamping Process.Queue	5.9413	8.95	0.00	22.2013	0.00	371.00
Ten.Queue	4.5096	0.06	4.4275	4.6178	0.00	10.0000
Trimming Process.Queue	1.9468	4.73	0.00	13.5515	0.00	351.00
Unload from Stamping Machine. Queue	0.1118	0.27	0.00	0.7827	0.00	72.0000
Unload from Trimming Machine. Queue	1.8526	3.38	0.00	9.9711	0.00	282.00

Table 4.12: Apec30T, before line balancing

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	115.34	64.36	35.9958	174.01	0.00	1182.00
Access Conveyor 2.Queue	22.2014	61.63	0.00	111.01	0.00	832.00
Arrange.Queue	14.7762	15.23	6.7173	36.3129	0.00	235.00
Feeding Process.Queue	13.8965	37.28	0.00	67.5976	0.00	1040.00
Load to Trimming Machine. Queue	11.5732	24.94	0.00	46.8055	0.00	958.00
Pick And Fill.Queue	18.5425	17.06	7.1946	37.9853	0.00	236.00
Stamping Process.Queue	73.3872	118.19	0.00	239.23	0.00	1551.00
Ten.Queue	4.2297	0.66	3.7882	4.8603	0.00	10.0000
Trimming Process.Queue	47.7425	119.32	0.00	218.99	0.00	1530.00
Unload from Stamping Machine. Queue	234.44	246.13	45.7287	544.52	0.00	1642.00
Unload from Trimming Machine. Queue	59.1871	164.30	0.00	295.94	0.00	2352.00

Table 4.13: Apec30T, after line balancing

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	111.04	132.88	0.3182	239.82	0.00	2120.00
Access Conveyor 2.Queue	4.9784	10.80	0.1904	20.2661	0.00	345.00
Arrange.Queue	0.0934	0.18	0.00	0.3227	0.00	112.00
Feeding Process.Queue	18.9277	47.14	0.00	86.5614	0.00	1241.00
Load to Trimming Machine. Queue	113.03	273.35	0.00	505.21	0.00	1648.00
Pick And Fill.Queue	1.6856	3.44	0.00	6.3725	0.00	113.00
Stamping Process.Queue	72.4440	96.79	0.00	202.07	0.00	1502.00
Ten.Queue	4.1030	0.93	3.4395	5.2770	0.00	10.0000
Trimming Process.Queue	78.0393	196.33	0.00	359.97	0.00	1667.00
Unload from Stamping Machine. Queue	168.44	137.00	42.2323	293.84	0.00	1503.00
Unload from Trimming Machine. Queue	8.9838	24.94	0.00	44.9192	0.00	821.00

Improvements were made in terms of reducing the unnecessary delay such as:

- The rolling delay station is deleted as it is not necessary to use the slide to roll the canister into the operator station. This is because only one operator handling the end station. Therefore there is no need to roll into the canister to the station which its capacity is more than the capacity that can be handled by an operator. A single operator can handle not more than 10 canisters at one time but the table can accommodate about 100 canisters. Therefore it would be a waste there.

- The conveyor length also is decrease as it took longer time to transfer the canister where else the exact distance from stamping machine to trimming machine is less than the conveyor length. Also the conveyor 2 length which transfer the canister from the trimming machine. The conveyor 2 is either its length is decreased or its speed is increased. In this project, conveyor 2 speed is increased two times its original speed. It will eliminate the operator idle time as from the observation, operator have idle time due to waiting for the canister to be transferred and rolled to the operator's station.

- Line balancing method is applied to all resources. Synchronization is made between machine and machine and human and machine.

The results show that the bottleneck of each station is recognized and minimized. This shows smooth production rates are achieved. Before the decrease of the time waiting, the resources show a slow productivity. Operator, being humans will have lower utilization rate compare to the machine resources. But now, the average utilization rate is shown in the following figure:

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.1424	0.00	0.1368	0.1438
Loader	0.6835	0.03	0.6580	0.7014
Operator	0.03212047	0.00	0.02930138	0.03389657
Stamping Machine	0.4462	0.01	0.4246	0.4516
Trimming Machine	0.2299	0.01	0.2213	0.2359
Unloader 1	0.7339	0.03	0.7065	0.7531
Unloader 2	0.4155	0.02	0.4000	0.4264

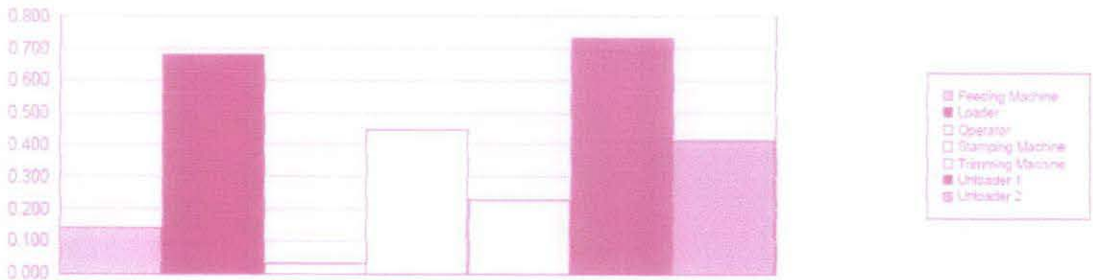


Figure 4.23: APEC20T, before line balancing

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.6811	0.02	0.6429	0.6875
Loader	0.3708	0.01	0.3507	0.3749
Operator	0.02731526	0.00	0.02591673	0.02784029
Stamping Machine	0.5563	0.01	0.5260	0.5625
Trimming Machine	0.4326	0.01	0.4091	0.4373
Unloader 1	0.5316	0.01	0.5026	0.5374
Unloader 2	0.4326	0.01	0.4091	0.4373

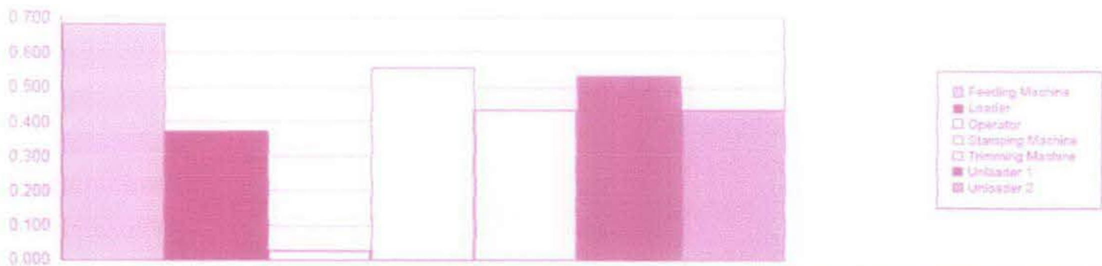


Figure 4.24: APEC20T, after line balancing

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.1469	0.00	0.1469	0.1469
Loader	0.6024	0.07	0.5168	0.6750
Operator	0.8325	0.14	0.6610	0.9531
Stamping Machine	0.4611	0.01	0.4492	0.4641
Trimming Machine	0.2008	0.02	0.1750	0.2128
Unloader 1	0.7378	0.05	0.6911	0.7968
Unloader 2	0.3606	0.03	0.3143	0.3821

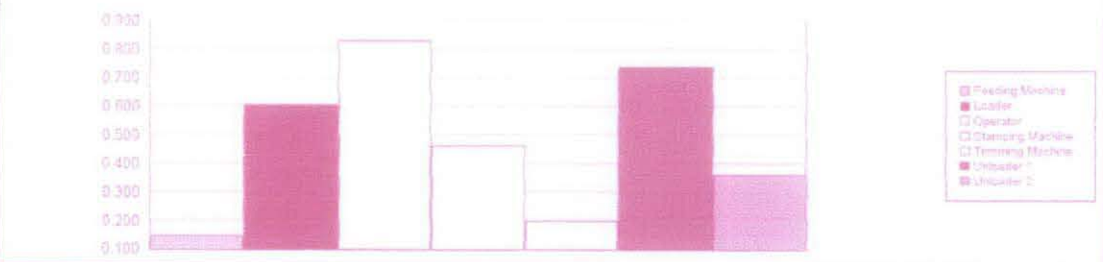


Figure 4.25: APEC30T, before line balancing

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.8769	0.10	0.7359	0.9201
Loader	0.4067	0.04	0.3859	0.4560
Operator	0.04185914	0.00	0.04075575	0.04351071
Stamping Machine	0.6642	0.09	0.5831	0.7291
Trimming Machine	0.4263	0.02	0.4134	0.4414
Unloader 1	0.6520	0.09	0.5969	0.7349
Unloader 2	0.4546	0.02	0.4409	0.4708

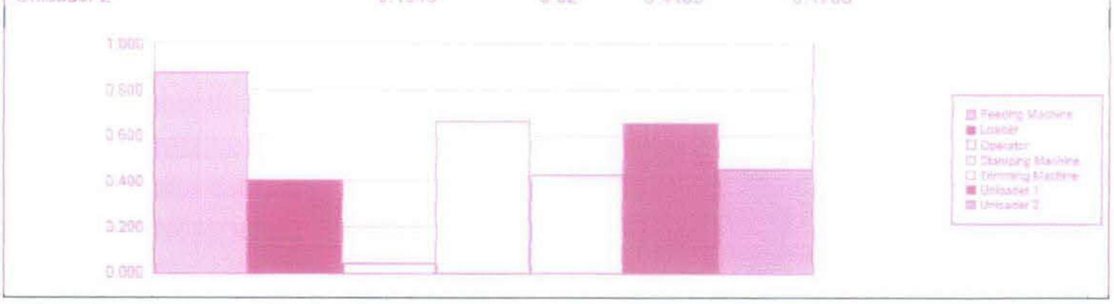


Figure 4.26: APEC30T, after line balancing

The resources utilization has increased slightly. From above figure we can see that some stations have higher utilization than others. For a more detailed improvement, manpower can be added at these stations to improve the productivity and reduce downtime resulting from manpower fatigue. Below show the summary and the analysis of utilization before and after line balancing:

Table 4.14: Line balancing summary

Line Balancing	Apec20T		Apec30T	
	Before	After	Before	After
Feeding Machine	0.1424	0.6811	0.1469	0.8769
Loader	0.6835	0.3708	0.6024	0.4067
Stamping machine	0.4462	0.5563	0.4611	0.6642
Trimming Machine	0.2299	0.4326	0.2008	0.4263
Unloader 1	0.7339	0.5316	0.7378	0.6520
Unloader 2	0.4155	0.4326	0.3606	0.4546

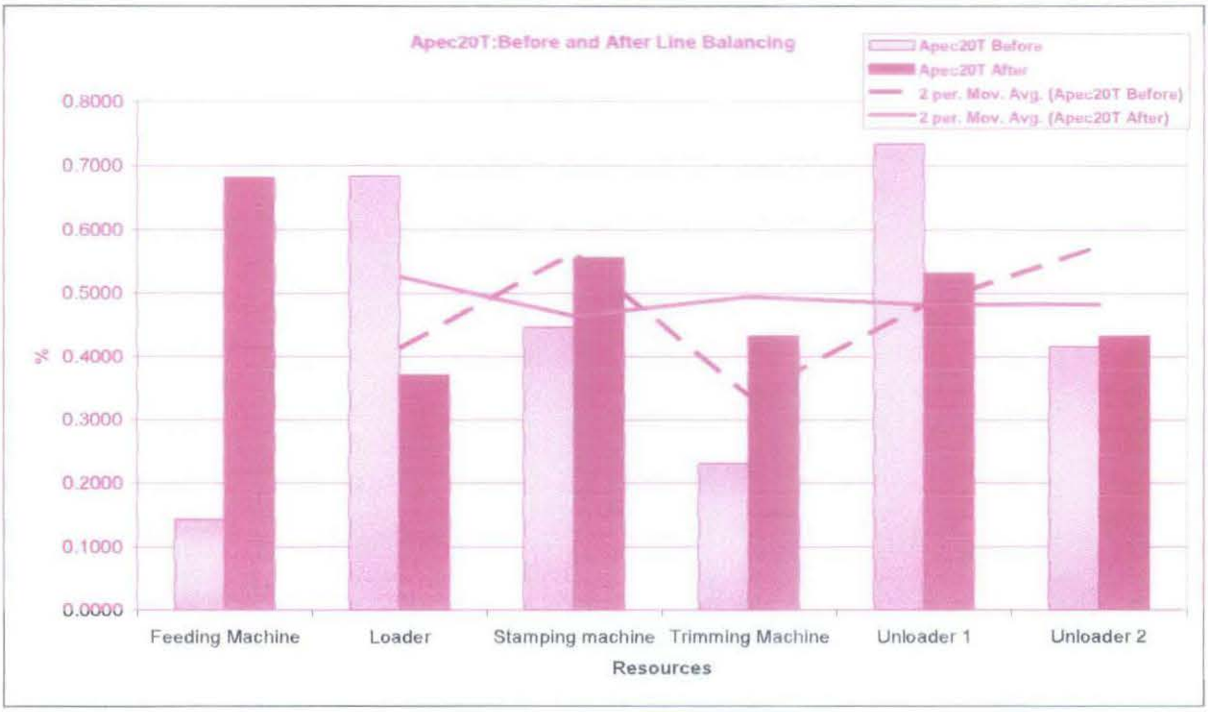


Figure 4.27: Apec20T utilization bar charts comparison

Figure 4.28: APEC30T utilization bar charts comparison

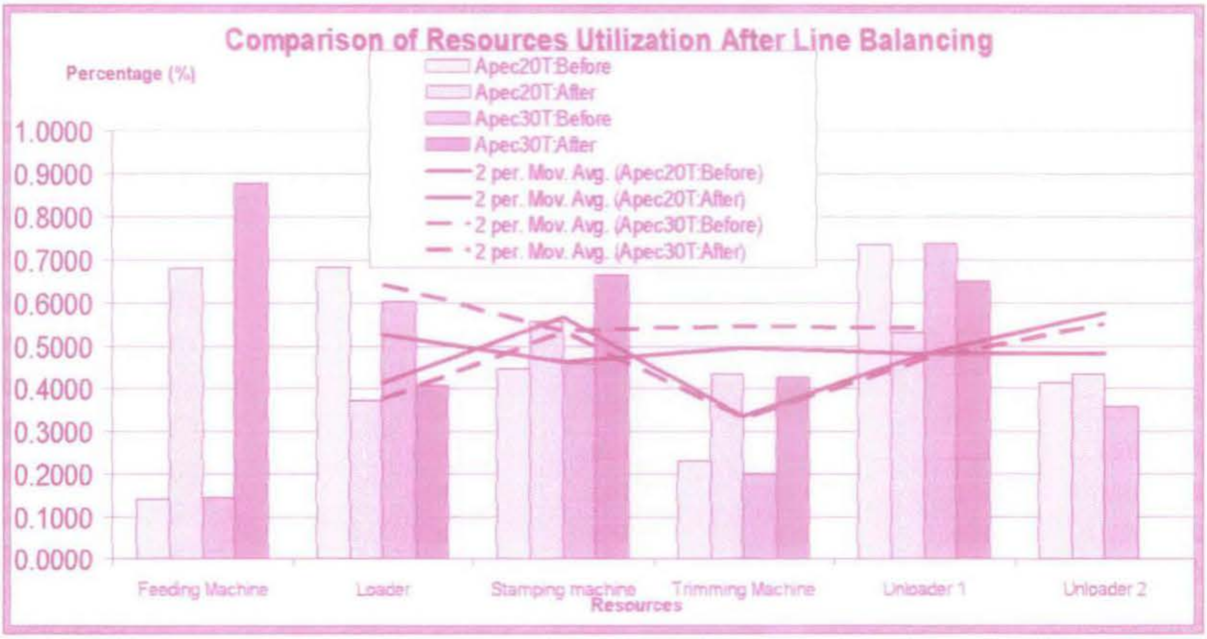


Figure 4.29: APEC20T and APEC30T Utilization rate after line balancing

4.7 "What-if" Analysis Results

The simulation models are often subject to errors caused by the estimated parameter(s) of underlying input distribution function. "What-if" analysis is needed to establish confidence with respect to small changes in the parameters of the input distributions. However the direct approach to "what-if" analysis requires a separate simulation run for each input value. The model allows several "what if" scenarios to be simulated. The model used is the improved line after line balancing method is applied. For example Line APEC20T was improved by increasing and decreasing the cycle time of the machine resources. The conveyor speed is increased doubled from its original speed. Output is increased by 11.813%. Below is the best result chosen after conducting several what-if simulations:

Table 4.15: Production rate after what-if analysis

Output	Before	After	% increase
Apec20T	8237	9210	11.81255311
Apec30T	7354	9130	24.15012238

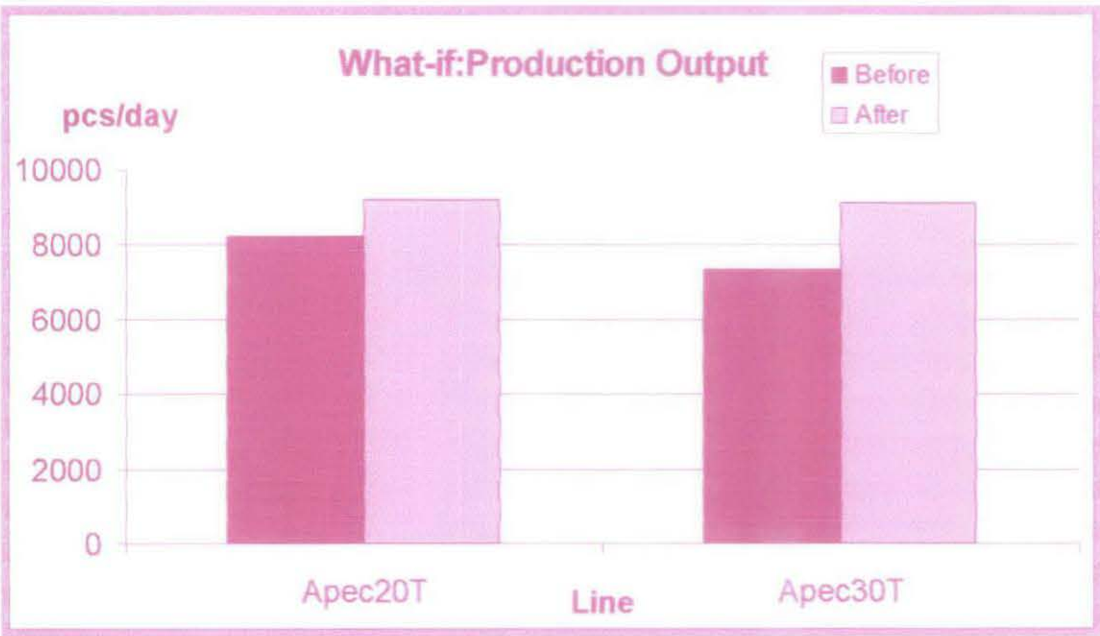


Figure 4.30: Graph of What-if production output for APEC20T and APEC30T

The increase of the production is high but cannot be increased further because it means that the output is coming in at a very fast rate and it will take up more workspace at each station. We want only a minimal increase to meet the objective without unnecessarily spend money on expanding the floor.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Model and simulation process need a lot of practice on manipulating and make use full of the tools and panel of the ARENA. The simulink tools make it easier for analyst to create a model which represents the actual system accurately. Several of commercial simulation software also provides a simulink tools and extra features like 3D animation, mathematical analysis report and etc. Therefore, no wander that a lot of big organizations and institution has make useful of simulation software in a means to improve their system and increase profit. For this project, the objectives of simulation is to enhance productivity of the manufacturing system by decreasing the cycle time and eliminate waste, to evaluate manufacturing system productivity and to create an effective part supply schedule to prevent inventory overflowing. This project reaffirmed the following major guidelines for the simulation process:

- Commit enough resources to gather the required data in a timely fashion. This study took longer than expected primarily due to the extensive effort needed to collect the data.

- Use the right level of abstraction for the simulation model. Too much detail will unnecessarily bog down the analyst in an extensive effort to collect data and build the model. Too little detail results in a model that doesn't provide the needed answers.

- Spend data collection effort for critical data elements. Initially build the model with data that is easily available. Exercise the model to understand the impact of the major factors. Spend time improving the accuracy of the data that has a large impact on the outputs.

- Focus on key outputs. Simulation models can generate multitudes of data. The key performance metrics for the decision should be identified upfront and the model output reports designed to generate those parameters.

- Verify and validate the model as much as possible. Build internal cross checks for verifying the model code. For example, the validation calculations were carried out in two different ways and compared to ensure that model was working as designed, which are by pieces/hour and pieces/day. For a model of this nature where there is no operating system with which to compare, the model is validated based on expert reviews (a consultant from Rockwell Automation).

From the discussion, both ARENA model for APEC20T and APEC30T has error less than 5% for productivity per hour and productivity per day by comparing with the actual system data production index daily. For APEC20T, the percentage error for productivity per hour is 0.548446% and error for productivity per day is 0.24548%. For APEC30T, the percentage error for productivity per hour is 1.5625% and error for productivity per day is 1.5774%. Therefore the ARENA model can be used to evaluate the line performance and improvement can be made on the system based on the ARENA model.

5.2 Recommendation

- There are further work to be considered both is the development of the model and experimental design
- Expand model to include the assembly line and outsource line (paint) of the filtration products.
- Perform additional validation and testing to determine improvements that can be made in the model, the planning process, and in the larger system.

REFERENCES

[1] Flood, J.E. (1998) Telecommunications Switching, Traffic and Networks, Chapter 4: Telecommunications Traffic, New York: Prentice-Hall.

[2] Penttinen A., (Fall 1999). Chapter 9 – Simulation, Lecture Notes: S-38.145 - Introduction to Teletraffic Theory, Helsinki University of Technology

[3] W. David Kelton, Randall P. Sadowski, Deborah A. Sadowski, (1998) Simulation with Arena, Mc Graw Hill 2nd Edition,

[4] Nurul Faezah Mohhid, Modelling and Simulation of a Manufacturing System Using ARENA, University Technology of PETRONAS

[5] www.arenasimulation.com

[6] www.arenasolutions.com/news/news/StartMagazine_Award04.pdf

[7] J. Aune, (1974) System simulation: A technique for sawmill productivity analysis and design.

[8] Chalice, Robert W, (2005), Stop Rising Healthcare Costs Using Toyota Lean Production Methods - 38 Steps for Improvement, ISBN 0-87389-657-2

[9] Eur. J. Oper. Res. 54 (1991) R.M. O'Keefe, I.L. Pitt, Interaction with a visual interactive simulation. And the effect of cognitive style,

[10] K.H. Kempthorne, (1978), "Whole mill simulation of small log sawmills with head sawyers" Proceedings of the 1978 Winter Simulation Conference, Vol. 2, pg. 684-692.

[11] P.Y.K. Chau, (1993), Decision support using traditional simulation and visual interactive simulation. Inf. Decis. Technol. pg 63-76

[12] Annex C, "Data Verification, Validation, and Certification," IEEE 1278.4, Recommended Practice for Distributed Interactive Simulation -- Verification, Validation, and Accreditation, 1997.

[13] Rothenberg, Jeff, "A Discussion of Data Quality for Verification, Validation, and Certification (VV&C) of Data to be Used in Modeling," Rand Project Memorandum PM-709-DMSO, Rand, August 1997. This is an essential guide on

data quality assessment and data V&V. Includes considerations for metadata used in judging data quality and supporting data V&V.

[14] Becker C. and Scholl, A. (2004) `A survey on problems and methods in generalized assembly line balancing, European Journal of Operations Research, in press. Available on-line at http://dx.doi.org/doi:10.1016/j.ejor.2004.07.023. Journal article.

[15] Falkenauer, E. (1997) `A Grouping Genetic Algorithm for Line Balancing with Resource Dependent Task Times', Proceedings of the Fourth International Conference on Neural Information Processing (ICONIP'97), University of Otago, Dunedin, New Zealand, November 24-28, 1997. Pp 464-468. Conference proceedings.

APPENDIXES

Appendix I: MORTGAGE REVIEW CLERK CRYSTAL REPORT

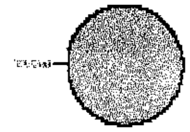
23:31:24 **Category Overview** September 20, 2007

Mortgage Review Analysis

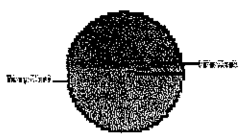
Replications: 1 Time Units: Hours

Key Performance Indicators

All Entities	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	5,541
Wait Cost	0
Total Cost	5,541



All Resources	Average
Busy Cost	5,541 *
Idle Cost	199
Usage Cost	0
Total Cost	5,740



* These costs are included in Entity Costs above.

System	Average
Total Cost	5,740
Number Out	241

Model Filename: C:\Documents and Settings\azwin azhar\My Documents\Mortgage Review Page 1 of [illegible]

Mortgage Review Analysis

Replications: 1 Time Units: Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Value	Maximum Value
Application	1.9180	(Insufficient)	1.0491	2.8730

NVA Time

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Wait Time

	Average	Half Width	Minimum Value	Maximum Value
Application	14.5984	(Insufficient)	0.00	31.2434

Transfer Time

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Other Time

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Total Time

	Average	Half Width	Minimum Value	Maximum Value
Application	16.5144	(Insufficient)	1.4216	33.4522

Cost

VA Cost

	Average	Half Width	Minimum Value	Maximum Value
Application	22.9923	(Insufficient)	12.5532	34.4763

NVA Cost

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Wait Cost

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Other Cost

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Transfer Cost

	Average	Half Width	Minimum Value	Maximum Value
Application	0.00	(Insufficient)	0.00	0.00

Mortgage Review Analysis

Replications: 1 Time Units: Hours

Entity

Cost

Total Cost	Average	Half Width	Minimum Value	Maximum Value
Application	22.9923	(Insufficient)	12.5532	34.4763

Other

Number In	Value
Application	258.00

Number Out	Value
Application	241.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Application	6.9931	(Correlated)	0.00	22.0000

23:31:24 Category Overview September 20, 2007

Mortgage Review Analysis

Replications: 1 Time Units: Hours

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Review Application	1.9160	(Insufficient)	1.0461	2.8790

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Review Application	14.5984	(Insufficient)	0.00	31.3434

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Review Application	16.5144	(Insufficient)	1.4216	33.4522

Accumulated Time

Accum VA Time	Value
Review Application	461.76

Accum Wait Time	Value
Review Application	3518.22

Total Accum Time	Value
Review Application	3979.98

Cost per Entity

VA Cost Per Entity	Average	Half Width	Minimum Value	Maximum Value
Review Application	22.9922	(Insufficient)	12.5532	34.4763

Wait Cost Per Entity	Average	Half Width	Minimum Value	Maximum Value
Review Application	0.00	(Insufficient)	0.00	0.00

Total Cost Per Entity	Average	Half Width	Minimum Value	Maximum Value
Review Application	22.9922	(Insufficient)	12.5532	34.4763

Accumulated Cost

Accum VA Cost	Value
Review Application	5541.14

Model Filename: C:\Documents and Settings\azwin azhar\My Documents\Mortgage Review Page 4 of 8

23:31:24 **Category Overview** September 20, 2007

Mortgage Review Analysis

Replications: 1 Time Units: Hours

Process

Accumulated Cost

Accum Wait Cost	Value
Review Application	0.00

Total Accum Cost	Value
Review Application	8541.14

Other

Number In	Value
Review Application	250.00

Number Out	Value
Review Application	241.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Review Application.Queue	14.6615	(Insufficient)	0.00	31.2134

Cost

Waiting Cost	Average	Half Width	Minimum Value	Maximum Value
Review Application.Queue	0.00	(Insufficient)	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Review Application.Queue	6.0177	(Correlated)	0.00	21.0000

Model Filename: C:\Documents and Settings\azwin azhar\My Documents\Mortgage Review Page 5 of 6

Mortgage Review Analysis

Replications: 1 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Mortgage Review Clerk	0.9854	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Mortgage Review Clerk	0.9854	(Insufficient)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Mortgage Review Clerk	1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization	Value
Mortgage Review Clerk	0.9854

Total Number Seized	Value
Mortgage Review Clerk	242.00

Cost

Busy Cost	Value
Mortgage Review Clerk	5541.14

Idle Cost	Value
Mortgage Review Clerk	199.25

Usage Cost	Value
Mortgage Review Clerk	0.00

Appendix II: ROCKWELL SEEKING APPROVAL LETTER

UNIVERSITI TEKNOLOGI PETRONAS

Assoc Prof. Dr Mohd Noh Karsiti,
Head of Programme
Electrical Electronics Engineering Programme,
University Technology PETRONAS
Bandar Seri Iskandar
31750 Tronoh, Perak.
Tel: 05-3687800

Mr. Mohd Zaini Kamaruddin,
Human Resource Department,
UMW TOYOTA ASSEMBLY SERVICES SDN BHD,
Jalan Utas 15/7, P.O.Box 7052
40915 Shah Alam, Selangor, Malaysia

17th August 2007

Sir,

Seeking Approval for Conducting Data Gathering Exercise in Companies.

With regards to the matter above, I need your consent on having my student Azwin bt Azhar, to gather data for use in her Final Year Project at your company. My staff, Dr Nordin Saad has been liaising with Ms Jessica Tan a consultant to the Rockwell Technologies on the project the student will be conducting. I with the assistance of Dr Nordin Saad, will be overseeing that the student will be doing a research for the university purposes only and abide to the intellectual property issues and the matters that related to it.

2. For this purpose, I seek your approval to allow the student to do site data collection and process/operation observation in your company for a certain period of time depending on the data requires in the modeling.

3. As related to the Final Year Project oral presentation/dissertation the confidentiality of the data/information will be upheld.

Your kind consideration is highly appreciated. Thank you.

Yours truly,

Assoc Prof Dr Mohd Noh Karsiti
Head of Programme
Electrical and Electronics Engineering Programme,
University Technology PETRONAS

cc:

1. Dr. Nordin Saad
Electrical and Electronics Engineering Programme,
University Technology PETRONAS

2. Ms Jessica Tan
Managing Director
JT Consultant Sdn Bhd
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Kawasan 3
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41200 Klang

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Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia

Appendix III: PRODUCTION INDEX DAILY – APEC 20 T

Production Index Daily - Apec 20 T 2

From: 9/1/2007 To: 9/30/2007 Line: Apec 20 T 2

Date	QUANTITY: COGM	QUANTITY: No. of PO run	QUANTITY: Qty Packed	QUANTITY: Qty Produced	QUALITY: Reject Cost Component	QUALITY: Reject Cost In-process	QUALITY: Reject Cost Setting	QUALITY: Reject PPM In-process	QUALITY: Reject Qty In-process	QUALITY: Reject Qty Setting	PRODUCTIVITY: Prod Rate	PRODUCTIVITY: Productivity	PRODUCTIVITY: Productivity Per Hour	AVAILABILITY: Actual Prod Time (h)	AVAILABILITY: Avail Prod Time (h)	AVAILABILITY: Availability	AVAILABILITY: Change over Time (h)	AVAILABILITY: Comp Delay Time (h)	AVAILABILITY: Machine Breakdown Time (h)
9/1/2007	$2,509.38	2	6370	6375		$2.05	$0.00	0.00	5	0	500	110.87%	554	11.50	11.50	100.00%	0.00		
9/2/2007	$1,770.22	1	4322	4325		$1.25	$0.00	0.00	3	0	500	109.25%	545	7.92	8.08	97.94%	0.00		0.17
9/3/2007	$4,660.56	2	11457	11460		$1.25	$0.00	0.00	3	0	500	112.26%	561	20.42	21.00	97.22%	0.00		0.58
9/4/2007	$4,356.58	3	10038	10044		$2.46	$0.00	0.00	6	0	500	105.09%	530	20.08	20.83	96.40%	0.00		0.75
9/5/2007	$4,570.65	2	11160	11167		$2.87	$0.00	0.00	7	0	500	110.75%	554	20.17	20.83	96.80%	0.00		0.67
9/6/2007	$4,751.50	3	11602	11609		$2.87	$0.00	0.00	7	0	500	113.72%	568	20.42	20.83	98.00%	0.00		0.42
9/7/2007	$2,863.52	2	7038	7045		$2.87	$0.00	0.00	7	0	500	112.72%	564	12.50	13.00	96.15%	0.00		0.50
9/10/2007	$3,240.62	3	7916	7919			$0.00	0.00		0	500	82.68%	413	19.08	20.67	92.34%	0.00		1.59
9/11/2007	$3,809.90	2	9298	9301		$1.23	$0.00	0.00	3	0	500	111.09%	555	16.75	21.25	78.82%	0.00		4.50
9/12/2007	$1,831.96	2	4595	4598		$1.25	$0.00	0.00	3	0	500	111.47%	557	8.25	8.42	98.02%	0.00		0.17
9/14/2007	$2,161.51	2	5278	5281		$1.23	$0.00	0.00	3	0	500	104.75%	524	10.08	10.25	98.37%	0.00		0.17
9/19/2007	$2,901.94	2	7087	7090		$1.23	$0.00	0.00	3	0	500	112.59%	563	12.58	12.92	97.42%	0.00		0.33
9/20/2007	$3,970.82	3	9503	9509		$3.27	$0.00	0.00	6	0	500	107.29%	536	18.08	18.75	96.44%	0.00		0.67
9/21/2007	$4,704.08	3	11465	11470		$2.05	$0.00	0.00	5	0	500	110.33%	552	20.83	21.25	98.04%	0.00		0.42
9/22/2007	$1,752.21	1	4278	4281		$1.23	$0.00	0.00	3	0	500	103.78%	519	8.25	8.42	98.02%	0.00		0.17
9/24/2007	$4,757.70	3	11618	11624		$2.46	$0.00	0.00	6	0	500	112.55%	563	20.58	20.92	98.41%	0.00		0.33
9/25/2007	$4,572.39	3	11163	11171		$3.27	$0.00	0.00	8	0	500	111.39%	558	20.08	20.50	97.97%	0.00		0.42
9/26/2007	$4,580.30	3	11207	11215		$3.27	$0.00	0.00	8	0	500	113.09%	565	19.83	20.17	98.35%	0.00		0.33
9/27/2007	$2,310.91	1	5642	5646		$1.64	$0.00	0.00	4	0	500	115.02%	575	9.75	10.00	97.50%	0.00		0.25

Wednesday, January 09, 2008 Production Index Daily - 9/1/2007 - 9/30/2007 - Apec 20 T 2 Page 1 of 2

Production Index Daily - Apec 30 T 1

From: 9/1/2007 To: 9/30/2007 Line: Apec 30 T 1

Date	QUANTITY				QUALITY						PRODUCTIVITY			AVAILABILITY					
	COGM	No. of PO run	Qty Packed	Qty Produced	Reject Cost Component	Reject Cost In-process	Reject Cost Setting	Reject PPM In-process	Reject Qty In-process	Reject Qty Setting	Prod Rate	Productivity	Productivity Per Hour	Actual Prod Time (h)	Avail Prod Time (h)	Availability	Change over Time (h)	Comp Delay Time (h)	Machine Breakdown Time (h)
9/1/2007	$2,253.20	1	5500	5506		$2.05	$0.00	0.00	5	0	500	104.85%	524	10.50	11.58	90.65%	0.00		1.08
9/2/2007	$1,562.71	1	3818	3818			$0.00	0.00		0	500	99.60%	498	7.67	7.92	96.84%	0.00		0.25
9/3/2007	$4,095.41	3	9991	10001		$4.09	$0.00	0.00	10	0	500	102.57%	513	19.50	20.67	94.35%	0.00		1.17
9/4/2007	$4,048.39	2	9877	9891		$5.73	$0.00	0.00	14	0	500	101.01%	505	19.58	21.08	92.89%	0.00		1.50
9/5/2007	$3,973.08	2	9693	9707		$4.91	$0.00	0.00	12	0	500	100.85%	504	19.25	20.33	94.67%	0.00		1.08
9/6/2007	$3,216.74	3	6049	6078		$15.53	$0.00	0.00	29	0	500	107.26%	536	11.33	15.17	74.73%	0.00		3.83
9/7/2007	$3,460.66	2	6985	7020		$19.80	$0.00	0.00	35	0	500	91.07%	455	15.42	17.58	87.68%	1.00		1.17
9/10/2007	$1,078.77	2	5122	5137		$3.15	$0.00	0.00	15	0			270	19.00	20.33	93.44%	0.00		1.33
9/11/2007	$443.94	1	2111	2114		$0.63	$0.00	0.00	3	0			529	4.00	4.83	82.76%	0.00		0.83
9/17/2007	$1,664.80	2	2945	2945			$5.50	0.00		10	500	36.43%	182	16.17	20.17	80.17%	0.00		4.00
9/18/2007	$3,454.54	4	6150	6169		$10.64	$0.00	0.00	19	0	500	68.86%	344	17.92	20.00	89.58%	0.00		2.08
9/19/2007	$1,651.65	2	2971	2991		$11.20	$0.00	0.01	20	0	500	73.25%	366	8.17	10.08	80.99%	0.00		1.92
9/20/2007	$2,664.58	3	5716	5755		$18.28	$10.45	0.01	39	20	500	101.56%	508	11.33	13.83	81.93%	0.25		2.25
9/21/2007	$1,408.88	3	4351	4416		$18.15	$0.00	0.01	65	0	500	103.91%	520	8.50	14.08	60.36%	2.00		3.58
9/22/2007	$590.18	1	2541	2566		$5.75	$0.00	0.01	25	0	500	62.84%	314	8.17	9.50	85.96%	0.00		1.33
9/24/2007	$1,298.12	3	4177	4187		$3.20	$0.00	0.00	10	0	500	100.49%	502	8.33	13.50	61.73%	1.75		3.42
9/25/2007	$3,898.99	2	9517	9526		$2.09	$0.00	0.00	9	0	500	105.26%	527	18.08	20.08	90.04%	0.00		2.00
9/26/2007	$3,770.06	3	9193	9211		$7.37	$0.00	0.00	18	0	500	103.79%	519	17.75	19.92	89.12%	0.00		2.17
9/27/2007	$6,065.01	5	14801	14818		$6.96	$0.00	0.00	17	0	500	105.74%	529	28.00	30.17	92.82%	0.00		2.17

Appendix V: APEC 20 T CATEGORY OVERVIEW CRYSTAL REPORT

[illegible] **Category Overview** February 15, 2008

[illegible]

Unnamed Project

Replications: 5 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	55

Model Filename: C:\Documents and Settings\[illegible]\Desktop\[illegible] Page 1 of 5

Unnamed Project

Replications: 5 Time Units: Hours

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.05433058	0.00	0.05428179	0.05437343	0.05370255	0.05531221

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.0956	0.00	0.0955	0.0957	0.05452571	0.1054

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.05162567	0.00	0.05162567	0.05162567	0.05152203	0.05273040

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.02971442	0.00	0.02968651	0.02974017	0.02851069	0.03075292

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Canister	618.00	0.00	618.00	618.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Canister	605.00	0.00	605.00	605.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	12.1274	0.02	12.1123	12.1425	0.00	19.0000

Unnamed Project

Replications: 5 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.00056079	0.00	0.00056079	0.00056079	0.00	0.00114221
Access Conveyor 2.Queue	0.00097763	0.00	0.00097763	0.00097763	0.00	0.00201713
Arrange.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Feeding Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Load to Trimming Machine. Queue	0.00004137	0.00	0.00004137	0.00004137	0.00	0.00010300
Pick And Fill.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Stamping Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Ten.Queue	0.00797736	0.00	0.00795951	0.00799453	0.00	0.01842997
Trimming Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Stamping Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Trimming Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.3149	0.00	0.3149	0.3149	0.00	1.0000
Access Conveyor 2.Queue	0.5465	0.00	0.5465	0.5465	0.00	2.0000
Arrange.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Feeding Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Load to Trimming Machine. Queue	0.02320722	0.00	0.02320722	0.02320722	0.00	1.0000
Pick And Fill.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Stamping Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Ten.Queue	4.4176	0.00	4.4135	4.4217	0.00	10.0000
Trimming Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Stamping Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Trimming Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00

Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1439	0.00	0.1439	0.1439	0.00	1.0000
Loader	0.6988	0.00	0.6988	0.6988	0.00	1.0000
Operator	0.03424563	0.00	0.03337673	0.03523162	0.00	1.0000
Stamping Machine	0.4518	0.00	0.4518	0.4518	0.00	1.0000
Trimming Machine	0.2348	0.00	0.2348	0.2348	0.00	1.0000
Unloader 1	0.7525	0.00	0.7525	0.7525	0.00	1.0000
Unloader 2	0.4239	0.00	0.4239	0.4239	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1439	0.00	0.1439	0.1439	0.00	1.0000
Loader	0.6988	0.00	0.6988	0.6988	0.00	1.0000
Operator	0.03424563	0.00	0.03337673	0.03523162	0.00	1.0000
Stamping Machine	0.4518	0.00	0.4518	0.4518	0.00	1.0000
Trimming Machine	0.2348	0.00	0.2348	0.2348	0.00	1.0000
Unloader 1	0.7525	0.00	0.7525	0.7525	0.00	1.0000
Unloader 2	0.4239	0.00	0.4239	0.4239	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Loader	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Stamping Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Trimming Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

03:26:00 **Category Overview** February 15, 2008

Values Across All Replications

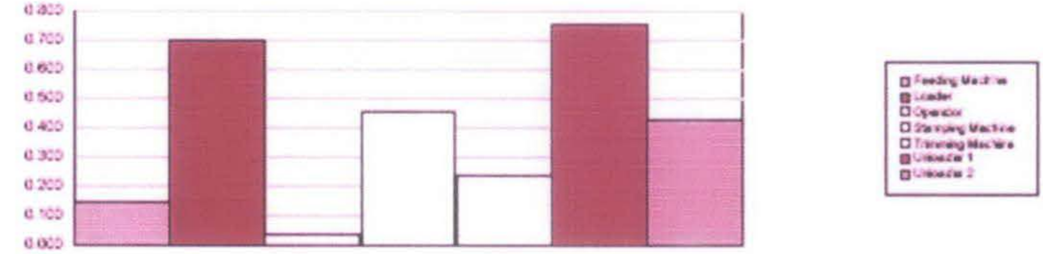
Unnamed Project

Replications: 5 Time Units: Hours

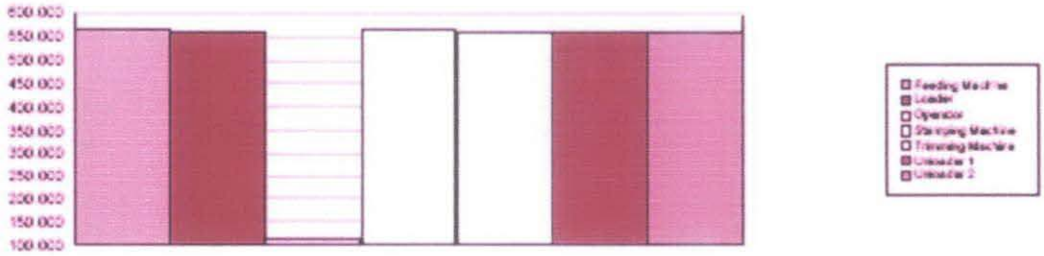
Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.1439	0.00	0.1439	0.1439
Loader	0.6988	0.00	0.6988	0.6988
Operator	0.03424663	0.00	0.03337673	0.03529162
Stamping Machine	0.4518	0.00	0.4518	0.4518
Trimming Machine	0.2348	0.00	0.2348	0.2348
Unloader 1	0.7525	0.00	0.7525	0.7525
Unloader 2	0.4239	0.00	0.4239	0.4239



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	563.00	0.00	563.00	563.00
Loader	561.00	0.00	561.00	561.00
Operator	110.00	0.00	110.00	110.00
Stamping Machine	563.00	0.00	563.00	563.00
Trimming Machine	560.00	0.00	560.00	560.00
Unloader 1	562.00	0.00	562.00	562.00
Unloader 2	559.00	0.00	559.00	559.00



Model Filename: C:\Documents and Settings\azwin azhar\Desktop\STAMPING\Model 3_front Page 5 of 5

09:51:03 **Category Overview** February 15, 2008

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Key Performance Indicators

System

	Average
Number Out	822

Model Filename: C:\Documents and Settings\[illegible]\Desktop\STAMPING\Model 3_[illegible] Page 1 of 5

Unnamed Project

Replications: 5 Time Units: Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.05406536	0.00	0.05382553	0.05423563	0.02528563	0.05570652

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	5.3292	4.97	1.5707	12.0569	0.00083856	25.5044

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.05161113	0.02	0.05102013	0.05385100	0.03614088	1.5450

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.5620	0.50	0.1697	1.2331	0.01234440	2.9214

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
Canister	9654.00	58.70	9581.00	9700.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
Canister	8991.60	646.95	8187.00	9495.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	314.65	280.45	101.31	689.74	0.00	1655.00

Unnamed Project

Replications: 5 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.00933860	0.02	0.00065955	0.03545674	0.00	0.6397
Access Conveyor 2.Queue	0.3066	0.27	0.1103	0.6596	0.00	2.5270
Arrange.Queue	0.00036949	0.00	0.00	0.00043070	0.00	0.01313320
Feeding Process.Queue	0.02273557	0.05	0.00	0.0965	0.00	1.6255
Load to Trimming Machine. Queue	0.00143915	0.02	0.00004155	0.00635803	0.00	0.6514
Pick And Fill.Queue	0.00653917	0.02	0.00	0.03013319	0.00	1.6594
Stamping Process.Queue	0.03316507	0.04	0.00	0.05275572	0.00	1.0074
Ten.Queue	0.00654531	0.00	0.00602501	0.00946740	0.00	1.6573
Trimming Process.Queue	0.04561974	0.13	0.00	0.2291	0.00	1.6641
Unload from Stamping Machine. Queue	0.04913642	0.05	0.00	0.1135	0.00	0.6943
Unload from Trimming Machine. Queue	0.05944185	0.05	0.00	0.1166	0.00	1.3254

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	4.6369	12.02	0.2947	21.9837	0.00	360.00
Access Conveyor 2.Queue	175.38	159.76	61.4250	402.97	0.00	1519.00
Arrange.Queue	0.00456704	0.01	0.00	0.02311525	0.00	31.0000
Feeding Process.Queue	14.7745	29.55	0.00	65.3633	0.00	916.00
Load to Trimming Machine. Queue	0.6001	2.10	0.02357434	3.8234	0.00	58.0000
Pick And Fill.Queue	0.3426	0.57	0.00	1.5662	0.00	32.0000
Stamping Process.Queue	18.2620	19.95	0.00	33.2762	0.00	729.00
Ten.Queue	4.4326	0.14	4.2590	4.5942	0.00	10.0000
Trimming Process.Queue	24.0543	56.80	0.00	122.32	0.00	1293.00
Unload from Stamping Machine. Queue	25.1356	25.05	0.00	73.7175	0.00	568.00
Unload from Trimming Machine. Queue	32.1870	24.32	0.00	62.5472	0.00	906.00

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1424	0.00	0.1368	0.1438	0.00	1.0000
Loader	0.6835	0.03	0.6580	0.7014	0.00	1.0000
Operator	0.03212047	0.00	0.02900133	0.03339657	0.00	1.0000
Stamping Machine	0.4462	0.01	0.4245	0.4516	0.00	1.0000
Trimming Machine	0.2259	0.01	0.2213	0.2359	0.00	1.0000
Unloader 1	0.7339	0.03	0.7065	0.7531	0.00	1.0000
Unloader 2	0.4155	0.02	0.4000	0.4264	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1424	0.00	0.1368	0.1438	0.00	1.0000
Loader	0.6835	0.03	0.6580	0.7014	0.00	1.0000
Operator	0.03212047	0.00	0.02900133	0.03339657	0.00	1.0000
Stamping Machine	0.4462	0.01	0.4245	0.4516	0.00	1.0000
Trimming Machine	0.2259	0.01	0.2213	0.2359	0.00	1.0000
Unloader 1	0.7339	0.03	0.7065	0.7531	0.00	1.0000
Unloader 2	0.4155	0.02	0.4000	0.4264	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Loader	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Stamping Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Trimming Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

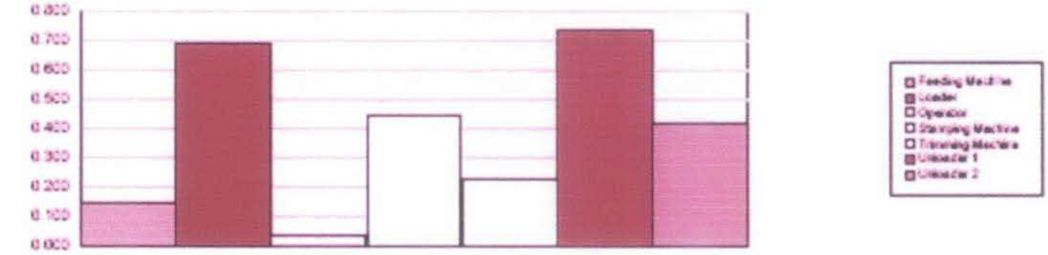
Unnamed Project

Replications: 5 Time Units: Hours

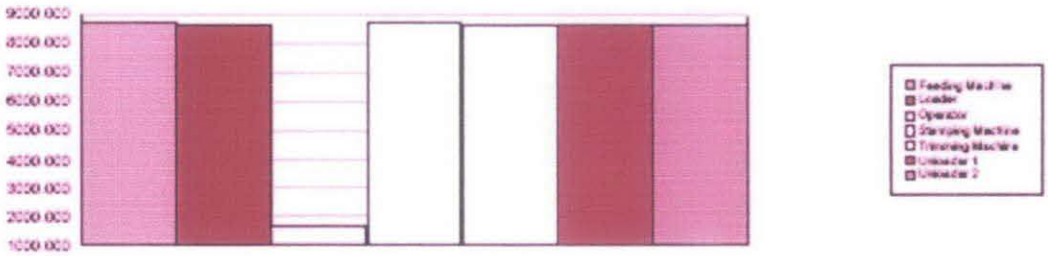
Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.1424	0.00	0.1368	0.1438
Loader	0.6835	0.03	0.6580	0.7014
Operator	0.03212047	0.00	0.02930138	0.03389657
Stamping Machine	0.4462	0.01	0.4246	0.4516
Trimming Machine	0.2299	0.01	0.2213	0.2369
Unloader 1	0.7339	0.03	0.7065	0.7531
Unloader 2	0.4155	0.02	0.4000	0.4264



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	8751.80	236.52	8411.00	8837.00
Loader	8610.00	335.16	8286.00	8835.00
Operator	1634.00	117.41	1488.00	1726.00
Stamping Machine	8731.60	292.59	8310.00	8837.00
Trimming Machine	8609.00	335.16	8287.00	8834.00
Unloader 1	8612.20	334.79	8291.00	8837.00
Unloader 2	8609.00	335.16	8287.00	8834.00



Appendix VI: APEC 30 T CATEGORY OVERVIEW CRYSTAL REPORT

03:35:58 **Category Overview** February 15, 2008

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Key Performance Indicators

System

	Average
Number Out	52

Model Filename: C:\Documents and Settings\azwin azhar\Desktop\STAMPING\Model 3_consta Page 1 of 5

03:35:58 **Category Overview** February 15, 2008

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.07151464	0.00	0.06897742	0.07554636	0.00541452	0.1020

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.1056	0.01	0.0928	0.1164	0.00024036	0.1914

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.05950567	0.00	0.05744654	0.06171653	0.05617210	0.06172057

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.07914130	0.01	0.06295574	0.07950844	0.01185557	0.1420

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
Canister	618.00	0.00	618.00	618.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
Canister	551.80	20.43	532.00	572.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	37.9290	5.15	27.8775	45.7524	0.00	91.0000

Model Filename: C:\Documents and Settings\azwin azhar\Desktop\STAMPING\Model 3_conata Page 2 of 5

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.00082433	0.00	0.00082433	0.00082433	0.00	0.00166440
Access Conveyor 2.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Arrange.Queue	0.00350536	0.01	0.00185653	0.01582653	0.00	0.0906
Feeding Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Load to Trimming Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00
Pick And Fill.Queue	0.01522376	0.01	0.00761212	0.02775283	0.00	0.0946
Stamping Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Ten.Queue	0.00804465	0.00	0.00798342	0.00811076	0.00	0.01866958
Trimming Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Stamping Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Trimming Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.4626	0.00	0.4626	0.4626	0.00	1.0000
Access Conveyor 2.Queue	0.00	0.00	0.00	0.00	0.00	1.0000
Arrange.Queue	0.5268	0.34	0.1262	0.8608	0.00	5.0000
Feeding Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Load to Trimming Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00
Pick And Fill.Queue	0.9304	0.35	0.4665	1.2861	0.00	5.0000
Stamping Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Ten.Queue	4.4401	0.02	4.4208	4.4666	0.00	10.0000
Trimming Process.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Stamping Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unload from Trimming Machine. Queue	0.00	0.00	0.00	0.00	0.00	0.00

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1470	0.00	0.1470	0.1470	0.00	1.0000
Loader	0.6956	0.00	0.6956	0.6956	0.00	1.0000
Operator	0.9516	0.04	0.9008	0.9696	0.00	1.0000
Stamping Machine	0.4643	0.00	0.4643	0.4643	0.00	1.0000
Trimming Machine	0.2352	0.00	0.2352	0.2352	0.00	1.0000
Unloader 1	0.7962	0.00	0.7962	0.7962	0.00	1.0000
Unloader 2	0.4224	0.00	0.4224	0.4224	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1470	0.00	0.1470	0.1470	0.00	1.0000
Loader	0.6956	0.00	0.6956	0.6956	0.00	1.0000
Operator	0.9516	0.04	0.9005	0.9696	0.00	1.0000
Stamping Machine	0.4643	0.00	0.4643	0.4643	0.00	1.0000
Trimming Machine	0.2352	0.00	0.2352	0.2352	0.00	1.0000
Unloader 1	0.7962	0.00	0.7962	0.7962	0.00	1.0000
Unloader 2	0.4224	0.00	0.4224	0.4224	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Loader	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Stamping Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Trimming Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

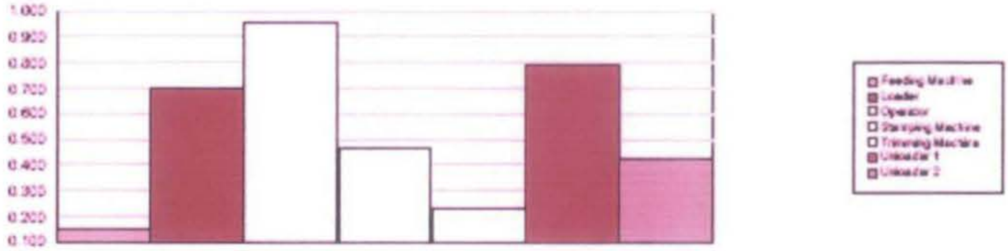
Unnamed Project

Replications: 5 Time Units: Hours

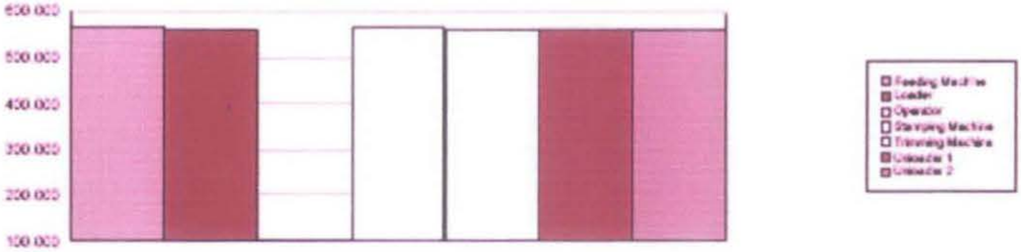
Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.1470	0.00	0.1470	0.1470
Loader	0.6956	0.00	0.6956	0.6956
Operator	0.9516	0.04	0.9008	0.9696
Stamping Machine	0.4643	0.00	0.4643	0.4643
Trimming Machine	0.2352	0.00	0.2352	0.2352
Unloader 1	0.7962	0.00	0.7962	0.7962
Unloader 2	0.4224	0.00	0.4224	0.4224



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	563.00	0.00	563.00	563.00
Loader	558.00	0.00	558.00	558.00
Operator	102.80	3.56	99.00	107.00
Stamping Machine	563.00	0.00	563.00	563.00
Trimming Machine	557.00	0.00	557.00	557.00
Unloader 1	562.00	0.00	562.00	562.00
Unloader 2	557.00	0.00	557.00	557.00



09:59:53 **Category Overview** February 15, 2008

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	747

Model Filename: C:\Documents and Settings\azwin azhar\Desktop\STAMPING\Model 3_consta Page 1 of 5

Unnamed Project

Replications: 5 Time Units: Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.07188769	0.00	0.07022811	0.07283554	0.02537019	0.1460

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	6.6135	3.33	3.9759	11.5577	0.00	47.2336

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.1206	0.17	0.05638015	0.3653	0.00614942	21.0941

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	1.4972	0.62	0.8878	2.2175	[illegible]	4.3384

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
Canister	10166.60	74.44	10056.00	10213.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
Canister	7569.40	1,387.13	6251.00	9302.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	965.36	412.49	514.33	1325.45	0.00	3962.00

Unnamed Project

Replications: 5 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.2136	0.13	0.05473904	0.3619	0.00	2.0937
Access Conveyor 2.Queue	0.04410119	0.12	0.00	0.2205	0.00	0.6900
Arrange.Queue	0.3181	0.33	0.1444	0.7881	0.00	2.5314
Feeding Process.Queue	0.02470459	0.07	0.00	0.1202	0.00	1.2451
Load to Trimming Machine.Queue	0.00416281	0.01	0.00	0.01758468	0.00	2.0456
Pick And Fill.Queue	0.3305	0.35	0.1465	0.8063	0.00	2.5350
Stamping Process.Queue	0.1297	0.21	0.00	0.4253	0.00	2.7562
Ten.Queue	0.00977725	0.00	0.00755977	0.01123389	0.00	4.7357
Trimming Process.Queue	0.08659531	0.23	0.00	0.4350	0.00	2.3266
Unload from Stamping Machine.Queue	0.4142	0.45	0.05123433	0.9371	0.00	2.9156
Unload from Trimming Machine.Queue	0.1176	0.33	0.00	0.5673	0.00	2.0921

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	115.34	84.35	35.9953	174.01	0.00	1162.00
Access Conveyor 2.Queue	22.2014	61.63	0.00	111.01	0.00	832.00
Arrange.Queue	14.7762	15.23	6.7173	36.3129	0.00	236.00
Feeding Process.Queue	13.6965	37.28	0.00	67.8576	0.00	1040.00
Load to Trimming Machine.Queue	11.5732	24.94	0.00	46.3055	0.00	853.00
Pick And Fill.Queue	18.5429	17.05	7.1946	37.9663	0.00	236.00
Stamping Process.Queue	73.3872	116.19	0.00	239.23	0.00	1551.00
Ten.Queue	4.2297	0.55	3.7862	4.8603	0.00	10.0000
Trimming Process.Queue	47.7425	119.32	0.00	218.93	0.00	1530.00
Unload from Stamping Machine.Queue	234.44	246.13	45.7267	544.52	0.00	1542.00
Unload from Trimming Machine.Queue	59.1871	154.32	0.00	295.94	0.00	2382.00

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1469	0.00	0.1469	0.1469	0.00	1.0000
Loader	0.6024	0.07	0.5169	0.6760	0.00	1.0000
Operator	0.6323	0.14	0.5610	0.9531	0.00	1.0000
Stamping Machine	0.4511	0.01	0.4492	0.4641	0.00	1.0000
Trimming Machine	0.2008	0.02	0.1750	0.2125	0.00	1.0000
Unloader 1	0.7376	0.05	0.6911	0.7963	0.00	1.0000
Unloader 2	0.3606	0.03	0.3143	0.3821	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1469	0.00	0.1469	0.1469	0.00	1.0000
Loader	0.6024	0.07	0.5169	0.6760	0.00	1.0000
Operator	0.6323	0.14	0.5610	0.9531	0.00	1.0000
Stamping Machine	0.4511	0.01	0.4492	0.4641	0.00	1.0000
Trimming Machine	0.2008	0.02	0.1750	0.2125	0.00	1.0000
Unloader 1	0.7376	0.05	0.6911	0.7963	0.00	1.0000
Unloader 2	0.3606	0.03	0.3143	0.3821	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Loader	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Stamping Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Trimming Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

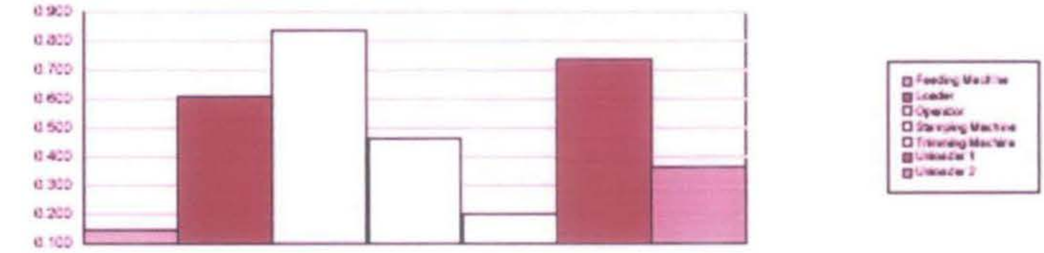
Unnamed Project

Replications: 5 Time Units: Hours

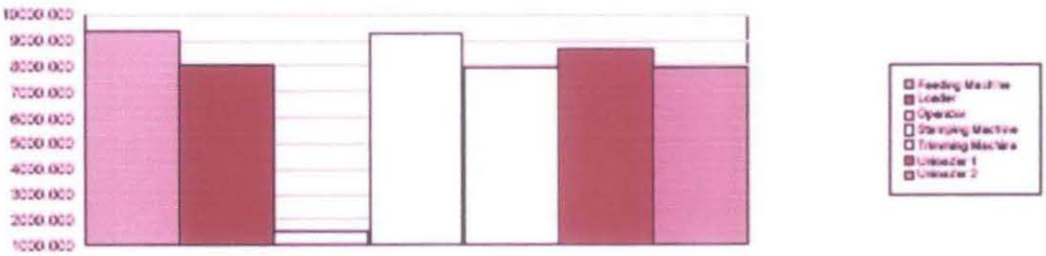
Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.1469	0.00	0.1469	0.1469
Loader	0.6024	0.07	0.5168	0.6750
Operator	0.8325	0.14	0.6610	0.9531
Stamping Machine	0.4611	0.01	0.4492	0.4641
Trimming Machine	0.2006	0.02	0.1750	0.2128
Unloader 1	0.7378	0.05	0.6911	0.7968
Unloader 2	0.3606	0.03	0.3143	0.3821



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	9377.00	0.00	9377.00	9377.00
Loader	8051.60	956.32	6906.00	9023.00
Operator	1497.60	150.77	1360.00	1671.00
Stamping Machine	9317.20	166.00	9076.00	9377.00
Trimming Machine	7926.60	755.87	6906.00	8400.00
Unloader 1	8682.20	562.75	8133.00	9377.00
Unloader 2	7926.60	755.87	6906.00	8400.00



Appendix VII: APEC 20 T CRYSTAL REPORT AFTER LINE BALANCING AND WHAT IF ANALYSIS

17:57:45 **Category Overview** March 29, 2008

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	921

Model Filename: C:\Documents and Settings\azwin azhar\My Documents\STAMPING\Model 3_ Page 1 of 5

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.04926464	0.00	0.04906906	0.04942522	0.03480330	0.05091469

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	4.8070	2.33	3.1070	7.5993	0.04203079	18.0399

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.05128026	0.00	0.05101358	0.05155167	0.02614880	0.1556

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.5036	0.29	0.3323	0.7825	0.02614319	1.6231

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
Canister	10734.80	45.15	10687.00	10781.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
Canister	10079.40	497.58	9352.00	10572.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	312.51	134.94	203.02	499.47	0.00	1141.80

Unnamed Project

Replications: 5 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.00037825	0.00	0.00027774	0.00057899	0.00	0.00186333
Access Conveyor 2.Queue	0.00035721	0.00	0.00033694	0.00037532	0.00	0.00077381
Arrange.Queue	0.00011757	0.00	0.00	0.00050512	0.00	0.01425149
Feeding Process.Queue	0.01264979	0.03	0.00	0.08854651	0.00	0.9321
Load to Trimming Machine. Queue	0.00001362	0.00	0.00	0.00009675	0.00	0.04285364
Pick And Fill.Queue	0.00399711	0.01	0.00	0.01810905	0.00	0.7576
Stamping Process.Queue	0.01346258	0.02	0.00	0.04938894	0.00	0.8229
Ten.Queue	0.00395546	0.00	0.00360636	0.01023738	0.00	0.9491
Trimming Process.Queue	0.00462462	0.01	0.00	0.01220292	0.00	1.4353
Unload from Stamping Machine. Queue	0.00024850	0.00	0.00	0.00173650	0.00	0.1565
Unload from Trimming Machine. Queue	0.00411324	0.01	0.00	0.02016593	0.00	0.6252

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.1651	0.05	0.1244	0.2593	0.00	1.0000
Access Conveyor 2.Queue	0.1588	0.01	0.1514	0.1675	0.00	1.0000
Arrange.Queue	0.00519042	0.01	0.00	0.02256751	0.00	34.0000
Feeding Process.Queue	7.8215	14.34	0.00	39.8495	0.00	459.00
Load to Trimming Machine. Queue	0.00521026	0.02	0.00	0.04347179	0.00	22.0000
Pick And Fill.Queue	0.1762	0.25	0.00	0.7229	0.00	34.0000
Stamping Process.Queue	5.9413	8.95	0.00	22.2013	0.00	371.00
Ten.Queue	4.5096	0.05	4.4275	4.5175	0.00	10.0000
Trimming Process.Queue	1.9456	4.73	0.00	13.5515	0.00	351.00
Unload from Stamping Machine. Queue	0.1116	0.27	0.00	0.7227	0.00	72.0000
Unload from Trimming Machine. Queue	1.6526	3.38	0.00	9.3711	0.00	282.00

Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1438	0.00	0.1433	0.1438	0.00	1.0000
Loader	0.7014	0.00	0.7013	0.7014	0.00	1.0000
Operator	0.03602153	0.00	0.03418242	0.03720979	0.00	1.0000
Operator 2nd	0.00	0.00	0.00	0.00	0.00	0.00
Stamping Machine	0.4516	0.00	0.4516	0.4516	0.00	1.0000
Trimming Machine	0.2359	0.00	0.2358	0.2359	0.00	1.0000
Unloader 1	0.7531	0.00	0.7531	0.7531	0.00	1.0000
Unloader 2	0.4264	0.00	0.4264	0.4264	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1438	0.00	0.1433	0.1438	0.00	1.0000
Loader	0.7014	0.00	0.7013	0.7014	0.00	1.0000
Operator	0.03602153	0.00	0.03418242	0.03720979	0.00	1.0000
Operator 2nd	0.00	0.00	0.00	0.00	0.00	0.00
Stamping Machine	0.4516	0.00	0.4516	0.4516	0.00	1.0000
Trimming Machine	0.2359	0.00	0.2358	0.2359	0.00	1.0000
Unloader 1	0.7531	0.00	0.7531	0.7531	0.00	1.0000
Unloader 2	0.4264	0.00	0.4264	0.4264	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Loader	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator 2nd	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Stamping Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Trimming Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

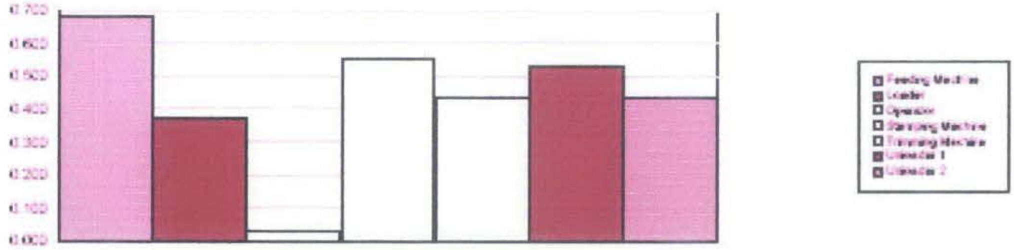
Unnamed Project

Replications: 5 Time Units: Hours

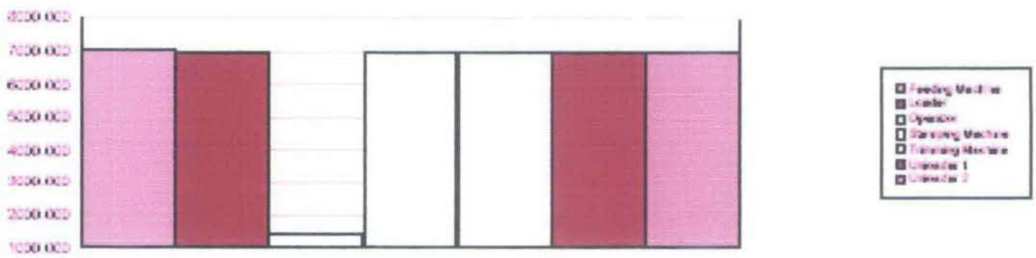
Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.6811	0.02	0.6429	0.6875
Loader	0.3708	0.01	0.3507	0.3749
Operator	0.02731526	0.00	0.02591673	0.02784029
Stamping Machine	0.5563	0.01	0.5260	0.5625
Trimming Machine	0.4326	0.01	0.4091	0.4373
Unloader 1	0.5316	0.01	0.5026	0.5374
Unloader 2	0.4326	0.01	0.4091	0.4373



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	7004.43	160.45	6611.00	7070.00
Loader	6990.57	156.92	6611.00	7068.00
Operator	1395.43	31.31	1320.00	1412.00
Stamping Machine	6991.86	157.28	6611.00	7069.00
Trimming Machine	6990.14	156.71	6611.00	7067.00
Unloader 1	6991.71	157.28	6611.00	7069.00
Unloader 2	6990.00	156.71	6611.00	7067.00



Appendix VIII: APEC 30 T CRYSTAL REPORT AFTER LINE BALANCING AND WHAT IF ANALYSIS

18:57:32 **Category Overview** March 22, 2008

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	913

Model Filename: C:\Documents and Settings\azwin azhar\My Documents\STAMPING\Model 3_ Page 1 of 5

Unnamed Project

Replications: 5 Time Units: Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.03973646	0.00	0.03540095	0.04039781	0.00399750	0.14255856

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	7.9322	6.55	0.8039	15.7562	0.00	59.2830

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.06550297	0.00	0.05438370	0.05630613	0.03664597	1.4244

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.00	0.00	0.00	0.00	0.00	0.00

Total Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	0.6579	0.70	0.1519	1.5664	0.01055417	5.9268

Other

Number In

	Average	Half Width	Minimum Average	Maximum Average
Canister	11305.60	126.99	11136.00	11413.00

Number Out

	Average	Half Width	Minimum Average	Maximum Average
Canister	9779.20	1,425.89	7923.00	10957.00

WIP

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Canister	505.01	452.73	103.54	1014.95	0.00	3715.00

Values Across All Replications

Unnamed Project

Replications: 5 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	0.04284132	0.12	0.00053315	0.2121	0.00	0.6765
Access Conveyor 2.Queue	0.00332712	0.00	0.00031723	0.00034539	0.00	0.00077735
Arrange.Queue	0.00152126	0.00	0.00	0.00739471	0.00	0.05744522
Feeding Process.Queue	0.01596665	0.04	0.00	0.07726575	0.00	3.3477
Load to Trimming Machine. Queue	0.01331468	0.02	0.00	0.03522670	0.00	0.9551
Pick And Fill.Queue	0.03524017	0.05	0.00	0.1445	0.00	2.0154
Stamping Process.Queue	0.4642	0.92	0.00	1.7040	0.00	4.6665
Ten.Queue	0.00944177	0.00	0.00644929	0.01063765	0.00	3.1705
Trimming Process.Queue	0.04396392	0.12	0.00	0.2180	0.00	1.7262
Unload from Stamping Machine. Queue	0.1918	0.32	0.02624680	0.6465	0.00	3.5979
Unload from Trimming Machine. Queue	0.1040	0.29	0.00	0.5175	0.00	1.9355

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Access Conveyor 1.Queue	36.1276	65.62	0.2645	126.30	0.00	1215.00
Access Conveyor 2.Queue	0.1572	0.01	0.1595	0.1726	0.00	1.0000
Arrange.Queue	0.07520882	0.20	0.00	0.2655	0.00	119.00
Feeding Process.Queue	51.0962	136.37	0.00	247.50	0.00	2095.00
Load to Trimming Machine. Queue	6.7497	9.35	0.00	17.6207	0.00	265.00
Pick And Fill.Queue	1.8930	3.35	0.00	7.1422	0.00	120.00
Stamping Process.Queue	297.62	553.45	0.00	1045.37	0.00	2930.00
Ten.Queue	4.4176	1.19	3.2231	5.2929	0.00	10.0000
Trimming Process.Queue	25.0062	55.41	0.00	105.92	0.00	1079.00
Unload from Stamping Machine. Queue	149.15	219.32	14.6516	397.59	0.00	2103.00
Unload from Trimming Machine. Queue	51.9477	143.43	0.00	252.69	0.00	1695.00

Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1457	0.00	0.1411	0.1469	0.00	1.0000
Loader	0.3736	0.05	0.3023	0.4149	0.00	1.0000
Operator	0.04366563	0.01	0.03561506	0.04869518	0.00	1.0000
Stamping Machine	0.4504	0.01	0.4458	0.4641	0.00	1.0000
Trimming Machine	0.2036	0.03	0.1663	0.2273	0.00	1.0000
Unloader 1	0.7760	0.03	0.7294	0.7968	0.00	1.0000
Unloader 2	0.3657	0.05	0.3022	0.4062	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	0.1457	0.00	0.1411	0.1469	0.00	1.0000
Loader	0.3736	0.05	0.3023	0.4149	0.00	1.0000
Operator	0.04366563	0.01	0.03561506	0.04869518	0.00	1.0000
Stamping Machine	0.4504	0.01	0.4458	0.4641	0.00	1.0000
Trimming Machine	0.2036	0.03	0.1663	0.2273	0.00	1.0000
Unloader 1	0.7760	0.03	0.7294	0.7968	0.00	1.0000
Unloader 2	0.3657	0.05	0.3022	0.4062	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Feeding Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Loader	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Operator	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Stamping Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Trimming Machine	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Unloader 2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

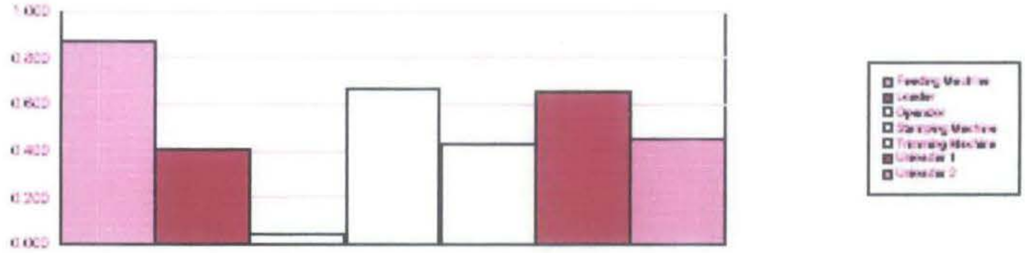
Unnamed Project

Replications: 5 Time Units: Hours

Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	0.8769	0.10	0.7359	0.9201
Loader	0.4067	0.04	0.3659	0.4560
Operator	0.04165914	0.00	0.04075575	0.04351071
Stamping Machine	0.6642	0.09	0.5831	0.7291
Trimming Machine	0.4263	0.02	0.4134	0.4414
Unloader 1	0.6520	0.09	0.5969	0.7349
Unloader 2	0.4546	0.02	0.4409	0.4708



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Feeding Machine	9929.00	1,124.78	8333.00	10419.00
Loader	8717.60	782.42	8271.00	9774.00
Operator	1698.40	66.23	1646.00	1756.00
Stamping Machine	9491.20	1,231.38	8332.00	10418.00
Trimming Machine	8525.80	341.72	8270.00	8829.00
Unloader 1	9037.20	1,204.66	8273.00	10186.00
Unloader 2	8526.40	342.17	8269.00	8829.00