MODEL DEVELOPMENT OF SINGLE UNIT MACHINE CAPACITY MEASURE FOR PRODUCTION PLANNING AND CONTROL

by

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LIST OF ABBREVIATIONS

BOM	Bill of Materials
CAPS	Capacity Optimization Planning System
CM	Constraints Management
CRP	Capacity Requirements Planning
CT	Cycle Time
CVT	Conversion Time
EC	Effective Capacity
EOQ	Economic Order Quantity
EUPH	Effective Unit Per Hour
EXT	External Labour Activities
Ext_CVT	External Conversion Time
ExtT_CC	External Time for Change Consumables
ExtT_RBSU	External Time for Run Based Setup
ExtT_TBA	External Time Based Activities
IC	Integrated Circuits
INT	Internal Labour Avtivities
JIT	Just In Time
MA	Machine Availability
MACH	Machine Activities
MachT_CC	Machine Time for Change Consumables
MachT_CVT	Machine Conversion Time

MachT_RBSU	Machine Time for Run Based Setup
MachT_TBA	Machine Time Based Activities
MH	Manufacturing Hour
MHBTBA	Mean Hour Between Time Based Activities
MPS	Master Production Schedule
MRP II	Manufacturing Resource Planning
MRP	Material Requirement Planning
MTBA	Mean Time Between Assist
MTBF	Mean Time Between Failure
MTTA	Mean Time To Assist
MTTR	Mean Time To Repair
MU	Machine Utilization
MUBCC	Mean Unit Between Change Consumables
MUBRBSU	Mean Unit Between Run Based Setup
nCV	Quantity of Conversion
PC	Protective Capacity
PFA	Personal Fatigue and Delay Allowances
PLC	Product Life Cycle
PM / Cal	Preventive Maintenance and Calibration Time
PPC	Production Planning & Control.
PUPH	Pure Unit Per Hour
RCCP	Rough Cut Capacity Planning
SCAPS	Stochastic Capacity Optimization System

SDT	Scheduled Downtime
SDT_{CC}	Change Consumables Down Time
SDT_{RBSU}	Run Based Set Up Down Time
SDT_{TBA}	Time Based Activities Down Time
TOC	Theory of Constraints
USDT	Unscheduled Downtime
$USDT_{Assist}$	Assist Down Time
$USDT_{Facilities}$	Facilities Downtime
$USDT_{Repair}$	Repair Down Time
WIP	Work-in Process
WW	Work Week

PEMBANGUNAN MODEL UKURAN KAPASITI SESEBUAH MESIN UNTUK PERANCANGAN DAN KAWALAN PENGELUARAN

ABSTRAK

Perancangan dan Kawalan Pengeluaran (PPC) adalah berkaitan dengan perancangan dan kawalan seluruh aspek pengeluaran termasuk mengurus bahan-bahan, menjadualkan mesin-mesin dan tenaga pekerja, dan menyelaras pembekal-pembekal dan pelanggan-pelanggan utama. Pihak pengurusan mempunyai tanggungjawab yang asas dalam mewujudkan keupayaan memenuhi permintaan semasa dan masa akan datang. Ciri-ciri penting bagi PPC adalah berhubung kait dalam menentukan takat kapasiti jangka masa pendek dan sederhana secara aggregat. Penyelidikan ini menumpu kepada pembangunan satu Model Kapasiti Mesin untuk mengukur kapasiti sesebuah mesin. Model dibangunkan dalam tiga fasa dengan menggunakan persamaan matematik analisis yang diperolehi dari parameter operasi. Ia kemudian diterjemah kepada pengaturcaraan komputer yang umum dalam bentuk templat "Spreadsheet". Fasa Pertama mengenal pasti dan mengkategorikan pembolehubah-pembolehubah asas. Fasa Kedua membentuk pembolehubah-pembolehubah model dari pembolehubah-pembolehubah asas. Fasa Ketiga membentangkan pembangunan pembolehubah-pembolehubah model terakhir yang dikehendaki dalam membuat pengiraan kapasiti. Model telah disahkan boleh membuat semakan bagi memastikan setiap nilai yang dimasukan adalah logik dan benar. Beberapa senario telah direka bagi menunjukkan model yang dibina adalah fleksibel, tepat dan logik dalam mengkaji faktor-faktor

mempengaruhi Kapasiti Efektif (EC) bagi sebarang proses. EC yang terkira berupaya mengesan kapasiti terhad dan boleh diterapkan ke dalam pengendalian perancangan pemilikan mesin. Pembangunan model tidak memerlukan kos tambahan bagi membeli sebarang pengaturcaraan komputer atau kemudahan yang mahal. Pendekatan pengiraan model dapat memberi cara-cara penyelesaian dalam sebarang keadaan yang berbeza. Kebaikan-kebaikan ini telah meningkatkan penerimaan industri dan tahap pengamalan.

MODEL DEVELOPMENT OF

SINGLE UNIT MACHINE CAPACITY MEASURE FOR

PRODUCTION PLANNING AND CONTROL

ABSTRACT

Production Planning and Control (PPC) is concerned with planning and controlling all aspects of manufacturing, including managing materials, scheduling machines and people, and coordinating suppliers and key customers. Providing the capability to satisfy current and future demand is a fundamental responsibility of operations management. The important characteristic of PPC is concerned with to determine capacity levels over short and medium terms in aggregated terms. This research focuses on developing a Machine Capacity Model for single unit machine capacity measure. The model development consists of three main development phases constructed using analytical mathematical equation derived from operational parameters and translated into a common computer programming presented as spreadsheet template. The First Phase involves in identifying and categorizing the independent variables. The Second Phase develops the model variables by adopting the independent variables. The Third Phase presents on the development of final decision model variables. The model built in self-check function being verified to assure true and logic input value. Validation scenarios are designed to test model is flexible, credible and logic to aid in study factors affecting Effective Capacity (EC) of any unit process. EC able to apply in detecting capacity constraint and can be adapted to check on and generate machine procurement

planning. The model development does not require any extra cost to purchase any expensive software or facility. Computational approaches of the model have the requisite flexibility to yield solutions under different circumstances. Therefore these advantages increase the industrial acceptance and practical level.

CHAPTER 1

INTRODUCTION

1.0 Background

In this chapter, Production Planning & Control (PPC) is put into perspective and a framework for its exploration is provided. PPC is concerned with planning and controlling all aspects of manufacturing, including managing materials, scheduling machines and people, and coordinating suppliers and key customers. According to Corsten and May (1996), the purpose of PPC is to plan and control the production process with regard to time quantity. It addresses decisions on the acquisition, utilization and allocation of production resources to satisfy customer requirements in the most efficient and effective way.

PPC has become more challenging as manufacturing companies adapt to a fast-changing market. Thomas (2000) even mentioned that the goals of a high volume manufacturing facility are to supply customers and to stay economically competitive. Competition is marked by volatile demand, shorter product life cycles, globalization, mass product customization and time to market. Wang (2005) found out competitions take place between supply chains instead of individual companies. The ability of sharing data among collaborating companies with regards to forecast, order, production status, and capacities is crucial for continual enhancement of the deliverability and obtaining more market shares. This turbulent environment requires the companies to plan and control their production in such a way that the disruptions in performance of their production systems are minimised in order to remain competitive.

1.1 Production Planning & Control (PPC)

The essential task of the PPC system is to manage efficiently the flow of material, the utilisation of the equipment and people, and to respond to customer requirements by utilising the capacity of suppliers, that of internal facilities, and (in some cases) that of customers to meet customer demand. PPC can be broken roughly into three time horizons: Long Term, Medium Term and Short Term.

In the long term, PPC is responsible for providing information to make decisions on the appropriate amount of capacity to meet the market demands of the future. Operation managers make plans concerning what they intend to do, what resources they need, and what objectives they hope to achieve. They will use forecasts of likely demand which are described in aggregate terms. Nahmias (2004) insist a capacity strategy must take into account a variety of factors including among others the predicted patterns of demand, costs of constructing and operating new facilities, new technologies and competitors' strategies. The planning activities will be concerned mainly to achieve financial targets. Budgets will be put in places which identify the costs and revenue targets which are intended to achieve.

Medium term planning and control is concerned with both planning and control in more details (and re-planning if necessarily). The focus is more on maintaining appropriate levels of raw material, work in process and finished goods inventories in the correct locations to meet market needs. Stephen et al. (2007) explained it as after collecting orders, which consist of the type of products, quantity, delivery date and location preference, production management must develops an initial production plan within a specific time frame by considering the manufacturing capacity, workforce level, inventory level, quota availability and other factors to fulfill demand. Contingencies will have been put in place which allows for slight deviations from the plans.

In the short term, detailed scheduling of the resources is required to meet production requirements. This involves time, people, material, machine and facilities. As the day to day activities continue, PPC must track the use of resources and execution results to report on material consumption, labour utilisation, machine utilisation, completion of customer orders and other important measures of manufacturing performance. Maria (2000) deals with production smoothing, by leveling the load of the workstations, production smoothing allows a regular material flow, shorter manufacturing lead times, and lower work in process. This is one of the keys of success of Just In Time and Lean Production.

1.2 The Role of Capacity Planning in Production Planning & Control (PPC)

PPC is often seen as encompassing two major activities: Planning & control of materials and planning & control of capacities. Capacity refers to the productive capacity of the operations facilities to provide the range of goods or service to be sold in the market place. Examples of capacity include machine or equipment, man power and plant size. Capacity can be measured either by the availability of its input resources or by the output which is produced. Which of this measures is used partly depends on how stable is the mix of outputs. It is usually expressed as the volume of the throughput within a given time period. Bakke and Hellberg (1993) concluded that insufficient capacity can cause late deliveries and high levels of work-in-process in manufacturing systems, while excess capacity can be a waste of expensive resources due to low utilization levels.

On the other hand, Ferrari et al. (1983) defined capacity planning as the class of the problems related to the prediction of when in the future the capacity of an existing system will become insufficient to process the installation's workload with a given level of performance. However, Vollmann et. al. (1997) stated that the objective of capacity planning is to ensure the right matches between the available capacity in specific work centers and the capacity required achieving planned production. Consequently, according to Wu and Chang (2006), at operational level, capacity planning refers to the decision of solving the short-term capacity disequilibrium problem. Woonghee et al. (2005) mentioned capacity planning decisions affect a significant portion of future revenue.

Swaminathan (2000) noted products undergo operations (often more than once) on different machine before completion. As identified by Smolink (1983), lack of machine availability hampers the smooth flow of production and results in long work-in-process queues (inventory) and frequent machines changes which consumes time resulting in under utilization of the system. Hankins and Rovito (1984) and Luggen (1991) discuss the details of planning function insures the availability of required machines and is concerned with determining sufficient numbers to support the production plan. This has shown that machine capacity planning does play a role in the overall capacity planning perspective.

1.3 Machine Capacity Planning

Manufacturing companies allocate millions of dollars every year for new types of machine for their facilities. Typically these are special purpose machine which are made to order. Since most industry size is very large with nearly hundred or more machines, it is important to find the optimal machine capacity plan within a reasonable time. Complex production processes, expensive equipment and sophisticated customer requirements demand machine capacity planning methodologies that promotes agile response in a complex production environment.

Determination of the required number of machine to support the production plan is an important decision; an effective machine capacity planning policy is essential for efficient operation. Zubair and John (1997) used a production plan as a basis to compute the requirements for each machine type. In a simple environment, machine capacity planning is the calculation of the number of machines needed to manufacture forecasted product demands. The calculation is an algebraic equation where the number of machines needed equals the time required divided by the time available.

The consequences of having too few copies of machines are long production lead times and low routing flexibility. Planning for too many copies increases the investment in machines. Inadequate machine planning results in low machine utilization and an unacceptable level of downtime leading to decreased productivity. Although the determination of the required number of machines to support the production plan is an important decision, Gray et al. (1993) found that research on this issue is still deficient.

1.4 Problem Statement

In today's environment, management are faced with a forecast of demand which is unlikely to be either certain or constant. The product demand is highly volatile and therefore it is difficult to predict the demand profile for the mix of products over several months or years. Traditionally, production planning decisions were resolved through experience judgment. It can result in a large gap between planned and needed capacity when the actual demand materializes. Such a planning approach has often led to either lower utilization of machines (if the actual demand realized is less than projected) or have led to shortages (if actual demands are higher or if the mix changes).

The determination of the number of machines needed to produce forecasted product demands, is particularly difficult because of its sensitivity to product mix, the uncertainty in future demand, the long lead time for obtaining machine and large machine costs. Since most of the machines are very expensive and some might have a special function even a slight enhancement in the management's decision-making process might lead to significant financial improvement in the company's performance. This has made the machine capacity planning an intricate task.

In addition to that carrying out the task in solving the machines capacity levels over short terms required vast amount of information, such as product flows, random yields, diverse equipment characteristics, interactions relationship between complicating characteristics of operational parameters such as effective unit per hour, availability, scheduled down time, un-scheduled down time, conversion or set-up, preventive maintenance and calibration.

In order to overcome the above problems, the management needs to compute what machine capacity (product output) can and do provide by given a product volume and set of operational parameters. The management must have interest in developing a machine capacity planning approach that hedges against the uncertainty in future demands. Resulting from that, machine requirement is planned and the tools have a high utilization while meeting the demand projections.

1.5 Research Objectives

This research has several objectives, which are:

1. Understanding and identify interactions relationship between complicating characteristics of operational parameters such as effective unit per hour, availability, scheduled down time, un-scheduled down time, conversion, preventive maintenance and calibration within the model.

2. Derive and develop a set of mathematical equation for mathematical model used in the determination of the optimal machine requirement in the capacity planning.

3. Provide a Machine Capacity Model for machine capacity planning that incorporates the uncertainty in demand forecasts and provides methods using common computing environment and data collection.

4. Verify and validate Machine Capacity Model through a set of possible planning scenario by using a real case study.

1.6 Scope of Research

Common and widely use manufacturing industry operational parameters were being recognized, identified and systematically categorized based on the Industrial Engineering stand point. By applying Industrial Engineering Mathematics and Industry Physics, all operational parameters are interpreted into sets of equation. Understanding on their integrated relationship, these variables are further developed to create a series of model input and output variables.

In this research, machine capacity planning problem for semiconductor manufacturing industry will be addressed. The scope is strategic machine capacity level decisions on aggregate capacity planning over short term and medium term in PPC. The research will present a Machine Capacity Planning Model for Die Preparation process in a semiconductor industry that utilizes the information in scenario based forecast estimates and generates an efficient procurement plan. By recognizing that each product requires multiple operations, it is explicitly focus on assigning one operation to one tool types in each period in the machine capacity model. Since the existing methodology in capacity planning in the industry is based on deterministic demand forecast, assumption is made that the demand is given.

1.7 Outline of the Thesis

Chapter 1 introduces and outlines the research and places the rest of the work in context. The Production Planning & Control (PPC) is introduced and the problems associated with it are explained. The objectives of the thesis are also stated in this chapter.

Chapter 2 reviews on the work of PPC. The main objectives of this chapter are to present knowledge and understanding the work of PPC and the work developed to tackle PPC, especially capacity planning.

Chapter 3 presents the development of a Machine Capacity Model. The execution model in mind would have to posses a mathematical model based on derivation and development of a set of mathematical equations from operational parameters.

Chapter 4 provides verification and validation of the Machine Capacity Model developed. The details results of the verification and validation proved that the model developed works and demonstrates the flexibility for execution and proliferation in a wide range of applications.

Chapter 5 covers comparison of the results, lessons learnt and the reasoning behind them.

Chapter 6 presents the conclusion on this research work. This chapter ends with the future work continuation.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

This chapter reviews on current literature related to the production planning and control in general and machine capacity planning in particular. The main objectives of this chapter are to present the knowledge and the understanding of the work of machine capacity planning in production planning & control. Literatures discussed on model approaches are reviewed to gain an understanding of the current state of the researches in the literatures. Finally, summary and implications of the review will be addressed.

2.1 Production Planning and Control Issues

Production planning and control is in essence a decision making process which the resources (i.e. manpower, equipment and tools) are distributed in line with pending orders. According to Wang and Wu (2003) they are arranged in a fixed timeframe as the basis for manufacturing. Chan et al. (2006) have mentioned that effective production planning and control can result in reduction of manpower, work-in-process, inventory cost, and other production costs by minimizing machine idle time and by increasing the number of on-time job deliveries.

But as production systems become more and more complex where many types of machines, workers and parts are involved, the production planning and control activities have become more and more complicated and harder to execute and coordinate. Kim (2003) commented that PPC becomes even more difficult when the production systems need to adapt to fast changing market needs. According to Gilbert and Schonberger (1983), before the development of the computer technology, PPC function were mainly accomplished manually, some of the common techniques used were the two-bin system, economic order quantity (EOQ), and reorder point. Although PPC has been heavily concerned by manufacturers, it is still a typically human domain. Stoop and Wiers (1996) stated that the task of planning production units can become complicated and time-consuming. Humans are not well equipped to control or optimize large and complex systems, and the relations between actions and effects are difficult to assess.

In fact only a very few manufacturers have automated planning to the extent that an official plan can be regenerated once a week, say, over a weekend. More typical is the situation in which a planning cycle consumes one or several weeks, involving a number of management meetings to negotiate trade-offs and to obtain "buy-in" to the plan. This lengthy planning process inevitably means that quotations of delivery dates to customers must be made based on old and conceivably stale plans and / or on very sketchy supply-side information. It also means that a sizable proportion of production release is made in response to demand forecasts rather than actual customer orders. Hence, computerized techniques and information systems are commonly regarded as means to improve the PPC.

Taylor (1994) noted during the 1960s, when computers began to be used in the manufacturing industry, material requirement planning (MRP) technique was developed by Joseph Orlicky and MRP has been used in America since 1970s. Zijm and Buitenhek (1996) reported that many manufacturing companies have adopted the MRP and Manufacturing Resource Planning (MRP II) as a means for production control and materials coordination.

MRP is concerned primarily with manufacturing materials while MRP II is concerned with the coordination of the entire manufacturing production, including materials. The basic planning procedure of MRP and MRP II starts from a Master Production Schedule (MPS) which contains the planned production quantities of end products (MPS items) for a certain planning horizon. It then uses the manufacturing Bill of Materials (BOM: product structure) to calculate the time phased needs of subassemblies, parts and raw materials. The basic question however is: What is a satisfactory and realistic MPS? To answer this question one has to consider the planning problem from two angles: the demand point of view and the capacity point of view. Unfortunately, MRP does not consider capacity at all. Berry et al. (1988) commented MRP ignored very dynamic elements of the shop-floor environment such as capacity limitations and lead time. In fact the Rough Cut Capacity Planning (RCCP) module of MRP II concerns only the long-term capacity availability on a high aggregation level while Capacity Requirements Planning (CRP) performs just a check on the amount of capacity needed. In case of mismatch between available and required capacity it is left to the planner to adjust the MPS.

While Western manufacturer were engaging in developing MRP and MRP II, Japanese organizations were formulating their own PPC methods; Just In Time (JIT). Spencer (1992) revealed the concept emerged from the study of the Japanese automobile industry during the 1970s. JIT is based on the philosophy of eliminating any activities that do not add value. According to Amerine et al. (1993), its goal is to get the material to its next processing station just at the time it is needed. This requires eliminating variability within a system. It is difficult, if not impossible to eliminate all the variability from a complex manufacturing system. The shop floor has to increase buffer size, which in turn would increase the work-in process (WIP); however, this goes against the JIT philosophy. According to Rice and Yoshikawa (1982), the weakest area in JIT is master production planning.

Another production planning and control approach, developed by Israeli physicist Eli Goldratt in the late 1970s, is the Theory of Constraints (TOC). Spencer and Cox (1995) pointed out TOC has subsequently evolved to become known as Constraints Management (CM). It recognizes that the strength of any chain is dependent upon its weakest link (bottleneck), which is what restrains the system's throughput. Managing the bottlenecks throughput manages the systems throughput. To maximize it, the bottleneck must utilize all of its available capacity.

These three techniques, MRP, JIT and CM are the most commonly used in manufacturing today. However, they are not interchangeable: one system may be appropriate for a particular manufacturing situation but not for another. In real world situation the demand implicit in product and business plans will be used as the input in capacity plan. In business planning, the context is likely to be transferring the demand data to capacity planning. Bretthauer (1996) suggested that the capacity planning decision must take into account the product demand forecasts, existing capacity levels, the costs of changing capacity, the impact of capacity changes on the performance of the manufacturing system, and the company's manufacturing strategy. During periods of increasing demand it may become necessary to add capacity to some or all of the work stations to satisfy the demand and maintain stable operating conditions in the plant. If demand is expected to decrease for a long period of time, then it may be cost effective to reduce capacity.

As this research is concern, it is focus in determining the timing and size of capacity changes over a finite number of time periods. With this on-going challenge of production planning in the industry as a background, the last ten years have seen rapid development capacity planning methodology and practices.

2.2 Capacity Planning in Production Planning & Control

Capacity planning has received significant attention in the literature. In practice, before any production planning can take place, capacity should first be analyzed during business planning sessions. A typical hierarchy of capacity planning usually consists of three phases. In the first phase, the overall planning of resources is performed followed by a rough-cut capacity planning to validate the particular master production schedule. In the second phase, the evaluation of capacity plans is based on detailed material requirements. Finally, in the last phase, a finite loading or an input-output analysis based on the supply and demand of capacity is applied. Because the lead time of capacity provisioning is long, capacity planning tasks can be classified by their planning horizon as been discussed in Chapter 1. Hopp and Spearman (1996) suggested capacity planning framework to be divided into three basic levels, as;

i. strategy - long term planning,

ii. tactics - medium term planning and

iii. control - short term planning.

In the long term, the objective of capacity planning is to prepare for plant transition in anticipation of new process technology and new product and to support strategic plans of business. The capacity of the business needs to be checked against the production plan in order to ensure an achievable plan. During these business planning sessions, the long-term should be analyzed and discussions regarding the purchase of equipment or facilities should be prioritized. These are obviously major decisions with huge capital expenditures. As the decision to increase capacity is not straight forward and can be extremely costly, management may need to fully consider on alternative procurement plan attached with financial data.

In the medium term, capacity can be changed by machine purchase and decommission. According to Nazzal et al. (2006) capacity planning in this time frame is mainly a machine portfolio configuration problem. It should be noted that capacity is expanded in small increments, by gradually populating the factory with more machines. The granularity of planning is at the critical machine and major process stage level. In addition, on a monthly basis a production report is generated, demonstrating expected future demand and the production necessary action to meet that demand. If there is not enough capacity, extra shift, overtime or subcontract work may be needed.

In the short-term, Chou et al. (2007) concluded that the overall capacity is largely fixed, but with some room for adjustment through equipment set-up change-over (i.e., alternative routing). The granularity of capacity requirement analysis is at the machine and process step level. If actual capacity is consistently less than demand capacity, capacity constraint must be identified; these constraints may be cause by process bottleneck, machine capacity bottleneck, labor skills bottleneck and etc. Capacity constraint identification is important for production line balancing. A balanced production line will help to manage the throughput close to the bottleneck as possible. It should be properly managed to balance the workload, ensuring an even flow of work to avoid unnecessary Work In Progress (WIP) built up.

From the study of Yang et al. (2007), in industries in which manufacturing capacity is flexible and requires little capital investment, business planning of product lines, marketing, and pricing does not have to be tightly integrated with capacity planning. Capacity planning can be done sequentially after business planning is completed. However, if capacity investment requirement is large and investment is irreversible, capacity planning must be integrated with business planning; otherwise, financial well-being would be subjected to serious risk. Therefore, the corporate business strategy must be translated to, supported by, and integrated with its capacity strategy. Dimitris et al. (2005) stated that since each time a company considers expanding productive capacity, it must consider a myriad of possibilities. Even after the decision to expand capacity is given, it remains to resolve key issues such as when, where and how much all these under the two main competing objectives in capacity planning which are:

i. maximization of market share and

ii. maximization of capacity utilization

Bakke and Hellberg (1993) emphasized that company should have a good sense of its current capacity and at what percentage it is operating. If capacity planning overestimates the available capacity, WIP levels will escalate, and late deliveries will ensue. Conversely, an underestimation of the available capacity may lead to the underutilization of resources and lost sales. The success of the matching between the required and the available capacity depends on their correct identification. Ineffective capacity planning may lead to production line running close to full-capacity but most of the products go to inventory. Capacity planning should be considered in a framework of strategy planning in order to address the whole problem. Nahmias (2004) stressed on a capacity strategy must take into account a variety of factors including among others the predicted patterns of demand, costs of constructing and operating new facilities, new technologies and competitors' strategies. To address these, a proactive approach is proposed to review on capacity planning challenges and problems.

2.3 Capacity Planning Challenges and Problems

There are a variety of considerations that go into the development and implementation of an optimization model for capacity planning in PPC. A number of factors may complicate the tasks of capacity planning and scheduling, namely; volatile demands / demand uncertainty; products completion lead times, rising costs and evolving technologies, as well as long capacity procurement lead times and etc as elucidate as follows:

2.3.1 Volatile Demands / Demand Uncertainty

Actual demand fluctuates around the mean of the demand distribution, this fluctuation constitutes demand uncertainty. However, the expected demand can also vary through time, such as when seasonality is present. In such cases the true mean of the demand distribution is not stationary through time. Stephen (1999) verified that in most contexts, future demand is at best only partially known, and often is not known at all. The demands are unpredictable and are lost if the manufacturer does not have enough capacity during a period of high demand. Thus, even though demand is known to be uncertain, as been identified from the research of Karabuk and Wu (2001), two types of uncertainties are identified: one is capacity estimation and the other is demand volatility. Consequently, one relies on a forecast for the future demand. To the extent that any forecast is inevitably inaccurate, one must decide how to account for or react to this demand uncertainty. In some cases, the manufacturer can outsource production, but this may not be cost efficient during periods of high demand. The only certainty is that what has been planned will not be what is being manufactured. The conventional logic of capacity planning is to have sufficient capacity which will satisfy product demands.

Enn (2002) dealt with uncertainty in customer demand by using a safety stock inventory. In theory, safety stock inventory is used to meet customer requirements when the demand is unexpectedly high, due to either random variation around the mean demand or forecast bias. Order for additional production lots are initiated whenever the projected inventory level fall below the desired safety stock level. Other researchers Liang and Chou (2003) utilized the real-option theory in determining capacity level in an uncertain environment of demand: reactive and conservative. Capacity decisions are made by taking into consideration the option of waiting for more demand information to materialize. This method amounts to a conservative strategy. An alternative strategy is to reactively adjust the capacity plan according to changes in demand forecast. However, if the demand is volatile, or capacity investment is irreversible, or the lead time of capacity expansion is long, this strategy could easily lead to imbalance between the capacity and demand.

2.3.2 Products Completion Lead Times

Chan et al. (2006) comprehended that nowadays manufacturers are required to produce product with good quality and also with on-time delivery. Time during which an order is backordered represents the production lead time for that order. Lead time management is necessary to prevent manufacturing line facing congestion and hence, late deliveries. Linet et al. (1997) advised that to remain competitive, it is desired to quote short lead times and produce at a reasonable cost. On the other hand, quoted lead times should be adhered to in order to secure the customer. The ability to improve lead times has a great effect on the ability of a company to respond quickly to market demand. However, according to Wang et al. (2005), in the actual operational scenario, sales are prone to over commit capacity to customers to have more business. Due to the actual capacity limitation, more and more delinquent orders that cannot be fulfilled are expedited on shop floor, normal schedules will be disturbed resulting in more changeovers and longer waiting time for other lots. Tulin et al. (1997) commented sales department of some company establishes firm orders for the next three weeks. Then, planning is carried out just by listing three weeks' firm orders to the manufacturing department and letting the manufacturing people do what they can in order to assign valid due dates. The absence of a formal due date setting procedure may lead to working too many overtime hours in order to squeeze production lead time and achieve a high customer service level.

One of the approaches in solving this problem was proposed by Zijm et al. (1996), where they developed a method to determine the earliest possible completion time of any arriving job, without sacrificing the delivery performance of any other job in the shop. The system at any time predict realistic lead times and thereby realistic delivery dates but at the same time allows these lead times to depend on the current work load. Lead times are estimated based on the amount of work in the shop, and with a workload-oriented release procedure.

On the other hand, Azevedo (2000) presented an order promise system aims at helping the planners to improve the efficiency, precision and reliability of customer due date calculation. The order promise system offers real-time management of customer orders and capacity checked determination of delivery dates. The first level is concerned with the interaction with the customer, allowing the reception of inquiries. The second level comprises the rough planning engine to determine proposals of delivery dates and their overall costs. The rough planner automatically starts consulting iteration, with trial dates until a solution that is "acceptable" in terms of production costs and delivery lead-times is achieved. Such solution can then be routed back to the customer for approval. Referring to similar scenario, Enn (2002) used safety lead times to cover for completion time uncertainty. Variability in flow times occurs due to fluctuations in loading and other uncertainty on the shop floor. Inserting safety lead times increases the probability that a product will be completed by its due date and also due to quantity uncertainty.

2.3.3 Changes in Technology & Products

Technology changes rapidly, which has meant that new products are being introduced into the market all the time. Moreover, the life cycle of products is becoming shorter, making forecasting future demand even more intricate. This surge in demand casts an important problem for the manufacturing firm, since production capacity must be decided once and for all. The rate of change in products and technology makes it difficult for manufacturers to have a good estimate of future machine requirements. For an innovative product characterized by short product lifecycle and high demand uncertainty, investment in capacity buildup has to be done cautiously. Otherwise either the product's market diffusion is impeded or the manufacturer is left with unutilized capacity.

To address this concern, Robin et al. (2005) found many manufacturers, primarily those in high-tech industries, prefer to maintain a negligible amount of finished good inventory especially for technology base products, particularly the highly profitable, facing rapidly declining prices and a high risk of obsolescence. In fact, building up inventories ahead of demand may not be economically sound for application-specific such as the integrated circuits (IC). It is due to high-tech products are in a sense as "perishable" and usually been assumed that it is with zero finished goods inventory. Marco et al. (2000) implied a trade-off between acquiring greater capacity; i.e. incurring higher investment costs, and losing part of the demand. This loss may be moderated, but only to some extent, by building up inventory before the peak occurs (eventually by deliberately delaying product launch), or by accepting backorders during the peak. These options have drawbacks, since carrying inventory comes at a cost, while delaying product launch leads to losing sales in the short run and may also reduce market share in the future. Concerning backorders, these may be associated with a cost due to discounting or to the offering of complementary benefits. Nemoto et. al. (1996) and Potti and Mason (1997) commented that shorter product life cycle have also made it necessary to reduce the cycle times while maintaining the same level of production capacity. Many benefits may be attributed to reduced cycle times, including shorter learning curves, reduced scrap, and general process improvement.

Although capacity planning problem has been analyzed in the past, the machine capacity planning, the basis of capacity management, has largely been ignored in the manufacturing industry. Chou et al. (2007) noticed that a core issue of capacity planning is to configure the machine capacity planning. In next section, focus on research work in problems, models and approaches are being discussed based on the findings from previous researchers.

2.4 Machine Capacity Planning Models and Approaches

Various techniques for solving machine capacity planning problems have been developed. These techniques involve the use of linear programming, non-linear programming, stochastic programming and mix-integer programming.

Yang (2000) depicted a linear programming based system, called the Capacity Optimization Planning System (CAPS) to reconcile product-demand forecasts with the available or planned manufacturing capacity and to generate requests for capital investments. CAPS identify tens of millions of dollars in revenue opportunities with avoiding significant unnecessary capital expenditures. Francisco et al. (2005) revised the work of this system; they describe a method using stochastic integer programming called Stochastic Capacity Optimization System (SCAPS). Given multiple demand scenarios together with associated probabilities, the aim is to identify a set of machines that is a good compromise for all these scenarios in which expected value of the unmet demand is minimized subject to capacity and budget constraints.

On the other hand, Chen (2000) developed a stochastic programming model for strategic decisions related to long-term technology and capacity planning. The model using a scenario approach to capture dynamic demands and uncertainty associated with product life cycle (PLC) demands. On the same situation, Swaminathan (2000) presented a model based on stochastic program with recourse for machine procurement planning. This model enables a manufacturer to plan for a set of possible demand scenarios that utilizes the information in scenario based