

**THE ANALYTICAL APPROACH TO  
IMPROVE CAPACITY OF AN  
UNRELIABLE MULTISTAGE  
PRODUCTION LINE**

**Muhammad Marsudi**

# **THE ANALYTICAL APPROACH TO IMPROVE CAPACITY OF AN UNRELIABLE MULTISTAGE PRODUCTION LINE**

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OF AN UNRELIABLE MULTISTAGE PRODUCTION LINE

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## FOREWORD

The manufacturing industry has to strive continually in order to increase efficiency in product development so as to stay competitive and sustainable. However, the development of new products is costly as it normally requires a new manufacturing system and production resources. This situation is forcing the manufacturing industry to optimize the utilization of existing manufacturing system to enable the development of mixed products that is, a combination of existing and new products. A manufacturing system capable of processing mixed products normally has a complex structure due to its multi-stage production lines for example in the automotive industry. The production capacity of this type of manufacturing system has to be optimized in order to reduce time-to-design, optimize utilization of multi-stage product lines and analyze cycle time of the manufacturing system. Based on the statement above, this book discusses the development of a mathematical model that has capability to analyze capacity of production system consisting of more than ‘three stations, two buffers, two products’ by using a spreadsheet MS Excel. Clearly, this book describes the analytical approach to improve capacity of an unreliable multistage production line.

I hope this book can be a reference for readers in understanding the problems related to the optimization of the manufacturing system. And finally thanks to all those who helped the publication of this book. Thank you.

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## **CHAPTER I**

### **INTRODUCTION**

Modern production lines increasingly accentuate small batch production with high variability of products. More importantly, the large scale of automation and integration of manufacturing systems, which has become possible with the availability of low cost computers and communication networks, has permitted more efficiency in meeting production requirements and has lead to lower cost and higher-quality products. However, the capacity of such a system is dependent upon the reliability of all its components parts that is when an accidental breakdown occurs it is critical to quickly isolate the causes and take an appropriate corrective action. Accidental breakdown can affect the availability of production system, especially multistage production system, that results an substantial loss of capacity. A multistage production system itself is a production line composed of stations connected in series and every two successive stations are separated by a finite capacity buffer, and additionally the system also can process the mix of products.

The problem, is it possible to analyze and improve the capacity of an unreliable multistage production line? One of the solutions to solve this problem is by creating a model to estimate the capacity of this type of production systems where many parameters are considered. These parameters would be set-up time, the product mix, and the reliability of the stations composing the system. Recent review of the literature has shown that the most of the models published in this area did focus on one-product type environment (Dossenbach, 2000, Holmstrom, 2006). Buzacott (1993) presented a model for a production line composed of two stations and one buffer. Later, Gershwin and Berman (1995) reformulated the same problem tackled by Buzacott (1993) and presented a different approach to solve it. Both models are based on the Markov chain modelling techniques.

All the above-mentioned papers studied the case of production lines processing one product type. Walid A. Kader (2006) presented more specific to the study of a multi-product production line composed of unreliable machines and finite buffers with the aim to estimate the capacity by taking into account the failure and repair of the stations and the contribution of buffers in terms of cycle time minimization. There are two production systems studied by Walid A. Kader (2006), firstly is the system that consists of 2 stations 1 buffer 2 products, and secondly is the system consisting of 3 stations 2 buffers 2 products.

Based on the above description, this book will discuss the study of development of a mathematical model that has capability to analyze capacity of production system consisting of more than ‘three stations, two buffers, two products’ by using a spreadsheet

MS Excel. The scope of discussion is focused on automotive product with metal material produced by a multistage production line. For this purpose, the efforts to optimize capacity utilization have been focused only on critical workstation or bottleneck workstation at the multistage production line.

This book is written in the order as follows: Chapter 1 is introduction which is followed by Chapter 2. Chapter 2 discusses the previous studies related to the issue of models in optimizing of manufacturing system. Chapter 3 describes methodology used in this study, mathematical model and MS Excel<sup>®</sup> development, and Visual Basic<sup>®</sup> application. Chapter 4 discusses analyzed data that is collected from industry by using mathematical model. Chapter 5 discusses simulation model and validation of mathematical model by using ARENA<sup>®</sup>. And finally Chapter 6 is conclusion and closing word.

## **CHAPTER II**

### **LITERATURE REVIEW**

Chapter 2 will cover many topics related to manufacturing system. These topics include manufacturing analysis, capacity analysis, manufacturing cycle time analysis, and mathematical model validation of manufacturing system.

#### **2.1 MANUFACTURING ANALYSIS**

Manufacturing system analyzes play an important role in new product development. A design should be changed to become a real product through processes in manufacturing system. Therefore it is very important to evaluate performance of manufacturing system as a part of product development processes. To more understand previous studies relating to manufacturing system, the following discussion will be presented.

##### **2.1.1 Model**

The critical data in predicting manufacturing cycle time is processing time at each of stages needed to produce a product from that the existing product designs. There are various model and technique to predict processing time, and some of them are by using DFM approaches. There are clearly differences between processing time prediction at detail design phase and that one at conceptual design phase. For detail design phase, accurately planning processes, manufacturing process simulations, or time predicting models, are activities that can be made (Herrmann, Chincholkar, 2000; Minis, Herrmann, Lam, 1996). For existing product, processing time and setup time should have been available at product process planning of this existing product. Anyway only a few models are needed for conceptual design phase and this is usually only critical design data given (Govil, Manish, 1999).

There are two types of manufacturing cycle time can be discussed. Firstly is to consider a manufacturing system that will work out a big part of job sequences of new product. The size of these sequences could be constant or has many variations. For this condition product development team need to predict the average manufacturing cycle time of these job sequences. Secondly is to consider a manufacturing system that will work out a small part of job sequences of new product. For this case product development team need to determine the total manufacturing cycle time, that is starting from the first job sequence until the last job sequence finished. The type of this system is usually used at industries having ordering system as engineer-to-order or make-to-order, those industries that respond to user special order and industries



that need to know the possibility time to complete all user order. This type is nearly the same with due date determination approach.

### 2.1.1.1. Steady state performance model

The following will be described model types that are able to be used for predicting the average of manufacturing cycle time at steady state condition. This steady state means product mix - included throughput of new product, and key resources of manufacturing system are constant. Next some steady state models will be discussed. They are conveyor model, fixed lead time model, discrete-event simulation, cyclic production scheduling model, queuing system models and approximations, and hybrid model.

**Conveyor model.** This model (Hopp, Wallace, Spearman, 1996) predicts manufacturing cycle time  $W$  for a job sent to conveyor line CONWIP that has already  $n$  task waiting for being processed.  $T_P$  is practical lead time minimum, and  $r_P$  is practical production rate:

$$W = (n/r_P) + T_P$$

(2.1)

This formulae can be used to predict manufacturing cycle time  $W$  of a job with  $n$  components waiting for being processed at a line where this line just process one component for each time unit. In this case the line produces  $r_P$  parts per unit time, and each component needs  $T_P$  time unit in average for moving during the line.

This model is also useful in predicting completed manufacturing cycle time  $T$  a set of task  $s$ . If  $W$  is average manufacturing cycle time of a task, and release rate is a task for each  $t$  unit time, and in this case

$$T = (s - 1) t + W$$

(2.2)

**Fixed lead times model.** In this model each sequence of job is finished at a certain fix of time. This time does not depend on both throughput and availability capacity in the system. One application of this model for example is material requirements planning (MRP) system. The model usually determines specifically a fix lead time for each workstation based on performance of that station before. The application of this model is more suitable for a facility having resemblance between parts and their assemblies, and product assembling is also not too much changed.

**Discrete-event simulation model.** This model can be used to predict manufacturing cycle time for almost manufacturing system. There are many simulation packages available (Simulation Software Survey, 1999) that possible to be used for simulation (Banks, Jerry, 1998; Law, Averill, Kelton, 1991). By running the simulation program will make possible for someone to know mean of manufacturing cycle time for each product. Simulation has also benefit to prove or verification of analytical models made.

**Cyclic production scheduling model.** In the case of manufacturing system produce a set of repeated components, cyclic production scheduling models can be applied to determine periodic length and time for each period of each manufacturing process. Then this information can be used to identify manufacturing cycle time for each job. The example for this can be referred to Lee and Posner (1997). We can use this model to model mass production manufacturing system where some equipment such as hoist, robot, and other material handlings are used for moving materials between existing resources.

**Queuing system models and approximations.** Queuing model can be applied widely for manufacturing systems. This model is a network of queue where each node represents one manufacturing resource or workstation that differs from that others. If the information relating to both probability distribution of arriving job and the average processing time each job are known, we can determine average time for being in the system for each job. Generally the distribution of processing time for each job at one resource will influence the interarrival time distribution of resource that next visited by that job.

Papadopoulos *et. al.* (1993) discussed some queuing system models for transfer line, production line, and flexible manufacturing system. Some researches have also studied open queuing network, such as Buzacott and Shanthikumar (1993) that presented queuing network models for manufacturing systems, and Connors *et.al.* (1996) who have modeled facilities of fabrication

semiconductor wafer. Their hope objective is to analyze facilities fast by avoiding effort and time needed in making and running simulation model. They presented numerical results describing how the results from queuing network can be compared and near the same with the results taken from simulation model. The queuing network models are also basis or mathematical foundation for software of manufacturing system analyzes such as rapid modeling (Suri, 1989). Koo *et al.* (1995) described software that combined capacity planning model and queuing networks approach. They conclude that approaches can be accepted as long as uncertainty or variability is at moderate condition.

**Hybrid model.** At some cases simulation or queuing model is suitable used at critical resources (for example over utilization), while fixed lead times model is only suitable used at resources having low utilization. Hybrid model uses different model for different workstation.

#### **2.1.1.2. Evolving systems**

Evolving systems refers to manufacturing systems where product mix or resources availability changes significantly and this happen simultaneously with time changing along at a certain time horizon. This is also relevant with situation where throughput changes from time-to-time. Anyway it is possible to divide time horizon to become two or more stable periodic, and at this stable periodic we can use steady state performance models. Another way to solve this

problem is by neglecting unstable periodic in analyzing manufacturing system, or in other word, we use only steady state model as an approach to analyze manufacturing system.

### **2.1.2 Model comparisons**

Models have been discussed above are very variously. Besides the simple models we have also the complicated models. The following will be discussed comparisons between these models based on some criteria such as data requirements, computational effort, descriptive effort, accuracy approximation, and sensitivity analysis capability.

**Data requirements.** Fixed lead times model and conveyor model require the least data. Although some queuing models require more data, in fact this approach need only a few statistical data for each workstation. Cyclic production scheduling model require time data for each activity. Simulation models require a lot of data although the amount of data needed depend on the level of detail information required.

**Computational effort.** Computation time confines to amount running can be completed and this will cause limitation to a number of analyzes made. Fixed lead time model and conveyor model require a little computation, on the other hand queuing model really need more computation although its approach is straightforward. Cyclic production scheduling model tends to require more computation, meanwhile simulation models require

more and more computation especially when more detail result required.

**Descriptive Effort.** In fact some of these models can provide more completed information than that just about the average manufacturing cycle time information. Queuing network, cyclic production scheduling, and simulation models can also provide information concerning to resource utilization.

**Accuracy approximation.** Accuracy of each model depends on quality of data provided. In general, fixed lead time and conveyor models are less accurately, meanwhile queuing model has various or widely range distributed accuracy. If we use correctly simulation model, this model will give us the result data accurately. Anyway, simulation model is very useful to analyze resources that have complex link between one to other resources in manufacturing systems.

**Sensitivity Analysis Capability.** Sensitivity analysis is very important when product development team want to know the amount of change happen to manufacturing cycle time if changes made at both product design or manufacturing system. Fixed lead time and conveyor models have less information required, therefore they have less validity relating to sensitivity analysis evaluation. Cyclic production scheduling model has limit capability relating to this sensitivity analysis. Sensitivity analysis is very important to queuing network because manufacturing cycle time is as functions of processing time and other parameters, and

derivative approach is a way to get this sensitivity. Simulation models are less capable in sensitivity analysis although until now researchers still continue to develop the capability of these models relating to this sensitivity analysis.

## **2.2 CAPACITY ANALYSIS**

What we mention as capacity analysis is to compare manufacturing system capacity to the required capacity by product design. Manufacturing system capacity depends on time availability at a certain resource to produce a product and the time allocated at that resource to fabricate other products. On the other hand the product design requirements depend on setup time and processing time for each operation and also depend on the required throughput. Capacity analysis can be used to many things such as capacity availability, predicting of feasibility throughput maximum, give suggestion relating to release dates and other factors aiming to increase capacity of manufacturing system. It is sure that available capacity is not the same at each resource because the busy level at one resource differs to those other resources, besides also there is possibility of identical resources exist in the system so that they will be able to share their workload one to others. Then capacity requirements is not always the same at a certain observed resource because both setup time and processing time will differ from one operation to the next operation. Additionally available capacity could be changing from one time period to the next time period because of changing in product mix processed.

Taylor *et al.* (1994) used a capacity analysis model to determine maximum product quantity resulted at electronic assembling facilities. The analysis is conducted to a set of product that consists of existing products mixed to the detail design of new product. In the case of maximum production quantity is not enough, the design of new product should be changed in order to avoid production process at critical or bottleneck resources. By taken this action production quantity will be increased to the acceptable level. Anyway this capacity analysis model does not consider about manufacturing cycle time of the system.

Bermon *et al.* (1995) have studied a capacity analysis model at a production line producing various products. The approach made was focused not only to product design but also to have decision support that make possible to fast analysis. They defined available capacity as a number of operations that are capable to be finished by equipment in a day. When information about available equipment, products, and required operation are known, their approach is to allocate equipment capacities that conform to both required throughput and existing limitations. They put in cycle time data and allocated capacity at level below the existing available capacity. The differences between the existing available capacity and allocated capacity are mentioned as contingency factor. Good contingency factor will prevent the queuing time average of equipment groups more than processing time determined before. They used queuing model approach to model relationship between utilization and queuing time. By using



this approach they can verify capacity of manufacturing system in term of capable or not to achieve required throughput for reasonable manufacturing cycle time.

A few researchers described capacity planning approaches as a part of planning and control systems of traditional manufacturing (Hopp, Wallace, Spearman, 1996; Vollmann, Berry, Whybark, 1997). However these approaches find out how many times, when, what type, and where manufacturing system should to increase its capacity to get the required throughput. Therefore its general objective usually is to minimize equipment cost, inventory, and cycle time. The rest models of this capacity planning are very variously, and they usually need more data and computation to improve their accuracy. Anyway there are only a little of these approaches that consider about the effect of product design to manufacturing system performances and no one that discussed about it that related to multistage manufacturing system.

### **2.3 MANUFACTURING CYCLE TIME ANALYSIS**

The approaches for predicting manufacturing cycle time that we have discussed are by modeling manufacturing system for steady state performance and by scheduling or simulating manufacturing systems for unsteady state condition. Previous study related to manufacturability evaluation and partner selection for agile manufacturing stated that there are two approaches used to predict manufacturing cycle. These approaches are variant approach and generative approach. In the case of detail product design known,

the variant approach (Candadai, Herrmann, Minis, 1995, 1996) will start by looking at Group Technology codes that comprehensively describe product attributes. Next, this approach will try to find out the existing products made by potential partner and identify the products that have nearly the similar code with the new products that are going to be produced. The manufacturing cycle time of existing products that have similarity with the new products will be a guide for product development team to predict manufacturing cycle time of new products.

Generative approach (Herrmann, Chincholkar, 2000; Minis, Herrmann, Lam, 1996) has a little difference with variant approach and it lists a set of possible specific process planning of business partner. If process for the new product design is one of the listed processes planning, cycle time for each stage in process planning of that new product design can be calculated. In the case of production quantity or production size known, generative approach will calculate processing time needed for that determined production size, and combine this processing time to average of setup time plus queue time at related resource. Both these setup time and queue time are known based on hystorical data. For the next, this generative approach will sum all time at each stage of each process planning, and by this method will give a chance to product development team to know the effect of different business partner selection to determine manufacturing cycle time. Anyway this approach did not consider to the existing available capacity, and also did not conduct queue time adjustment when utilization increasing.

Govil (1999) assumed that cycle time for each manufacturing operation is one time period. Lead time for buying component might need a few times of period. This approach applied combined structure to create a tree of purchasing and manufacturing operations, and manufacturing cycle time is the longest one in this tree structure.

Meyer *et al.* (1998) has also presented an approach to compare designs of microwave modules. For each different design will use a different set of electronics component. Their approach was to find a process planning that was suitable with characteristics of selected components. After that they evaluated each design and process planning based on cost, system reliability, and maximum lead time to prepare selected components.

Veeramani *et al.* (1997, 1999) presented a system allowing to a manufacturing company to quick respond to requirement for quotations (RFQs). Their approach can be applied by manufacturing companies selling modified products those are modified from standard products having complicated sub-assembly components. Based on the specification relating to product performance that requested by customer, the system will display a product configuration, three dimension solid model, price quotation, delivery schedule, bill of materials (BOM), and a list of more favourable design complete with their possibility manufacturing problems. Subsequently the system will examine product design to observe its possibility processed at the existing

workshop. To have delivery schedule concerning to order the system will use data relating to shop floor status, current orders, and process planning, therefore the time needed to the new order can be identified. Although the system is not very detail described, but it likely has relationship with shop floor scheduling in determining completion date.

Elhafsi and Rolland (1999) studied a make-to-order manufacturing system and build a model that is able to determine delivery date for single user order. This model concerns to workload of the existing production line and possible to move some of orders to other production line, as a result both minimum cost and required delivery date can be predicted. Each production line is modeled as a single server queuing.

Soundar and Bao (1994) presented a planning that relates product design effects to manufacturing system. They suggested the using of mathematical models and simulation to predict various different performance parameters included manufacturing cycle time. Although their approach is very general, no result or example that be shown in their written paper.

## **2.4 MATHEMATICAL MODEL VALIDATION**

Mathematical model and simulation model are often to be used as a validation tool between one to each other. This means a mathematical model can be a tool to validate a simulation model,

or a simulation model can be a tool to validate a mathematical model.

Bulgak and Sander (1990) stated that if the number of workstation and pallet increase, the accuracy between results of mathematical model to results of simulation model will also increase. The statement of Bulgak and Sander is supported by study found by Zhuang et al. (1998).

Koo et al. (1995) stated the accuracy between results of mathematical model to results of simulation model depends on job arrival rate and job processing rate at a workstation of manufacturing system. To measure this accuracy, they introduce a parameter called error percentage. The error percentage is the differences between results of mathematical model to results of simulation model, and then divided by results of simulation model. The accepted maximum value for error percentage is 32%.

## **2.5 CONCLUSION**

Models of manufacturing system have been discussed in Chapter 2. This chapter 2 also discusses manufacturing cycle time, capacity analyzes, and validation of mathematical model based on simulation model. All topics discussed above are also completed by referring to the related findings by previous researchers. In briefly, research related to cycle time and capacity of manufacturing system are still relevant and important to study.

## **CHAPTER III**

### **MODEL DEVELOPMENT**

Chapter 3 discusses model development used to achieve the objective of this study. There are many topics will be discussed in this chapter, started from flow chart methodology, and then followed by description of methodology, mathematical model, the application of ARENA<sup>®</sup> software, validation of mathematical model, development of database on spreadsheet Excel<sup>®</sup>, and finally Visual Basic<sup>®</sup> application.

#### **3.1 FLOW CHART OF METHODOLOGY**

Flow chart of methodology as shown in Figure 3.1 aim to describe clearly any kind of activities involved to achieve objective of this

study. This flow chart also can give description related to scope of this study.

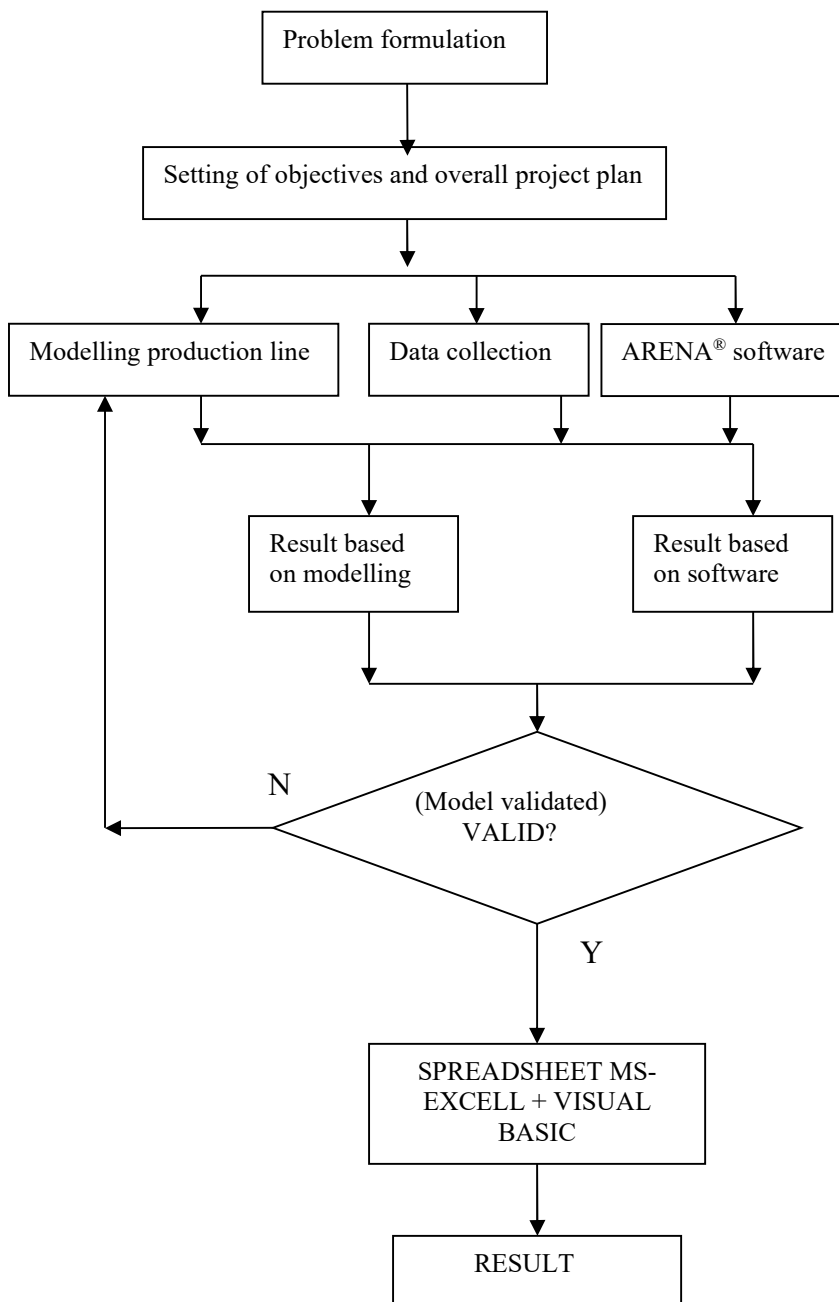


Figure 3.1 Flow chart of methodology

### 3.2 DESCRIPTION OF METHODOLOGY

Briefly, methodology in this study consists of three components:

- (a) Modelling production line system: to estimate the capacity by taking into account the failure and repair of the stations and the contributions of buffers in terms of cycle time minimization, a model based on Mathematical Model Approach will be developed.
- (b) Acquisition of real data from industrial partner: to implement the production line system model developed, the type of data collected at the industrial partner are:
  - (i) For each workstation
    - The number of resources available.
    - The mean time to failure for a resource.
    - The mean time to repair the resource.
  - (ii) For each existing product and the new product
    - The job size (number of parts).
    - The desired throughput (number of parts per hour of factory operation).
    - The sequence of workstations that each job must visit.
  - (iii) For each product-resource combination
    - The mean setup time (per job) at each workstation and its variance.



- The mean processing time (per part) at each workstation and its variance
- (c) The use of ARENA<sup>®</sup> software to examine the validity of production line system model developed: Based on the same input data achieved from the industrial partner, the output parameters of the model will be compared to the same output parameters resulted from ARENA<sup>®</sup>.

### 3.3 MATHEMATICAL MODEL

To model production line system, a mathematical model need to be developed. In this study, a mathematical model used by Wei (2001) and Wei & Thornton (2002) have been modified and applied. The model modification related to reliability factor of workstation has been developed that includes normal yield, scrap yield, and reduced yield.

The following are the symbols in the formulae of mathematical model used in this study:

$A_j$	=	availability of a resource at station $j$
$B_i$	=	job size of product $i$ at release
$c_j^a$	=	the squared coefficient of variation ( <i>SCV</i> ) of interarrival times at the resource $j$
$c_j^+$	=	<i>SCV</i> of the aggregate process time
$c_j^*$	=	<i>SCV</i> of modified aggregate process time
$c_{ij}^+$	=	<i>SCV</i> of the total process time
$c_{ij}^s$	=	<i>SCV</i> of the setup time

$c_{ij}^t =$	SCV of the part process time
$k =$	batch size number
$m_j^f =$	mean time to failure for a resource at station $j$
$m_j^r =$	mean time to repair for a resource at station $j$
$M_j =$	throughput time multiple at station $j$
$n_j =$	the number of resources in the workstation $j$
$R_i =$	the sequence of stations that the product $i$ must visit
$R_{ij} =$	the subsequence that precedes station $j$
$s_{ij} =$	mean job setup time of product $i$ at station $j$
$T_i =$	desired throughput of product $i$
$t_{ij}^+ =$	total process time of product $i$ at station $j$
$t_{ij} =$	mean part process time of product $i$ at station $j$
$t_j^* =$	modified aggregate process time at the workstation $j$
$TT_i =$	the total throughput time of jobs of product $i$
$TT_j^* =$	the average throughput time at station $j$
$u_j =$	the average resource utilization
$V_j =$	set of products that visit the workstation
$x_i =$	release rate of product $i$ (jobs per hour)
$Y_i =$	cumulative yield of product $i$ through $R_i$
$Y_{ij} =$	cumulative yield of product $i$ through $R_{ij}$
$y_{ik} =$	yield of product $i$ at station $k$
$y_{ij} =$	yield of product $i$ at station $j$
$y_{ij}^n =$	normal yield of product $i$ at station $j$
$y_{ij}^r =$	reduced yield of product $i$ at station $j$
$y_{ij}^s =$	scrap yields of product $i$ at station $j$

### 2.1.3 Yield

The cumulative yield is the product of the yields at each station that the product visits.

$$Y_i^n = \prod_{k \in R_i} y_{ik}^n \quad (3.1)$$

$$Y_i^r = \prod_{k \in R_i} y_{ik}^r \quad (3.2)$$

$$Y_i^s = \prod_{k \in R_i} y_{ik}^s \quad (3.3)$$

$$Y_i = (Y_i^n)(Y_i^r)(Y_i^s) \quad (3.4)$$

$$x_i = \frac{T_i}{(B_i Y_i)} \quad (3.5)$$

$$A_j = \frac{m_j^f}{m_j^f + m_j^r} \quad (3.6)$$

### 2.1.4 Process Time

The time spent by a job at station  $j$  is the sum of the part processing times and the setup time. The job size depends on the cumulative yield of the preceding operations.

$$t_{ij}^+ = B_i(Y_{ij})(t_{ij}) + \{2 - y_{ij}^s\}s_{ij} \dots \text{for processing workstation} \quad (3.7)$$

$$t_{ij}^+ = B_i(Y_{ij})(t_{ij}) + 2(s_{ij}) \dots \dots \dots \text{for inspection workstation} \quad (3.8)$$

$$(t_{ij}^+)^2 c_{ij}^+ = B_i Y_{ij} t_{ij}^2 c_{ij}^t + s_{ij}^2 c_{ij}^s \quad (3.9)$$

$$t_j^+ = \frac{\sum_{i \in V_j} x_i t_{ij}^+}{\sum_{i \in V_j} x_i} \quad (3.10)$$

$$(t_j^+)^2 (c_j^+ + 1) = \frac{\sum_{i \in V_j} x_i (t_{ij}^+)^2 (c_{ij}^+ + 1)}{\sum_{i \in V_j} x_i} \quad (3.11)$$

Equations (3.12) and (3.13) modify the mean and SCV for the process times by adding the effects of resource availability.

$$t_j^* = \frac{t_j^+}{A_j} \quad (3.12)$$

$$c_j^* = c_j^+ + 2A_j(1 - A_j) \frac{m_j^r}{t_j^+} \quad (3.13)$$

### 2.1.5 Performance Measures

The performance measures of interest are  $TT_j^*$ , the average throughput time (manufacturing cycle time) at each workstation while  $TT_i$ , the total manufacturing cycle time. Another important quantity is  $u_j$ , the utilization of the resources at station  $j$ . The manufacturing cycle time at each workstation is the sum of the average waiting time in the queue plus the average job processing time. The total manufacturing cycle time is the sum of the workstation manufacturing cycle times.

$$u_j = \frac{t_j^*}{n_j} \sum_{i \in V_j} x_i$$

(3.14)

$$TT_j^* = \frac{1}{2} (c_j^a + c_j^*) \frac{u_j^{(\sqrt{2n_j+2}-1)}}{n_j(1-u_j)} t_j^* + t_j^*$$

(3.15)

$$TT_i = \sum_{j \in R_i} TT_j^*$$

(3.16)

### 3.4 THE APPLICATION OF ARENA<sup>®</sup> SOFTWARE

ARENA<sup>®</sup> is a software basing on discrete simulation, user-friendly, Windows interface, and using SIMAN language for its output. The user is not connect directly to SIMAN codes, but ARENA<sup>®</sup> will translate each input to SIMAN codes. The application of ARENA<sup>®</sup> through an user-interface as shown in Figure 3.2.

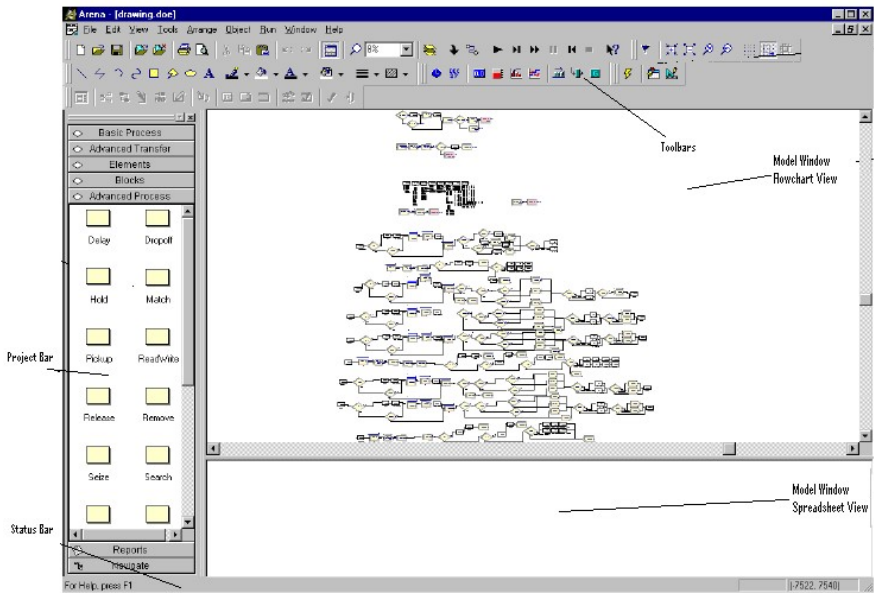


Figure 3.2. The user-interface of ARENA<sup>®</sup>

To build or modify an ARENA<sup>®</sup> model, the user can make a click on icons at 'Project Bar' and drag that icon to 'Model Window – Flowchart View'. The user can edit each icon through Pengguna *pop-up Window*. When the user develop a model and then running that model into ARENA<sup>®</sup>, ARENA<sup>®</sup> will soon evaluate the model and deliver a report as the result of analysis.

ARENA<sup>®</sup> is used in this study because it has a tool called PAN (*Process Analyzer*). This tool will help the user in analyzing the displayed output by ARENA<sup>®</sup>. The advantages of this tool are as follows:

1. PAN helps the user to avoid mistake in reading data.

2. The output can be classified based on a certain parameter, so the user will be easy to analyze each developed model.

Other than having capabilities to analyze process, ARENA<sup>®</sup> is also used in this study because it has modules that based on queuing theory and has dialog box in the form of Visual Basic<sup>®</sup> as user-interface.

### **3.5 VALIDATION THE DEVELOPED MATHEMATICAL MODEL**

To validate the developed mathematical model, the value of utilization and cycle time parameters that resulted based on mathematical model should be compared to those resulted based on ARENA<sup>®</sup> model.

### **3.6 DEVELOPMENT OF DATABASE ON SPREADSHEET EXCEL<sup>®</sup>**

A spreadsheet of Microsoft Excel<sup>®</sup> will make easy in application the formulae of mathematical model which have been described before, and this spreadsheet also can be a database for Basic<sup>®</sup> used in this study. .

A few spreadsheet will be built depends on type of product produced by studied industry, and it will be detailed again based on production line of each product. There are many workstations at a production line. Therefore generally, the developed spreadsheet

will consist of workstation data on spreadsheet row, and mathematical formulae on spreadsheet column. By entering workstations data and mathematical formulae in a spreadsheet, results in the form of graphic can be analyzed.

An example of spreadsheet is shown in Figure 3.3 below. Data in this figure is taken from an electronic industry based on a product namely Stationary Terminal Contact.

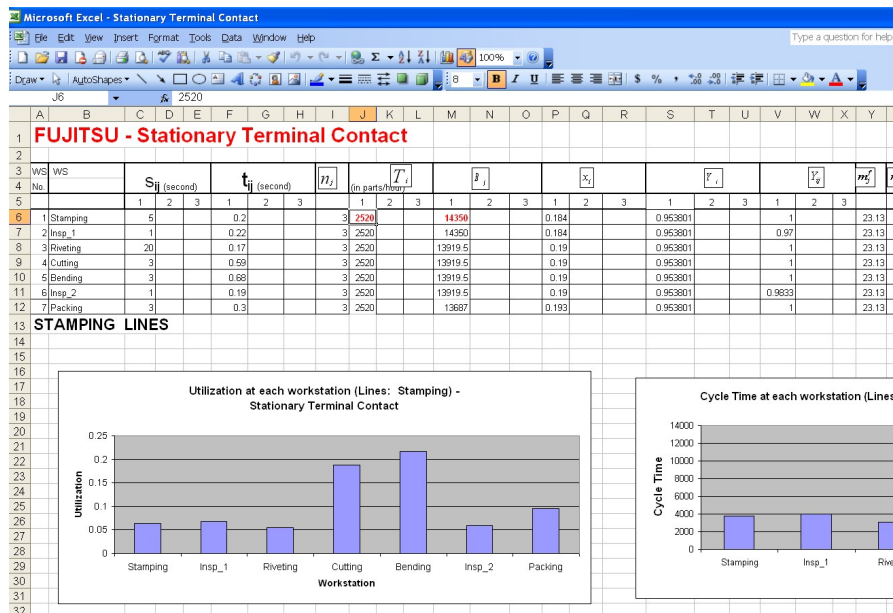


Figure 3.3 Display of spreadsheet- Excel<sup>®</sup> for analyzing Stationary Terminal Contact at an electronic industry

By changes input parameters, either throughput ( $T_i$ ) or batch size ( $B_i$ ) or number of resources ( $n_j$ ) in a workstation, many analysis can be analyzed.



### 3.7 VISUAL BASIC® APPLICATION

In this study, Visual Basic® will be applied to support the development a user-interface. This user-interface will be very helpful in analyzing parameters of cycle time and resource utilization of a certain analyzed industry. Flow chart to apply Visual Basic® in this study is shown in Figure 3.4.

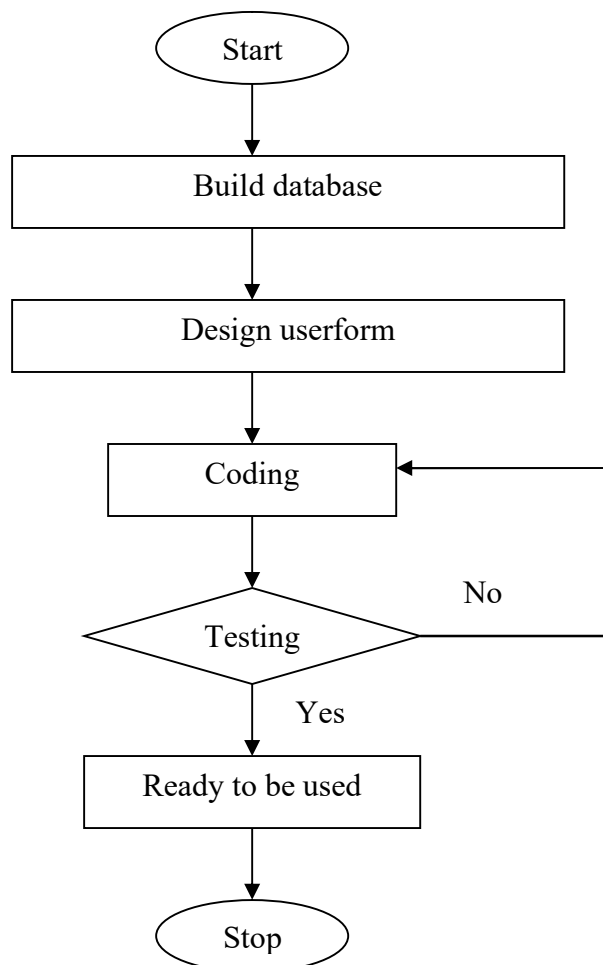


Figure 3.4 Flow chart to develop user-interface of Visual Basic®

### **3.8 CONCLUSION**

Chapter 3 has discussed methodology used in this study. Mathematical model and its formulae have been described, besides the development of a spreadsheet model to enter the mathematical formulae. Chapter 3 also discussed validation of mathematical model by using ARENA<sup>®</sup> and flow chart to develop an user-interface by using Visual Basic<sup>®</sup>.

## CHAPTER IV

### DECISION AND DISCUSSION: CASE STUDY AND MATHEMATICAL MODEL ANALYSIS

Analysis of data gotten from the industry will be discussed in this chapter. The analysis is based on mathematical model and then be combined to MS Excel – Visual Basic analysis. This chapter will begin by introducing the industry that is selected to be partner in this study. The name of that industry is XYZ.

#### 4.1 CASE STUDY: XYZ Company

XYZ Company produces WIP products such as reinforced instrument panel (*panel alatan bersetulang*), gusset (*guset*), and

case outer ashtray body (*badan luar tempat abu rokok*). All of these products will be sent to some car manufacturing industries. The main activity process at XYZ Company is stamping (*proses hantakan*).

Manufacturing system at XYZ Company produces batch size components where many components are produced simultaneously. The components need to be processed through many processes and machines before the final product resulted. Normally, the component will be firstly processed by pelubangan (*blanking*) to get blank form, and then followed by pembentukan (*forming*), pembengkokan (*bending*), penembusan (*piercing*), penembusan sesondol (*cam piercing*), pengetukan (*restrike*), pemukulan progresif (*progressive hammering*), trim (*trimming*), pembibiran (*flanging*), and pressing process by a powerful stamping machine.

Selected products to be studied at this XYZ Company are reinforced instrument panel PS B (*panel alatan bersetulang PS B*), gusset LH/RH (*gusset sisi kiri/sisi kanan*), and case outer ashtray body (*badan selongsong luar tempat abu rokok*). Both reinforced instrument panel PS B and gusset LH/RH are the existing products, on the other hand case outer ashtray body is a new product that will be processed at the same production line to that existing products line. Figure 4.1 shows gusset LH/RH produced by XYZ Company.



Figure 4.1 Gusset LH/RH

Source: XYZ Company 2007

#### 4.1.1 Reinforced instrument panel PS B

Figure 4.2 shows that the process for reinforced instrument panel PS B product is started by raw material to be processed at production line 80T (*talian pengeluaran 80T*) for pelubangan and pemeriksaan (*inspection process*), and then move to production line 110T for pembentukan and another pemeriksaan. The next processes are penembusan and pemeriksaan at production line 60T\_45T, before pembengkokan and pemeriksaan again at production line 80T. The last processes are penembusan sesondol and pemeriksaan at production line 60T\_45T.

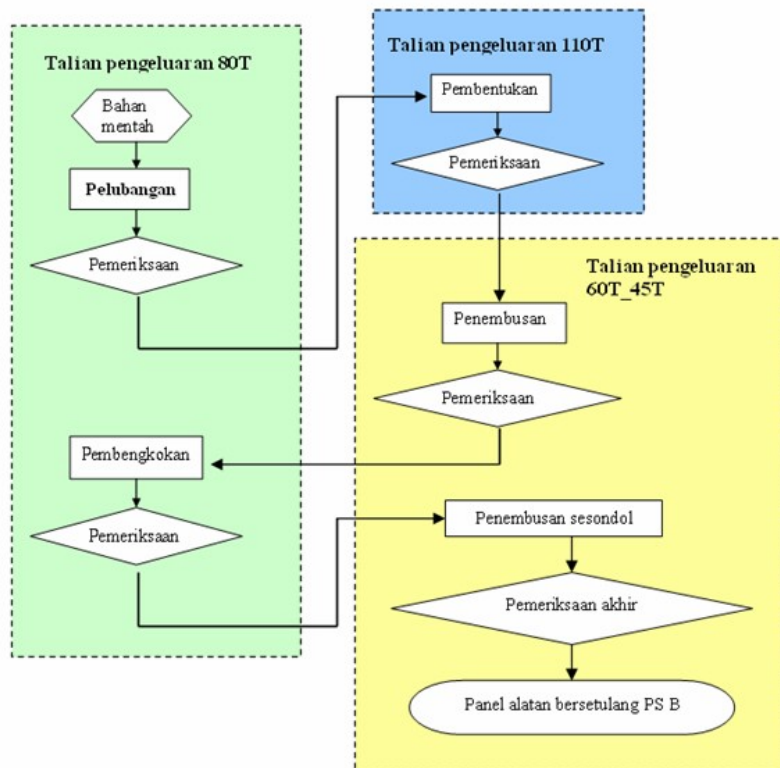


Figure 4.2 Process flow for reinforced instrument panel PS B

Source: XYZ Company. 2007

#### 4.1.2 Gusset LH/RH

Figure 4.3 shows the process flow for producing gusset LH/RH. The starting process is pelubangan and pemeriksaan at production line 80T, and then followed by pembungkakan, penembusan, and pemeriksaan processes. These the last three processes are at production line 60T\_45T.

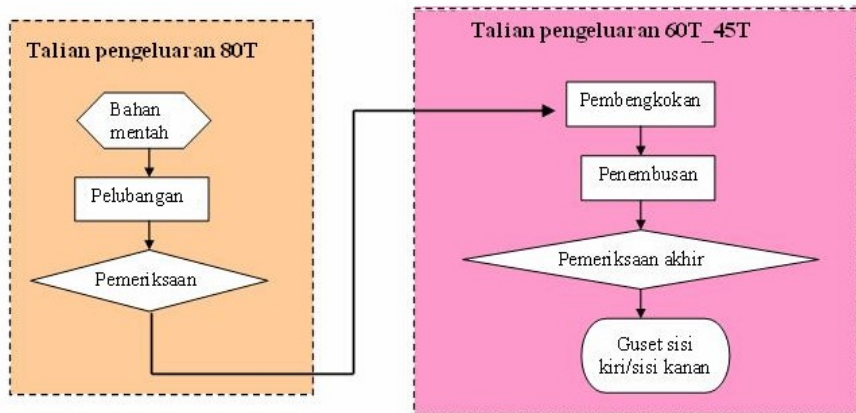


Figure 4.3 Process flow for gusset LH/RH

Source: XYZ Company. 2007

#### 4.1.3 Case outer ashtray body

Process for case outer ashtray body is shown in Figure 4.4. The process is started at production line 80T for pelubangan, pembentukan, and pemeriksaan. The next process is moved to production line 60T\_45T for pembungkakan and pemeriksaan again at production line 80T.

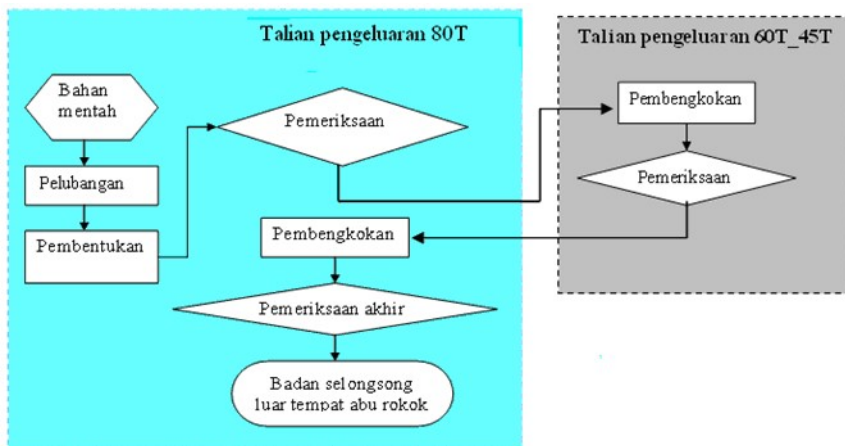


Figure 4.4 Process flow for case outer ashtray body

Source: XYZ Company. 2007

## **4.2 MATHEMATICAL MODEL ANALYSIS FOR PROCESSING SINGLE PRODUCT AT XYZ COMPANY**

As stated before, there are three types of products studied at XYZ Company. – two of them are existing products and another one is a new product. The existing ones are reinforced instrument panel PS B (*panel alatan bersetulang PS B*) and gusset LH/RH (*guset sisi kiri/sisi kanan*), and the new one is case outer ashtray body (*badan selongsong luar tempat abu rokok*). As discussed before in sub-chapter 4.1, process flows for these three products are shown briefly in Table 4.1.

Discussion for processing single product at XYZ Company will be focused on reinforced instrument panel PS B. The discussion will be divided into two parts, the first part is related to utilization and the second one discusses cycle time at each workstation.

### **4.2.1 Utilization at Each Workstation for Processing Single Product**

Based on Table 4.1, reinforced instrument panel PS B process is conducted on many workstations at three production lines. There are 4 workstations at production line 80T, 2 workstations at



production line 110T, and there are 4 workstations at production line 60T\_45T.

By using input data for parameters of normal yield, scrap yield, reduced yield, batch size and throughput those are 0.95, 0.98, 0.91, 50 units/batch and 80 units/jhour, respectively, utilization at each workstation can be analyzed as shown in Figure 4.5. All input data mentioned above are the actual data applied by XYZ Company

Figure 4.5 shows utilization at processing workstations are normally higher than utilization at pemeriksaan (inspection) workstations. Utilization at pelubangan, pembentukan, penembusan, pembengkokan, and penembusan sesondol workstations are 0.3, 0.85, 0.71, 0.82, and 0.9, respectively, on the other hand utilization at pemeriksaan 1 workstation is about 0.26. Figure 4.5 also shows that for processing reinforced instrument panel PS B, each machining process is always followed by inspection process. This happening is to make sure the quality of product produced is always in control.

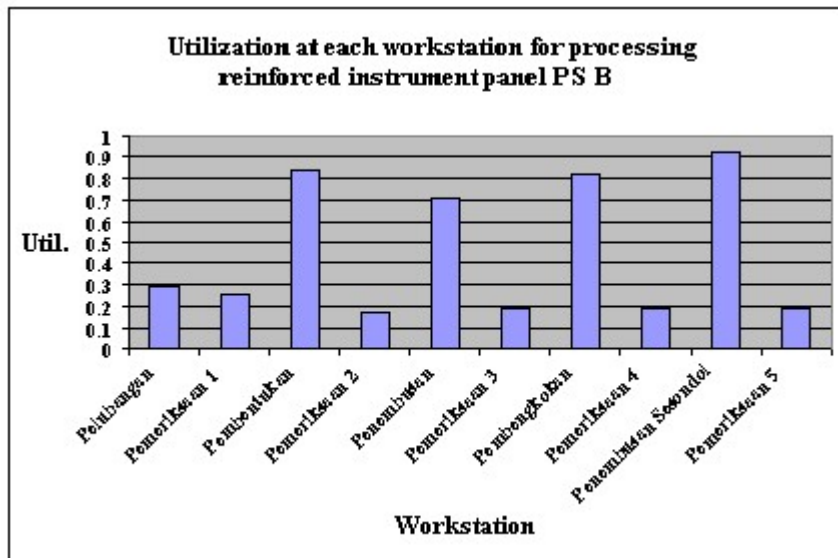


Figure 4.5 Utilization at each workstation for processing single product (reinforced instrument panel PS B) – XYZ Company

Table 4.1 Process flow for the existing and new products at XYZ Company.

Production line	Product 1 (existing) <i>Reinforced instrument panel PS B</i>		Product 2 (existing) <i>Gusset LH/RH</i>		New Product <i>Case outer ashtray body</i>	
	No. Process	Name of Process	No. Process	Name of Process	No. Process	Name of Process
<b>80T</b>	1	Pelubangan	1	Pelubangan	1	Pelubangan
	2	Pemeriksaan 1	2	Pemeriksaan 1	2	Pembentukan
	7	Pembengkokan			3	Pemeriksaan 1
	8	Pemeriksaan 4			6	Pembengkokan
				7	Pemeriksaan 4	
<b>110T</b>	3	Pembentukan				
	4	Pemeriksaan 2				
<b>60 T_45T</b>	5	Penembusan	3	Pembengkokan	4	Pembengkokan
	6	Pemeriksaan 3	4	Penembusan	5	Pemeriksaan 3
	9	Penembusan sesondol	5	Pemeriksaan 3		
	10	Pemeriksaan 5				

Source: XYZ Company, 2007

#### 4.2.2 Cycle Time at Each Workstation for Processing Single Product

Figure 4.6 shows cycle time at each workstation for processing single product of reinforced instrument panel PS B that is based on input parameters 50 units/batch and 80 units/hour for batch size and throughput, respectively.

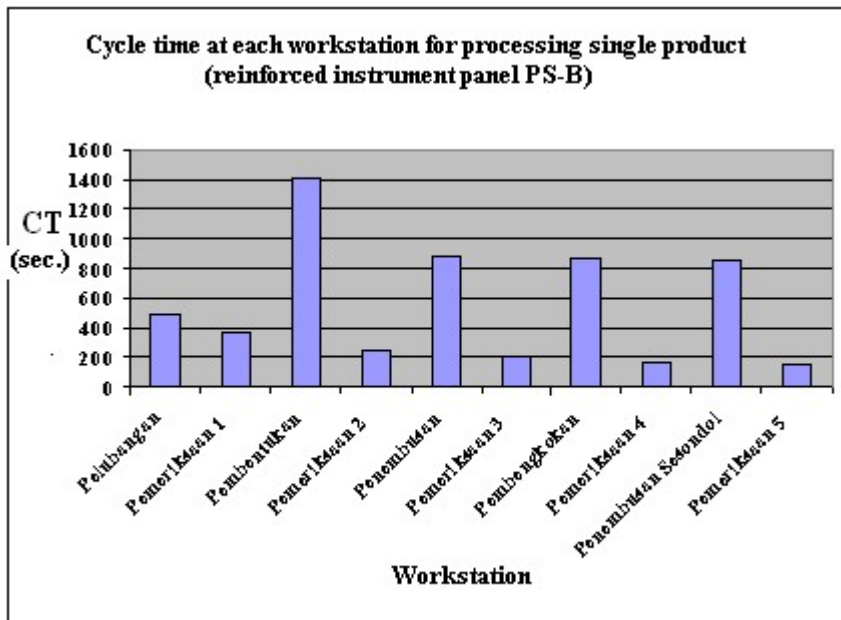


Figure 4.6 Cycle time at each workstation for processing single product (reinforced instrument panel PS B) – XYZ Company

Cycle time at pembentukan workstation is the longest compared to cycle time at other workstations (as shown on Figure 4.6). This result is exactly the same with the actual fact happening at XYZ Company.

This happens because the quantity of batch size at pembentukan workstation is bigger than those at other workstations.

### 4.3 MATHEMATICAL MODEL ANALYSIS FOR PROCESSING COMBINING PRODUCT AT XYZ COMPANY

Discussion related to this topic will be focused on two processing groups. The first group is the processing of two combining existing product (reinforced instrument panel PS B combined to gusset LH/RH), and the second group is the processing of three combining products i.e. two existing products will be combined to a new product (case outer ashtray body). For analysis purposes, the actual data at XYZ Company have been used as shown in Table 4.2.

Table 4.2 Determined quantities for throughput and batch size for processing combining products at XYZ Company.

Parameter	Combining two products		Combining three products		
	Reinforced instrument panel PS B	Gusset LH/RH	Reinforced instrument panel PS B	Gusset LH/RH	Case outer ashtray body
Throughput $T_i$ (unit/hour)	34	34	34	34	34
Batch Size $B_i$ (unit/batch)	102	102	102	102	102

Source: XYZ Company. 2007

Based on data throughput, batch size (both in Table 4.2), and also normal yield, scrap yield and reduced yield those are 0.95, 0.98 and 0.91 respectively, utilization and cycle time parameters for

processing combining products can be analyzed as shown in Table 4.3 to Table 4.5.

Table 4.3 Utilization and cycle time at each workstation of production line 80T based on throughput and batch size in Table 4.2

Workstations at production line 80T	$J$	$n$	Utilization		Cycle Time (second)	
			$u_j$		$CT_j$	
			Combi- ning two exixting products	Combi- ning three products	Combi- ning two exixting products	Combi- ning three products
Pelubangan	1	1	0.346	0.309	1490.7	866.3
Pembentukan (80T)	2	1	0	0.531	0	2087.1
Pemeriksaan 1	3	1	0.181	0.265	673.5	640.5
Pembengkokan (80T)	9	1	0.347	0.330	891.7	910.8
Pemeriksaan 4	10	1	0.079	0.158	175.4	376.8
Total Cycle Time $CT_j$					3231.3	4881.5

Table 4.4 Utilization and cycle time at each workstation of production line 110T based on throughput and batch size in Table 4.2

Workstations at production line 110T	$J$	$n$	Utilization		Cycle Time (sec.)	
			$u_j$		$CT_j$	
			Combi- ning two exixting products	Combi- ning three products	Combi- ning two exixting products	Combi- ning three products
Pembentukan (110T)	4	1	0.357	0.357	1433.2	1433.2
Pemeriksaan 2	5	1	0.072	0.072	249.6	249.6
Total Cycle Time $CT_j$					1682.8	1682.8

Table 4.5 Utilization and cycle time at each workstation of production line 60T\_45T based on throughput and batch size in Table 4.2

Workstations at production line 60T_45T	$J$	$n$	Utilization $u_j$		Cycle Time (sec.) $CT_j$	
			Combining two existing products	Combining three products	Combining two existing products	Combining three products
Pembengkakan (60T_45T)	6	1	0.508	0.494	2039.8	1982.7
Penembusan	7	1	0.605	0.605	2068.1	2068.1
Pemeriksaan 3	8	1	0.156	0.228	459.6	471.4
Penembusan sesondol	11	1	0.390	0.390	1728.6	864.3
Pemeriksaan 5	12	1	0.079	0.079	151.2	151.2
Total Cycle Time $CT_j$					6447.3	5537.7

Table 4.3 to Table 4.5 describe that at a determined quantity of both throughput and batch size, for combining two products, the highest utilization value is penembusan workstation i.e.60.5% at production line 60T\_45T. In cycle time parameter, pembengkakan (60T\_45T) workstation has the longest time compared to other workstations that is 2039.8 second (34 minutes). For processing combining three products, the highest utilization value is at penembusan workstation (60.5%), while the longest cycle time is at pembentukan (80T) workstation (2087.1 second or 34.8 minutes). Based on this results, either in the aspect of combining two products or combining three products, penembusan workstation needs to be attention because its utilization is still not optimum yet.. Utilization needs to be increased to get its optimum level. Briefly, utilization is not optimum yet if input data as stated in Table 4.2 (i.e. batch size =

102 units/batch) is used. Therefore to achieve the optimum value of utilization, it can be made by changing either throughput or batch size parameter, or clearly by changing release rate ( $x_i$ ) parameter. Release rate ( $x_i$ ) is utilization value divided by batch size value.

Next, Figures 4.7 and 4.8 are graphically display of data described in Table 4.3 until Table 4.5.

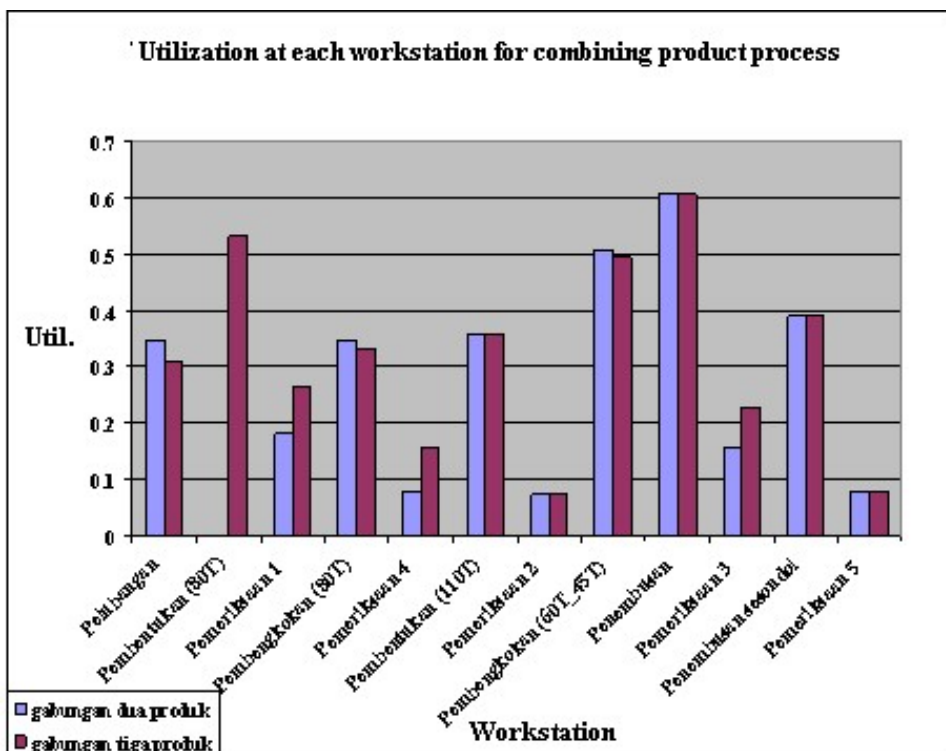


Figure 4.7 Utilization at each workstation for combining product process at

XYZ Company



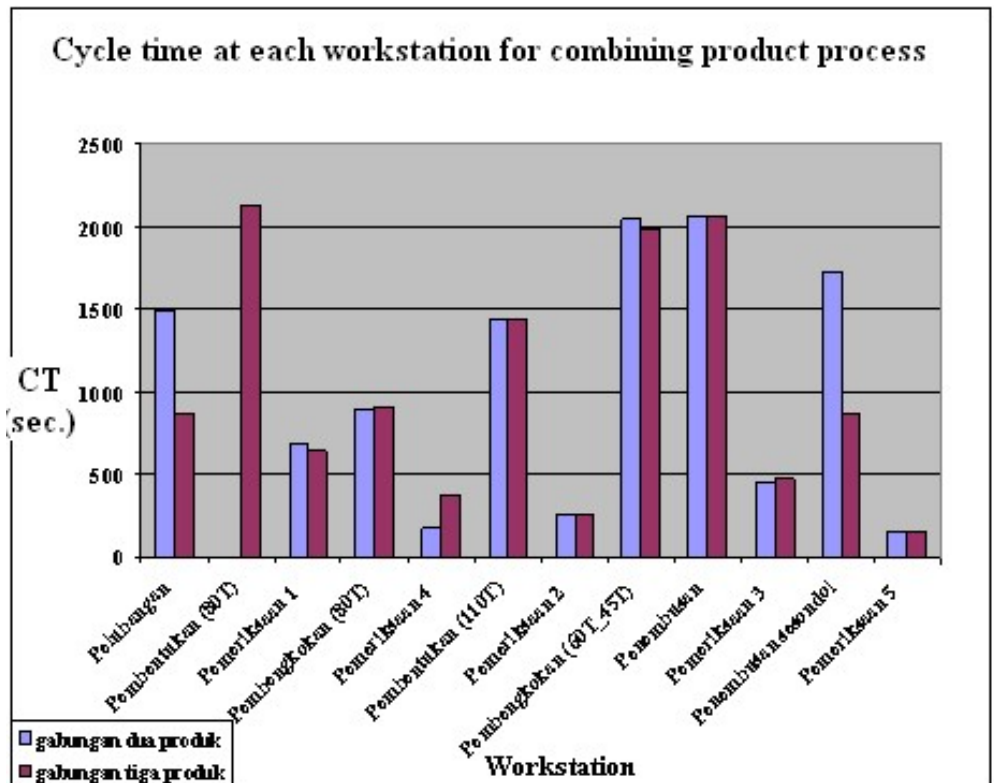


Figure 4.8 Cycle time at each workstation for combining product process at XYZ Company

The example to improve utilization for combining product process can be shown by changing throughput from 34 unit/hours to 56 units/hours while batch size is still 102 unit/batch. Table 4.6 displays the result based on these new input data. Figure 4.9 to Figure 4.12 display the comparison value of both utilization and cycle time for combining product process at after and before throughput changing conducted.

Another example to improve utilization is by changing batch size parameter from 102 units/batch to 120 units/batch, while

throughput parameter is 34 units/hour. Figure 4.13 displays the comparison cycle time results for processing combining two products, that is before and after changing to batch size has been done.

Table 4.6 Utilization and cycle time at each workstation after throughput is changed to 56 units/hour for processing combining products - XYZ Company

Workstation	$J$	$n$	Utilization $u_j$		Cycle Time $CT_j$ (second)	
			Combi- ning two exixting products	Combi- ning three products	Combi- ning two exixting products	Combi- ning three products
Pelubangan	1	1	0.570	0.508	2407.8	2005.1
Pembentukan (80T)	2	1	0	0.875	0	4263.6
Pemeriksaan 1	3	1	0.299	0.437	777.4	733.9
Pembengkokan (80T)	9	1	0.571	0.543	1783.4	2045.1
Pemeriksaan 4	10	1	0.130	0.261	350.7	409.8
Pembentukan (110T)	4	1	0.588	0.588	3975.9	3975.9
Pemeriksaan 2	5	1	0.118	0.119	439.2	517
Pembengkokan (60T_45T)	6	1	0.837	0.813	4079.7	3965.4
Penembusan	7	1	0.995	0.995	4136.3	5433.9
Pemeriksaan 3	8	1	0.257	0.375	508.5	558.9
Penembusan sesondol	11	1	0.642	0.642	2790.4	1728.6
Pemeriksaan 5	12	1	0.130	0.130	302.4	314

Figure 4.9 show that pembentukan (80T) workstation has not utilization value because this workstation is not involved for processing combining two products. Figure 4.9 also displays the increasingly of utilization at all workstations for processing combining two products if throughput increase from 34 units/hour to 56 units/hour (or increasingly 64.71). The result shows that the

highest increasingly is at penembusan workstation, because utilization has changed from 0.605 to 0.995, or it increases 64.46%. So for processing combining two products at penembusan workstation, the increasing 64.71% of throughput will increase 64.46% of utilization. By consideration the increasing value of utilization at all workstations, it can be concluded that the average increasing of utilization is 64.61%.

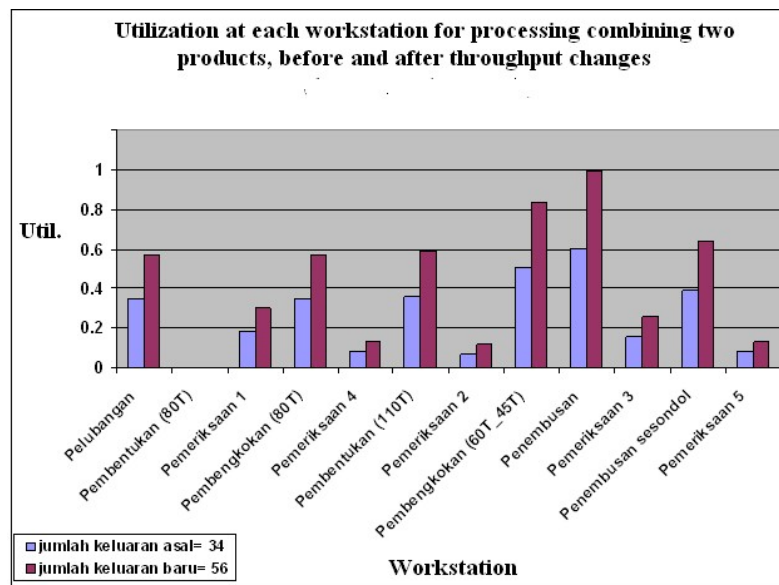


Figure 4.9 Utilization at each workstation for processing combining two products, before and after throughput changes

Figure 4.10 shows the increasing of cycle time at each workstation as a result of 64.71% increasingly of throughput. The maximum increasingly of cycle time happens at pembentukan (110T) workstation that is 2542.7 second or increase 177%, while the minimum increasingly of cycle time at pemeriksaan\_3 workstation

which is 48.9 second or increase only 10.64%. By considering percentage of increase of cycle time at all workstation, it can be said that the average percentage of increase of cycle time is 82%. Therefore, if throughput increases from 34 units/hours to 56units/hour, the average percentage of increase of cycle time is higher than the average percentage of increase of utilization.

Figure 4.11 shows utilization at each workstation for processing combining three products before and after changes to throughput parameter. The increase of utilization happens at all workstation that those maximum is at penembusan workstation by 0.39, while the minimum one is at pemeriksaan\_5 workstation by 0.051.

By considering percentage of increase of utilization at all workstation, it can be said that the average percentage of increase of utilization is 59.3%. Therefore, if throughput increases from 34 units/hours to 56units/hour or increase 64.71%, the average percentage of increase of utilization is 59.3% for processing combining three products.

Figure 4.12 shows cycle time at each workstation for processing combining three products. Based on data in this Figure 4.12, penembusan workstation has the longest cycle time compared to those other workstations. As described in Figure 4.11, penembusan workstation also has the highest utilization. Therefore, penembusan

workstation is a critical workstation in case of processing combining three products at XYZ Company..

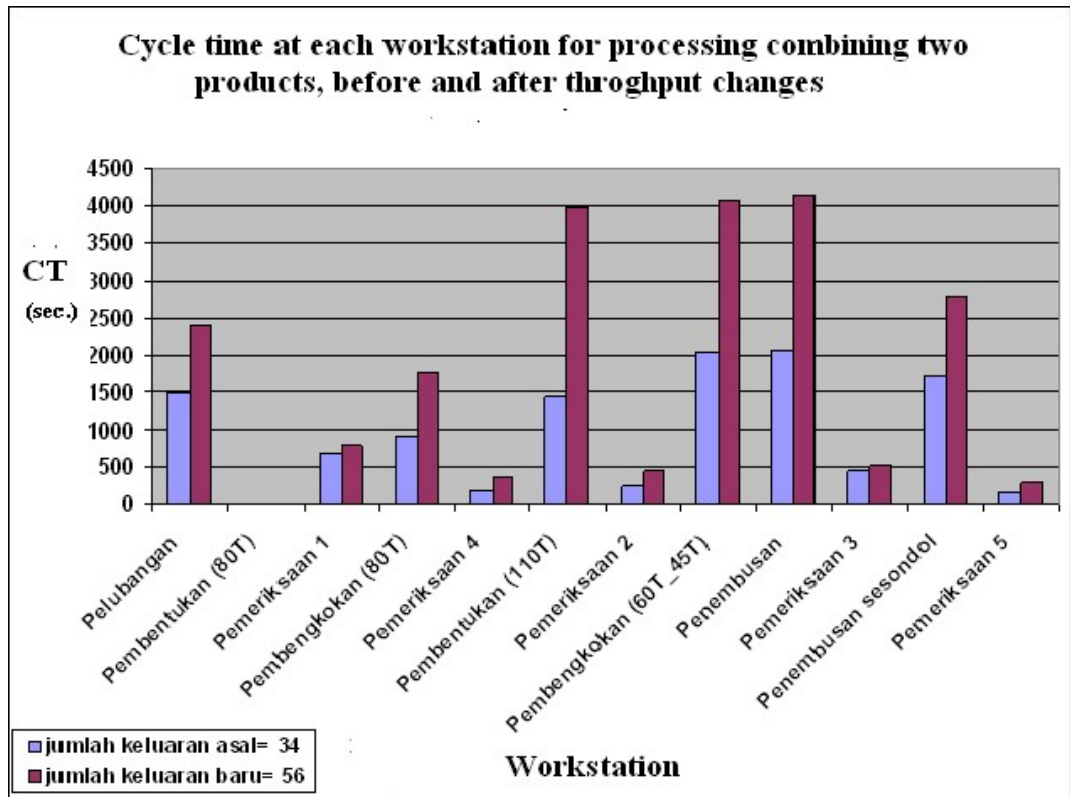


Figure 4.10 Cycle time at each workstation for processing combining two products, before and after throughput change

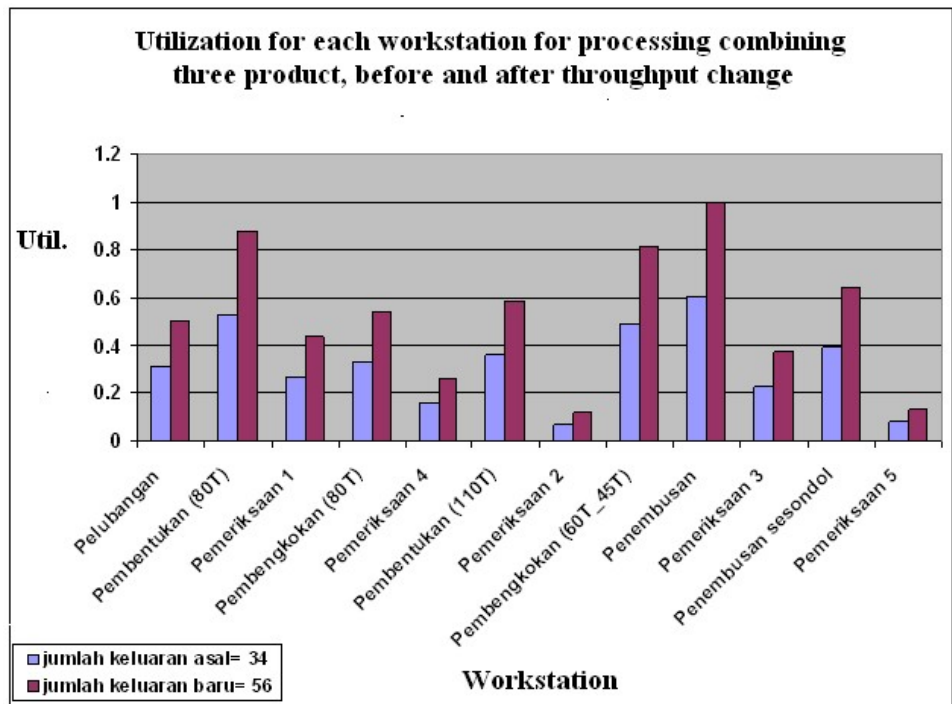


Figure 4.11 Utilization at each workstation for processing combining three products, before and after throughput change

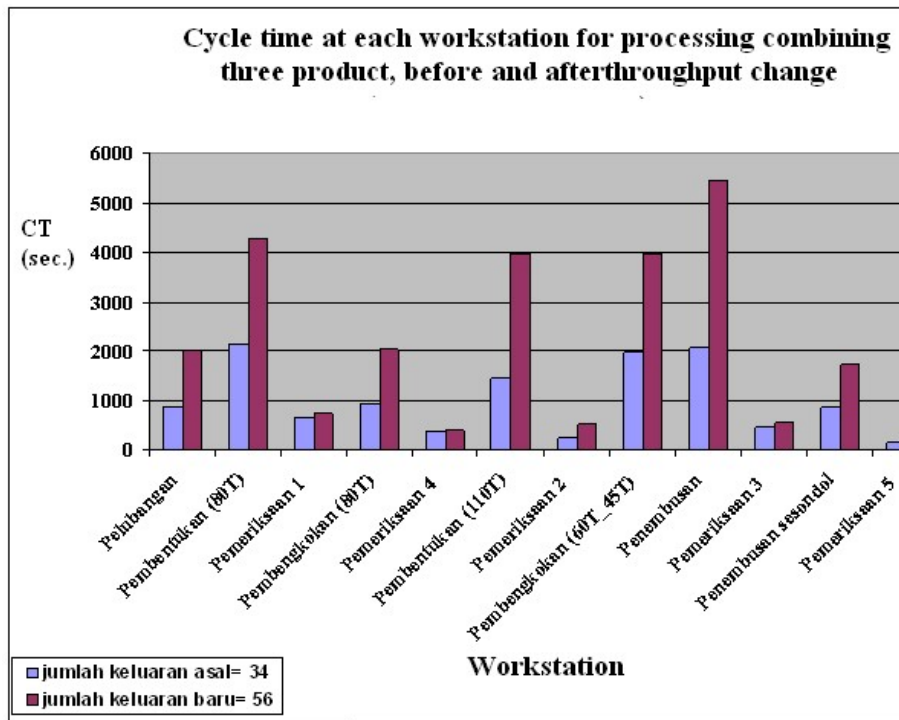


Figure 4.12 Cycle time at each workstation for processing combining three products, before and after throughput changes

Figure shows the increasing of cycle time at each workstation for processing combining two products after increasing of batch size from 102 units/batch to 120 units/batch (or increase 7.84%). Cycle time at penembusan workstation increases from 2068.1 second to 2433.1 second, or increase 17.65%. It can be stated that for processing combining two products, the increase 7.84% of batch size will result the increase 17.65% of cycle time,

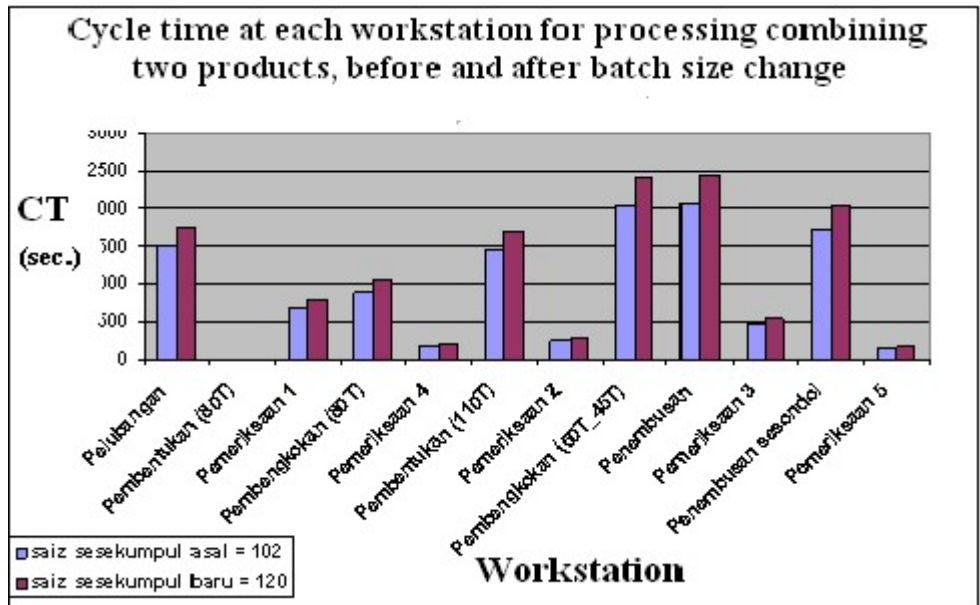


Figure 4.13 Cycle time at each workstation for processing combining two products, before and after batch size change

Figure 4.14 shows cycle time at each production line for processing combining product after changing to throughput which is from 34units/hour to 56units/hour. There is a clear difference of cycle time between processing combining two products to processing combining three products at production line 80T. Anyway, there are not too many differences of cycle time at production 110T and 60T\_45T. This happens because there is a machining process at pembentukan workstation of production line 80T for processing combining three products, on the other hand this machining process does not exist at pembentukan workstation of production line 80T for processing combining two products.



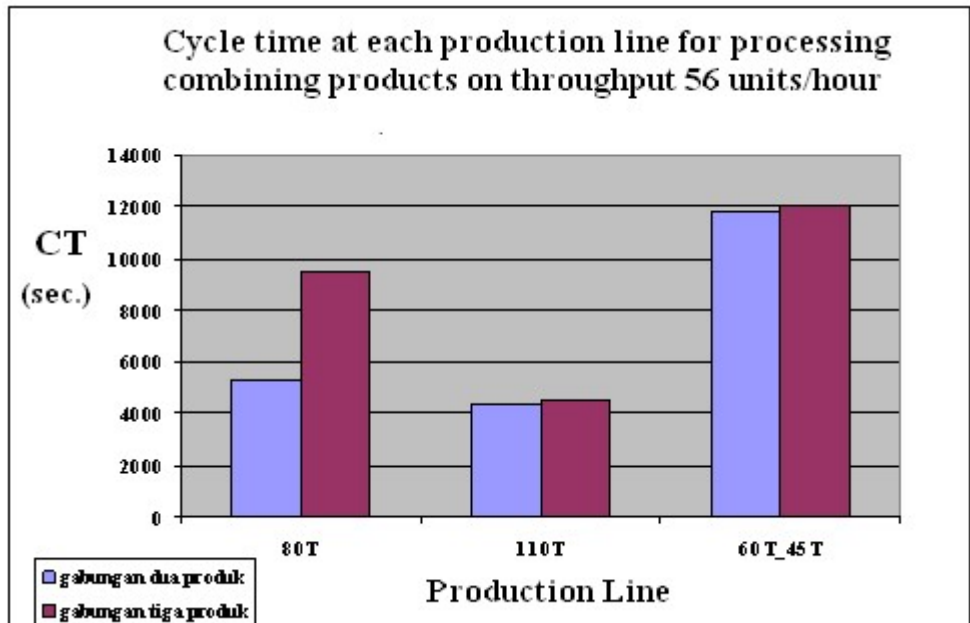


Figure 4.14 Cycle time at each production line for processing combining products on throughput 56 units/hour

#### 4.4 CONCLUSION

This chapter has discussed analysis of mathematical model applied or based on data from XYZ Company. The result shows the positive relationship between utilization to cycle time. The positive relationship means if utilization value increase, cycle time value also tend to increase. This chapter also has discussed *bottleneck workstation*, i.e. a workstation that has the highest utilization

compared to other workstations. This workstation also can be called as critical workstation because it becomes reference in determining optimization of resources utilization in multistage production lines.

## **CHAPTER V**

### **MATHEMATICAL MODEL VALIDATION BY SIMULATION**

This chapter will discuss validation of developed mathematical model by simulation model. For that purpose, collected data from studied industry will be analyzed by using ARENA<sup>®</sup>. And then with the same input data, the analysis results of mathematical model will be compared to the analysis result of ARENA<sup>®</sup>. The discussions in this chapter are divided into four chapters: data calculation by using ARENA<sup>®</sup>, comparison between results of mathematical model to those of simulation model, result discussion, and conclusion.

#### **4.5 DATA CALCULATION BY USING ARENA<sup>®</sup> AT XYZ COMPANY**

ARENA is a discrete-event simulation product that is developing by Rockwell Software. ARENA is used in wide variety of application areas such as Call centers, Business processes and Manufacturing.

Rockwell Software acquired ARENA, a package that used to be supplied by Systems Modeling. Rockwell software is a company that provides products especially to PLC industry. Company provides

total solutions for plants and industries in general. ARENA is a widely used discrete event simulation package. The company has partnership and resellers in many part of the world including US, Europe, and Australia.

Model development is done using templates and modules. Building a model is similar to creating a flowchart model. Modules are dragged and dropped to the model layout window. Data are fed in dialog boxes and spread sheet interface. Coding can be done using SIMAN or VBA for advanced features. ARENA is easy being cause of its modeling methodology and is flexible enough.

For model development, ARENA has nice features such as hierarchical modeling, application based templates, visual coding, integration with external programming languages (VB, and FORTRAN), import CAD and vision drawing, and conditional routing. However, one setback of Arena for developing a model is its inadequate method of merging models.

ARENA contains most of the standard distributions. It also has the ability to let the user create a new distribution. It can handle time dependent distributions (non-stationary Poisson process), it also has input distribution-fitting tool. ARENA has the necessary execution features. It has run setup, warm up period, replication specifications, and reset capability.

ARENA has a good 2D animation and nice animation feature. It can import Microsoft standard objects such as clipart, flexible animation path, good icon editor, wide collection of animation for different real life objects, and possibility to resize icons in model layout.

The package also has a good debugging tool it has a SIMAN command line prompt that can be used for debugging. Tracing output and other information can be extracted. Its breakpoints feature has ability to stop the model based on time, entity, and other conditions. ARENA also has a good tool, Process Analyzer, for conducting experiments.

For outputting results, ARENA uses Crystal report. The report can be customized. In addition the package has link to external packages such as spreadsheets, a database, text files, Visio and Visual basic. It also use DDE link. However, its business graphics is primitive and lacks some important tools.

In ARENA<sup>®</sup> application, entity entering a manufacturing system is a raw material of product. Finished good will be produced after this raw material processed by workstations along a production line. Simulation model creates raw material based on exponential distribution of interarrival time. ARENA<sup>®</sup> creates a certain raw material by determining processing time of raw material at each process along production line, and also by determining batch size which is the quantity of raw material in each batch.

ARENA<sup>®</sup> creates failure of product component as entity causing uncontrolled process. Each inspection process has a certain yield value. This means each inspection process will influence batch size of product that pass through it.

The quantity of product component will be re calculated when passing an inspection process. Figure 5.1 displays flow chart of this inspection.

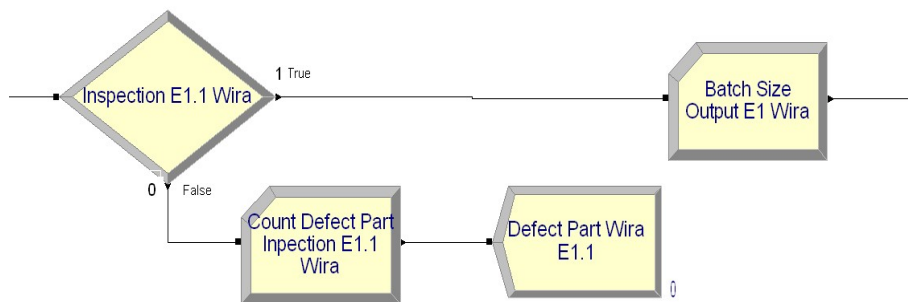


Figure 5.1 ARENA<sup>®</sup> logic for an inspection process

Discussion in this topic is focused on one type of existing product, two types of existing products, and three types of products which are combining two existing products and one new product. For one type category is reinforced instrument panel PS B, two types category is reinforced instrument panel PS B combined to gusset LH/RH, and for three types category is combined of reinforced

instrument panel PS B, gusset LH/RH, and case outer ashtray body which is a new product.

Input data to ARENA<sup>®</sup> is as shown in Tables 4.1 and 4.2. i.e. the information of process flow of product component, throughput and batch size. For processing single product, throughput and batch size is 80 units/hour and 50 units/batch, respectively. For processing combining products, throughput and batch size are as Table 4.2. Information in Table 4.2 is shown again in Table 5.1 The quantity of throughput and batch size for both processing single product and combining products mentioned here is the actual value used by XYZ Company.

Table 5.1 Throughput and batch size for processing combining product at XYZ Company (as shown in Table 4.2)

Parameter	Combining two products		Combining three products		
	Reinforced instrument panel PS B	Gusset LH/RH	Reinforced instrument panel PS B	Gusset LH/RH	Case outer ashtray body
Throughput $T_i$ (unit/hour)	34	34	34	34	34
Batch Size $B_i$ (unit/batch)	102	102	102	102	102

Source: XYZ Company. 2007

Based on information above, part of ARENA<sup>®</sup> user-interface for processing single product is shown in Figure 5.2., for processing combining two products in in Figure 5.3, and for processing combining three products is in Figure 5.4.

Figure 5.5 shows part of output as a result of ARENA<sup>®</sup> simulation for processing single product reinforced instrument panel PS B. As an example, output batch size at pemeriksaan\_1 workstation is 42 units. This quantity is as a result of difference between batch size entering pemeriksaan\_1 workstation (i.e 50 units) to quantity rejected by pemeriksaan\_1 workstation (i.e. 8 units). These parameters are shown in Figure 5.5 as Record Batch Size Output Inspection 1 (42), Batch Size Inspection\_1 (50) dan Count Defect Part Inspection 1 (8).



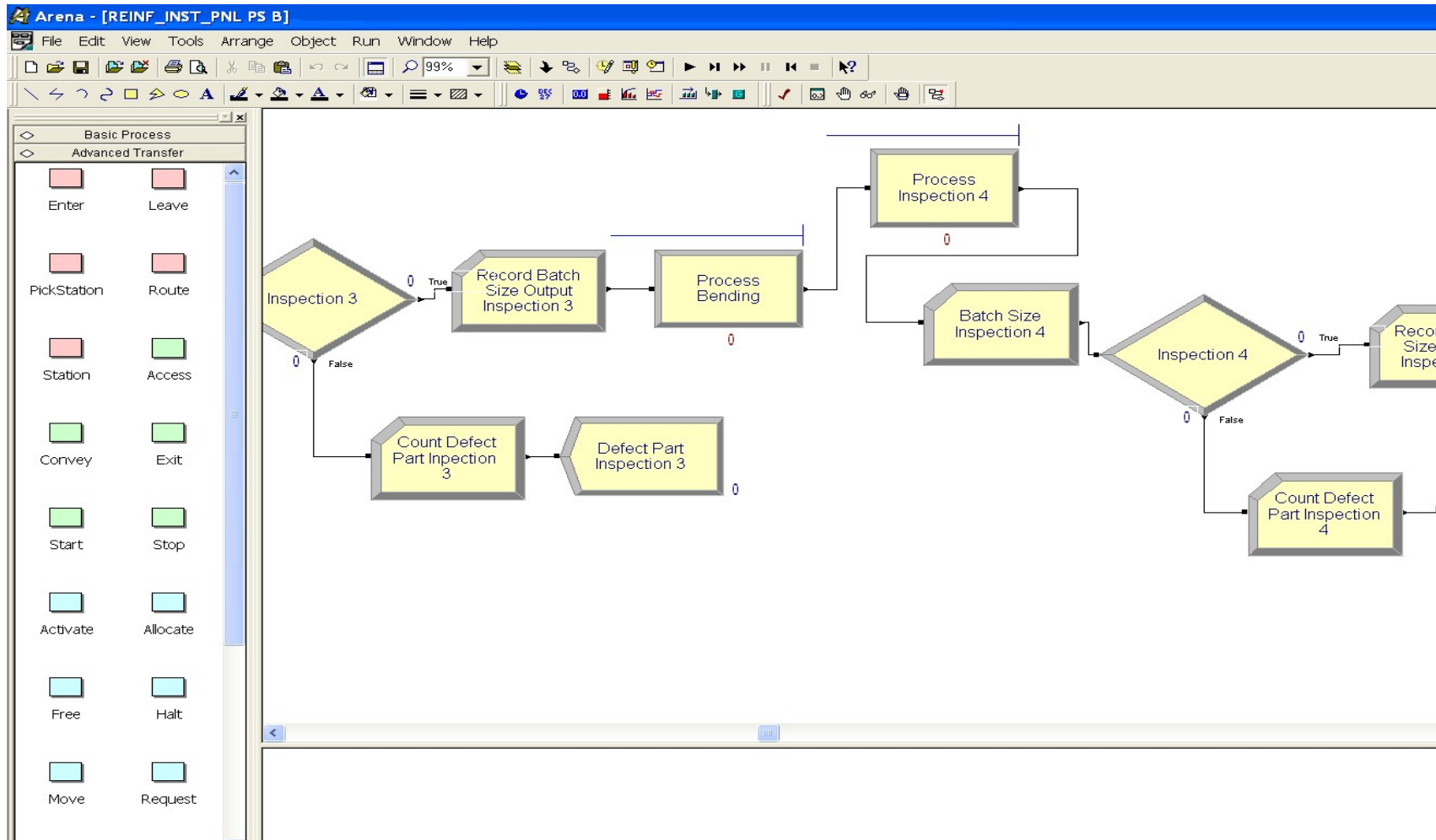


Figure 5.2 Part of ARENA<sup>®</sup> user-interface for processing single product (reinforced instrument panel PS B)

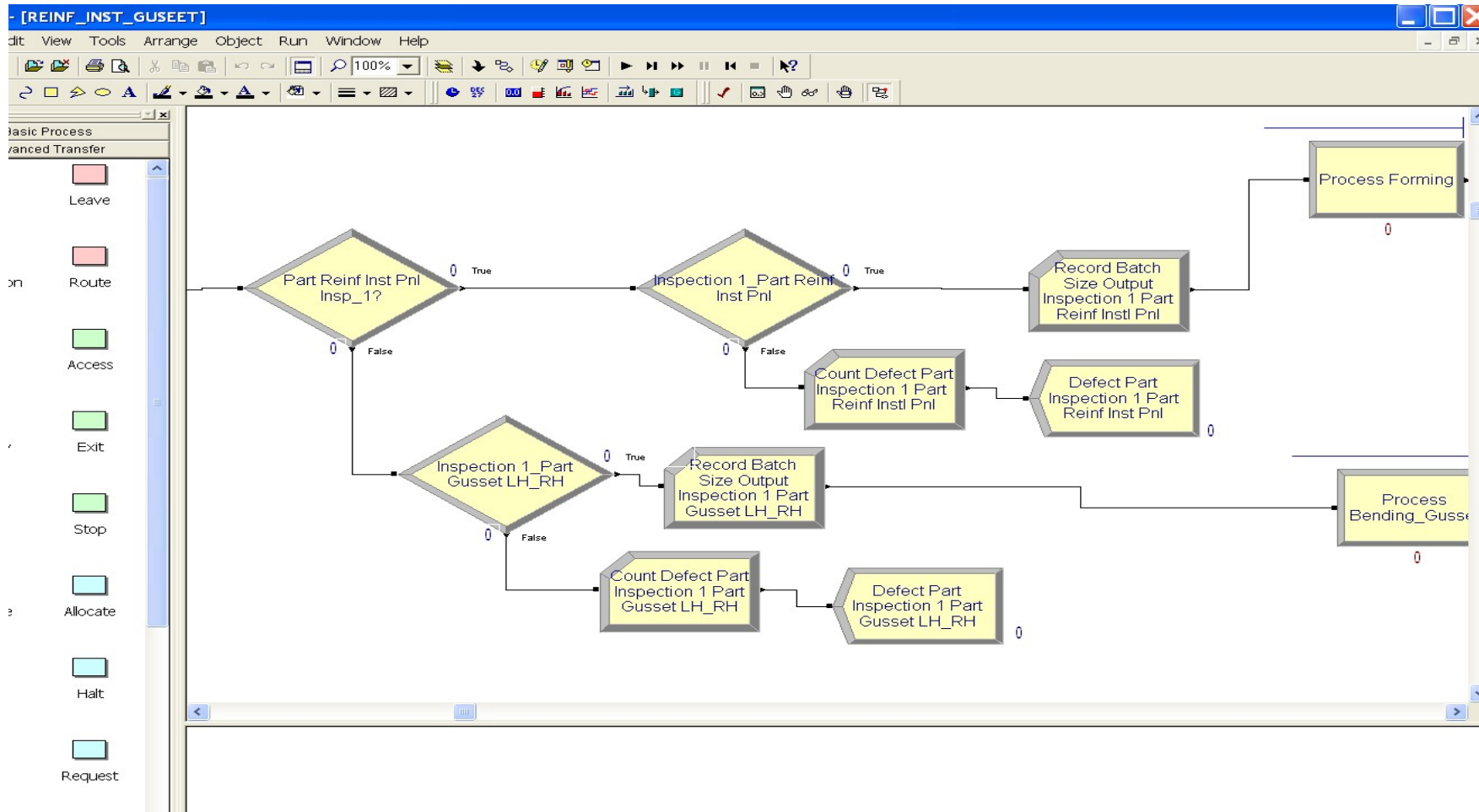


Figure 5.3 Part of ARENA<sup>®</sup> user-interface for processing combining two products (reinforced instrument panel PS B and gusset LH/RH)

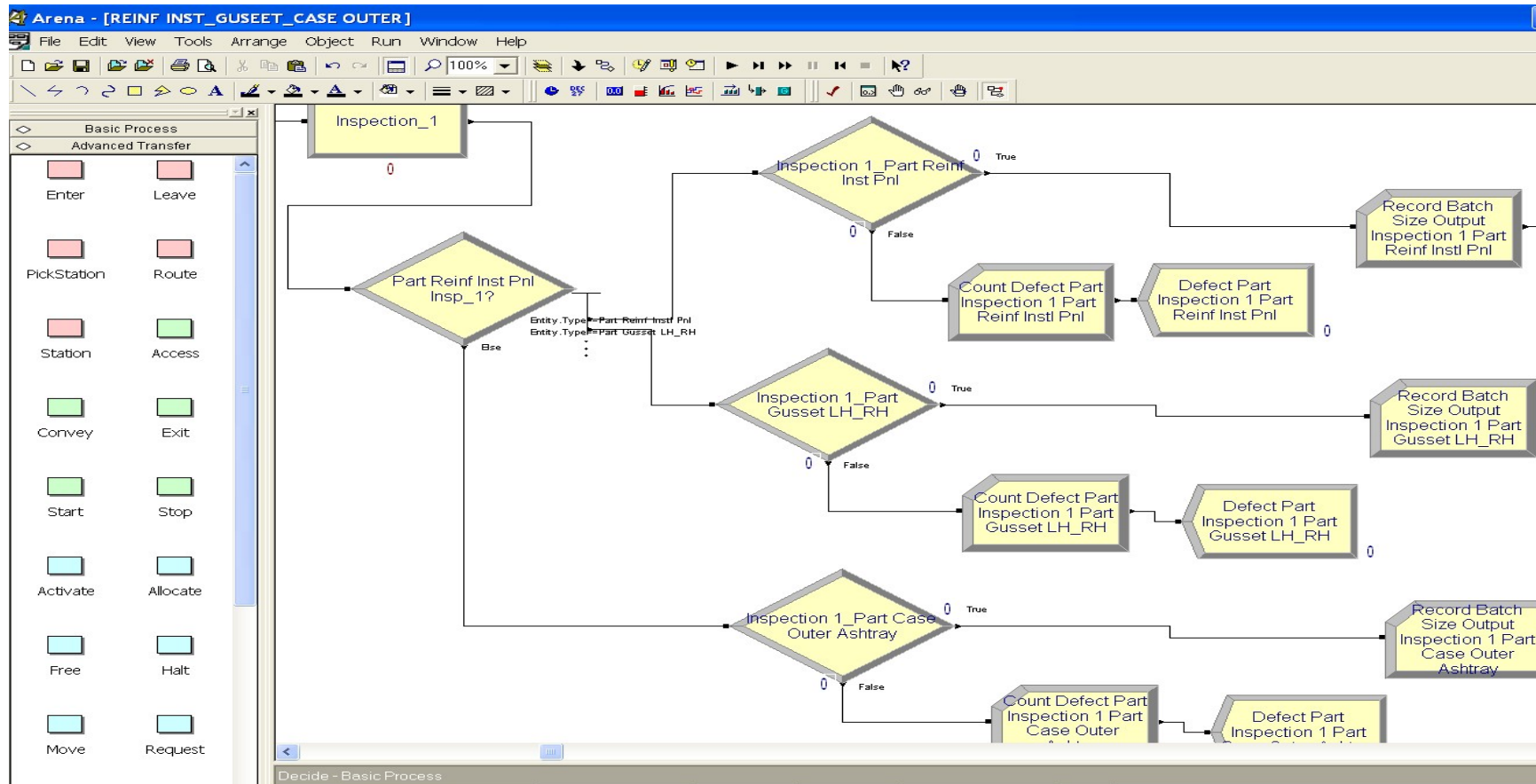


Figure 5.4 Part of ARENA<sup>®</sup> user-interface for processing combining three products (reinforced instrument panel PS B, gusset LH/RH and case outer ashtray body)

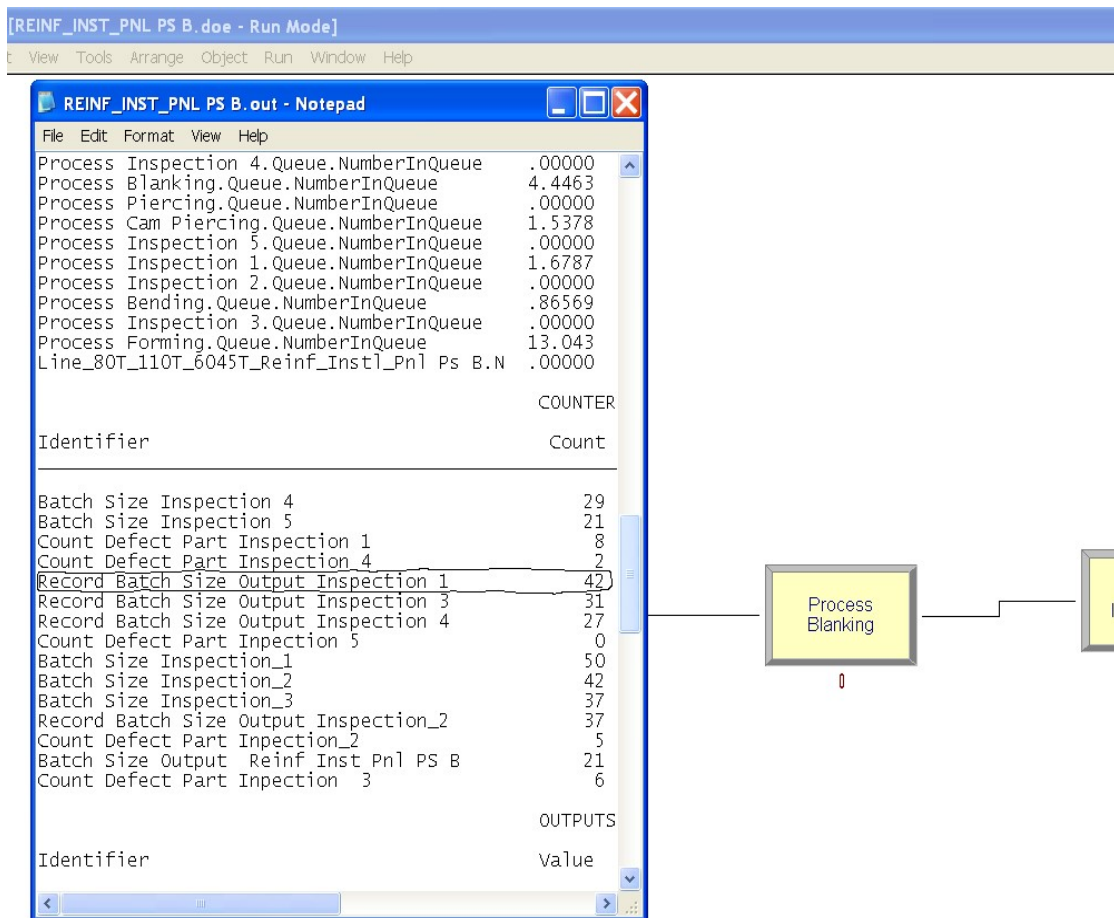


Figure 5.5 Part of output as a result of ARENA<sup>®</sup> simulation for processing single product (reinforced instrument panel PS B)

#### 4.6 COMPARISON BETWEEN RESULTS OF MATHEMATICAL MODEL TO RESULT OF ARENA<sup>®</sup> SIMULATION MODEL AT XYZ COMPANY.

Comparison between the results of optimization based on mathematical model to the result of optimization based on simulation model at industri XYZ Company is referred to parameters of batch size, utilization, and cycle time.

Table 5.2 displays comparison between mathematical model to simulation model for output batch size parameter resulted at each production line for processing single product and combining two products. On the other hand Table 5.3 shows comparison between mathematical model to simulation model for output batch size parameter resulted at each production line for processing single product and combining three products. Tables 5.2 and 5.3 also show the average value of output

batch size at each production line for processings of single product, combining two products and combining three products for both mathematical model and simulation model.

There is differences 2 units/batch for the average of output batch size for processing single product. For processing combining two products, the differences of the average of output batch size is the same which is 1 unit/batch for reinforced instrument panel PS B. On the other hand, the average of output batch size for gusset LH/RH is 0 unit/batch. Table 5.3 shows the average differences of output batch size for processing combining three products which are 5 units, 1 unit, and 2 units for reinforced instrument panel PS B, gusset LH/RH, and case outer ashtray body, respectively.

Table 5.2 Comparison between analyses of mathematical model to analysis of simulation model for output batch size parameter resulted at each production line for processing single product and processing combining two products (XYZ Company)

Production Line	Output Batch Size (unit/batch)								
	Single Product (Reinforced instrument panel PS B)			Combining two existing products (Reinforced instrument panel PS B + Gusset LH/RH)					
	Math. Model	Simulation Model	Diff. <sup>*)</sup>	Reinforced instrument panel PS B			Gusset LH/RH		
			Math. Model	Simulation Model	Diff. <sup>*)</sup>	Math. Model	Simulation Model	Diff. <sup>*)</sup>	
80T	28	27	1	56	55	1	102	102	0
110T	37	37	0	76	76	0	0	0	0
60T_45T	24	21	3	49	46	3	76	75	1
Average	30	28	2	60	59	1	89	89	0

<sup>\*)</sup> Absolute value

Table 5.3 Comparison between analyses of mathematical model to analysis of simulation model for output batch size parameter resulted at each production line for processing combining three products (XYZ Company)

<b>Output Batch Size (unit/batch)</b>									
<b>Production Line</b>	<b>Combining three products (Reinforced Instrument Panel PS B + Gusset LH/RH + Case Outer Ashtray Body)</b>								
	<b>Reinforced instrument panel PS B</b>			<b>Gusset LH/RH</b>			<b>Case outer ashtray body</b>		
	Math. Model	Simulation Model	Diff. <sup>*)</sup>	Math. Model	Simulation Model	Diff. <sup>*)</sup>	Math. Model	Simulation Model	Diff. <sup>*)</sup>
80T	56	49	7	88	87	1	65	68	3
110T	76	72	4	0	0	0	0	0	0
60T_45T	49	44	5	76	74	2	76	77	1
Average	60	55	5	82	81	1	71	73	2

<sup>\*)</sup> Average value

Table 5.4 shows the detail of Table 5.2 which is the output batch size of each workstation for each production line. As an example, the quantity of 28 units/batch (mathematical model, production line 80T, single process) in Table 5.2 is the same with 28 units/batch (mathematical model, single process, pemeriksaan\_4 workstation, production line 80T) in Table 5.4. This decision is resulted because workstation\_4 is the last workstation in the line of production line 80T.

Table 5.4 shows that for processing single product, the minimum difference which is 0 unit/batch happens at pelubangan workstation (production line 80T), pemeriksaan\_2 workstation (production line 110T), and penembusan workstation (production line 60T\_45T). On the other hand, the maximum difference that is 6 units/batch happens at penembusan sesondol workstation of production line 60T\_45T. For processing combining two products, the minimum difference which is 0 unit/batch happens at pelubangan workstation (production line 80T), and pemeriksaan\_2 workstation (production line 110T). On the other hand, the maximum difference that is 5 units/batch happens for processing gusset LH/RH at pemeriksaan\_1 workstation, pembengkokan, and penembusan workstations.

Table 5.4 Comparison between the analyses result of mathematical model to the analyses result of simulation model at each workstation for output batch size for processing single product and combining two products (XYZ Company)

Workstation of production line	Output Batch Size								
	Single Product (Reinf. Instrument Panel PS B)			Combining two existing products (Reinf. Instrument Panel PS B + Gusset LH/RH)					
	Mathemati- cal model	Simula- tion model	Differen- ces*)	Reinf. Instrument Mathemati- cal model	Panel PS B Simula- tion model	Differen- ces*)	Gusset LH/RH Mathemati- cal model	Simula- tion model	Differen- ces*)
<b>Line 80T:</b>									
Pelubangan	50	50	0	102	102	0	102	102	0
Pembentukan	0	0	0	0	0	0	0	0	0
Pemeriksaan 1	43.	42	1	88	88	0	88	83	5
Pembengkakan	32	29	3	65	68	3	0	0	0
Pemeriksaan 4	28	27	1	56	55	1	0	0	0
<b>Line110T:</b>									
Pembentukan	43	42	1	88	88	0	0	0	0
Pemeriksaan 2	37	37	0	76	76	0	0	0	0
<b>Line 60T_45T:</b>									
Pembengkakan	0	0	0	0	0	0	88	83	5
Penembusan	37	37	0	76	76	0	88	83	5
Pemeriksaan 3	32	31	1	65	68	3	76	75	1
Penembusan Sesondol	28	22	6	56	55	1	0	0	0
Pemeriksaan 5	24	21	3	49	46	3	0	0	0
Average	35	34	1	72	72	0	88	85	3

\*) Absolute value

Table 5.5 shows that for processing combining three products, the minimum difference of output batch size which is 0 unit/batch happens at pelubangan, and pembentukan workstations (production line 80T). On the other hand, the maximum difference that is 8 units/batch happens for processing reinforced instrument panel PS B at pembengkakan, and pemeriksaan\_3 workstations.

Table 5.5 shows that for mathematical model, the average of output batch size for reinforced instrument panel PS B, gusset LH/RH, and case outer ashtray body is 72 units/batch, 88 units/batch, and 85 units/batch, respectively (on the other hand, result of simulation model is 67 units/batch, 87 units/batch, and 87 units/batch, respectively). Differences between two models for the average of output batch size are 5 units, 1 unit, and 2 units for reinforced instrument panel PS B, gusset LH/RH, and case outer ashtray body, respectively.

Table 5.6 displays utilization comparison between mathematical model to simulation model for processings of single product, combining two products, and combining three products. The minimum difference for processing single product is 0.0068 at pemeriksaan\_1 workstation, and the maximum one is 0.0592 at pembengkakan workstation. For processing combining two products, the minimum difference is 0.0093 at penembusan workstation, and the maximum difference is 0.0914 at penembusan sesondol workstation. For processing combining three products, the minimum one is 0.0006 at pemeriksaan\_2 workstation, and the maximum one is 0.2099 at pembengkakan (60T\_45T) workstation. In case of mathematical model, the average of utilization for processing single product is 0.4570. This value is 0.2837 and 0.3182 for processing combining two products and combining three products, respectively. In case of simulation model, the average of utilization is 0.4550, 0.2869, and 0.3533 for processings of single product, combining two products, and combining three products, respectively. Based on these results, it is clearly that the differences between two models are 0.0020 for processing single product, 0.0032 for processing combining two products, and 0.0370 for processing combining three products.

Table 5.7 shows the difference between the results of mathematical model to the results of simulation model at each workstation for cycle time parameter. These



results are based on processing single product, processing combining two products, and processing combining three products. In processing single product, the minimum difference is 13.45 second at pemeriksaan\_3 workstation. In processing combining two products, the minimum difference is 1.239 second at pembentukan workstation, meanwhile in processing combining three products, the minimum one is 21.757 second at penembusan sesondol workstation. The maximum differences between two models are 436.2 second at pembentukan workstation for processing single product, 141.955 second at penembusan workstation for processing combining two products, and 487.8 second at pembentukan workstation for processing combining three products. For cycle time parameter, there are difference results between mathematical model to simulation model which are 43.5 second for processing single product, 0.1 second for processing combining two products, and 21.9 second for processing combining three products.

Table 5.5 Comparison between the result of mathematical model to the result of simulation model for output batch size parameter for processing combining three products (XYZ Company)

Workstation of production line	Output Batch Size								
	Combining three products								
	(Reinf. Instrument Panel PS B + Gusset LH/RH + Case Outer Ashtray Body)								
	Reinf. Instrument Mathemati- cal model	Panel PS B Simulation model	Differen- ces*)	Gusset LH/RH Mathemati- cal model	Simula- tion model	Differen- ces*)	Case Outer Ashtray Body Mathemati- cal model	Simula- tion model	Differen- ces*)
<b>Line 80T:</b>									
Pelubangan	102	102	0	102	102	0	102	102	0
Pembentukan	0	0	0	0	0	0	102	102	0
Pemeriksaan 1	88	85	3	88	87	1	88	90	2
Pembengkokan	65	57	8	0	0	0	76	77	1
Pemeriksaan 4	56	49	7	0	0	0	65	68	3
<b>Line 110T:</b>									
Pembentukan	88	85	3	0	0	0	0	0	0
Pemeriksaan 2	76	72	4	0	0	0	0	0	0
<b>Line 60T_45T:</b>									
Pembengkokan	0	0	0	88	87	1	88	90	2
Penembusan	76	72	4	88	87	1	0	0	0
Pemeriksaan 3	65	57	8	76	74	2	76	77	1
Penembusan Sesondol	56	49	7	0	0	0	0	0	0
Pemeriksaan 5	49	44	5	0	0	0	0	0	0
Average	72	67	5	88	87	1	85	87	2

\*) Absolute value

Table 5.6 Comparison between the result of mathematical model to the result of simulation model for utilization parameter at each workstation for processing single product, processing combining two products, and processing combining three products (XYZ Company)

Workstation of production line	Utilization at each workstation								
	Single Product (Reinf. Instrument Panel PS B)			Combining two existing products (Reinf. Instrument Panel PS B + Gusset LH/RH)			Combining three products (Reinf. Instrument Panel PS B + Gusset LH/RH + Case Outer Ashtray Body)		
	Mathemati- cal model	Simula- tion model	Differen- ces*)	Mathemati- cal model	Simula- tion model	Differen- ces*)	Mathemati- cal model	Simula- tion model	Differences*)
<b>Line 80T:</b>									
Pelubangan	0.2931	0.1815	0.1116	0.3459	0.4250	0.0791	0.3089	0.3763	0.0674
Pembentukan	0	0	0	0	0	0	0.5313	0.5515	0.0202
Pemeriksaan 1	0.2568	0.2500	0.0068	0.1813	0.1700	0.0113	0.2650	0.3166	0.0516
Pembengkokan	0.8164	0.8756	0.0592	0.3470	0.2750	0.0720	0.3300	0.3398	0.0098
Pemeriksaan 4	0.1863	0.2148	0.0285	0.0792	0.0472	0.0320	0.1583	0.1164	0.0419
<b>Line 110T:</b>									
Pembentukan	0.8404	0.8843	0.0439	0.3572	0.3984	0.0412	0.3572	0.4665	0.1093
Pemeriksaan 2	0.1698	0.1556	0.0142	0.0722	0.0611	0.0111	0.0722	0.0716	0.0006
<b>Line 60T_45T:</b>									
Pembengkokan	0	0	0	0.5083	0.5349	0.0266	0.4941	0.7040	0.2099
Penembusan	0.7058	0.7674	0.0616	0.6046	0.6139	0.0093	0.6046	0.7717	0.1671
Pemeriksaan 3	0.1970	0.1713	0.0257	0.1559	0.1104	0.0455	0.2280	0.2147	0.0133
Penembusan Sesondol	0.9180	0.8870	0.0310	0.3901	0.4815	0.0914	0.3901	0.2905	0.0996
Pemeriksaan 5	0.1863	0.1622	0.0241	0.0792	0.0382	0.0410	0.0792	0.0442	0.0350
Average	0.4570	0.4550	0.0020	0.2837	0.2869	0.0032	0.3182	0.3553	0.0370

\*) Absolute value

Table 5.7 Comparison between the result of mathematical model to the result of simulation model for cycle time parameter at each workstation for processing single product, processing combining two products, and processing combining three products (XYZ Company)

Workstation of production line	Cycle Time (second)								
	Single Product (Reinf. Instrument Panel PS B)			Combining two existing products (Reinf. Instrument Panel PS B + Gusset LH/RH)			Combining three products (Reinf. Instrument Panel PS B + Gusset LH/RH + Case Outer Ashtray Body)		
	Mathematical model	Simulation model	Differences <sup>*)</sup>	Mathematical model	Simulation model	Differences <sup>*)</sup>	Mathematical model	Simulation model	Differences <sup>*)</sup>
<b>Talian 80T:</b>									
Pelubangan	490	245	245	1490.7	1530.0	39.3	866.3	1091.1	224.8
Pembentukan	0	0	0	0	0	0	2087.1	1599.3	487.8
Pemeriksaan 1	370.1	337.5	32.6	673.5	612	61.5	640.5	918	277.5
Pembengkokan	874.2	1160	285.8	891.7	990.1	98.4	910.8	985.5	74.7
Pemeriksaan 4	172	290	118	175.4	170	5.4	376.8	337.5	39.3
<b>Talian 110T:</b>									
Pembentukan	1405	1193.8	211.2	1433.2	1434.4	1.2	1433.2	1352.9	80.3
Pemeriksaan 2	244.7	210	34.7	249.6	220	29.6	249.6	207.5	42.1
<b>Talian 60T_45T:</b>									
Pembengkokan	0	0	0	2039.8	1925.6	114.2	1982.7	2041.6	58.9
Penembusan	876.8	1036	159.2	2068.1	2210.1	142.0	2068.1	2238.0	169.9
Pemeriksaan 3	210.9	231.3	20.4	459.6	397.5	62.1	471.4	622.5	151.1
Penembusan Sesondol	847.3	1188.4	341.1	1728.6	1733.6	5.0	864.3	842.5	21.8
Pemeriksaan 5	148.2	210	61.8	151.2	137.5	13.7	151.2	128.3	22.9
Average	566.7	610.2	43.5	1032.9	1032.8	0.1	1008.5	1030.4	21.9

<sup>\*)</sup> Absolute value

The minimum and maximum differences for all three parameters are shown in Table 5.8. Table 5.9 displays the differences in the form of error percentage.

Table 5.8 The minimum and maximum differences between mathematical model to simulation model for batch size, utilization, and cycle time parameters (XYZ Company.)

Processing category	Output Batch Size (unit/batch)		Utilization		Cycle Time (second)	
	Minimum differences	Maximum differences	Minimum differences	Maximum differences	Minimum differences	Maximum differences
Single Product	0	6	0.0068	0.0592	20.4000	341.1
Two Products	0	5	0.0093	0.0914	1.2390	141.9550
Three Products	0	8	0.0006	0.2093	21.7570	487.800

Table 5.9 The minimum and maximum differences between mathematical model to simulation model stated in percentage error for batch size, utilization, and cycle time parameters (XYZ Company)

Processing Category	Percentage Error of Output Batch Size (%)		Percentage Error of Utilization (%)		Percentage Error of Cycle Time (%)	
	minimum	maximum	minimum	maximum	minimum	maximum
Single Product	0.00	27.27	2.72	6.76	8.82	28.70
Two Products	0.00	6.02	1.51	18.98	0.09	6.42
Three Products	0.00	14.04	0.84	29.82	2.58	30.50

The average value of both mathematical model and simulation model for parameters of output batch size, utilization, and cycle time at XYZ Company is shown in Table 5.10. And the average of percentage error for both mathematical model and simulation model is shown Table 5.11.

Table 5.10 The average value of both mathematical model and simulation model for parameters of output batch size, utilization, and cycle time (XYZ Company)

Processing Category	Parameter								
	Output Batch Size (unit/batch)			Utilization			Cycle Time (second)		
	Mathemati- cal model	Simulation model	Differen- ces <sup>*)</sup>	Mathematical model	Simula- tion model	Differen- ces <sup>*)</sup>	Mathematical model	Simula- tion model	Differences <sup>*)</sup>
Single Product	35	34	2	0.4570	0.4550	0.0020	566.7	610.2	43.5
Two Products	88	85	3	0.2837	0.2869	0.0032	1032.9	1032.8	0.1
Three Products	72	67	5	0.3182	0.3553	0.0370	1008.5	1030.4	21.9

<sup>\*)</sup> Absolute value

Table 5.11 Percentage error of average value of both mathematical model and simulation model for parameters of output batch size, utilization, and cycle time (XYZ Company)

Processing Category	Parameter		
	Percentage Error of Output Batch Size (%)	Percentage Error of Utilization (%)	Percentage Error of Cycle Time (%)
Single Product	5.88	0.44	7.13
Two Products	3.53	1.12	0.009
Three Products	7.46	10.41	2.12

## **4.7 RESULT DISCUSSION**

Comparison between the result of mathematical model to the result of simulation model has been discussed in sub-chapter 5.2. The next discussion is focused on the analysis of those results which have already displayed in Tables 5.9 and 5.11. Table 5.9 refer to the maximum and minimum differences between two models for only one workstation. On the other hand, Table 5.11 refers to the average value of all workstations.

### **5.3.1 The maximum of Percentage Error**

For a single stage manufacturing system Koo et al. (1995) stated that the maximum allowance of percentage error for results between mathematical model to simulation model is 32%. Tables 5.9 and 5.11 show the percentage error of output batch size, utilization, and cycle time, either for processing single product or processing combining products is lower than 32%. This result conforms to Koo et al. statement.

### **5.3.2 Quantity of Workstation at Processing Combining Product and Its Relationship to the Range Between Maximum to Minimum Value**

For processing combining products, Table 5.9 shows that the increase of quantity of workstation at a production line will cause the increase of range between maximum and minimum values for parameters of output batch size, utilization, and cycle time. This fact refers to the quantity of workstation at processing combining three products which

are more than the quantity of workstation at processing combining two products. Clearly, it can be referred to Table 5.9.

### **5.3.3 Quantity of Workstation and Its Relationship to the Accuracy of Result Between Mathematical Model to Simulation Model**

Processing combining products, either combining two products or combining three products, have workstation more than that processing single product. Comparison between processing single product to processing combining products for parameters output batch size, utilization, and cycle time describe that the accuracy of mathematical model to simulation model is better for processing combining product rather than that processing single product. This result conforms to the finding of Bulgak and Sander (1990), and Zhuang et al. (1998). To support this fact, Table 5.9 can be referred.

## **4.8 CONCLUSION**

Chapter 5 has discussed the analysis result of simulation model (ARENA<sup>®</sup>) related to collected data from the industry of XYZ Company. Next, this ARENA<sup>®</sup> is used to validate the developed mathematical model. Validation of mathematical model discussed in this chapter has been successful to show that the developed model is valid to use in analyzing a manufacturing system. This chapter is ended by discussion related to complexity of layout and quantity of workstation in a manufacturing system.



## **CHAPTER VI**

### **CONCLUSION AND CLOSING WORD**

#### **6.1 CONCLUSION**

This study has suggested a mathematical approach related to spreadsheet model to analyze utilization and cycle time of multistage manufacturing system. A multistage manufacturing system is a manufacturing system having more than 'three workstations, two buffers, and two processed products'.

The analysis of manufacturing system is related to existing product and new product processed by that manufacturing system. Therefore there are two possibilities for production. The first possibility is the manufacturing system just processes the existing product and the second one the manufacturing system also processes combining the existing and the new product. Processing the existing products combining to new product at the existing production line will make the benefits to a manufacturing industry. These benefits are in the aspect of cost reduction and also time reduction to develop a new product.

This study suggests a mathematical model to use in analyzing an existing manufacturing system by focusing on product development, capacity utilization, and cycle time. Clearly, this mathematical model has been a foundation to develop a supporting tool used to optimize manufacturing system.

This developed supporting tool uses a mathematical approach base on queuing theory and completed by spreadsheet MS Excel<sup>®</sup> and Visual Basic<sup>®</sup> as user-interface. To validation purpose of developed mathematical model, the analysis result of mathematical model is compared to the analysis result of simulation model of ARENA<sup>®</sup>. Data for these analyses is collected from a company i.e. XYZ Company. Data analysis based on mathematical model is discussed in Chapter 4, while Chapter 5 has discussed both data analysis using simulation ARENA<sup>®</sup> and mathematical model validation.

Based on discussion in Chapter 5, the validity of developed mathematical model can be accepted. This is because percentage error between the results of mathematical model to the results of simulation model is lower than 32% that is the allowable maximum value suggested by Koo et al. (1995).

## **6.2 CLOSING WORD**

As a closing word, it can be concluded the contribution of this study related to knowledge development and application in industry:

## **1. Development of supporting tool that has capability to analyze a manufacturing system and easily to operate**

By using Visual Basic® application as the user-interface of developed supporting tool, this tool is easy to operate, need not too many input data, and pass to get the result in analyzing a certain manufacturing system. Therefore, this developed supporting tool differs to supporting tool based on simulation which need too many and detail input data. The need to detail input data will cause the delay to get the result. This is one of disadvantages of the supporting tool based on simulation.

## **2. Consider the reliability factor of analyzed manufacturing system**

A mathematical formulae including reliability factor for analyzing multistage production line has been introduced in this study. This reliability factor refers to normal yield, scrap yield, and reduced yield. Based on the literature study discussed in Chapter 2, this reliability factor does not consider by any optimization model previously.

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