THE FRAMEWORK AND ANALYSIS TOOL TO EVALUATE THE EFFECT OF PRODUCT DESIGN TO THE PERFORMANCE OF MANUFACTURING SYSTEM

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ABSTRACT

Modeling of a manufacturing system enables one to identify the effects of key design parameters on the system performance and as a result to make correct decision. This paper proposes a manufacturing system modeling approach using a mathematical model approach based on real data from a selected company, Ciri Tegap Sdn. Bhd. The model was used to improve the existing system utilization in relation to product design and system performance. The model incorporates few parameters such as utilization, cycle time, throughput, and batch size. The study also showed that the validity of developed model is good enough to apply and the maximum value of relative error is 30%, just below the limit value 32%. Therefore, the model developed in this study is a valuable alternative model in evaluating a manufacturing system.

ABSTRAK

Permodelan sistem pembuatan membolehkan kita untuk mengenal pasti kesan perubahan parameter utama reka bentuk ke atas prestasi sistem dan akhirnya untuk membuat keputusan yang betul berkaitan reka bentuk sesuatu sistem. Kertas kerja ini mencadangkan pendekatan permodelan sistem pembuatan dengan menggunakan pendekatan model matematik yang direka berdasarkan data sebenar dari syarikat terpilih iaitu, Ciri Tegap Sdn. Bhd. Model ini telah digunakan untuk meningkatkan produktiviti sistem sedia ada dengan memanfaatkan proses reka bentuk produk dan prestasi sistem. Model ini menggabungkan beberapa parameter seperti penggunaan mesin atau stesen, tempoh masa kitaran, faktor kendalian, dan saiz hasil. Kajian ini juga menunjukkan bahawa kesahihan model yang dibangunkan adalah cukup baik untuk diguna pakai dan dimanfaatkan dengan nilai maksimum ralat relatif adalah 30%, masih di bawah had 32% yang dibenarkan. Oleh itu, model yang dibangunkan dalam kajian ini adalah satu model alternatif yang sangat berguna dalam menilai prestasi sistem pembuatan yang dikaji.

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CHAPTER 1

INTRODUCTION

Nowadays product varieties are increasingly introduced into the market. In this situation, the philosophy needed by a company to survive is by constantly changing from the old product to a new one, or by improving an existing product. This reflects the importance of product development for competitive advantage. However, design activities and product development are knowledge intensive activities that include market survey, function requirements, concept design, detail design, material and process selection, optimization, process control, testing and evaluation, manufacturing and production, and finally marketing (Ahmadi and Wang, 1999; Balachandra, 1991; Bralla, 1996; Burhanuddin and Randhawa, 1992).

1.1 Research Background

Developing successful new products requires the ability to predict the life cycle impact of design decisions at the early stage of product development. Downstream life cycle issues include considerations on how product will be made, shipped, installed, used, serviced, and retired or recycled. Ignoring downstream issues leads to poor product design that may cause unforeseen problems and excessive costs downstream (Cooper *et al.*, 2004).

Unfortunately, downstream life cycle needs are difficult to predict accurately during the early design phases. To overcome this problem, many researchers presented the results of their study using the concurrent engineering approach during product design. The Development of *Design for X* (*DFX*) methods is an important effort to actualize the application of this concurrent engineering (Gatenby and Foo, 1990). Some of these DFX methods also proposed the consideration of factors such as capacity analysis of manufacturing system, throughput, and cycle time at the early phase of product design.

Soundar and Bao (1994) presented a planning that relates product design effects to manufacturing system. They suggested the use of mathematical models and simulation to predict various performance parameters including manufacturing cycle time. The approach was however very general and no specific example was discussed in their paper.

Johnson and Montgomery (Aomar, 2000) presented a mathematical formulation for the product-mix problem as a constrained LP (Linear Programming) model. They found that many firms have benefited from the use of this LP model especially in making product-mix decision. In order to apply the LP model, many input data from the industry is required such as the minimum production level of each product type in the planning period, number of units of each resource that are required to produce one unit of each product type, and the amount of each resource available during the planning period.

Walid Abdul Kader (2006) presented a study on certain parameters of modern production lines (i.e. a production lines have multi-stage process) having a variety of product processes in a batch production environment, which is in relation to capacity estimation. These parameters include the set-up time, the product mix, and the reliability of the stations composing the systems. Anyway, the detail of suggested approach was not discussed in his paper.

The design of the product, among other things, affects the performance of the manufacturing system. Concurrent engineering research in this area has been focused on testing the manufacturability of a product at the initial design stage. The concurrent design of products and performance of manufacturing systems required to manufacture the product has been largely ignored. It is therefore necessary to integrate product design and manufacturing system performance.

1.2 Research Motivation

Based on discussion above, it can be concluded:

1. The importance of product development by a company to survive in its business.
2. Downstream life cycle issues in product development are difficult to predict accurately during the early design phase.
3. Many researchers presented their models that relate product design to manufacturing system. However, the detail of their models was not discussed in their papers.
4. The integration issue of product design and manufacturing system performance has been largely ignored.

1.3 Research Objectives

This study embarks on the following objectives:

1. To propose a robust framework that can be used to understand how introducing new product into an existing manufacturing system can affect the performance of the manufacturing system.
2. To propose a quick analysis tool to analyze the effect of a new product design to an existing manufacturing system.

1.4 Research Scope

This study 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.

1.5 Outline of the Report

This report is written in the order as follows: Chapter 2 discusses the previous studies related to the issue of models in optimization of manufacturing system. Chapter 3 describes methodology used in this study, mathematical model development. 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 software. And finally Chapter 6 is conclusion and closing words.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of Manufacturing Systems

Manufacturing stems from the Latin words manus (hand) and factus (make). Nowadays, by manufacturing we mean the process of converting raw material into a physical product (we do not consider services to be manufacturable). A system is a collection of elements forming a unified whole. Thus, a manufacturing system refers to any collection of elements that converts raw material into a product. We can identify manufacturing systems at four different levels.

- At factory level the manufacturing system is the factory (also referred to as plant, fabricator, or shortly fab). The elements of the system are areas and (groups of) machines.

- At area level the manufacturing system is an area of the factory with several machines or groups of machines (cells). The elements of the system are individual machines.

- At cell level the manufacturing system is a group of machines that are typically scheduled as one entity.

- At machine level, the manufacturing system is the individual machine (also referred to as equipment or tools). The elements of the system are machine components.

2.1.1 Single Machine

The most basic form of a manufacturing system is a single machine or workstation. The scientific and the systems aspects for a single machine is therefore of fundamental importance. The Peklenik model of manufacturing systems starts with a single machine which consists of a P system for positioning, K systems for kinematics and an E system for the transmission of energy (Peklenik J, 1971). The system has a feedback loop for control purposes and the summation point takes place at the cutting edge in the case of a metal cutting machine. While the level of sophistication of machine increases from CNC, DNC to adaptive control and intelligent control, the Peklenik model remains applicable with its elegant input-output systems approach based on cybernetics principles [(Peklenik J, 2003).

2.1.2 Manufacturing Cell

A component usually requires a number of different manufacturing steps and this means several machines are required for achieving the desired geometrical features. The arrangement of machine tools to form a manufacturing cell based on Similarity Principles for a family of parts represents the most efficient method for batch manufacturing. The Mitrofanov model for cellular manufacturing was further enhanced by numerous researchers in classification and coding group formation methods (K.K.B. Hon, 2007), and optimization techniques. Starting from the late 1960s, a new generation of highly automated manufacturing cells, often addressed as FMS, evolved from the original group technology concept.

2.1.3 Flow Line

For high volume production especially for consumer goods, a tightly coupled and finely balanced production line based on Henry Ford's principle is the best choice when minimum cycle time is the key objective. In this case, line balancing, materials handling, materials flow control in terms of push or pull mechanism become essential elements of consideration (K.K.B. Hon, 2007). In automotive industry, the Toyota model of JIT manufacturing systems has become the paradigm for high volume manufacturing of identical or non-identical products (K.K.B. Hon, 2007).

2.1.4 Factory

The original concept of manufacturing systems first proposed by Merchant is applicable to the entire factory. This means that the entire cycle from design, planning, programming, manufacturing, production control and dispatch should be considered as a complete system (K.K.B. Hon, 2007). The Merchant model will avoid the undesirable effects of seeking a local optimum performance instead of the global system optimum. More recent developments in holonic systems, digital factory, and fractal factory (K.K.B. Hon, 2007) are further advances made possible with the ever-increasing hardware and software computing power.

2.1.5 Production Network

The introduction of the internet and the realization of globalization provide the main drivers for the emergence of production network. The Wiendahl model of production network recognises the critical role of supply chain in the total manufacturing environment (Wiendahl, H.P. and Lutz, 2002). The idea of vertical integration of making all or most parts is long gone and it is replaced by a production network linked by supply chains where each node of the chain possesses its own core manufacturing competence. As this is an evolving idea, research in this area is at an early stage.

2.2 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.

2.2.1 Manufacturing System 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.

2.2.1.1. 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. TP is practical lead time minimum, and rP is practical production rate:

$$W = (n/rP) + TP \quad (2.1)$$

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 rP parts per unit time, and each component needs TP 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

$$T = (s-1)t + W \quad (2.2)$$

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 inter-arrival 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 researchers 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.

2.2.1.2. 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.

2.2.2 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.

2.3 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.

2.4 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 historical 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.

2.5 Performance Measurement Framework for Manufacturing Systems

The classical view of manufacturing based on 4M-man, machine, material and method is no longer adequate in the present environment as the coverage is too constrained. Today, the general approach for performance measurement is based on measuring input and output and yet there are other relevant dimensions for consideration. In the first instance, a viable framework is essential for the overall manufacturing functions. Based on the systems approach pioneered by Merchant and Peklenik and taking into account modern development in extended enterprises, a hierarchical 5-level approach will form the basic framework for this research (Wiendahl, H.P. and Lutz, 2002). The 5-levels cover machine, cell, line, factory and network. This framework recognises that the basic building block of a manufacturing system is a single machine or workstation and the highest macro-level is manifested in the form of a number of collaborative factories in a network formation, sometimes known as extended enterprise or virtual enterprise depending on the degree of coupling. The inclusion of cellular system and flow line is specifically based on the need to cover low, medium and high volume production.

Within each level, five major metrics are used for performance measurement, i.e., Time, Cost, Quality, Flexibility and Productivity as shown in Table 1.1. Under each metric, specific measures are used for measuring a specific characteristic on manufacturing performance at that level. The matrix framework thus covers all the essential elements for manufacturing from a systems point of view. Naturally, there are specific measures designed for different levels of manufacturing systems (K.K.B. Hon, 2007). A sub-set of the measures could be chosen for practical implementation or simulation for performance analysis for a particular manufacturing system (Cunha, P.F., Laureano, P and Henriques, E., 2001).

Table 2.1: Template - Performance measurement system for manufacturing system

Level	T	C	Q	F	P
Machine					
Cell					
Line					
Factory					
Network					

The scope of this framework is focused on those activities which are the direct responsibilities of the Manufacturing Department within a company. Therefore, performance in other areas such as marketing, customer satisfaction, share price, human resources are outside the scope of this framework.

2.6 Robustness of a system and design

A robust product design demonstrates that the intended functions and performance of a product would be minimally affected by environmental variations; this can also be stated as the product's ability to fulfill the function is insensitive, or robust, to the changes from those uncontrollable noise parameters.

A robust manufacturing system is important in the dynamic manufacturing environment. This is because the performance of a manufacturing system usually suffers from the variations of production conditions in an uncertain environment, such as mean inter-arrival times, probability distributions of input parts, mean service times, mean time to machine failure, and so on. A robust system can not only meet the performance criteria, but also not be sensitive to the variations of production conditions. Since the system can operate consistently as desired, it can effectively utilize production resources; hence, we can more accurately plan and control production schedules and delivery deadlines so as to reduce the safety stocks or other investments that are prepared for dealing with the variations in the uncertain environment. These are obviously advantageous for a business unit to add to its profitability.

Only a few published works have addressed robust manufacturing system design. Wild and Pignatiello (1991) proposed an experimental design strategy for designing robust systems using discrete-event simulation. This strategy was based on Taguchi methods for improving process quality in manufacturing. Wild and Pignatiello (1991) demonstrated the proposed strategy with an example of a job shop manufacturing system. In their example, only one evaluation criterion of system performance was considered, the mean time a part spends in the job shop. After employing an expected performance analysis that implements a three-step optimization procedure to the criterion, the optimal job shop design that is the most robust is found.

Mayer and Benjamin (1992) also followed Taguchi methods to design a robust manufacturing system using computer simulation experiments. They considered the average time of the most critical part among three parts in the system as the performance evaluation criterion in an illustrated example. Unlike Wild and Pignatiello's case, Mayer and Benjamin (1992) used the signal to noise (S/N) ratio as the analysis tool to find the robust design. Both methods described above heuristically find the most robust system designs that produce "optimal" performance in the prespecified region. In addition, it is recommended that an optimization procedure incorporating the Taguchi approach could be developed to find the "best" system design.

2.7 Summary

Models of manufacturing system have been discussed in Chapter 2. This chapter 2 also discusses manufacturing cycle time, capacity analyzes, and the performance measurement framework for manufacturing systems. In briefly, research related to cycle time and capacity of manufacturing system are still relevant and important to study. These two will be the main parameters that we will be using throughout this research in order to evaluate and measure the effect of product design to the performance of manufacturing system.

Robustness of a system is shown by system performance. The ability to produce many parts with different operation arrangement and condition is a very important characteristic of a robust framework and analysis tool in this study. An existing mathematical model and ARENA model will be used along in this research as reference and benchmarking besides real data from a company that we will be using as a sample in this research.

CHAPTER 3

METHODOLOGY

3.1 Description of Methodology

The methodology in this study consists of three components:

(a) Modeling 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 types 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 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.

Flow Chart of Research Activities

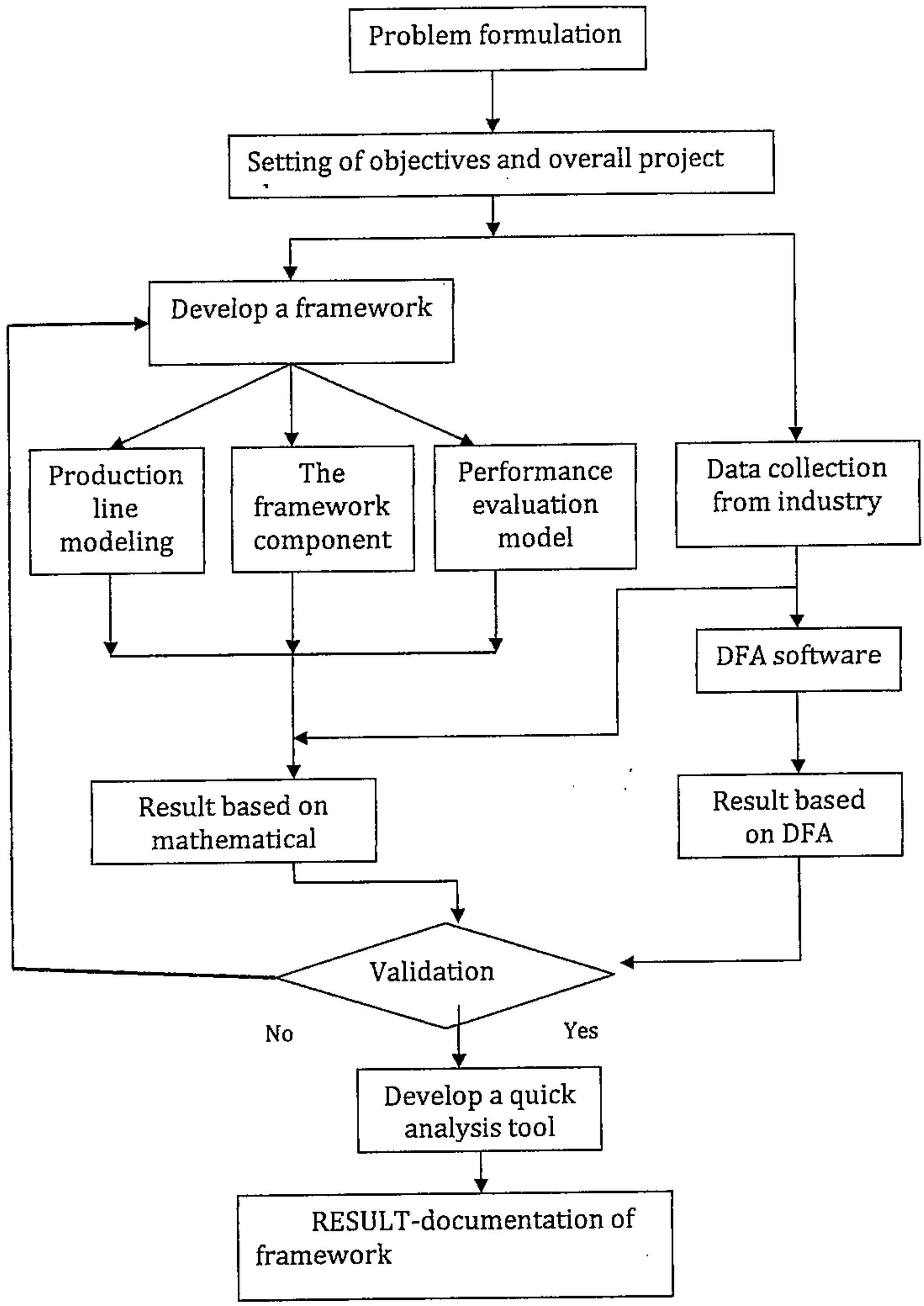

Figure 3.1 Research Flowchart

3.2 Mathematical Model

To model production line system, a mathematical model needs to be developed. In this study, a mathematical model used by 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^a_j = the squared coefficient of variation (SCV) of interarrival times at the resource j
c_j = SCV of the aggregate process time
c^*_j = SCV of modified aggregate process time
c_{ij} = SCV of the total process time
c^s_{ij} = SCV of the setup time
c^t_{ij} = SCV of the part process time
k = batch size number
m^f_j = mean time to failure for a resource at station j
m^r_j = 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

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