FIT MANUFACTURING: PRODUCTION FITNESS AS THE MEASURE OF PRODUCTION OPERATIONS PERFORMANCE

A thesis submitted to

Cardiff University,

for the degree of

Doctor of Philosophy

by

Zuhriah Ebrahim, BEng. (Hons), MSc.

Manufacturing Engineering Centre
School of Engineering, Cardiff University
United Kingdom

2011

ABSTRACT

Rapid changes in market demands have resulted in manufacturing companies having to remain competitive in order to survive. Therefore, a combination of manufacturing capabilities, such as leanness, flexibility, agility, responsiveness, and sustainability, is essential to manufacturing companies. However, the performance of manufacturing capabilities has not yet been measured through integrated manufacturing concepts. Consequently, this thesis presents a model for evaluating operations performance from the specific viewpoint of production capability, termed Production Fitness. In this respect, determination of Production Fitness refers to Fit Manufacturing systems in general. An assessment of Production Fitness is developed based on the concept of multidimensional performances through integration of three distinctive concepts: (i) *Lean Manufacturing (leanness)*, (ii) *Agile Manufacturing (agility)*, (iii) *Sustainability.*

The aim is to provide an index for Production Fitness, determined through a simpler, more useful, and objective system of assessment. In this way, the Production Fitness measures can be used as a decision support tool for production and marketing (e.g., Production Waste Index (PWI), Production Profitability Index, (PPI), Production Adaptability Index (PAI), Production Stability Index

(PSI), and Production Fitness Index (PFI)), as well as providing a means of avoiding common conflict between these two areas.

The Production Fitness measures were applied to six case studies of micro-SMEs with batch manufacturing processes in various industries. Results from the six case studies show that it is crucial for manufacturing companies to sustain an ideal PFI, which can be achieved through maximum PPI, consistent PAI, and ideal PSI. In the meantime, it is also important for manufacturing companies to achieve a higher PFI, especially in highly competitive market environments. Factors influencing the fitness indices are identified from the aspects of company and production characteristics. SWOT analysis results indicate that the PFI can be affected by company strengths, weaknesses, opportunities, and threats. Suggestions for improving Production Fitness are made using empirical evidence from previous studies on relevant aspects.

This thesis concludes that the Production Fitness measures can be applied to batch process types in various manufacturing industries where common production and sales data are applied.

DEDICATION

to Mak & Abah...

to Echa & Bann...

to Conani & Lik Lowa...

ACKNOWLEDGEMENTS

I thank ALLAH (my Lord) the all high, the all great and merciful who made it possible for me to conduct the PhD study and complete this thesis.

I am privileged to have Professor D.T. Pham as my supervisor. Countless thanks to him for his excellent guidance throughout my research, as well as his practical and positive thinking which was very useful during the most difficult stages of my research. His thoughtful advice and constant support extended to me will always be remembered. May ALLAH bless him and his family.

Special thanks to Cardiff University, the Manufacturing Engineering Centre (MEC), and the Engineering Research Office for the use of the facilities to pursue the research and complete this thesis. I would like to express my sincere gratitude to all the members of the MEC for their friendship and help, especially to Ms Celia, Ms Rhian and Ms Jeannete. Many thanks to all the members of the Fit Manufacturing team for sharing knowledge in our research field. I would also like to thank Ms Jan Morris-Krieshan who proof-read my thesis. Sincere thanks are also due to all the members of the Malaysian community in Cardiff for creating a cheerful, delightful, and entertaining student life.

I am very grateful and acknowledge the substantial financial support from Universiti Teknikal Malaysia Melaka (UTeM) and the Ministry of Higher Education Malaysia. My sincere gratitude also to the former Dean of the Manufacturing Engineering Faculty, Professor Dr. Hj. Mohd. Razali Muhammad for encouraging me to pursue the PhD study abroad, especially at Cardiff University. Unforgettable thanks to the current Dean, Dr. Hj. Mohd Rizal Salleh and the Head of the Manufacturing Management Department, Associate Professor Dr. Hj. Adi Saptari for their kindness and consideration for me to complete this thesis in Cardiff instead.

I would like to express my heartfelt thanks to the Managing Director of the RRAS Bakti Sdn. Bhd., Mr. Abdul Rahman for permitting me to conduct a case study at his company and also recommending me to his colleagues through which six companies finally agreed to participate. Warmest thanks to all the Managing Directors of the manufacturing companies that participated: Mr. Hj. Mohamed Idris Abu Bakar, Mr. Henry Chew, Mr. Kamarul Abdul Rahman, Mr. Hj. Jaafar Yacob, Mr. Hj. Mohd. Fairuz Ahmad, and Ms. Siti Aisyah Senin (on behalf of the late Dr. Suhaimi Ghazali), all of whom provided unconditional cooperation during my industrial visits and data collection.

Millions of thanks to my mum for what I have achieved in my life. Her unconditional support and consistent wishes have guided me to be a better person. I very much thank my dad who has financially supported my education up to this stage. To my younger sisters, Zuraine and Norliza, thank you so much for taking care of our parents during my absence. Last but not least, a special thanks to my lovely little niece and nephew, Nur Aisyah and Muhammad Imran for all their wishes made for me.

CARDIFF UNIVERSITY

PRIFYSGOL CAERDYDD

DECLARATION

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

Signed .... Date ...05/05/11........
(ZUHRIAH EBRAHIM)

STATEMENT 1

This thesis is being submitted in partial fulfilment of the requirements for the degree of PhD.

Signed .... Date ...05/05/11........
(ZUHRIAH EBRAHIM)

STATEMENT 2

This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references.

Signed .... Date ...05/05/11........
(ZUHRIAH EBRAHIM)

STATEMENT 3

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organisations.

Signed .... Date ...05/05/11........
(ZUHRIAH EBRAHIM)

CONTENTS

CHAPTER 2: LITERATURE REVIEW

CHAPTER 3: PRODUCTION FITNESS

CHAPTER 4: PRODUCTION FITNESS MEASURES

CHAPTER 6: RESULTS AND DISCUSSION

LIST OF FIGURES

Page no.

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

LIST OF TABLES

Page no.

CHAPTER 2

CHAPTER 4

CHAPTER 5

LIST OF APPENDICES

Page no.

APPENDIX A

APPENDIX B

APPENDIX C

ABBREVIATIONS

AM	Agile Manufacturing
BSC	Balance Score Card
DCR	Demand Change Ratio
DEA	Data Envelopment Analysis
EC	Effective Capacity
JIT	Just-In-Time
LM	Lean Manufacturing
NPI	New Product Introduction
PFCT	Product Family Classification Tree
PMS	Performance Measurement System
PWI	Production Waste Index
PPI	Production Profitability Index
PAI	Production Adaptability Index
PSI	Production Stability Index
PFI	Production Fitness Index
QCD	Quality-Cost-Delivery
SME	Small Medium Enterprise
SWOT	Strengths-Weaknesses-Opportunities-Threats
TQM	Total Quality Management

Chapter 1

Chapter 1
INTRODUCTION

1.1 Motivation

This research views production capabilities differently from the common perspective of manufacturing. Production Fitness is measured on the basis of Fit Manufacturing systems (Pham, et al., 2008a) which integrate Lean Manufacturing, Agile Manufacturing, and Sustainability concepts. The idea of Fit Manufacturing was initiated by the fitness analogy, particularly in the sport of cycling (Pham and Thomas, 2005). In this regard, a combination of leanness, agility, and sustainability is crucial to a cycling team to be competitive.

Production Fitness is viewed as being analogous to human fitness. Analysing production capabilities in a fitness perspective requires determination of fitness components and fitness measures. Although a number of manufacturing systems have been proposed since the 1980s, no specific operational performance measure has been developed for integrated manufacturing systems. Most of the proposed models are designed for measuring isolated capability, such as leanness (Bayou and de Korvin, 2008; Ray, et al., 2006; Wan and Chen, 2008), agility (Bottani, 2009; Shih and Lin, 2002; Tsourveloudis and Valavanis, 2002), flexibility (Bateman, et al., 1999; Wahab, 2005; Wahab and Stoyan, 2008), responsiveness (Kritchanchai, 2004; Matson and McFarlane, 1999), and sustainability (Calvo, et al., 2008; de Vos, et al., 2006; Singh, et al., 2007). These capability measures are designed on the basis of the concepts of Lean Manufacturing (leanness), Agile Manufacturing (agility), Flexible Manufacturing (flexibility), Responsive Manufacturing (responsiveness), and Sustainable Development (sustainability).

It is possible to have one indicator to represent the ultimate outcome from a number of production capabilities. This research attempts to provide a measurement index for indicating the status of Production Fitness. For instance, the Body Mass Index (BMI) is used to indicate the status of human weight in three categories: (i) *Underweight*, (ii) *Normal*, and (iii) *Overweight*. The BMI is related to human health, where underweight and overweight are commonly considered to be unhealthy. For instance, being fat for a child causes immediate harm, such as low self-esteem, and has consequences for adult health (Buchan, et al., 2007). In this regard, a person who is underweight or overweight is seen to have less opportunity for long-term survival.

Similarly, the Production Fitness Index is initiated to represent the level of production capability in respect of leanness, agility, and sustainability. The index can be used as an indicator of how fit the production is in relation to the rapid can be used as an indicator of how fit the production is in relation to the rapid changes of market demands. Thus, a combination of these capabilities can be regarded as essential for company survival, especially in highly competitive market environments. Furthermore, topics on LM, AM, and Sustainability concepts have been continually discussed among industrialists and academics, especially in respect of the impact of these three concepts on company performance.

As technology moves forward and as manufacturing becomes an increasingly global activity, it would be reassuring, periodically, to confirm the tie between production competence and business performance (Schmenner andVastag, 2006, p. 909). Thus, the main functions of the Production Fitness Index are:

- To assist manufacturing companies in achieving and sustaining ideal fitness and continued survival.

- To assist manufacturing companies in being competitive and able to survive.

Two questions arise in relation to the Production Fitness Index: (i) '*What to measure in Production Fitness?*' (ii) '*How to measure Production Fitness?*'. To answer the first question, recent reviews of Performance Measurement Systems (PMS) are studied in order to provide an appropriate performance measure, especially for current manufacturing environments (Hyland, et al., 2007; Neely, et al., 2005; Olsen, et al., 2007). In general, two fundamental requirements for designing PMS are determined as:

- a combination of financial and non-financial measures
- a content of multiple dimensional measures

Furthermore, this research is challenged to provide an objective rather than a subjective measure. The BMI is the best example of an objective measure. In this respect, only a quantitative approach should be applied to determine the fitness index. Most of the existing operational performance models have applied both qualitative and quantitative approaches to determine the measurement. For instance, techniques such as Fuzzy Logic and Analytical Hierarchical Process (AHP) are mostly applied to determine agility. These techniques rely on a qualitative approach to provide inputs which will later be converted into a number. In the case of leanness measures, most of the leanness measurement models have applied the qualitative approach through survey, observation, and interview. The Leanness index is determined by using Statistical Analysis methods (e.g., *t*-tests, Analysis of Variance (ANOVA), Confirmatory Factor Analysis (CFA) etc.) (Narasimhan, et al., 2006; Shah and Ward, 2007).

The Data Envelopment Analysis (DEA) technique (Wan, et al., 2007; Wan and Chen, 2008) can be described as an objective measure that is used for measuring leanness. The DEA application is considered complex to industrialists as the measurement results refer to the average of Decision Making Units (DMU) configurations. Another example of an objective measure for leanness is the Mahalanobis Distance technique (Srinivasaraghavan and Allada, 2006). With this technique, the measurement index is determined by the distance between an abnormal case and a normal case. However, it becomes less practical when the direction of abnormality is limited to cases where the characteristic of the variables are known.

Overall, the Production Fitness Index measure contemplates the BMI measure as a simple and useful model for objective measurement. The BMI has been widely applied at weighing machines which are publicly used (e.g., clinics, gyms, shopping complexes). In summary, this research is motivated by three distinct aspects:

- Production capabilities in the context of fitness.
- Index as the measurement for production capabilities.
- A simple and useful objective measure for leanness, agility, and sustainability.

1.2 Research Aim and Objectives

The aim of this research is to provide a measure of Production Fitness Index for manufacturing companies. The Production Fitness measures can be used as a decision support system for production and marketing to reduce conflict between the two units. To achieve the research aim, the following objectives are set:

(i) To clarify leanness, agility, and sustainability as dimensions of Production Fitness. The three dimensions are the pillars of Fit Manufacturing systems.

(ii) To identify the components of Production Fitness. The components are referred to as the functions of leanness, agility, and sustainability in a production system.

(iii) To determine the index for leanness, agility, and sustainability. The Production Fitness measures can be described as multidimensional.

(iv) To clarify the relationship between demand changes and the Production Fitness components. The changes of demand specifically refer to changes in demand quantity.

(v) To define the ideal Production Fitness. The ideal Production Fitness represents the constancy of maximum profitability (leanness), high adaptability (agility), and ideal stability (sustainability).

(vi) To identify the factors influencing Production Fitness. The influence factors refer to aspects of company and production characteristics.

(vii) To propose strategies for improving indices in the Production Fitness measures. The suggestions are justified by empirical evidence from literature studies on relevant aspects.

1.3 Research Scope

This research focuses on development of fitness measures for production operations, specifically the batch process type. The production operations are involved in manufacturing of various product models from a similar product family. For instance, in the case of the automotive industry, product family refers to the types of vehicle, such as bus, truck, and car. In this regard, there are various models of car (e.g., saloon, mini, multipurpose vehicle, compatible, and sports). The fitness measures will take place from the beginning of the manufacturing process (raw material preparation) to the end of the manufacturing process (delivery packaging process). Thus, the fitness measures consider production capacity that is generated by internal resources only.

1.4 Research Method

This research methodology comprises six stages:

(i) *Clarification* of leanness, agility, and sustainability as Production Fitness dimensions, which is conducted through both literature and analogical studies.

(ii) *Development* of Production Fitness measures that constitute leanness, agility, and sustainability measures.

(iii) *Application* for industrial visit, interview, and data collection to manufacturing companies (randomly).

(iv) *Validation* of the fitness measures by using historical data from case studies.

(v) *Identification* of the factors influencing Production Fitness from the aspects of company and production characteristics.

(vi) *Suggestions* for improving indices in the Production Fitness measures based on empirical evidence from a literature study on relevant subjects.

1.4.1 Case Study

To develop objective measures of Production Fitness, a quantitative approach is the most appropriate for this research. Thus, objective data are necessary for the fitness measures, which can only be collected by applying a case study method. In the meantime, empirical data from the case studies can be used to validate the theory of Production Fitness.

A study on manufacturing competence and business performance used empirical data from a large-scale survey to test the theoretical validity (Kim and Arnold, 1993). In addition, industrial case study was used to validate the importance of development costs and unit production costs on the component commonality decision (Jans, et al., 2008). In this respect, multiple sources of evidence (e.g., interviews, archival documents, and direct observation) can be applied to construct validity (Tellis, 1997). Empirical study offers understanding on what relationships exist and the importance of those relationships (Gaimon, 2008).

In order to achieve the research objectives, six case studies were employed as part of this research. The advantages of multiple cases are as follows (Willmott, 2010):

- Possibility of comparisons and contrasts.
- Facilitates exploration of different aspects of dimensions of phenomena that are concentrated in particular cases.
- More diverse materials for generating or testing theory.

1.4.2 Sample Size and Limitations

Since some of the information is confidential, only six out of 35 companies agreed to participate in interviews and data collection. However, the data analysis was likely to be time-consuming, as some of the archival data were not available and needed to be constructed by using other relevant data. Therefore, the six case studies were considered appropriate for the introduction of Production Fitness measures. All six manufacturing companies are classified as micro-SMEs (Verheugen, 2005). The sample size is further justified by the following reasons:

- SMEs are more accessible than large companies (Mativenga, 2010).
- The companies are comparable in terms of classification of company size.

1.4.3 Methods of Data Collection

Data were collected primarily through interviews, observations, and archival sources. Interviews were conducted with all levels of company organisation: Managing Director, Production Manager, Accountant, Production Engineer (Maintenance), and Operator. The observations were purposely conducted to study manufacturing process flow, common technical problems, quality problems (e.g., returned products, scraps and defects), and plant layout, which provide useful information for determining time losses. Archival data for five years have been used to determine patterns of Production Fitness in a particular period. Monthly archival data for a five-year period has been found practical for generating patterns of Production Fitness throughout the specified period in another study into the effect of new product development on company profit (Griffin, 1997).

1.4.4 Analysis Method

The Microsoft Excel Software Application is used to calculate production lead time and time losses, to generate results of Production Fitness measures, and to plot graphs. Analysis of the patterns from the graph is conducted through a comparison method. The results are compared in the aspects of demand quantity changes, size of variety, available production resources (operators, machines, and equipment), new product introduction, company characteristics, and production characteristics.

1.5 Thesis Outline

The remainder of this thesis is organised in six chapters.

Chapter 2 explores the evolution of manufacturing systems from 1900 until the present. Relatively, subjects related to Performance Measurement Systems (PMS) for manufacturing companies are reviewed, such as definitions, types, and guidelines for designing PMS. Existing measurement models for leanness, agility, and sustainability are also reviewed, as LM, AM, and Sustainability concepts are the pillars of Fit Manufacturing systems. Thus, the concept of Production Fitness measures is introduced at the end of the chapter.

Chapter 3 justifies the three pillars of Fit Manufacturing systems as the Production Fitness dimensions. The components of Production Fitness measures are identified based on the functions of leanness, agility, and sustainability in the production system.

Chapter 4 defines the Production Fitness measures which are developed from the concepts of leanness, agility, and sustainability. Measured indices in Production Fitness are determined as Production Profitability Index, PPI (leanness), Production Adaptability Index, PAI (agility), Production Stability Index, PSI (sustainability), and Production Fitness Index, PFI (integration of leanness, agility, and sustainability).

Chapter 5 proposes the strategies for improving the indices in the Production Fitness measures. Significant links are identified between: PPI and PAI; PPI and PSI; PAI and PSI; PPI, PAI, and PSI. Thus, the core and key functional elements are proposed as the factors that link to the improvement of the indices.

Chapter 6 presents and discusses the results of Production Fitness measures from six case studies. Relationships in Production Fitness are clarified from both internal and external aspects. In this regard, the internal aspects refer to the Production Fitness components, company characteristics, and production characteristics, while, the external aspects refer to changes of demand quantity.

Chapter 7 presents the main contributions and conclusions of this research. Suggestions for future research in this field are also provided.

Chapter 2

Chapter 2
LITERATURE REVIEW

2.1 Preliminaries

This chapter reviews four major subjects: the evolution of manufacturing systems, relationships in manufacturing systems, performance measurement systems, and the concept of Production Fitness measures. In the first section, the evolution of manufacturing systems will be discussed in parallel with the evolution of production characteristics, from 1900 until the present. The Fit Manufacturing system is among the recent models of manufacturing systems.

In the second section, the significance of Production Fitness measures will be explained in terms of relationships to manufacturing strategy, marketing strategy, and business strategy. Subsequently, Performance Measurement Systems (PMS) will be reviewed in the third section. Here, all aspects of PMS, such as definition, criteria/characteristics/attributes, relationships, types, existing models, and guidelines are included in the review. The review will be extended to operational performance measures which are designed for specific manufacturing concepts, such as leanness measures, agility measures, and sustainability measures. These measures are related to the pillars of the Fit Manufacturing systems: Lean

Manufacturing, Agile Manufacturing, and Sustainability. The third section will close with the identified key aspects of multiple performance measures for recent manufacturing environments. As a result of the literature review, the concept of Production Fitness measures will be outlined in the fourth section.

2.2 The Evolution of Manufacturing Systems

A manufacturing system can be simply defined as a method of organising production. However, the method has evolved with the changes in market demands and technology in manufacturing. The evolution of manufacturing systems is related to the four characteristics of production: (i) *Mass production*, (ii) *Economic production*, (iii) *Economic and flexible production*, (iv) *Economic, agile and sustainable production.*

Mass production was pioneered by Ford and introduced in the early 1900s (Holweg, 2007). Mass production means the manufacturing industry operates through high volume production. At this time, the economical factors were not an issue because of the uncompetitive market environments. After World War II, the Toyota Production System (TPS) introduced the production wastes elimination concept in order to increase productivity. This concept is capable of being simultaneously competitive in terms of price and quality (Hines, et al., 2004).

In the early 1980s, the LM concept was introduced as a western version of TPS (Papadopoulou and Ozbayrak, 2005). In the meantime, product variety had become one of the competitive priorities in manufacturing. The Flexible Manufacturing Systems (FMS) was introduced subsequently. Although the simultaneous application of both systems is possible, it is difficult because of the different concepts between LM and FMS. For instance, the LM systems require adoption of a Japanese working culture, whereas the FMS systems require high-skilled labour. Consequently, the concept of Flexible Manufacturing was introduced in respect of system flexibility and process flexibility (Zhang, et al., 2003).

As a result of technological advancements, rapid changes in market demand drove the existing manufacturing systems to be not only flexible, but also agile. In 1991, the concept of agile manufacturing was first introduced in the USA through the publication of a report entitled 21st Century Manufacturing Enterprise Strategy (Dove, 1991; Kidd, 1996; Yusuf, et al., 1999). The AM systems offer a package of economic and agile production where flexibility is part of agility (Fliedner and Vokurka, 1997; Helo, 2004; Jackson and Johansson, 2003; van Assen, 2000; Vokurka and Fliedner, 1998). As a flexibility system, the LM system is prerequisite to the AM system, where the aim of the AM is to combine the efficiency of LM with operational flexibility whilst delivering a customised solution at the cost of mass-production (Adeleye and yusuf, 2006; Causey, 1999; Sarkis, 2001).

The concept of AM has evolved through global competition in manufacturing and changing consumer demand with greater product variety and innovation, shorter product life-cycles, lower unit costs, and higher product quality. For instance, the Modular Production System was introduced to cater for low to medium technology consumer products (Rogers and Bottani, 1997). In the following year, the Intelligent Manufacturing concept was further discussed, particularly in the application of intelligent CIM in the near future (Kopacek, 1999).

In the 2000s, issues of sustainability became part of the manufacturing systems, such as sustainable product development (Kaebernick, et al., 2003; Kara et al., 2005), sustainable operations management (Kleindorfer, et al., 2005), sustainable performances (Labuschagne, et al., 2005), sustainable productivity improvement (Herron and Braiden, 2006), sustainable manufacturing organisation (Thomas and Grabot, 2006), economical sustainability (De Vos, et al., 2006), sustainable competitive advantage (Shahbazpour and Seidel, 2006), and sustainable manufacturing systems (Jayachandran, 2006). Overall, issues of sustainability have focused on the unsustainability of many current practices in the strategic use of advanced manufacturing technologies since they lead to increasing resource consumption in the aggregate by increasing market demand (Sonntag, 2000).

In a highly competitive environment, short lead time, more variants, low and fluctuating volumes, and low price are the new requirements for the new generation of manufacturing systems (Bi, et al., 2008). This phenomenon has led to a number of new concepts for manufacturing systems, such as:

- *Micro-factory* (Okazaki, et al., 2004).
  - which encompasses a new technical subject that integrates machinery, processing and control systems. In addition, the concept of Micro-factory offers economising in energy consumption.

- *Reconfigurable Manufacturing Systems (RMS)* (Bi, et al., 2008; ElMaraghy, 2005).
  - which has the ability to reconfigure hardware and control resources at all functional and organisational levels in order to adjust production capacity and functionality in response to sudden changes in market or in regulatory requirements.

- *Responsive Manufacturing Enterprise* (Saad and Gindy, 2007).
  - which aims to achieve rapid, flexible and integrated development, and manufacture of innovative products at a price the customer is prepared to pay.

- *Changeable Manufacturing* (Hoogenraad and Wortmann, 2007; Wiendahl, et al., 2007).
  - which is a distinctive definition from re-configurability, in which changeability is defined as the characteristics to accomplish early and foresighted adjustments of factory structures and processes on all levels to change impulses economically.

- *Fit Manufacturing* (Pham, et al., 2008a)
  - which is the integration of LM, AM, and Sustainability concepts to achieve long-term survival, especially in a highly competitive environment.

It can be noted that Fit Manufacturing is the only concept which has specifically emphasised the sustainability concept as one of the pillars in manufacturing systems. Sustainability in Fit Manufacturing specifically refers to the economic sustainability of manufacturing companies (Pham et al., 2007; Pham, et al., 2008b).

Overall, it can be seen that manufacturing systems have evolved with additional characteristics without omitting the existing one. For instance, the LM and Flexibility concepts are parts of the AM concept. Manufacturing systems in the 21st century have evolved from the AM concept with more deterministic criteria, such as responsiveness, re-configurability, and changeability. Figure 2.1 illustrates the evolution of manufacturing systems from 1900 until 2010.

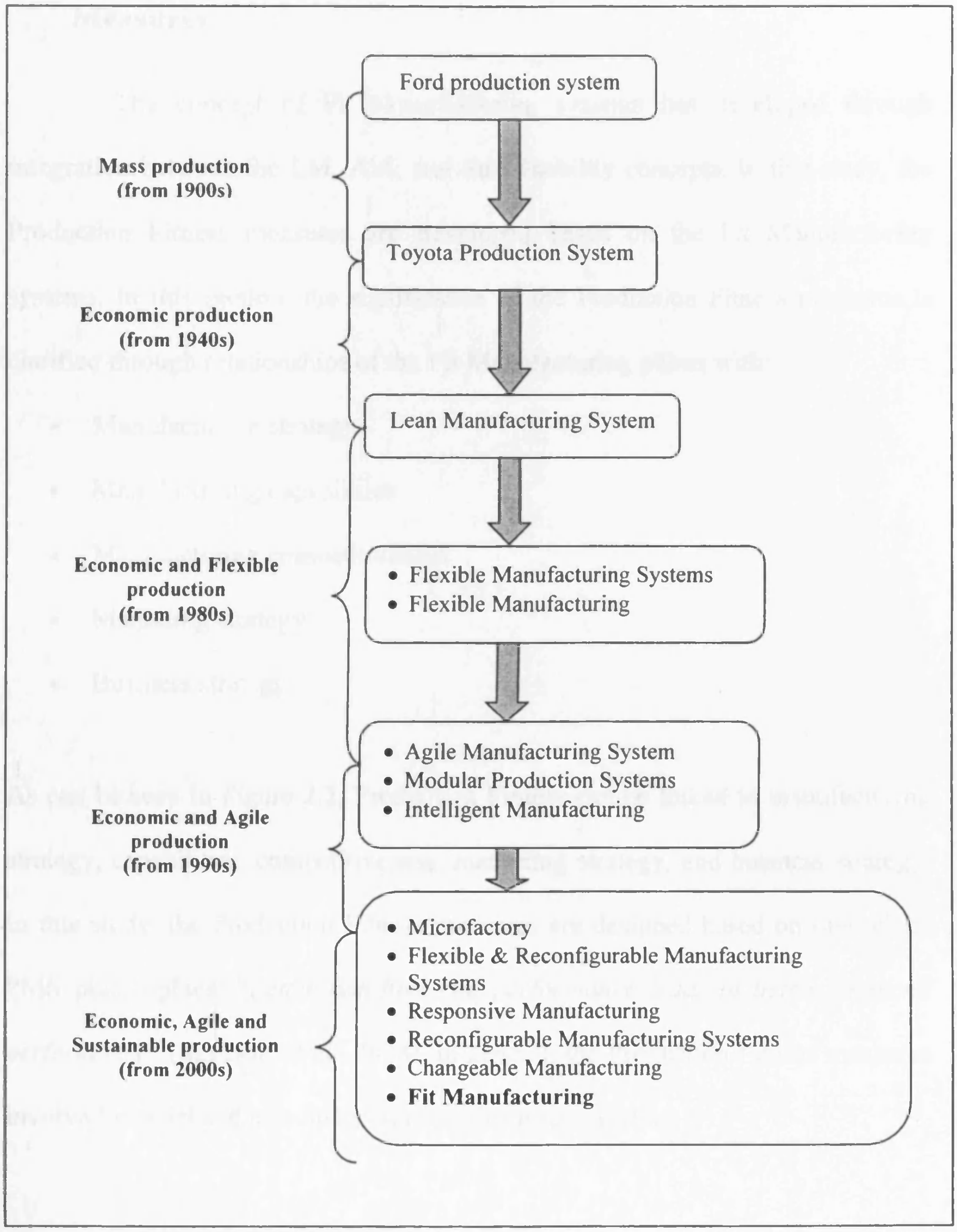


Figure 2.1: The Evolution of Manufacturing Systems

2.3 Fit Manufacturing: The Significance of Production Fitness Measures

The concept of Fit Manufacturing systems has developed through integration between the LM, AM, and Sustainability concepts. In this study, the Production Fitness measures are developed based on the Fit Manufacturing systems. In this section, the significance of the Production Fitness measures is clarified through relationships of the Fit Manufacturing pillars with:

- Manufacturing strategy
- Manufacturing capabilities
- Manufacturing competitiveness
- Marketing strategy
- Business strategy

As can be seen in Figure 2.2, Production Fitness can be linked to manufacturing strategy, capabilities, competitiveness, marketing strategy, and business strategy. In this study, the Production Fitness measures are designed based on one of the PMS philosophies: "*Better non-financial performance leads to better financial performance*" (Skrinjar, et al., 2008). In general, the Production Fitness measures involve financial and non-financial measures respectively.

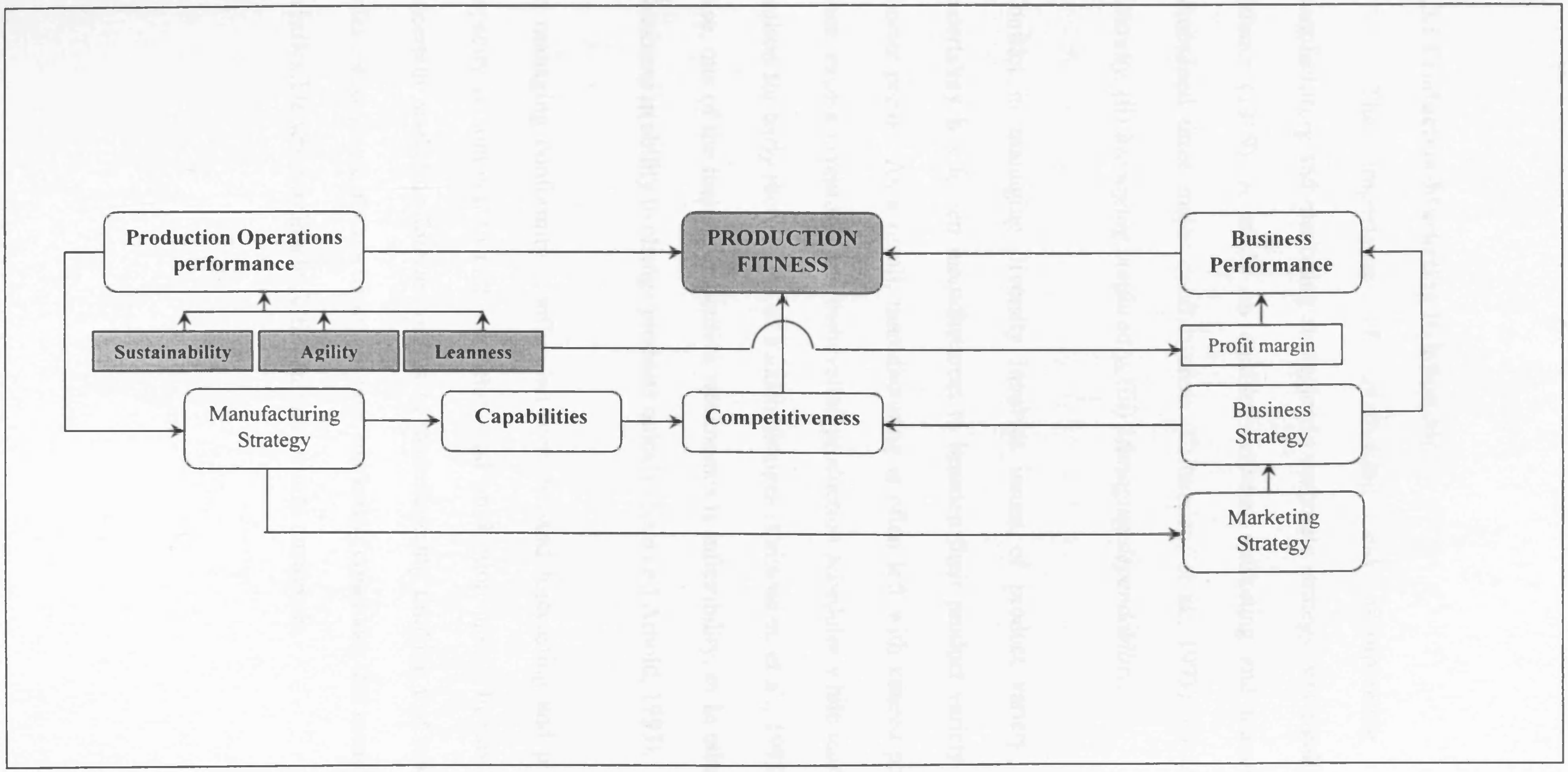


Figure 2.2: Relationships in Production Fitness

2.3.1 Production-Marketing Relationship

The importance of interlinking and incorporating between manufacturing and marketing strategies in corporate strategy was highlighted by Skinner (1969). A study on conflict between marketing and manufacturing determined three major conflict areas (Crittenden, et al., 1993): (i) *Managing diversity,* (ii) *Managing conformity,* (iii) *Managing dependability.*

Conflict in managing diversity involves issues of product variety. Demand uncertainty has forced manufacturers to broaden their product variety within a shorter period. As a result, manufacturing is often left with unused production lines, excess inventory, and dishevelled production schedules while marketing is praised for early recognition of sudden changes (Crittenden, et al., 1993). In this case, one of the major competitive weaknesses is inflexibility, or in other words, weakness in ability to change products quickly (Kim and Arnold, 1993).

In managing conformity, conflict between demand forecasting and production capacity is common to both marketing and production units. In this instance, uncertain marketing forecast results in manufacturing thinking that marketing's sales forecasts are always wrong. In turn, marketing concludes that manufacturing is inflexible when it fails to fulfil commitments to customers.

Conflict in managing dependability involves delivery performance and quality performance. According to Crittenden, et al. (1993), if manufacturing has idle capacity, marketing would use on-time delivery as a part of their promotion strategies. However, manufacturing operations do not always operate as planned, which ultimately delays delivery schedules. Similarly, the study has also revealed that marketing frequently expects manufacturing to produce the "perfect" product. In turn, quality control receives considerable blame resulting from shorter product life cycles and speed to market marketing strategies, while at the same time driving down manufacturing costs in order to meet competition.

In short, it can be noted that the conflict areas between manufacturing and marketing are related to manufacturing objectives and marketing objectives (refer to Table 2.1). As a solution, a decision support system is necessary to overcome these conflicts. Here, the Production Fitness measures can be used as a decision support system for decision-related meetings involving production and marketing units.

Table 2.1: A Typology of Conflict Areas between Marketing and Manufacturing (Crittenden, et al., 1993, p. 301)

No.	Area of Conflict	Marketing Objective	Manufacturing Objective
1.	*Managing diversity*		
	a. Product line length/breadth	Many & complex models	Few & simple models
	b. Product customisation	Customer specifications	"Stock" products
	c. Product line changes	Product changes immediately; high risk	Planned, only necessary changes; low risk
2.	*Managing conformity*		
	a. Product scheduling	Constant change	Inflexible
	b. Capacity/facility planning	Accept all orders	Critically evaluate "fit" of orders
3.	*Managing dependability*		
	a. Delivery	Immediate; large inventory	As soon as possible; no inventory
	b. Quality control	High standard	Reasonable control

2.3.2 Important Issues in Manufacturing Strategy

Manufacturing strategy seeks to provide supply that satisfies market demand by determining how and at what rate to manufacture products (Crittenden, et al., 1993). In addition, a central focus of manufacturing strategy competes through manufacturing operations by aligning manufacturing capabilities with market requirements (Voss, 2005). In this regard, the Production Fitness measures are designed as a decision-making tool for determining short-term and long-term plans in manufacturing strategy and marketing strategy.

Significant links between Production Fitness and manufacturing strategy are identified through four important issues in manufacturing strategy:

- Components of manufacturing strategy
- Competitiveness
- Capabilities
- Relationships.

2.3.2.1 Components of manufacturing strategy

A study on the content of manufacturing strategy has identified the components of manufacturing strategy as:

- ❖ *Manufacturing mission* is derived directly from the business strategy that states the manufacturing function.

- ❖ *Manufacturing objectives* is defined concisely in measureable terms that state expected results.

- *Manufacturing policy* is defined by resources or functions performed by manufacturing.

- *Distinctive competence* can be defined in terms of uniqueness that gives strength to manufacturing in dealing with competition.

(Schroeder, et al., 1986)

The study claims that manufacturing strategy can be most effective by supporting overall strategic directions of the business and providing for competitive advantages. Table 2.2 presents the components in manufacturing strategy in rank order.

Table 2.2: The Components of Manufacturing Strategy

No.	Manufacturing Mission	Manufacturing Objective	Manufacturing Policy	Distinctive competence
1.	*Quality & reliability*	Quality	Quality of the product	Consistent quality & delivery
2.	*Customer service* (delivery, warranty, field service)	Delivery performance	Management of the work force	Short turnaround & high quality assurance
3.	*Economic performance* (efficiency, productivity, unit cost)	Flexibility to change volume	Treatment of suppliers & vendors	Very knowledgeable work force
4.	*Flexibility* (volume, product)	Flexibility to change product	Professional & managerial development	Flexible to change
5.	*Resource & equipment utilisation* (capacity, output)	Employee relations	Inventory & distribution levels	High efficient & volume oriented
6.	*Technology* (product, process)	Inventory turnover	Development of new process technology	
7.	Organisational development	Equipment utilisation	Focus of facilities	
9.	Employee & community relations		Facilities location	
10.	Inventory control		Vertical integration	

Notes:

1- Components of manufacturing mission, objective, policy and distinctive competence (Dangayach and Deshmukh, 2001, p. 910; Schroeder, et al., 1986, pp. 410-412)

2- The components of manufacturing mission are in rank order of priority and importance.

3- The components of manufacturing objective are in rank order of highest to lowest.

4- The components of manufacturing policy are in rank order of highest to lowest percentage of response by manufacturing managers.

5- The components of distinctive competence are some examples of what managers saw as distinctive competencies in manufacturing.

2.3.2.2 Competitiveness

In the aspect of manufacturing strategy, issues of competitiveness often refer to the components of competitive priority. Table 2.3 presents the components of competitive manufacturing that have been used through different terms as follows: (i) *Competitive priorities*, (ii) *Production competence*, (iii) *Core competency*, (iv) *Core capabilities*. The terms used are actually synonyms of each other.

According to Kim, et al. (1993), competitive priorities are the competitive components in the manufacturing competence concept. The study concludes that the concept of manufacturing competence should focus on what is critically important for a company to compete effectively in the marketplace. A subsequent study on the same subject uses similar components to measure manufacturing performances. However, the term "production competency" is used instead (Choe, et al., 1997).

A recent study on production competence also uses similar components for measuring manufacturing performance with additional components of competitive priority (Schemenner and Vastag, 2006). Vic and Kaussar (2001) determine the core competency requirements as: *(i) Market access competencies* (e.g., sales and marketing); *(ii) Integrity-related competencies* (e.g., quality, delivery); *(iii) Functionality-related competencies* (e.g., innovative products). The requirements are based on the types of core competence introduced by Prahalad and Hamel (1994).

In respect of core capabilities, competitive priority is defined based on internal and external perspectives. In this respect, the cost and price, product conformance, and throughput time and delivery speed are the pairs of cause and effect from the internal and external perspective (Swink and Hegarty, 1998, p. 377).

Table 2.3: The Components of Competitive Manufacturing

Competitive priorities		**Production competence** (Choe, et al., 1997)	**Core competency** (Vic and Kaussar, 2001)	**Core capabilities** (Swink and Hegarty, 1998)
(Kim and Arnold, 1993)	(Schemenner and Vastag, 2006)			
Low defective rate	Product performance feature	Quality	Quality	Quality
Dependable delivery	Quick & reliable delivery	Dependability of supply	Dependable delivery	Quick delivery
Mix change	Flexibility	Flexibility of volume	Flexibility	
Price	Low cost product	Cost efficiency		Cost
	Rapid new product introduction	Design of product	New product uniqueness	
	Product customisation			
			Sustainable demand	

2.3.2.3 Capabilities

Capabilities in manufacturing strategy have been referred to as the system's ability to compete on basic dimensions such as quality, cost, flexibility, and time (Hsafizadeh, et al., 2000. Swink and Hegarty (1998) view manufacturing capabilities on two aspects: Growth capabilities, and Steady-stated capabilities. They divide Growth capabilities into three types: (i) *Capability to improve (efficiency and productivity);* (ii) *Capability to innovate (new resources, methods or technologies);* (iii) *Capability to integrate (wider range of product/process technology).* The Steady-state capabilities are more elementary and include acuity, control, agility and responsiveness.

Manufacturing capability is related to operations capability, where the acquisition of operations capability refers to three factors (Tan, et al., 2004): (i) *Organisation's commitment to quality management;* (ii) *Just-In-Time practices*; (iii) *Effectiveness of new product development process.* In this regard, the outcome from these three factors yields competitive advantages such as low cost, high flexibility, and short lead times.

In terms of other perspectives of capabilities, organisational capabilities are related to manufacturing capabilities. The latest study proposes the concept of capability embeddedness for a sustainable competitive advantage. The capability embeddedness concept is based on the combination of various resources to form capabilities, which in turn can be combined to develop higher-order capabilities and impact on overall performance (Grewal and Slotegraaf, 2007, p. 455).

In summary, Production Fitness represents the manufacturing capabilities that contribute to sustainable competitive advantage. Adapted from the concept of capability embeddedness, Production Fitness is generated from the integration of three essential sources of capabilities in manufacturing: (i) *Lean (LM concept);* (ii) *Agile (AM concept);* (iii) *Sustainable (Sustainability).*

2.3.2.4 Relationships

In general, the relationship between manufacturing and business has been empirically studied from a manufacturing and a business perspective (e.g., Schroeder et al., 1986; Kim et al., 1993; Choe et al., 1997; Swink and Hegarty, 1998; Hsafizadeh et al., 2000; Tan et al., 2004). Results from the studies confirm the positive relationships between manufacturing (e.g., strategy, competencies, and capabilities) and business (e.g. strategy, business performance, and operations performance). Table 2.4 presents a summary of identified relationships from empirical studies. From Table 2.4, the identified relationships in manufacturing strategy are illustrated in Figure 2.3. Figure 2.4 presents an abstract of relationships in manufacturing capabilities, which are also based on the relationships presented in the Table 2.4.

Overall, the relationships between manufacturing and business correspond to the nature of 'fit'. As was seen earlier, Figure 2.2 is a summary of Figure 2.3 and Figure 2.4 that illustrates Production Fitness as manufacturing competitiveness. In this regard, Production Fitness is measured through the operations performance.

Table 2.4: Relationships in Manufacturing Strategy, Competitiveness, and Capabilities

Manufacturing Strategy (Roth and Miller, 1992; Schroeder, et al., 1986; Swink and Hegarty, 1998)	**Manufacturing Competence** (Choe, et al., 1997; Hsafizadeh, et al., 2000; Kim and Arnold, 1993)	**Manufacturing Capabilities** (Choe et al., 1997; Hsafizadeh, et al., 2000; Krasnikov and Jayachandran, 2008; Nath, et al. 2010; Tan et al., 2004)
• Established link between manufacturing policies & objectives.	• Significant statistical relationships with some performance measures such as ROA and profit ratio.	• Positively related to firm performance.
• Manufacturing mission derived from business strategy or competitive environment.	• Positively related to business performance.	• Positively defined by capability of quality management, JIT, and new product design and development.
• Manufacturing objectives are very consistent with business strategy.	• Positively related to operations performance (Job shops process and batch process).	• Operation decisions on process choices not only affect current operation capability, but also set the framework for development of capabilities in the future.
• The distinctive competitiveness to be a very good match with manufacturing mission and objectives.		• Product complexity has no relationship with cost leadership
• Manufacturing strategy follows business strategy and marketing strategy.		• Product complexity is positively related to innovative differentiation.
• Emphasising improvement, control, integration and acuity result in successful pricing function of product differentiation.		• Product complexity is positively related to integration.
• Emphasising control and agility result in successful delivery speed (for standard product design).		
• Emphasising integration and acuity result in successful delivery speed (for new product design).		
• Emphasising acuity, control and responsiveness result in successful delivery reliability.		
• Related to three types of performance measures: *Relative manufacturing capabilities; Relative managerial success; Economic performance.*		

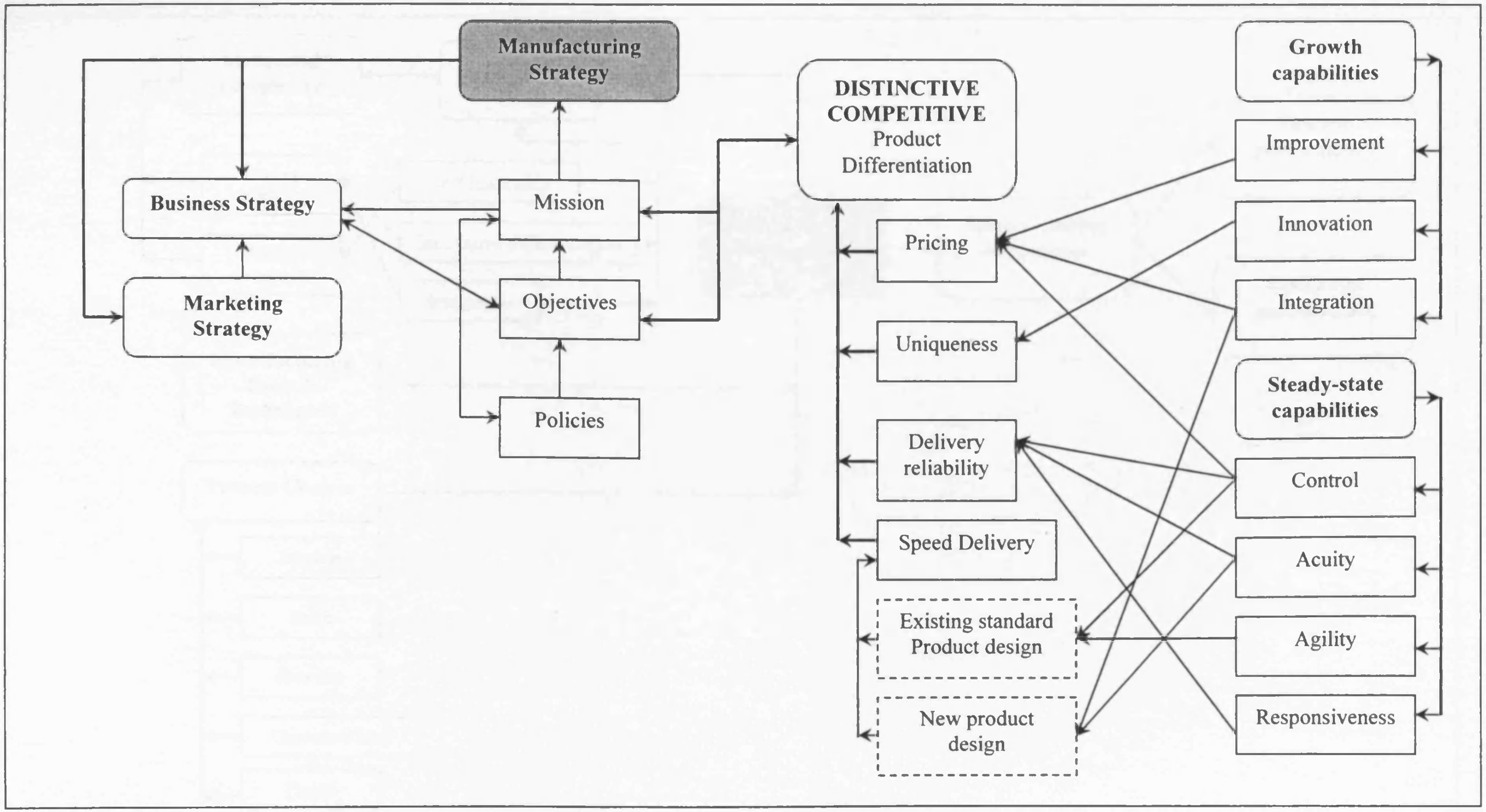


Figure 2.3: Relationships in Manufacturing Strategy

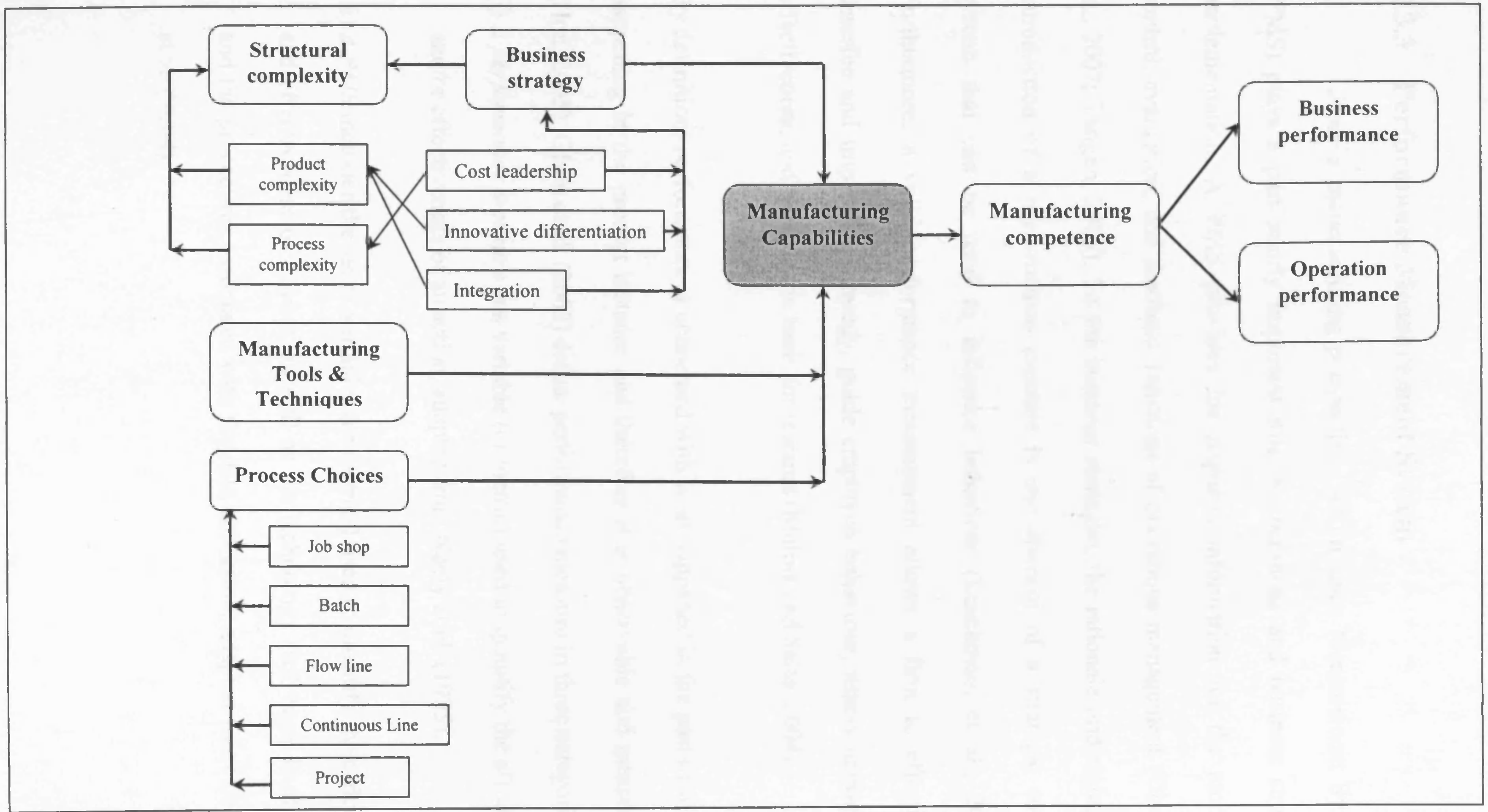


Figure 2.4 Relationships in Manufacturing Capabilities

2.3.3 Performance Measurement System

From a manufacturing perspective, Performance Measurement System (PMS) plays a particularly important role in operations and business strategy implementation. A PMS provides the requisite information for the monitor, control, evaluation, and feedback functions of operations management (Olsen,et al., 2007; Tangen, 2005). To the business strategist, the rationale underlying the introduction of a performance measure is one element of a strategic control system that can be used to influence behaviour (Leachman, et al., 2005). Furthermore, a valid performance measurement allows a firm to effectively describe and implement strategy, guide employee behaviour, assess managerial effectiveness, and provide the basis for rewards (Malina and Selto, 2004).

By definition, performance is concerned with what happened in the past or what is happening in the present instance and therefore it is observable and measurable (Hon, 2005). Olsen et al. (2007) define performance measure in three categories:

(i) *A performance measure* is a variable (or metric) used to quantify the efficiency and/or effectiveness of an action, adapted from Neely et al. (1995).

(ii) *A PMS* includes the set of variables (or metrics) used to quantify the efficiency and effectiveness of actions, as well as the technology (software, hardware) and the procedures associated with the data collection, adapted from Lohman et al. (2004).

(iii) *A performance measurement management system* (PMMS) encompasses the interactions between the PMS and its management actions and environment, adapted from Neely et al. (1995).

Three key functions of PMS are (Hyland, et al., 2007): (i) *to communicate performance expectation*, (ii) *to identify performance gaps*, (iii) *to support decision-making*. The criteria of PMS effectiveness are determined as causality, continuous improvement and process control (Olsen, et al., 2007). Earlier, Malina and Selto (2004) introduced the attributes of the performance measure as:

- informative
- benefits outweigh costs of collection
- reflective in system causality
- communicative in strategy
- incentive for improvement
- better decision-making

In particular, Hon (2005) specifies the characteristics of performance measures as: (i) *Integrated across the organisational functions*; (ii) *Satisfied with multi-goal performance systems*; (iii) *Transparent and direct;* (iv) *Providing data for reviewing past performance and planning future performance;* (v) *Adaptive to changes in external environments (e.g., NPI, new global competitors, new technology and new business models).*

In relation to the PMS functions, criteria, attributes, and characteristics, the results of a study revealed the existence of a significant and positive association between PMS and the business strategy (Hoque, 2004). The PMS is also positively related to manufacturing strategy where the PMS benefits from continuous improvement methods, particularly in areas such as quality conformance, customer satisfaction, productivity and delivery reliability (Hayland, et al., 2007). In this way, the positive relationships between PMS and business and manufacturing strategy have supported the model of Production Fitness shown in Figure 2.2.

In general, the PMS can be divided into two types, financial measures and non-financial measures. The financial measures gauge the performance of the firm as a whole and its business units but not any further, such as Returns of Investment (ROI), Returns on Equity (ROE), Returns on Sales (ROS), Economic Value Added (EVA) and net earnings (Hoque, 2004; Jusoh, et al., 2008; Leachman, et al., 2005). The non-financial measures are usually more complicated, ubiquitous, and cannot be easily rolled up or cascaded down within an organisation (Hon, 2005). Some examples of non-financial measures are: product quality, customer satisfaction, on-time delivery, efficiency and utilisation, set up time reduction, shop floor employee involvement in problem solving, etc. (Abdel-Maksoud, et al., 2005; Fullerton and Wempe, 2009).

Combination of financial and non-financial measures is known as multiple performance measures. The following are the most notable multiple performance measures (Bernard and Gianni, 2003; Bititci, et al., 2000; Hon, 2005):

- Performance Criteria (PC) System - 1985

  The aim is to provide guidelines for developing a performance criteria system for decision making in dealing with the implementation of a PC system (Globerson, 1985).

- SMART pyramid - 1988

  Consists of a four level pyramid of objectives and measures: (i) *Corporate vision/strategy*, (ii) *Business unit market and financial objectives*, (iii) *Business unit operational objectives and priorities*, (iv) *Departmental operational criteria and measures.*

  (Cross and Lynch, 1988).

- Balance Performance Measurement Matrix - 1989

  Explores the four basic principles of performance measures as: (i) *Performance measures derived from strategy*, (ii) *Performance measures are hierarchical as well as integrated across business functions*, (iii) *Performance measures must support the company's multidimensional environment*, (iv) *Performance measures must be based on a thorough understanding of cost relationships and cost behaviour*

  (Keegan, et al., 1989).

- Performance Measurement Questionnaire (PMQ) - 1990

  The aims are to help managers identify the improvement needs of their organisation, to determine the extent to which the existing performance measures support improvements, and to establish an agenda for the performance measure improvements (Dixon, et al., 1990).

- Performance Measurement for World Class Manufacturing - 1991
  Explores the three primary reasons of why new performance measures are required: (i) *Traditional management accounting is no longer relevant for the world class manufacturing environment*, (ii) *Customers are requiring higher standards of quality performance, and flexibility*, (iii) *Management techniques used in production plants are changing significantly.*
  (Maskell, 1991)

- Results and Determinants framework - 1991
  Classifying the measures into two basic types, which are related to results (competitiveness and financial performance) and determinants of the results (quality, flexibility, resources utilisation, and innovation) (Neely and Kennerley, 2002).

- Balanced Scorecard (BSC) - 1992
  The BSC measures are linked together on a cause-and-effect relationship covering four perspectives: (i) *Financial*, (ii) *Customer*, (iii) *Internal business process*, (iv) *Learning and growth.*
  (Kaplan and Norton, 1996).

- Integrated Performance Measurement System -1997
  The model involves two critical components with respect to the content and structure of the PMS, which are Integrity and Deployment. The viable systems model (VSM) provides a framework for assessing the integrity of the PMS. The audit methods are developed to assess the integrity and deployment of the PMS (Bititci, et al., 1997).

- <u>Performance Prism - 2001</u>

  Consists of five interrelated facets for organising PMS that are linked to performance perspectives: (i) *Stakeholder satisfaction;* (ii) *Strategies;* (iii) *Process;* (iv) *Capabilities*; (v) *Stakeholder contributions.*

  (Neely et al., 2001)

The most popular of the performance measurement frameworks has been the Balanced Scorecard (Bernard and Gianni, 2003; Bryant. et al., 2004; Hon, 2005). According to Business Intelligence, 71% of large companies in the UK use BSC, while in the US, almost 50% of 1,400 global businesses apply some kind of BSC (Jusoh, et al., 2008, cited from Paladiono, (2000)). Even in Malaysia which is a developing country, 30% of manufacturing companies have adopted the BSC (Jusoh et al., 2008). A review of the BSC will be discussed in the following section.

An effective PMS interacts with both internal and external environments. There are many factors that may affect the PMS. Thus, the control variables, such as country of operation, plant size, plant age, market share, and process choices need to be used to control the systematic biasing effects (Ketokivi and Schroeder, 2004). In particular, the workforce size is potentially important. The CIMA (1993) survey found that a growing workforce generates control problems and a greater need for explicit performance measurements (Abdel-Maksoud, et al., 2005). In addition, the types of industry in manufacturing sectors inevitably influence the scope and emphasis of various potential non-financial measurements of factory performance. For instance, each entrant for the Britain's Best Factories Award has to complete a self-assessment questionnaire that covers the plant profile, the nature of manufacturing operations, the cost structure, the inventory profile, the employee profile, product innovation, management information and market positioning (Neely et al., 2005). In short, measuring virtually every aspect of the business is noteworthy.

As a general guideline for the PMS design, Hon (2005) suggests that the PMS should be dynamic and should evolve with and adapt to the changing internal and external environment. In particular, Neely et al. (2005) provide a simple guideline for analysing the PMS through the levels of PMS:

(i) At the level of individual measures,

- What performance measures are used?
- What are they used for?
- How much do they cost?
- What benefit do they provide?

(ii) At the next higher level (PMS),

- Have all the appropriate components (internal, external, financial, non-financial) been covered?
- Have measures which relate to the rate of improvement been introduced?
- Have measures which relate to both long and short-term objectives of the business been introduced?

- Have the measures been integrated, both vertically and horizontally?
- Do any of the measures conflict with one another?

(iii) At the highest level (Performance Measurement Management System),

- Whether the measures reinforce the firm's strategies.
- Whether the measures match the organisation's culture.
- Whether the measures are consistent with the existing recognition and reward structure.
- Whether some measures focus on customer satisfaction.
- Whether some measures focus on what the competition is doing.

Similarly, Tangen (2005) suggests three levels of performance measures where a company should start with designing the lowest level of a PMS. He suggested two simple questions for designing the PMS as:

➢ *What should be measured?*

- refers to system requirements, such as support strategy and selection of both financial and non-financial performance.

➢ *How should it be measured?*

- refers to measure requirements of individual performance measure, such as: have an appropriate formula and include necessary specifications.

In summary, an effective PMS should be related to business strategy and manufacturing strategy. Thus, the PMS should be designed according to functions, criteria, attributes, and characteristics. The general guidelines provided for designing and analysing PMS can be used to design the Production Fitness measures. In the case of manufacturing systems, the PMS is represented by operational performance measures (also known as manufacturing performance measures).

2.3.3.1 Operational performance measures

PMS consists of a number of individual performance measures and relates to the environment within which it operates (Neely et al., 2005). Thus, operational performance is usually measured as a composite of several performance dimensions (Ketokivi and Schroeder, 2004). For instance, manufacturing performance is measured by cost, quality, delivery dependability, and flexibility (Leachman, et al., 2005; Neely, et al., 2005).

Manufacturing performance can be grouped according to the relation of the measures to measurement aspects. The five fundamental aspects in manufacturing performance measures are determined as quality, time, cost, productivity, and flexibility (Hon, 2005; Neely, et al., 2005):

(i) *Performance measures relating to quality*

Performance measures are focussed on issues such as the number of defects produced, cost of quality, customer satisfaction and process control (e.g., SPC and Six Sigma).

(ii) *Performance measures relating to time*

Time has been described as both a source of competitive advantage (Neely, et al., 2005). Some examples of time performance measures are: average lead time, changeover time, cycle time, machine downtime, on time delivery, and set up time.

(iii) *Performance measures relating to cost*

The management accounting systems are responsible for the design of the cost performance measures, which is closely related to profitability. Some examples of cost performance measures are: overhead cost, scrap cost, set up cost, total quality cost, unit labour cost, unit manufacturing costs, unit material costs, and WIP cost.

(iv) *Performance measures relating to productivity*

Productivity is conventionally defined as the ratio of total output to total input. It is formally defined as a measure of how well resources are combined and used to accomplish specific desirable results. Some examples of the productivity performance measures are machine productivity, assembly line effectiveness, and overall equipment effectiveness (OEE).

(Neely, et al., 2005).

(v) *Performance measures relating to flexibility*

It is a known fact that flexibility has a positive effect on manufacturing system performance if it is properly utilised by the control system (Baykasoglu and Ozbakir, 2008). Flexibility in manufacturing presents in multi-dimensions, such as mix flexibility, rerouting flexibility, changeover flexibility, volume flexibility, and material flexibility.

Results from an industrial survey on the use of performance measurement indicate that quality measures are the most well-established and best-understood (Hon, 2005). In contrast, the results show that flexibility measures are the least used by companies. For productivity measures, effective capacity of a machine, machine utilisation, and labour productivity are identified as the most important measures to manufacturing companies. Hon (2005) concludes that companies are most concerned with overall lead-time, on-time delivery, operating costs, inventory level, and scrap rate. However, results from a later study show that more than 70% of the companies surveyed rated product price as more important than three years ago (Hyland, et al., 2007). Meanwhile, conformance quality, delivery speed, and delivery reliability are rated as being of greater importance than three years previously.

In respect of relationships in manufacturing performance measures, it can be noted that manufacturing performance is related to manufacturing practices. The results of a study show evidence that companies employing TQM or TPM extensively are very likely to pay close attention to all performance measures whereas JIT seems more focused on delivery and quality performance (Abdel-Maksoud, et al., 2005). An earlier study found that JIT was associated with fast deliveries, low cost, and low cycle time (Ketokivi and Schroeder, 2004). The study concludes that as far as competitive performance is concerned, practices must be implemented for the right reasons. A later study concludes that manufacturing performance can be improved through greater R&D commitment and time compression during production (Leachman, et al., 2005). Continuous Improvement practice is proved to have the strongest influence on improved quality conformance and also contributes strongly to higher customer satisfaction, increased productivity, and improved delivery reliability (Hyland, et al., 2007). Accordingly, it can be noted that manufacturing performance measures are directly affected by manufacturing practices.

In summary, it can be concluded from this review that the five aspects in operational performance measures are still important in current manufacturing environments. In addition, manufacturing practices play an important role in manufacturing performance. In this respect, there are operational performance measures that have been specifically designed for particular manufacturing practices, such as leanness (LM practice), agility (AM practice), and sustainability (Sustainable Development concept).

2.3.3.2 Lean Manufacturing and leanness measures

The LM concept was first introduced by Womack et al. (1990), after studying the Japanese style of manufacturing, specifically the Toyota Production System, in the 1980s. The term 'leanness' has often been used in LM performance. Several models of leanness measure have been introduced since the early 2000s. Earlier, the first model of lean production performance was developed to assess changes in an effort to introduce lean production (Karlsson and Ahlstroem, 1996). The main purpose of the model is to find measurable determinants of what constitutes such a system in a manufacturing company which has not yet established a metric for the leanness measure.

In 2000 and 2001, the Lean Enterprise Self-Assessment Tool (LESAT) was developed by an industrial/governmental/ academic team under the auspices of the Lean Aerospace Initiative (LAI) at the Massachusetts Institute of Technology (Nightingale and Mize, 2002). It is a tool for self-assessing the present state of leanness of an enterprise and its readiness for change. The tool is organized into three assessment sections: (i) *Lean transformation/leadership*; (ii) *Life cycle processes*; (iii) *Enabling infrastructure*. LESAT is more applicable as an indicator of lean enterprise transformation rather than as a leanness indicator (Hallam, 2003).

In 2001, the lean indicators were determined through a survey of manufacturing companies on the use and usefulness of the lean indicators (Sanchez and Perez, 2001). A year later, the concept of "leanness" was introduced as a research instrument for measuring the degree of leanness possessed by manufacturing companies (Soriano-Meier and Forrester, 2002). Similarly, based on the qualitative method, a survey of a more specific industry was performed, in this case for the UK ceramics tableware industry. The lean metric was derived from the mean result of the statistical analysis.

In 2004, a model of lean production index was constructed by three indices (Kojima and Kaplinsky, 2004): (i) *Flexibility index,* (ii) *Quality index* (iii) *Continuous Improvement index*. The lean production index was calculated by aggregating the average scores in each of the three sub-indices. A survey of South African component firms was applied to measure the indices by using the weighting method. Two years later, the first quantitative method was applied for the lean assessment metric, known as the Mahalanobis Distance technique (Srinivasaraghavan and Allada, 2006).

Non-financial measures were employed to determine production leanness, such as percentage of maximum demand – minimum demand, changeover time (minutes), percentage of scrap in relation to sales, percentage of on time deliveries, and percentage of Kaizen events undertaken. In using this method, the leanness metric can only be calculated based on the degree of abnormality between the groups. However, the procedure to identify the direction of abnormality is limited to cases where the characteristic of the variables is known. This appears quite impractical for performing the leanness measure. In fact, the study experienced a lack of data points for comparison. As a result, additional data points were generated through experience and judgement.

In the same year, a lean index for the wood products industry was introduced by using the quantitative method (Ray, et al., 2006). Similarly, non-financial measures were used to determine the lean index, mainly in the aspects of productivity and turnover: (i) *Wood product*, (ii) *Non-wood product*, (iii) *Production*, (iv) *Energy*, (v) *Inventory*, (vi) *By-product*, (vii) *Supplies*, (viii) *Raw turnover*, (ix) *Inventory turnover*, (x) P*roduct turnover*. The data were processed using the SAS procedure PROC FACTOR which was developed by the SAS Institute in 2002. Here, data manipulation was conducted to make sure all the factor scores became positive numbers. For particular case studies, the Lean Index was determined by:

$$\text{Lean Index} = \exp\,(1.5 + \text{Factor score})$$

Unfortunately, data manipulation may need to be revised as new data sets are added. The same formula of the Lean Index cannot be used for different sets of data. This indicates the inconsistency of the measurement technique. Another leanness index was introduced in the same year, but using a qualitative method. A survey was conducted among 130 manufacturing plants drawn from past award winners and finalists in "Americas's Best" competition (Naramsimhan, et al., 2006). Plant leanness was assessed based on the LM practices implementation, such as team working, supplier partnership, JIT, Cellular Manufacturing etc.

Despite the leanness index, the study contributes to the most important fact regarding relationship between leanness and agility. The results indicate that while the pursuit of agility might presume leanness, pursuit of leanness might not presume agility. Thus, it can be noted that the integration of leanness and agility is essential for competitiveness. In the same year, the lean metric for assessing supply chain was introduced. The Analytic Network Process (ANP) was performed to determine the leanness index of the supply chain (Agarwal, et al., 2006). Non-financial measures were used, such as cost, quality, service level, and lead time. The ANP technique relies on survey results from a group of experts in a particular subject.

The number of lean performance models introduced has prompted the LM founder to highlight the concept of leanness measure. He claims that good performance on any or all of these lean metrics may be a worthy goal, but to turn them into abstract measures of leanness without reference to business purpose is a significant mistake (Womack, 2006). In this regard, the model of Production Fitness shown in Figure 2.2 corresponds to the business strategy.

In 2007, a study on a key set of leanness measurement items suggested 10 underlying components of production leanness which were based on lean practices, such as supplier feedback, supplier JIT, customer involvement, pull system, continuous flow, set up reduction, SPC, TPM and empowerment (Shah and Ward, 2007). In the same year, a leanness index of a Value Stream Mapping (VSM) was introduced by considering cost, time and output value (Wan, et al., 2007). The quantitative method was applied through the Data Envelopment Analysis (DEA) technique. The DEA is capable of determining the ideal leanness. However, the resulting leanness score may slightly overestimate the actual leanness level of the mapped system, since it is created from the average of Decision Making Units (DMUs) configurations.

In 2008, a study on leanness measure for manufacturing systems was conducted. The study aims to develop a systematic, long-term measure of leanness (Bayou and de Korvin, 2008). The financial indicators of leanness are processed by using the Fuzzy Logic technique (e.g., sales, current assets, market share, inventory costs, and finished goods cost). In this respect, the measure is considered as a single performance measure since it involves only financial variables. Furthermore, the Fuzzy Logic technique relies on results of the qualitative method used to assess a particular subject.

In the same year, another leanness measure for manufacturing systems was introduced (Wan and Chen, 2008). The study measures leanness through the integration of the DEA technique and Slack-based Measure (SBM) technique. As the DEA concept is based on input over output, cost and time are selected as the two input variables, whilst the finished products and customer satisfaction (i.e. quality, on-time delivery, service level etc.) are the outcomes of a production process. As mentioned earlier, the ideal leanness has not been precisely determined by the DMUs configurations.

Furthermore, the SBM is a DEA model that deals directly with slacks in the input and output variables. It is applied to determine the weight for DMUs and the efficiency score (leanness level) through the linear program. In this case, the slack conditions are created by the five undesirable conditions illustrated. In this respect, the slack conditions may vary by the period of measure, which means there is a possibility of misplacing the slack condition in the linear program.

In summary, the proposed models of leanness measures can be divided into two categories: qualitative measures and quantitative measures. By using the qualitative measure, the leanness metric is determined subjectively rather than objectively. In most cases, leanness has been measured based on the LM practices not by the output basis. Up to this time, only a few leanness measures have applied the quantitative measure. The multiple dimensional performance measure can be considered as not yet established because the proposed models consider either financial or non-financial variables for assessing manufacturing leanness.

Overall, the proposed models of leanness measure provide a good insight into leanness indicators for developing a multiple dimensional performance of manufacturing/production leanness.

2.3.3.3 Agile Manufacturing and agility measures

AM is an integration of technologies, people, facilities, information systems, and business process (Shih and Lin, 2002). In this regard, various definitions of agility were generated in order to relate with the AM concept. The key words and phrases that link to the agile paradigm have been suggested as fast, adaptable, robust, virtual corporations, reconfiguration, dynamic teaming and transformation of knowledge (Kidd, 1996). The measure of agility began to be introduced in the early 2000s in parallel with the introduction of leanness measure.

In 2001, the measure of agility was performed by a benchmarking technique. The benchmarking for agility is defined as benchmarking within an agile environment or benchmarking agile programs (Sarkis, 2001). The study aimed to determine possible measures for change metrics, such as technology, demand, process change, resource change, and environmental change. A method for evaluating enterprise agility was introduced in the same year (Yusuf et al., 2001). The agility metric is determined by the scale used in the survey, which is subjective rather than objective.

In 2002, a model of agility index was introduced through the application of Fuzzy Logic technique (Shih and Lin, 2002). Four agility dimensions have been used, such as responsiveness, competency, flexibility, and quickness. The inputs of the Fuzzy Logic are provided by the results from an expertise evaluation. Thus, there is a possibility that a different result of agility index could be determined from the agility evaluation that uses different expertise. In the same year, another model for enterprise agility measure was introduced which applies the Fuzzy IF-THEN rules and mathematical formulation to measure agility. Accordingly, agility is assessed through production infrastructure, market infrastructure, people infrastructure, and information infrastructure (Tsourveloudis and Valavanis, 2002).

The fuzzy rules are derived to represent accumulated human expertise, which means the qualitative method is performed to determine the value of each parameter. The following model was introduced to measure the agility of Mass Customisation (MC) product manufacturing. The Multi-grade Fuzzy Assessment technique is applied to evaluate the agility of a MC enterprise's organisation management, MC products design, and MC manufacture (Yang and Li, 2002).

Similarly, an expertise is used to determine the weight for each parameter before converting to fuzzy number.

In 2003, another Fuzzy Logic model was introduced to measure agility (Khoshsima, 2003). Similar to the Fuzzy model developed by Tsourveloudis and Valanis (2002), the IF-THEN rules are performed to determine the agility index. In the following year, the Petri Nets technique was applied to determine the state space probabilities needed for the complexity measure (Arteta and Giachetti, 2004). In this distance, agility was linked to the complexity measure. The study hypothesises that agile systems and processes are based on ease of change. High agility is presented by low overall cost and time resulting from the ease with which activities in the evaluated systems or processes can change. In reality, estimating the cost and time of unanticipated changes is difficult. As a result, the agility index could be measured inaccurately.

In 2006, a measure for agility index was proposed by the same study that introduced the measure for leanness index (Agarwal, et al., 2006; Narasimhan, et al., 2006). A model for a measure agility index of the supply chain was proposed in the same year. The Fuzzy Logic technique was applied to determine the agility index (Lin, et al., 2006a). The same technique is applied to the model of agility measure for enterprise (Lin, et al., 2006b). This model is extended from the previous model introduced in 2002. The latest model contains 24 agility capabilities compared to 15 agility capabilities in the previous model.

The following year, a model of enterprise agility measure was proposed. The Analytic Hierarchy Process (AHP) technique and Bayesian Belief Networks (BBN) technique are applied to the model (Liu and Zheng, 2007). Both techniques rely on expert knowledge and experience to evaluate enterprise agility. In 2008, another Fuzzy Logic model for measuring agility was proposed. This study presents a different view of agility assessment from previous Fuzzy Logic models. Agility is viewed from the aspect of capabilities and competencies. A questionnaire survey is performed to evaluate agility before proceeding into the Fuzzy Logic linguistic.

In the same year, a decision support system (DSS) for quantifying and analysing agility was introduced, known as DESSAC. DSS, one of the major applications of software engineering was used to develop the DESSAC (Vinodh, et al., 2008). The DESSAC system has also been supported by Visual Basic 6.0 as the front end and Microsoft Access as the back end. A questionnaire is applied to assess the existing agility level that refers to the 20 agile criteria. The agility index is determined from the results of the questionnaire, which is subjective rather than objective.

In 2009, another model of enterprise agility measure was proposed. Based on two case studies, agility is assessed through observations, interviews and questionnaires (Bottani, 2009). The Fuzzy Logic technique is applied to convert the results from the qualitative method into a Four-point Fuzzy linguistic scale so that the agility index can be determined. In the same year, a further model of agility measure for MC systems was proposed through the 2-tuple Linguistic Computing approach (Wang, 2009). Here, the Fuzzy numbers are employed to determine the agility index.

In this case, the linguistic information with a pair of values is called 2-tuple. The 2-tuple is composed of a linguistic term and a number. As the Fuzzy Logic technique relies on the results from qualitative method, the decision making squad is functioned to evaluate the MC systems. A model for calculating the long-term cost of software in an agile production environment was proposed in the same year. The proposed agility index is determined by the ability of a company to timely and profitably exploits windows opportunity of upcoming commercial opportunity (Dimitropoulos, 2009). The model is functioned by financial variables, such as delivery daily revenue, adaptation daily cost, and production daily cost.

In summary, most of the proposed models for agility measure are developed through the application of Fuzzy Logic technique. It may be noted that enterprise agility is assessed based on agility drivers and criteria.

2.3.3.4 Sustainability concept and sustainability measures

In general, the sustainability concept refers to the concept of sustainable development. The three aspects of sustainability are determined as: environment, economy, and society. Consequently, the concept of sustainability metrics was initiated through a combination of eco-efficiency, socio-economic, and socio-ecological metrics (Sikdar, 2003).

From a manufacturing perspective, the sustainability concept has often been referred to as the eco-product and eco-process, which concerns product recycle and disposal, amount of pollution/hazards generated from the manufacturing process and resources consumption (Al-Yousfi, 2004; Calvi, et al., 2008; Sonntag, 2000). In an earlier study, six main aspects of production sustainability were proposed as:

(i) Energy and material use (resources)
(ii) Natural environment (sink)
(iii) Social justice and community development
(iv) Economic performance
(v) Workers
(vi) Products

(Veleva and Ellenbecker, 2001)

A recent overview of sustainability assessment methodologies provides a compilation of sustainability measures that have been used in respect of environment, economy, and society (Singh, et al., 2009). It can be noted that no specific sustainability measure for manufacturing or production is included. The relevant sustainability measure for manufacturing companies is Product-based Sustainability Index. Thus, it can be concluded that the sustainability measure for manufacturing companies has not yet been established. Most of the proposed models for the sustainability measure are designed for various aspects, such as:

- *Sustainable development indicators for industry: A general framework* (Azapagic and Perdan, 2000).
- *Sustainability assessment in the German Detergent Industry: From stakeholder involvement to sustainability indicators* (Seuring, et al., 2003).
- *Sustainable development indicators for the mining and mineral industry* (Azapagic, 2004).
- *Assessing the sustainability performances of industries* (Singh, et al., 2007).
- *Development of composite sustainability performance index for steel industry* (Singh, et al., 2007).

However, there are some models of sustainability measure that are considered relevant to manufacturing companies. In 2005, a composite sustainable development index was proposed specifically to compare the sustainability performance of companies in a specific sector (Krajnc and Glavic, 2005). The composite sustainable development index contains the three dimensions of sustainability: environment, economy, and society. A mathematical model is applied to determine the composite sustainability index. In this case, qualitative descriptions may be more appropriate for certain aspects (i.e., societal aspects) even though the quantitative indicators are possible for the mathematical model. The AHP technique is applied to provide inputs for the mathematical model. Several types of expertise are involved in the weighting process.

A later study has proposed sustainability as the latest competitive dimension of manufacturing performance in response to market, technology and social trends (Shahbazpour and Seidel, 2006). The study emphasises the potential trade-off between sustainability and manufacturing competitive priorities (e.g. quality, cost, delivery, and flexibility). The issue of manufacturing technologies and sustainability have been discussed in an earlier study. It concludes that the strategic use of manufacturing technologies has significance for drafting sustainable consumption policy (Sonntag, 2000). In both studies, sustainability has been viewed from the aspect of eco-environmental products.

In the same year, the first economic sustainability measure of a company was proposed through a Knowledge Discovery in Data-bases (KDD) method. The KDD is often called data mining, which combines methods of statistical data analysis, machine learning, and data-base management systems (DBMS) (De Vos, et al., 2006). The study hypothesises that the economical sustainability of a manufacturing company can be achieved through continuous improvements, particularly in product processing, which are related to the best practices. The ranking figures are performed to determine the level of economic sustainability of a company. Results from a questionnaire and financial data function as the inputs for the KDD.

In 2008, a model of sustainability index was introduced based on the criteria of agile manufacturing systems. Sustainability is viewed as the long-term survival of the system in its environment, which has been referred to as the ability to generate variety in a dissipative process that allows a decrease of entropy (complexity) inside the system (Calvo, et al., 2008). In this regard, the manufacturing systems are regarded as open systems. Thus, sustainability for a manufacturing system is defined as the ratio between utility and complexity (internal). The model is tested by using a simulation method, which has several disadvantages (Banks, 1998; Davis, et al., 2007) such as:

- *Simulation modelling and analysis can be time consuming and expensive.*
- *Model building requires special training* – it is learned over time and through experience.
- *Simulation eliminates complexity in order to focus on the core aspects of phenomena and so uses computational representations that are often*

stark – the result can be an overly simplistic and distant model that fails to capture critical aspects of reality.

The study contributes a useful theory for measuring the sustainability of a manufacturing system through the quantitative approach. However, it could have less implication for the industrialist who prefers a simple model for a performance measurement system (in general) without special training and additional/specific data collections.

In summary, the existing models of sustainability measures have been designed to meet the requirements of a sustainable development concept that focuses on environmental, economic, and societal factors. A model of the economic sustainability measure for manufacturing companies has not yet been proposed. Overall, the proposed models provide a list of sustainability indicators that are useful for new models and extended/improved models of sustainability measure.

2.3.3.5 The essence of multidimensional performance measures

Hon (2005) illustrates the evolutionary nature of performance measurement from the 1960s to the 1990s as:

COST → PRODUCTIVITY → QUALITY → MULTIDIMENSIONAL

The traditional Managing Accounting Systems (MAS) have been criticised on their level of adequacy as PMS for highly competitive environments (Abdel-

Maksoud, et al., 2005; Fullerton and Wempe, 2009; Hoque, 2004; Jusoh, et al., 2008), which means stand-alone financial measures would not be appropriate for recent business environments. Therefore, a combination of financial and non-financial measures is essential for designing manufacturing performance measures. Ketokivi and Schroeder (2004) have argued that if operational performance is indeed multidimensional, creation of a composite as a summated scale would be appropriate. They have also claimed that manufacturing operations and practices are strategic, which contributes to competitive manufacturing performance in multiple dimensions.

In general, non-financial measures are more reliable for changes in the internal and external environment of the manufacturing system (Abdel-Maksoud, et al., 2005). Other advantages of non-financial measures are:

- 'Day-to-day' control of manufacturing and distribution operations is best handled with non- financial measures (Abdel-Maksoud, et al., 2005) so that top management can closely monitor, whereas financial results are only reported every quarter of the year (Neely, et al., 2005).

- Non-financial measures are reliable for both short and long-term plans and are not easily manipulated by managers (Hoque, 2004; Jusoh, et al., 2008; Tangen, 2005).

In fact, prior studies have shown how non-financial performance can be best combined with financial performance measures to obtain the best measurement of performance in a competitive environment (Jusoh, et al., 2008). From a study of the examination of multiple performance measures, Bryant et al. (2004) conclude that a higher profit can be gained through new products for improved customer satisfaction and emphasis on both financial and non-financial measurement systems.

The results of another study suggest that ignoring the multidimensionality of operational performance and manufacturing goals leads to incomplete understanding and modelling of the practice-performance relationships (Ketokivi and Scheroeder, 2004). Furthermore, environmental uncertainties in recent years have forced a multidimensional performance, whilst cost, productivity, and quality have remained as important measures. In short, the issue of multi-dimension indicates that the reliability of existing PMS still needs to improve with the changes in business environments. The BSC, which is the most popular PMS applied in manufacturing industries, has been criticised since it was first introduced. Following are the weaknesses of BSC that have been highlighted by the critics.

- *Mixed results.*

  Manufacturing firms with greater usage of internal business process, and innovation and learning measures, will experience improvement in performance. However, the usage of financial and customer measures have no significant effect on firm's performance (Jusoh, et al., 2008; Norreklit, 2000).

- *A number of important gaps between the theory and reality of BSC implementation* (Olsen, et al., 2000) *such as:*
  - not being effectively for business strategy – e.g., "firms which compete on quality or time place most emphasis on performance measures that match their strategies, while those that compete on price do not", criticised by Neely et al. (1994).
  - not being effectively linked to factory operations, criticised by Ghalayini et al. (1997).
  - absence of a competitive dimension and lack of specification for the performance dimensions that determine success, criticised by Kennerley and Neely (2002).

- *Not a generic measure.*
  Although BSC should ideally be tailored to each firm's unique strategy, evidence shows that managers tend to rely on generic measures, particularly as a measure of the outcome of each perspective (Bryant, et al., 2004).

- *Time dimension is not part of the scorecard.*
  It is problematic if a cause-and-effect relationship requires a time lag between cause and effect (Norrekllit, 2000).

In summary, multidimensional performance should contain financial and non-financial measures, where both types of measure affect each other. In other words, multiple measures provide better information on changes in the economy and competition (Bryant, et al., 2004).

2.4 Concept of Production Fitness Measures

Leachmann et al. (2005) claim that performance is usually reported for each individual indicator rather than in a consolidated manner, which is through an aggregate index of performance. Despite a number of proposed PMS with a combination of financial and non-financial measures, the BSC model has been the most popular among the manufacturing industries. However, the BSC is not considered to be a sufficient multidimensional PMS yet, as it does not integrate with other performance measures. Other examples of isolated multidimensional performance measure are: Leanness for LM practice, agility for AM practices, and sustainability for Sustainable Development concept.

Furthermore, most of the performance measurement models apply a combination of qualitative and quantitative approaches. In the case of index measurement, the application of a qualitative approach invites ambiguity, because of the subjectivity of the performed survey through observation, interviews, and questionnaires. Although the normalisation and weighting of indicators are applied to convert the qualitative results to quantitative form, it has been found that in general, they are associated with subjective judgements, which reveals a high degree of arbitrariness without mention of systematically assessing critical assumptions (Singh, et al., 2009). As a result, the index could be imprecisely determined. For instance, in leanness measure, Wan and Chen (2008) argue that surveys are by nature subjective, and the predefined lean indicators of a questionnaire may not fit every system perfectly. In addition, interviews and questionnaires are not suitable for a periodical measurement system (e.g., daily, weekly, monthly, and annually). In contrast, the quantitative approach provides objective results of the performance measure. Thus, it can be concluded that the existing models of manufacturing performance have not yet applied a purely quantitative approach with integrated multidimensional measure.

Therefore, the concept of Production Fitness measures will be based on the multidimensional performance with integration of distinctive manufacturing concepts. In view of this, the characteristics of Production Fitness measures are determined as:

(i) Production Fitness indicator represents the *integrated performance measures* of leanness, agility, and sustainability.

(ii) The Production Fitness measures can also be defined as integration between *strategic performance* (referring to specific manufacturing concept/practices) and *operational performances* (e.g., productivity, quality, cost, time, flexibility, agility, and sustainability).

(iii) The Production Fitness measures contain *a combination of financial and non-financial items.*

(iv) The Production Fitness measures will be determined by using *a purely quantitative approach.*

(v) The Production Fitness measures will be applied for *a short-term periodical measure* (weekly/monthly), which later can be used as *a long-term periodical measure* (annual review).

(vi) The inputs for the Production Fitness measures will be based on *common production and sale data*, such as defective quantity, production input/output quantity, sales quantity, minimum price per unit product, labour cost, etc.

(vii) The results of the Production Fitness measures will be determined by the *Microsoft Excel software* applications.

The essence of the integrated performance to the Production Fitness measures is determined on the basis of how the company manoeuvres profitability. According to Neely et al. (2005), every business should be able to assess the true profitability of the sectors it trades in, understand product costs, and know what drives overheads. Unfortunately, marketing and manufacturing people are sometimes more cost-oriented than profit-oriented. In this regard, the ideal indicators for determining positive outcomes (e.g. profit, sales quantity) from cost-oriented and profit-oriented strategies are necessary for production and marketing people.

Therefore, the integrated performance of LM, AM, and Sustainability in the Production Fitness measures would be able to indicate the ideal performance for cost-oriented and profit-oriented strategies. The leanness measure has always been related to performance of profit-oriented strategies. On the other hand, the agility and sustainability measures can be related to the performance of cost-oriented strategies. The non-financial items are important to Production Fitness measures due to the following evidence:

- Results from a study confirm that the non-financial manufacturing performance measures are the key component for financial success from lean strategies (Fullerton and Wempe, 2009).

- The higher the manufacturing flexibility (an indicator for internal business process), the better the financial performance (Jusoh, et al., 2008) where manufacturing flexibility is part of the manufacturing agility.

- An organisation is always adapting to its environment (Malina and Selto, 2004). To reflect current conditions, agility performance should be part of the Production Fitness measures.

In summary, the concept of Production Fitness measures is applicable to competitive environments, internally, and externally. The internal competitive environment is viewed from the aspect of production capability to maintain ideal Production Fitness. The external competitive environment, on the other hand, it is viewed from the aspect of production capability to achieve a higher level of Production Fitness as compared to the competitors. Thus, a fit production will be determined through the achievement of both ideal and high level Production Fitness.

2.5 Summary

This chapter has reviewed the evolution of manufacturing systems and the main aspects relating to the PMS of a manufacturing system. The concept of Production Fitness measure is developed based on the determination of gaps from existing PMS models and the three pillars of the Fit Manufacturing systems.

Chapter 3

Chapter 3
PRODUCTION FITNESS

3.1 Preliminaries

The main function of production is to transform customer orders into products. The efficiency of production systems relies on the production capability to transform the orders into products, provided that the manufacturer and customer share mutual benefits. The concept of Fit Manufacturing systems is developed from the integration of Lean Manufacturing (LM), Agile Manufacturing (AM), and Sustainability concepts (Pham, et al., 2008a). In this study, Production Fitness represents an integrated production capability generated from the Fit Manufacturing concept. Consequently, Production Fitness can be determined through production leanness, agility, and sustainability.

This chapter consists of three main sections that explain the structure of Production Fitness. The components in the structure are justified through a study of the literature and explained using a metaphor. The objective of the literature study is to identify the key factors that contribute to production leanness, agility, and sustainability. The identified key factors and their justification are discussed in Section 3.2.

Since the term 'fit' has always been connected to fitness, the human body system analogy and the human fitness components analogy are employed to explain the necessity of leanness, agility, and sustainability as the measures of Production Fitness. The commonalities between the human body system and a manufacturing system are discussed in Section 3.3. In addition, the functionality of the human fitness components have been compared with the three pillars of Fit Manufacturing systems.

In section 3.4, the components of leanness, agility, and sustainability are justified in respect of production performances (e.g., profitability and productivity). Evidence from the literature study has been used to justify the significance of the components to production fitness. The complete structure of production leanness, agility, and sustainability is presented in three different diagrams (refer to Figure 3.7, Figure 3.8 and Figure 3.13).

3.2 Concept of Fit Manufacturing

A Fit Manufacturing system works through the integration between LM, AM, and Sustainability concepts. The necessity for the three concepts in Fit Manufacturing systems was illustrated by the 'Fit concept' analogy of athletic performance in the team cycling competition (Pham and Thomas, 2005). The roles of each team member, Climber, Sprinter, and Leader, were clearly described in comparison to the manufacturing environment. To win the competition, the climber should keep his/her *body lean*, the sprinter should be *responsive and flexible*, whilst the leader should *sustain* his power and control to redress any failures due to *imbalance* between the climber and the sprinter.

In short, a fit team is structured by the integration of capabilities in respect of leanness, agility, and sustainability in the appropriate amount to meet the requirements of the current business environment.

3.2.1 Lean Manufacturing Concept

Lean Manufacturing was derived from the Toyota Production System. In effect, it is a refinement and modification of the Toyota Production System (Papadopoulou and Ozbayrak, 2005). The LM concept works to maximise the output through minimising the inputs (resources). The term 'lean' has been defined as a system that utilises less (inputs) to create the same outputs as a mass production system, while contributing increased varieties for the end customer (Panizzolo, 1998). Wastes elimination is the foundation of the LM concept. In most industrial case studies, reducing wastes has been the focus of LM (Hopp and Spearman, 2004; Treville and Antonakis, 2006; Womack, et al., 1990). The production wastes are classified into seven types:

i. Overproduction
ii. Defects
iii. Unnecessary inventory
iv. Inappropriate processing
v. Excessive transportation
vi. Waiting
vii. Unnecessary motion

(Hines and Taylor, 2000)

The effectiveness of LM concept is usually measured on the basis of the implementation of its tools and techniques (Karlsson and Ahlstroem, 1996; Sanchez and Perez, 2001; Shah and Ward, 2003, 2007; Soriano-Meier and Forrester, 2002; Srinivasaraghavan and Allada, 2006). The tools and techniques are functioned for eliminating/reducing the production wastes. Therefore, the amount of production wastes can be used as a platform in determining manufacturing efficiency. In fact, cost efficiency has been claimed as the primary performance outcome of leanness (Christopher and Towill, 2001; Mason-Jones, et al., 2000; Shah and Ward, 2003). Overall, leanness in the Fit Manufacturing systems is defined as the capability of the manufacturing system to operate at minimum possible costs.

3.2.2 Agile Manufacturing Concept

From the aspect of manufacturing, the term agile refers to the characteristic of manufacturing systems that serves a highly competitive business environment. However, agile is not a standalone character but a combination of flexibility, speed, and responsiveness (Jin-Hai, et al., 2003; Khoshsima, 2003; Meredith and Francis, 2000; Yusuf et al., 1999). Therefore, agile characteristics are essential for the unpredictable changes in market demands. In other words, the AM concept has been driven by unpredictable changes where agility can be scaled through adaptability to changes. Agility has also been quoted as ability to change (Arteta and Giachetti, 2004; Khoshsima, 2003; Sherehiy, et al., 2007) which refers to the capability to adapt.

In short, the ability to change and the ability to adapt actually represent responsiveness. A conclusion to be drawn from the literature study on the AM concept is that responsiveness in agility consists of two types of actions (Brown and Bessant, 2003; Helo, 2004; Khoshsima, 2003; Ramasesh, et al., 2001; Sarkis, 2001; Sharifi and Zhang, 1999; Tsourveloudis and Valavanis, 2002; Vazquez-Bustelo, et al., 2007; Wang, 2009):

- Promptly responding to change.
- Exploiting changes and taking advantage of them as opportunities.

In this study, the two types of action are termed 'Re-activeness' and 'Pro-activeness'. Re-activeness is defined as reactions caused by things that happen or have happened. In this, re-activeness can be scaled through flexibility characters as flexibility having been determined as the capability to react in the planned changes (Sahin, 2000; Vokurka and Fliedner, 1998). In particular, re-activeness has been scaled by using the two measures of product mix flexibility:

- Range (product variety and volume variety)
- Response (changeable capability) (Van Hop, 2004; Wahab, 2005)

In general, pro-activeness is defined as advanced reactions before things happen (Oxford, 2009). From a manufacturing perspective, pro-activeness is closely related to innovativeness (Adeleye and Yusuf, 2006; Ren et al., 2003; van Assen, 2000; Yusuf et al., 1999). It has been claimed that pro-activeness contributes to winning profit, winning market share, and winning customers (Helo, 2004; Kidd, 1996). Thus, pro-activeness is scaled by two measures of New Product Introduction (NPI): *Speed* and *Variety* (Ramasesh, et al., 2001).

Agility in Fit Manufacturing systems is applied to the entire aspects of manufacturing, such as Scheduling, Supply Chain, Workforce, Routing, Distribution Channels, Physical Infrastructure, Technologies, Product Mix, Market Tracking and Information Structure (Pham, et al., 2008a). However, agility in Production Fitness is particularly focused on the aspect of product mix. In this respect, agility is viewed as the capability to transform the orders promptly into products. Nowadays, production capability is challenged by the rapid changes of market demands. Therefore, agility, through the characteristics of re-activeness and pro-activeness, is capable of responding to market demands, market changes, and market opportunities (Yang and Li, 2002). It can be concluded that a combination of re-activeness and pro-activeness as production agility is crucial in relation to the rapid changes of market demands, specifically in product variety and volume variety.

3.1.3 Sustainability Concept

The basic definition of sustainability is the ability to keep (something) going over time and continuously (Oxford, 2009). The concept of sustainability was developed through the concern for economic sustainability, environmental sustainability, and societal sustainability resulting from industrial activities. The three aspects of sustainability have affected each other. For instance, economic sustainability affects environmental sustainability and societal sustainability by providing the capability to develop a higher education level and healthy environment for society.

The impact of economic sustainability can be viewed either from a global or specific aspect. However, the accumulated impacts on a specific aspect subsequently become a global aspect. For instance, economic sustainability of a manufacturing company is important, not only to the company, but also to the country. Therefore, this study specifically focuses on the economic sustainability of manufacturing companies. In this sense, economic sustainability is referred to as the ability to operate with less time, high value-added activities, and minimum cost (Barlow, 2003; Geyer, et al., 2005; Kaebernick, et al., 2003; Liyanage, 2007; Sonntag, 2000). Thus, a sustainable manufacturing company may be defined through economic sustainability.

Sustainability in the Fit Manufacturing systems refers to economic sustainability through sustainable demand-supply balance (Pham, et al., 2008a) The Fit Manufacturing systems correspond to sustainable demand and sustainable capacity, especially when these involve new demands. New markets and customer/product diversification are seen as critical for company survival.

3.3 Analogical Studies

The analogy of the human body system and the analogy of human fitness components are studied to identify the commonality between the human system and the manufacturing system. The objective of the analogical studies is to determine the necessity of the three pillars in the Fit Manufacturing systems compared to the human body system and human fitness components.

3.3.1 Analogy of the Human Body System

The commonality between the human body system and the manufacturing system are discovered through this analogy. Figure 3.1 and Figure 3.2 illustrate the workflow of the input-output in both the systems. Several commonalities have been identified.

First, in respect of commonality, continual fundamental input is critical to both the human body and the manufacturing systems. Otherwise, both systems would be paralysed. As the human will die as a result of the absence of oxygen, this is considered the fundamental input of the human body system. Similarly, the manufacturing system will only function with continual customer orders. In this case, a dysfunctional manufacturing system means the absence of customer orders.

The second commonality refers to the output of both systems in using the same performance indicators such as agility, flexibility, speed, and responsiveness. In the human body system, more energy is needed to achieve higher performance. Similarly, more products are needed, especially a variety of products, in order to be competitive in the face of unpredictable market demands.

In the case of the third commonality, the output rate relies on the input volume. More oxygen is needed for human activities which require a high level of performance (e.g., running, swimming, and climbing). Similarly, more orders are needed for manufacturing systems in a highly competitive market. In this way, a high rate operating level is essential for both systems.

With regard to the fourth commonality, the output rate depends on the system's efficiency. In both systems, efficiency refers to maximising the output from the minimum possible input. In order to achieve this, efficient processes are needed in transforming the input into the output. For instance, in the human body system, this refers to how efficiently the cardiovascular system supplies the oxygen to the muscles system before transforming into energy. Similarly, the production outputs depend on how efficiently the production system transforms the orders into products.

In summary, continual fundamental input is essential for the fitness of both the human body system and the manufacturing system. System fitness is determined by the efficiency applied in processing the fundamental input into the output. In this way, the performance indicators represent the level of system efficiency in a competitive environment.

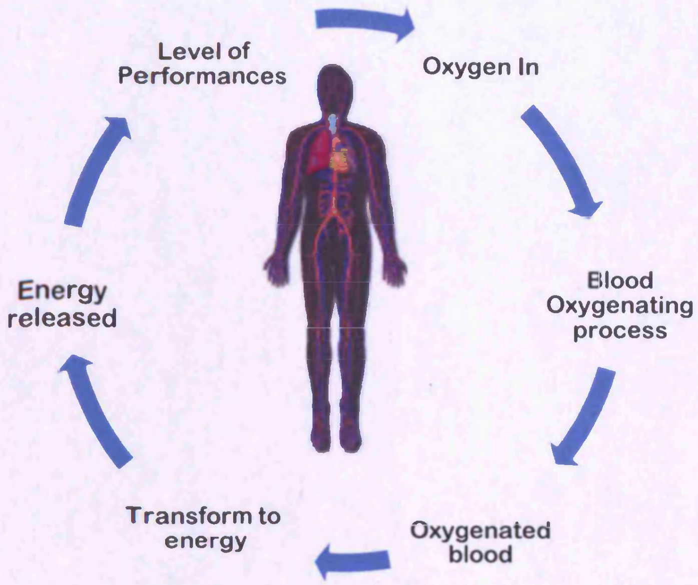


Figure 3.1: The Human Body System

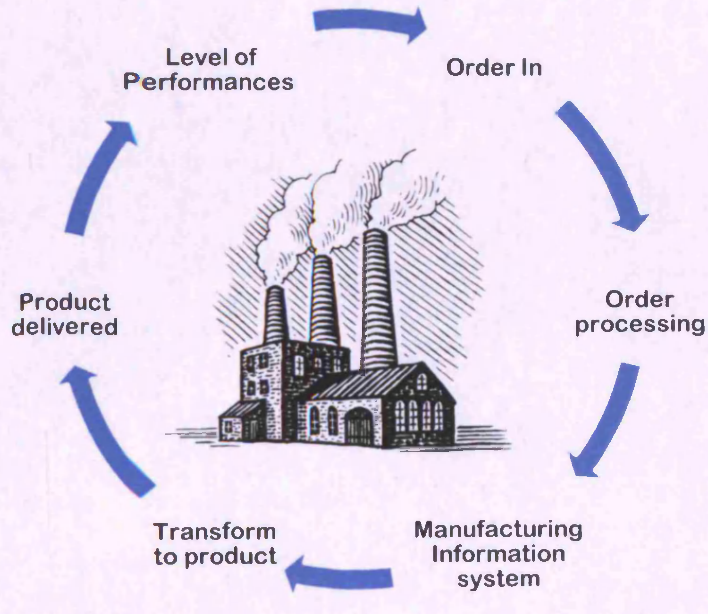


Figure 3.2: The Manufacturing System

3.3.2 Analogy of the Human Fitness Components

Fitness is generally defined as the quality of being suitable to fulfil a particular role or task (Oxford, 2009). Human fitness is classified into two types (Hoffman, 2006): (i) *Health-related fitness,* (ii) *Skill-related fitness.* Health-related fitness refers to the positive health of the human. In this respect, positive health could affect the Skill-related fitness of the human (Lamb, et al., 1998). Skill-related fitness refers to human physical fitness at a high level of performance (Amika, et al., 2006). In the early research, the components of human fitness were grouped according to two fitness types (Biddle, 1987; Hockey, 1997) as follows:

- *Health-related fitness* – Cardio Respiratory Efficiency/Endurance, Flexibility, Muscular Strength and Body Composition.
- *Physical fitness* - Flexibility, Agility, Speed, Reaction Time, Power, and Strength.

However, later studies grouped all the components under human fitness components. In total, there are ten components of human fitness (Amika, et al., 2006; Hoffman, 2006; Lamb, et al., 1988; MacKenzie, 2008; Ortega, et al., 2008):

i. *Muscle Strength*
   - refers to the muscle strength on contracting against resistance.

ii. *Muscle Endurance*
   - refers to muscle ability in prolonging the maximum contraction

iii. *Flexibility*
   - refers to extended range of motion.

iv. *Reaction Time*

- refers to the time taken to respond to a stimulus.

v. *Speed*

- refers to quick execution of movements.

vi. *Power*

- refers to the combination of strength and speed to produce maximum muscular contraction instantly.

vii. *Agility*

- refers to quick movements in opposing directions.

viii. *Balance*

- refers to the controlling body position either in stationary or moving.

ix. *Cardiovascular Fitness*

- refers to the ability of the cardiovascular to supply blood continuously.

x. *Body Composition*

- specifically refers to the amount of body fat.

The adaptation of human fitness components as manufacturing fitness components cannot be a direct process. Instead, the human fitness components should be justified through a wider aspect, rather than as individual components. In order to be comparable with the manufacturing system, the ten human fitness components are viewed from two aspects: Function and Relationship.

With regard to the first aspect, flexibility, agility, responsiveness, and strength are the function of capabilities of muscles and cardiovascular functions. Relatively, maintenance of correct body composition is necessary to avoid excess fat in tissues and muscles. Excess fat can influence other fitness components, such as agility and responsiveness (Ortega, et al., 2008). Most athletes keep their levels of body fat to a minimum, as the higher the percentage of the body fat, the poorer the performance (MacKenzie, 2008). Similarly, excess fat can be regarded as production wastes in the manufacturing systems. It can be noted that lean human body and lean production is essential for achieving a high level of system performance. Thus, leanness as a component of production fitness is clearly justified.

In respect of the second aspect, the relationships within the fitness components have been clarified in a number of studies on human fitness:

i. Agility is the combination of speed, balance, power and co-ordination. In this case, reaction time influences the speed of movement parts (Ortega, et al., 2008).

ii. Agility is the ability to change the body's direction accurately and quickly while moving rapidly (Hockey, 1977).

iii. Achieving agility requires a combination of speed, balance and power (Walden, 2008).

iv. Agility is described by four basic internal criteria: change, accuracy, quickness, and rapid movement, which consequently have been related to speed, balance, strength, and power (Lamb, et al., 1988).

v. Flexibility improves balance and balance affects agility during movement (dynamic balance) (Walden, 2008).

vi. Power is generated by strength and speed (Lamb, et al., 1988; Walden, 2008).

Overall, agility can be viewed as multi-characteristic, being performed through a combination of flexibility, speed, power, strength, and balance. The sustainability element in human fitness can be related to balance. In this respect, in addition to a lean human body, sustainable balance and sustainable cardiovascular fitness are also important for achieving a high level of performance.

Thus, human fitness components can be classified into three categories: Leanness, Agility, and Sustainability, as demonstrated in Figure 3.3. Coincidently, the categories match with the three pillars of Fit Manufacturing systems.

3.4 Production Fitness Components

Results from the analogical studies show that it is possible to consider the human body system and human fitness components in determining production fitness components. In the human body system analogy:

- *Muscles* in the human fitness components have a similar function as production unit.

- *The cardiovascular* functions in supplying oxygenated blood to the tissues and muscles. Similarly, the marketing unit is responsible for supplying orders to the production unit.

The performance of the human body system relies on muscular and cardiovascular fitness. This analogy is compatible with the manufacturing system, which specifically refers to production and marketing fitness.

In the human fitness components analogy, the fitness components can be grouped under the three pillars of Fit Manufacturing systems. In addition to the analogy, the three pillars of Fit Manufacturing systems have been clearly justified through the literature study. Figure 3.4 presents the components of production fitness. In this regard, each component is supported by the following key concepts:

- Minimum production wastes determine Leanness.
- Responsiveness to change determines Agility.
- Demand-Capacity balance determines Sustainability.

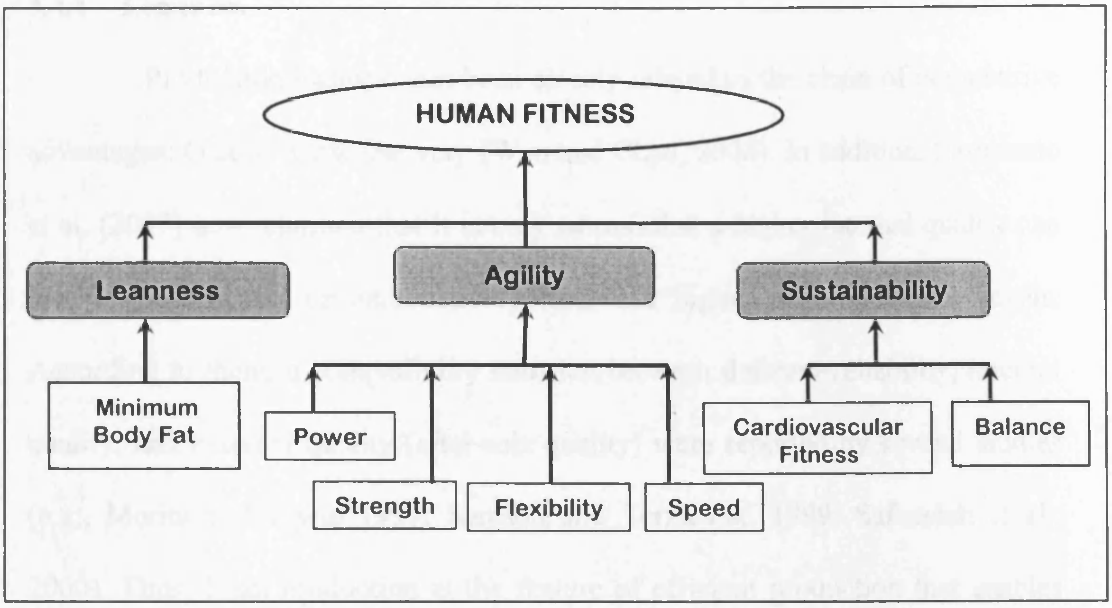


Figure 3.3: The Human Fitness Components in the Aspect of Function and Relationship

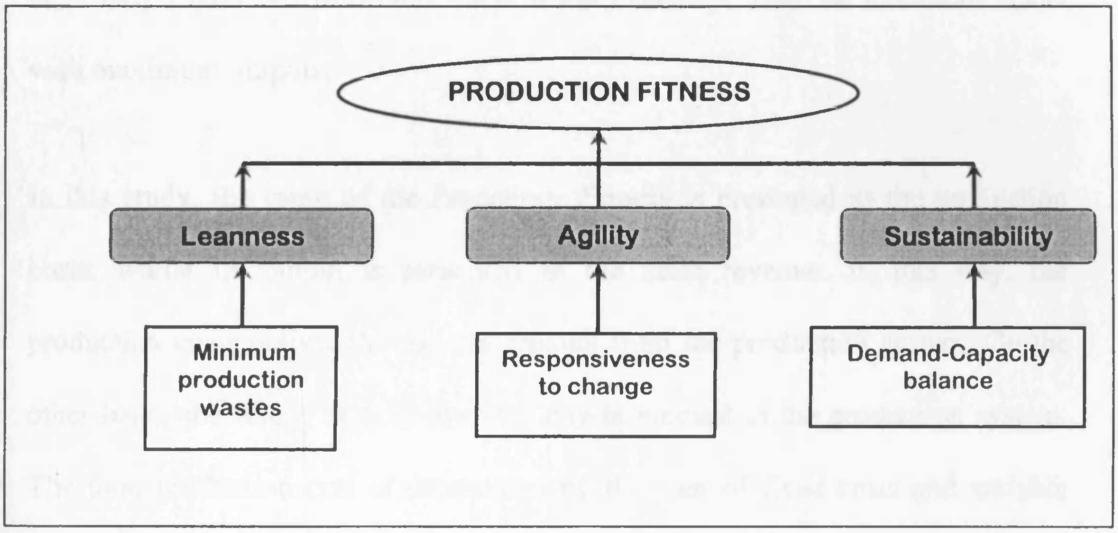


Figure 3.4: The Components of Production Fitness and its Concept

3.4.1 Leanness

Production leanness has been closely related to the chain of competitive advantages: Quality-Cost-Delivery (Wan and Chen, 2008). In addition, Sarmiento et al. (2007) have claimed that it is only natural that a higher internal quality can lead to both higher on-time delivery rates and higher external quality levels. According to them, a compatibility situation between delivery reliability, internal quality, and external quality (after-sale quality) were reported by several studies (e.g., Morita and Flynn 1997; Samson and Terziovski 1999; Safizadeh et al., 2000). Thus, Lean production is the feature of efficient production that enables high quality products with low production costs and on-time delivery performance to be produced. According to the lean definition, the input-output dimensions are used in determining effectiveness and efficiency of lean production (Womack, et al., 1990). Figure 3.5 illustrates the efficiency concept based on minimum inputs with maximum outputs.

In this study, the input of the Production Fitness is presented as the production costs, whilst its output is presented as the sales revenue. In this way, the production costs deliver the pay-out amount from the production system. On the other hand, the return sales deliver the pay-in amount to the production system. The total production cost is determined by the sum of fixed costs and variable costs. The cost of unit product can be determined by dividing the total production costs by the total number of unit products.

Meanwhile, the sales revenue is determined by the price per unit product with the profit. Thus, the profit margin is determined by the difference between maximum cost of unit product and minimum price of unit product. However, neither cost nor price of unit product would remain, as they actually depend on the market value. Figure 3.6 illustrates the inconsistency in total production cost and sale price that affects profit margin. It shows that the profit margin can be expanded or shrunk either by total production cost or sale price.

In the case of a price competitive market, sales and marketing strategies might not be sufficient to maintain the profit margin. Thus, minimizing the production costs would be the only alternative to maintaining the profit margin. For that reason, the wastes elimination concept has been considered an effective approach for minimizing the total production cost (Bhasin and Burcher, 2006; Hines and Taylor, 2000; Shah and Ward, 2003). In this way, cost efficiency is a primary performance outcome through leanness (Narasimhan, et al., 2006). Previously, the LM concept had already been hailed as a cost reduction mechanism (Womack and Jones, 1994).

Determining the production wastes is in fact an awkward process, because some of the production wastes are visible while others are not. Overproduction, scraps/defects, and unnecessary inventory are visible production wastes, which can be directly determined by the unit quantity. However, inappropriate processing, excessive transportation, unnecessary motion, and waiting are invisible production wastes that exist in the production lead time. This latter type of production waste can only be determined by differentiating the value-added activities and non- value-added activities within the production time. Examples of common non-value added activities in production are machine stoppage, queuing, waiting for parts, unnecessary processes etc.

These non-value-added activities would later cause unnecessary overtime and idle time for production operations. As a result, this will increase the total production cost. At the same time, production is unable to produce the quantity demanded within the specified period. The problem becomes critical in a competitive market environment (e.g., reliable delivery and low price). This will finally scale down future sales due to customer dissatisfaction.

In conclusion, the key factors of lean production can be determined through the input and output amount. In this study, the input amount is represented by the sources of pay-out amount. Conversely, the output amount is represented by the pay-in amount. Thus, efficient production, or so called leanness, can be achieved by minimising the pay-out amount, while at the same time maximising the pay-in amount. The structure of leanness is shown in Figure 3.7.

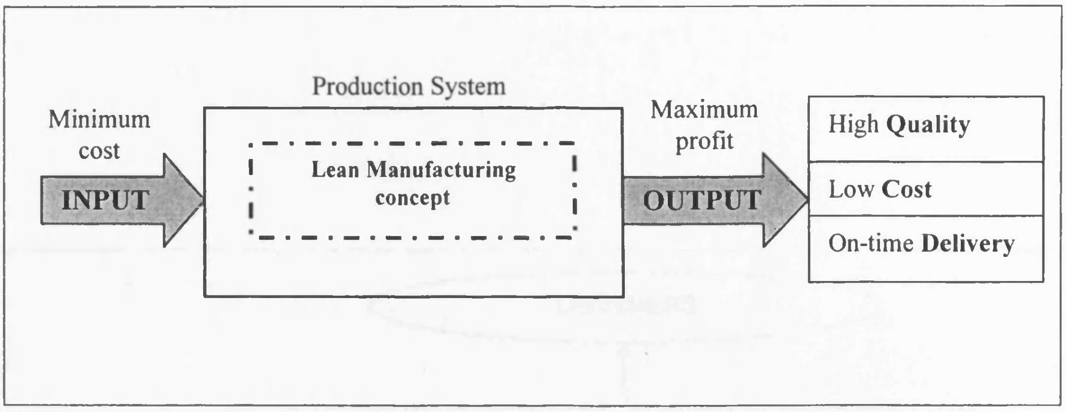


Figure 3.5: The Concept of Production Efficiency Based on Minimum Input and Maximum Output.

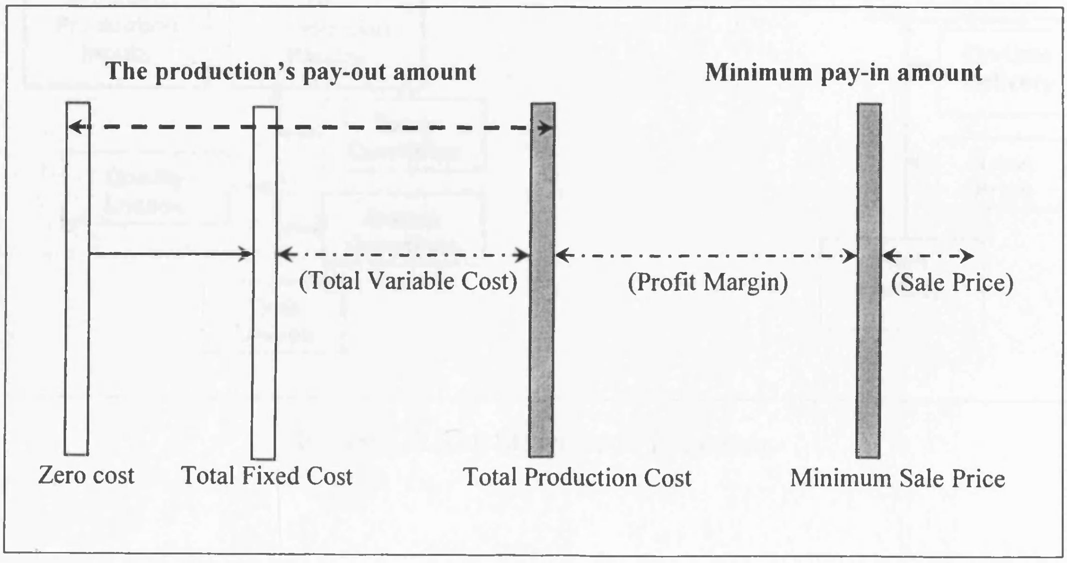


Figure 3.6: The Profit Margin that Affected by Inconstant Total Production Cost and Sale Price

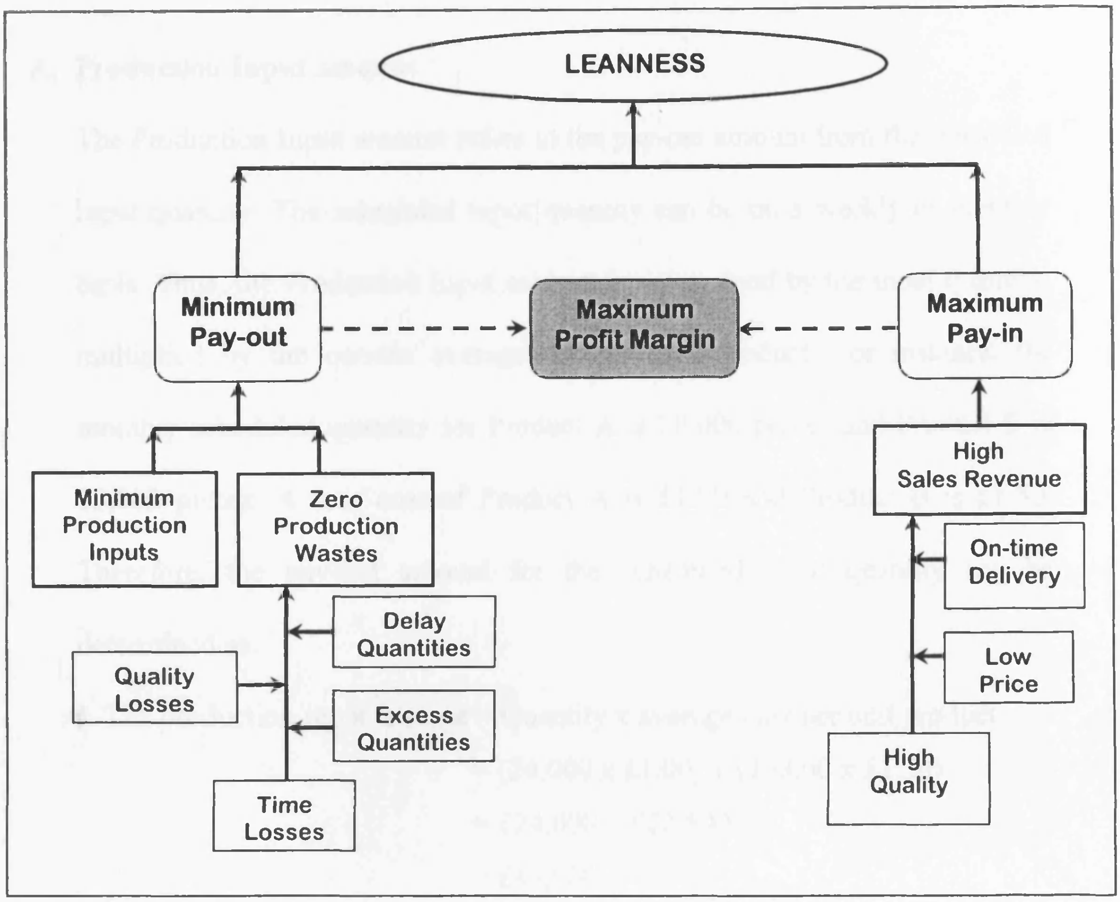


Figure 3.7: The Structure of Leanness

3.4.1.1 Minimum production pay-out amount

Production pay-out amount is determined by the sum of fixed costs and variable costs. In this study, the pay-out amount is accounted by the sum of the Production Input amount and the Production Wastes amount.

A. Production Input amount

The Production Input amount refers to the pay-out amount from the scheduled input quantity. The scheduled input quantity can be on a weekly or monthly basis. Thus, the Production Input amount is determined by the input quantity, multiplied by the current average cost of unit product. For instance, the monthly scheduled quantity for Product A is 20,000 pieces and Product B is 15,000 pieces. A unit cost of Product A is £1.00 and Product B is £1.50. Therefore, the pay-out amount for the scheduled input quantity can be determined as:

- The production input amount = Quantity x average cost per unit product
  = (24,000 x £1.00) + (15,000 x £1.50)
  = £24,000 + £22,500
  = £46,000

In turn, the pay-out amount of the scheduled input quantity is expected to be paid-in back by the sales revenue. In fact, the adequate sales revenue is a basic company need for survival (Womack and Jones, 1994).

B. Production Wastes amount

The Production Wastes amount is determined by the sum of unplanned costs resulting from production wastes. Unlike Production Input amount, the Production Wastes amount comprises the costs that will not be paid-in back by the sales revenue. This is because the production wastes are assumed to be non-saleable products.

In this study, the seven production wastes are divided into four major categories: *(i) Quality losses; (ii) Excess quantities; (iii) Delay quantities; (iv) Time losses*. Accordingly, the Production Wastes amount will be calculated based on the four categories of production wastes instead of individual production wastes.

i. <u>Quality losses</u>

Quality problems occur before and after the products have been sold. In this study, the quality problems are regarded as production loss. Therefore, the quality losses are divided into two types: *(i) In-house quality losses; (ii) After-sale quality losses.*

The In-house quality losses refer to the shortage in quantity of finished goods caused by quality problems. This shortage quantity can be determined by the difference between scheduled input quantity and output quantity. For instance, the scheduled input quantity at the beginning of the manufacturing process for Product A is 24,000pcs. Its output quantity (finished goods) at the final process is only 20,108pcs. Therefore:

- The quality loss quantity = 24,000pcs – 20,108pcs
  = 3,892pcs.

After-sale losses have a close relationship with quality reliability and delivery reliability. Hence, the After-sale quality losses refer to returned products that are still within the warranty period. After-sale returned products are mainly due to three reasons: quality problems (functional and features), wrong delivery, and wrong product specifications.

Since the returned products are within the warranty period, they have to be replaced or repaired without any additional cost to the customer. In turn, the cost will be charged to the current total production cost. In this case, the quantity of replaced products will be added into the current scheduled input quantity. In addition, the costs of the repaired products raised by the additional costs on labour charged (specialist), new parts etc. will be included.

Consequently, the amount of quality loss is determined by the sum of In-house quality losses amount and the sum of After-sale quality losses amount. In this way, the charged cost for the returned products would depend on the types of quality loss. For instance, the In-house quality losses quantity of Product A is 3,892pcs and Product B is 868pcs for the month of January 2010. Within the same period, the manufacturer has received returned products that are 500pcs of Product A and 100pcs of Product B. Assuming that all the returned products have to be replaced with a new one, the current average cost of unit product for Product A is £1.00 and Product B is £1.50. Thus, the total pay-out amount of the quality losses for January 2010 can be determined as:

- Quality losses amount = In-house quality loss + After-sale quality loss
  = (3,892 + 500)(£1.00) + (868 + 100)(£1.50)
  = £1,492.00

ii. <u>Excess quantities</u>

Excess quantity in Production Fitness refers to the overproduction quantity that has not yet been ordered by the customers. In this study, the excess quantity can be generated by overproduction quantity and finished-goods inventory.

The overproduction quantity could be caused either by a forecasting error or large batch size. However, this study focuses on the latter cause, as the application of LM concept will lead to a smaller batch size (Hancock and Zayko, 1998; Oliver, et al., 1996; Papadopoulou and Ozbayrak, 2005). Theoretically, the average cost of unit product will be reduced as the volume increases (Slack, 1997). However, the theory is only valid for the produced quantity that is equal to the demand quantity. In this case, zero cost is accounted from inventory (due to overcapacity) and overtime (due to shortage capacity).

Overproduction occurs when the production output quantity is more than the demand quantity. Overproduction quantity can be determined by the difference between sale quantity and output quantity. In this study, the sale quantity represents the demand quantity. For instance, 15,000pcs of Product A and 12,000pcs of Product B have been ordered for January 2010. At the end of the month, the total production output for Product A is 20,108pcs and Product B is 13,555pcs. Thus:

- The Excess Quantity of Product A = 20,108pcs - 15,000pcs
  = 5,108pcs

- The Excess Quantity of Product B = 13,555pcs - 12,000pcs
  = 1,555pcs

Then, the sum of pay-out amount for the overproduction quantity can be determined by multiply the overproduction quantity with the current average cost of unit product.

- Excess quantity amount = Product A + Product B
  = (5,108)(£1.00) + (1,555)(£1.50)
  = £7,440.50

This study considers the finished goods inventory to be the source of excess quantity. The finished goods inventory refers to old stock finished goods from the previous month. The old stock finished goods quantity would increase the total production cost if there is a cost charged for storage. Furthermore, the sale price of the old stock finished goods is likely to be reduced. As a result, the pay-out amount of old stock finished goods can be determined by multiplying the quantity with the average cost of unit product (at the particular production date) plus the current storage cost (if relevant).

iii. Delay quantities

A study on the role of inventory in delivery-time competition claimed that the cost of a delay is the price and the interest rate for delay; the probability of the delay increases when the capacity of the firm decreases (Li, 1992, p. 187). Consequently, delay quantities in Production Fitness refer to postponed delivery of finished goods to customers. The delivery is considered postponed if the length of the postponement is taken into the subsequent months.

Delay quantities normally occur due to low production productivity, quality problems, raw material shortage, transportation problems, etc. In this study, delay quantities caused by low production productivity and quality problems will be counted as production waste. In this case, the amount of delay quantities is determined by the minimum sale per unit product, assuming that there will be zero pay-in amount for the delay quantities on the particular month. For example, the delivery of 500 units of Product B has been postponed to the following month. The minimum sale price per unit Product B is £4.00. Thus, the amount of delay quantities loss for January 2010 can be determined as:

- Delay loss amount = (500)(£4.00)
  = £2,000.00

iv. <u>Time losses</u>

Time losses are mainly caused by invisible production wastes: Motion, Transportation, Waiting, and Processing. However, they can also be caused by visible production wastes (e.g., defects and overproduction). This is because producing the defects and the overproduction are considered to be non-value- added activities in the production time.

There are two categories of causes of time loss: external causes and internal causes. The external causes cannot be controlled by the production system (Muchiri and Pintelon, 2008), such as:

- Material shortage
- Energy shortage
- Transportation problem from logistics
- Poor weather

On the other hand, internal causes refer to the production resources: manpower and equipment, and can be controlled by the production system. However, the internal causes consist of planned time losses and unplanned time losses, where planned time losses cannot be avoided. Some examples of planned time losses are:

- Annual shutdown
- Scheduled maintenance
- Set up times (changeover and quality adjustment)
- Unpaid break time

Unplanned time losses, on the other hand, are most likely due to mistakes, carelessness, system errors, etc. These losses can be avoided by using the planned time losses. Some examples of unplanned time losses are:

- Machine breakdown
- Machine stoppage
- Man power shortage (absenteeism)
- Operation errors
- Safety and health environmental problems

In this study, time losses are identified through idle time and overtime. Idle time is defined as a period when there is no single product being produced. For instance, the planned production time of Product A and Product B for

January 2010 is 150hours. The standard working hours for January 2010 are 172hours. Thus:

- The idle time = 172hours – 150 hours
  = 22hours.

The planned time losses are not regarded as production idle time, but have already been included in the total production time. However, it is necessary to minimise the planned time in order to increase production productivity. Unlike planned time losses, unplanned time losses are a source of idle time.

Overtime is defined as an extended production time from the planned production time. Sometimes, overtime is necessary in fulfilling the required demands, provided the sales revenue is above the profit-loss break-even point. However, unnecessary overtime is considered to be part of the time losses. This is because unnecessary overtime is usually caused by ineffective production operations. For instance, the planned production time of Product A and Product B for February 2010 is 120hours. After some period, the production could not meet the planned output quantity required for immediate overtime. At the end of the month, the actual production time to produce the planned output quantity is 140hours. Thus:

- The overtime = Actual Production Time – Planned Production Period
  = 140hours – 120hours
  = 20hours

In summary, idle time and unnecessary overtime can be used as indicators of production productivity. The idle time increases the total production cost through ineffective utilisation of production resources (operators, machines and equipment). Similarly, unnecessary overtime increases production cost through high labour cost due to additional working hours and also high utilities cost (i.e., electricity, water etc.).

3.4.1.2 Maximum production pay-in amount

In Production Fitness, sales revenue is the only source of the pay-in amount. In fact, a study found that the cost and price are clearly linked to leanness (Aitken, et al., 2002). In this study, the pay-in amount is considered as the payback amount for the total production cost. However, the pay-in amount can be either with profit or without profit. The profit is determined by the difference between pay-in amount and pay-out amount. The larger the pay-in amount, the higher the profit will be.

In this study, the term profit margin is applied to indicate the gap between maximum production cost and minimum sale price, as shown at Figure 3.6. Accordingly, the profit margin relies not only on the sales and marketing strategies, but also on production efficiency.

3.4.2 Agility

According to a number of studies on manufacturing systems, agility is a combination of a number of capabilities: flexibility, responsiveness, quickness, and competencies (Khoshsima, 2003; Lin et al., 2006; Sharifi and Zhang, 2001; Shih and Lin, 2002). In addition, a recent review on manufacturing agility noted that the agility attributes consist of flexibility, adaptability, responsiveness, and speed (Sherehiy, et al., 2007). Therefore, agility is considered not as a standalone characteristic, but as a combination of a number of characteristics.

In addition, a study found that manufacturing agility is related to competitive capabilities and the business environment (Yusuf and Adeleye, 2002). Another study found a positive relationship between manufacturing capabilities and business performance (Li, 2002). In this study, the manufacturing capabilities refer to agility. Furthermore, the study also found a positive relationship between flexibility and business performance. In fact, the most widely applied definition of agility in many studies on manufacturing systems refers to agility as a set of capabilities (Helo, 2004; Jackson and Johansson, 2003; Khoshsima, 2003; Sahin, 2000; Sarkis, 2001):

"*Agility is a set of capabilities and competencies that organisation needs to thrive and prosper in a continuously changing and unpredictable business environment*".

The relationship between agility and other capabilities has been widely discussed in manufacturing systems research. For instance, flexibility was claimed to be a prerequisite to agility (Jackson and Johansson, 2003). It has also been suggested that agility is a combination of flexibility and responsiveness (Khoshsima, 2003), which was later confirmed by industrial case studies (Vazzquez-Bustelo and Avella, 2006). In earlier research, the combination of flexibility and speed was regarded as an entity of agility (Meredith and Francis, 2000). In addition to that, agility has been described as the incorporation of more than speed and flexibility (Kidd, 1996). Flexibility was claimed to be the responsive capability in planned changes, whilst agility is the responsive capability in unplanned changes (Sahin, 2000; Vokurka and Fliedner, 1998).

Consequently, it may be concluded that agility actually represents responsiveness in two characteristics: *(i) Re-activeness; (ii) Pro-activeness.* Re-activeness generally refers to a quick reaction to an event, whilst pro-activeness refers to reaction in advance prior to an event. In this context, re-activeness actually presents flexibility as the ability to change production volume or production mix (Sarmiento, et al., 2007, p. 369). Therefore, this study refers to re-activeness as the capability of the production system to respond in a high product mix environment. High product mix is commonly known as product mix flexibility constitutes high product variety and high volume variety. At the same time, the pro-activeness is specifically referred to as the capability of the production system to respond to the speed and variety of new product introduction.

In addition to manufacturing capabilities, agility has in effect relied on manufacturing capacity. This capacity can be obtained by using three methods: *(i) Production; (ii) Sub-contract; (iii) Purchase.* However, this study specifically focuses on the manufacturing capacity that is obtained by using production capacity. Here, production capacity refers to capacity in terms of time and quantity. In other words, production capacity is determined by the maximum available time and the maximum possible quantity.

In summary, agility in Production Fitness is determined by high production capabilities and effective production capacity. Figure 3.8 describes the structure of agility through effective capacity and high capabilities. Here, re-activeness and pro-activeness have distinct roles in responding to unpredictable changes in the current market environment.

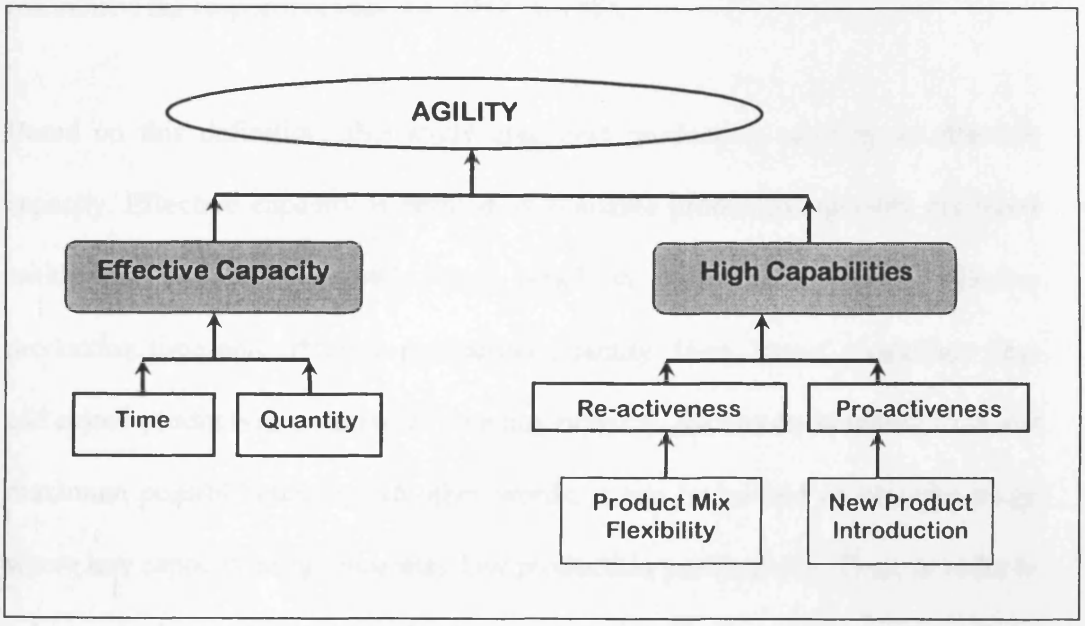


Figure 3.8: The Structure of Agility

3.4.2.1 Effective capacity

In general, capacity simply means the amount of volume a system is capable of capacitating. For the production system, capacity refers to quantity and time. Specifically, production capacity is defined as how economically (fast, easy, saving) the production can operate or change from one state to another (Van Hop, 2004). In addition, increasing capacity is one of the many ways to improve manufacturing responsiveness (Li, 1992, p. 195).

Based on this definition, this study considers production capacity as effective capacity. Effective capacity is defined as available production quantity produced within the maximum possible time which is determined through effective production time and effective production quantity. Here, actual production time and actual production quantity will be compared to maximum available time and maximum possible quantity. In other words, it can be termed as capacity usage where low capacity usage indicates low production productivity. Thus, in order to achieve high production productivity, more production quantity would be expected in a shorter production time.

However, sometimes low capacity usage could also be caused by low demand from customers. In this case, the sales and marketing unit has to improve their strategies in order to increase demand so that production capacity could be used effectively.

3.4.2.2 High capabilities

In this study, high capabilities refer to the production capability to produce varieties of product and volume to match with current market demands. In fact, high product variety and new product introduction are the output of agility (Ramesh and Devadasan, 2007). In this respect, higher product variety requires product mix flexibility that can be achieved through production re-activeness. At the same time, production has to be pro-active in providing high product variety for their customers. Therefore, re-activeness and pro-activeness are the two major components that have contributed to high production capability.

A. Re-activeness

Re-activeness in Production Fitness relies on the three aspects of product mix flexibility: product variety; volume variety; and number of available resources. Product variety represents the total number of different products that the production system is capable of producing. Similarly, the volume variety refers to the number of different packaging volumes. The amount of production resources refers to the number of current operators, machines and equipment.

i. <u>Product Variety</u>

Product variety can be determined by using a product structure diagram, which is called Product Family Classification Tree (PFCT). The PFCT diagram is a part of the product structuring methodology that was proposed by O'Donnell (1996) through his research on product structure management. The PFCT diagram provides product information in a hierarchical tree structure (O'Donnell, et al., 1996).

Compared to other product structures, such as AP 214 (Mannisto, et al., 1998), and Design Structure and Manufacturing Structure (Svensson and Malmqvist, 2002), the PFCT diagram is more applicable in determining the product variety. The PFCT diagram presents the product hierarchy through product specifications. The ranged product specifications are similar to specifications that have been referred by customers in placing the order. Hence, more specifications mean higher product variety.

Figure 3.9 shows an example of the PFCT diagram for a product family - the car manufacturer. The top level (level 1) represents the abstract of the product. The abstract of the product is commonly known as Product Family (i.e. Car, Beverage, Home Entertainment etc.). This is followed by level 2, which is the product types (i.e. Types of car: mini, saloon, convertible, MPV, 4WD etc.). The instance design of the product, commonly termed as product model, is placed at level 3. Then, the product specifications are allocated at the following levels. In this example, the PFCT diagram represents the product structure in a larger organisation, such as a company's division, subsidiary etc.

The PFCT diagram can also be applied for product structure in a smaller organization, such as a production unit. In this case, the top level of the PFCT diagram always begins with a particular product model. Figure 3.10 shows an example of the PFCT diagram for a product model - the mini car. The 2^{nd} level indicates the product instance design. The following levels indicate the product specifications that are similar to the customer's preferences.

Thus, the product variety can be determined through the sum of product instance designs (2^{nd} level) and product specifications (following levels). If any similar specifications are used with different product instance designs, these will be counted as one item. For example (referring to Figure 3.10), the items 'manual' and 'petrol' in the 4^{th} level are used by both product instance designs: M1.5 and M1.6. Therefore, the number of varieties for the product specifications in the 4^{th} level is 10 instead of 12. In total, the Mini car has 12 varieties of product preference.

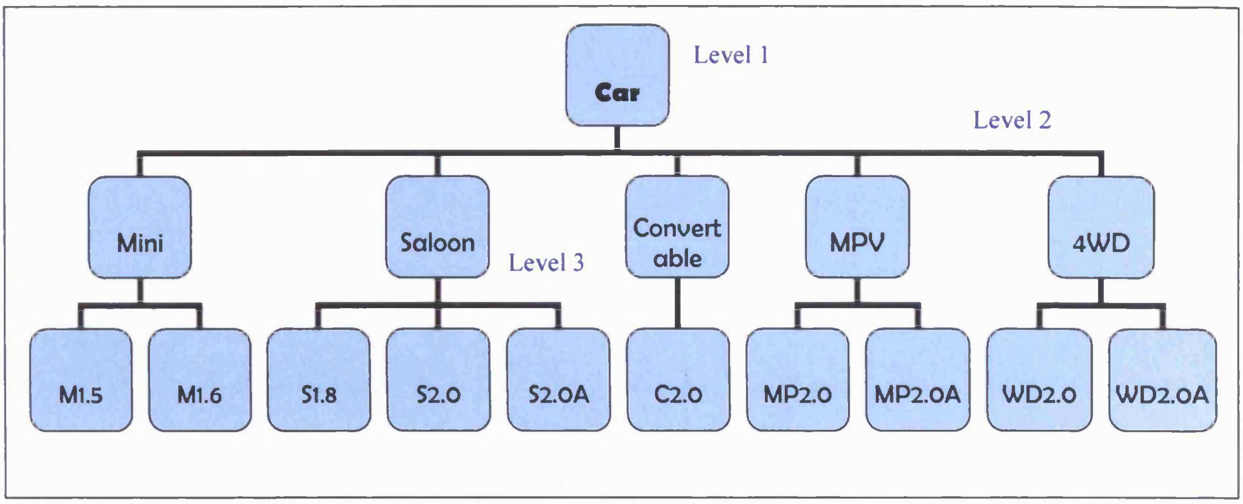


Figure 3.9: The Product Family PFCT Diagram

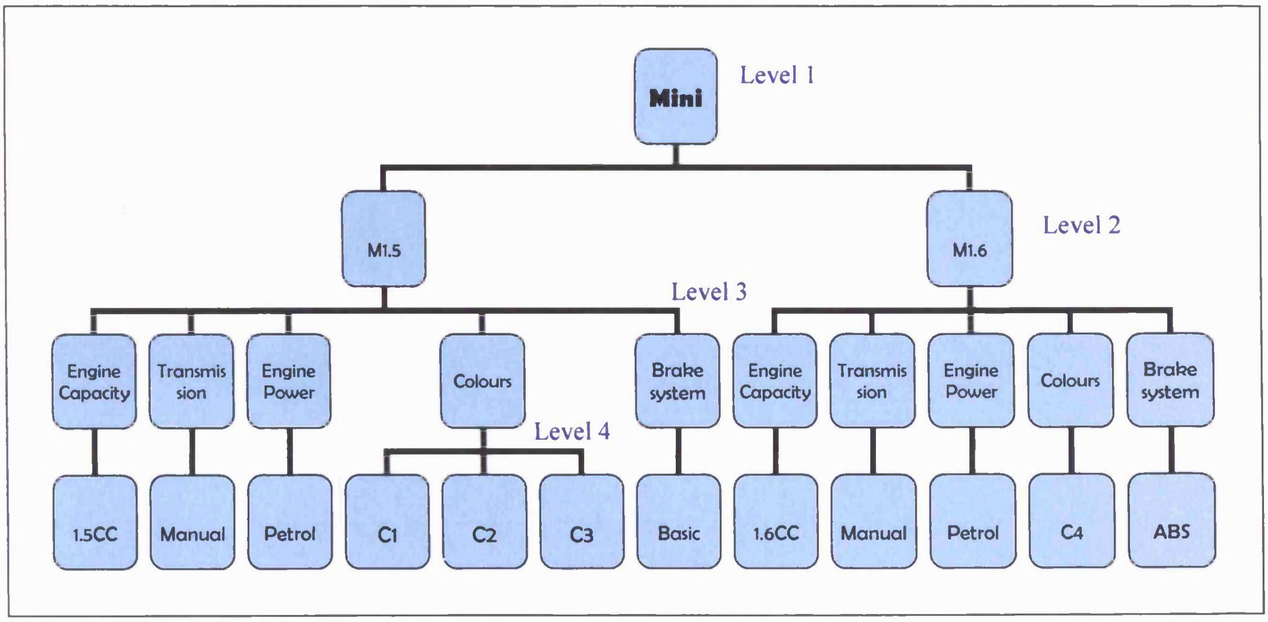


Figure 3.10: The Product Model PFCT Diagram

ii. Volume Variety

In this study, the volume variety refers to the packaging volume of finished goods, provided a high variety in packaging volume is one of the sales and marketing strategies for increasing sales revenue. The packaging processes are considered to be part of the manufacturing process for two reasons: the packaging costs and the time taken. The packaging costs (e.g., labour cost and material costs) are part of the variable costs, whilst the packaging time is part of the production lead time.

In addition, the packaging volumes are related to the production batch size. Increasing the packaging volume variety may be required in order to increase or reduce the current production batch size. Otherwise, the packaging process would have a shortage quantity or excess quantity because of the mismatch between the production batch size and the packaging volume. Thus, volume flexibility in the production system is essential for a high variety of packaging volume. Moreover, an earlier study shows that volume flexibility is positively related to firm performance (Jack and Raturi, 2002). However, volume flexibility is found to be a conundrum in agile manufacturing that affects business performance, such as sales turnover, net profit, market share etc. (Yusuf, et al., 2003). Hence, the volume flexibility can be considered as part of production agility characteristics.

A similar method is applied to determine the volume variety by using the PFCT diagram. Figure 3.11 presents the volume variety PFCT diagram for beverage products. The 1st level represents the product family, followed by the packaging stages in level 2. The packaging stages are normally standard to most of the manufacturing industry in the form of product packaging and delivery packaging. The following levels represent the packaging instance design and its specifications. The size of volume variety can be determined by the sum of items in the 3rd level onwards. For instance, the variety of packaging volumes for the beverage products is eight.

iii. Resources

Resources in manufacturing are generally referred to as manufacturing assets such as operators, machines, equipment, buildings, and materials. In this study, the production resources refer to the operators, machines and equipment. These resources directly affect the production capacity. In fact, production agility relies on the resource capabilities. For instance, two production lines with the same number of resources could produce a different product variety. In this case, the production line with a high product variety is considered more agile than the other. Hence, minimum production resources with high productivity would lead to high production efficiency.

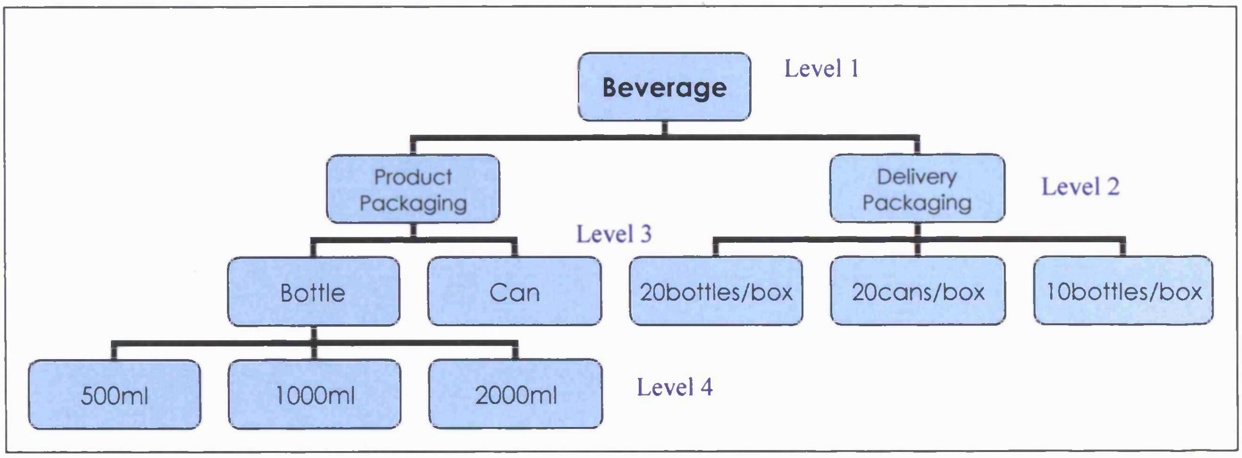


Figure 3.11: The Volume Variety PFCT Diagram
For Beverage Products

B. Pro-activeness

The capability of responding in advance, without waiting for things to happen, constitutes pro-activeness. Accordingly, pro-activeness is characterised by quickness and competencies. In many studies on the AM concept, pro-activeness and innovation have been claimed as part of manufacturing agility (Adeleye and Yusuf, 2006; Ren, et al., 2003; van Assen, 2000; Yusuf et al., 1999). Furthermore, a study on the relationship between pro-activeness and performance found manufacturing pro-activeness to be positively related to company performance (Ward, et al., 1994). Therefore, pro-activeness can be justified as part of the agility structure.

In this study, production pro-activeness refers to speed and variety of New Product Introduction (NPI). In a highly competitive market environment, NPI has been considered one of the competitive strategies. Moreover, NPI actually increases the current product variety and volume variety (if applied). In the rapid changes of market demands, being late to market may increase the risk of obsolescence because of competitor activity, shifts in customer preferences, or some other uncontrollable force (Carbonell and Rodriguez, 2006, p. 5). Thus, speed to market may help ensure at least some realisation of profit.

A study on the impact of product innovativeness concluded that profit maximisation occurs at a higher speed and that the maximum profitability is higher for product improvements than for line addition (Langerak and Hultink, 2006, p. 209). In this regard, NPI in production fitness is defined as any new items added at any level in a current product variety PFCT diagram and volume variety PFCT diagram within the period - January to December. The new items can be new product features, new product functions, and new product packaging. Here, the objectives of NPI are to respond to the required demands and to generate a continual demand flow into the production system.

i. **New Product Variety**

The variety of NPI plays an important role in production pro-activeness. Furthermore, variety has been quoted as one of the order's winning criteria (Meredith and Francis, 2000).

In this study, the NPI variety refers to the total number of new items encountered from the product features, product functions and product packaging volumes. It can be determined by using the PFCT diagram. A different weighting factor will be applied at each level in the PFCT diagram. The weighting details will be discussed in the next chapter.

ii. Speed of New Product Introduction

Speed is claimed to be one of the competitive priorities in manufacturing industries (Bottani, 2009; Ren, et al., 2003; Sherehiy, et al., 2007). In this respect, speed commonly refers to speed of delivery and speed in NPI. Speed of delivery has less impact on manufacturing responsiveness because the product is expected to work properly whether subject to on-time or late delivery (Sarmiento, et al., 2007, p. 375) while the quality of the product remains unaltered. Furthermore, a study has proved that guaranteeing a shorter delivery time is not necessarily more profitable (So and Song, 1998, p. 36).

From the aspect of speed in NPI, a study has revealed that profit maximisation occurs at a higher speed of NPI (Langerak and Hultink, 2006). In addition, innovation speed is positively related to positional advantage (Carbonell and Rodriguez, 2006). In this study, the positional advantage was defined as deferential superiority of the product compared with competing products on the basis of image, technical performance, and quality.

Consequently, this study focuses only on speed in NPI rather than speed in delivery. Adapted from the NPI speed definition of Carbonell and Rodriguez (2006), NPI speed is defined as the pace of progress that a company displays in innovating and commercialising a new product. NPI speed is normally scaled on the basis of date of the new products that have been produced. The term 'introduction' refers to the date of first production for sale from the manufacturing facility (Griffin, 1993).

3.4.3 Sustainability

Sustainability in Production Fitness refers to stability between market demand and production capacity. In this respect, a continual demand on the production system is crucial for economic sustainability of a company. It can be viewed from a sustainable flow of pay-out amount and pay-in amount. Here, the role of production capacity is to fulfil demand promptly. Otherwise, either shortage capacity or overcapacity would give a negative sign to production efficiency.

Production and marketing are responsible for balancing demand and capacity. Imbalanced demand-capacity would result in a shortage capacity or overcapacity. Shortage capacity occurs when demand is higher than production capacity, whilst overcapacity is the opposite. Shortage capacity tends to have long-term effects (i.e., losing customer loyalty). On the other hand, overcapacity causes manufacturing companies to absorb additional inventory costs, which finally increases total manufacturing costs.

Shortage capacity, formerly known as under-capacity, occurs when demand is higher than available capacity. If production capacity is continuously experiencing shortage, the opportunity for future sales revenue will fade. Conversely, over-capacity occurs when demand is lower than the available capacity. In this case, production capacity would be underutilised if demand remains low. Thus, the average cost of producing each unit will increase because of the fixed costs of the factory being covered by fewer units produced (Slack, 1997).

The more successful the task of balancing demand and production capacity, the more likely the business will succeed (Sheldon, 2006). Figure 3.12 illustrates the concept of balance between consumer demand and production capacity. In this study, production sustainability is determined by two main components: Demand and Capacity. The structure of production sustainability is shown at Figure 3.13. In this respect, a sustainable co-ordination between production and marketing are crucial to ensure the stability of demand and capacity.

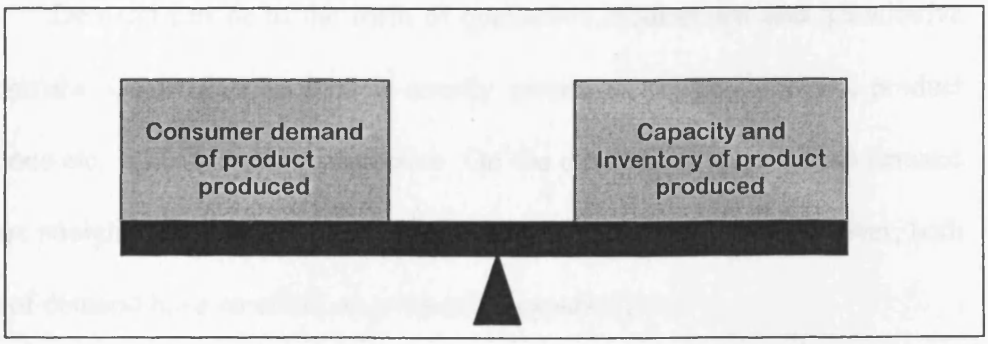


Figure 3.12: The Balance between Demand and Supply (Sheldon, 2006).

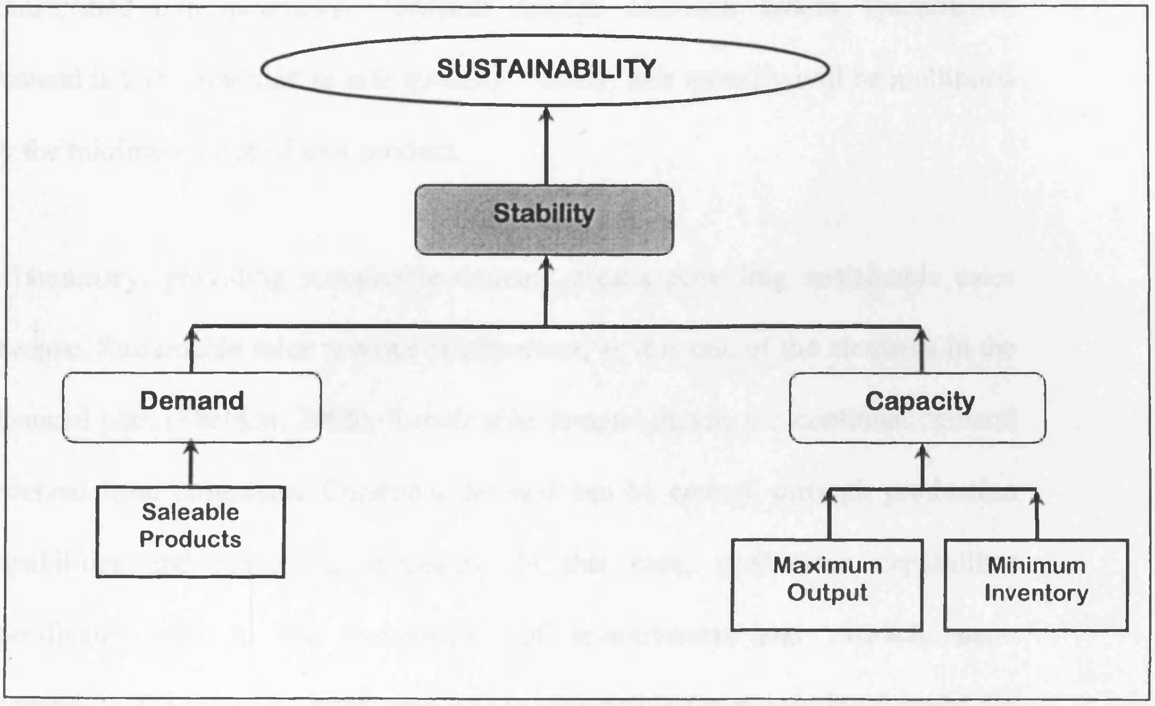


Figure 3.13: The Structure of Sustainability

3.4.3.1 Continuous Demand

Demand can be in the form of qualitative requirement and quantitative requirement. Qualitative demand is usually present in product features, product functions etc., which is more subjective. On the other hand, quantitative demand is more straightforward in that it refers to the quantity of products. However, both types of demand have an effect on production capabilities.

This study focuses on quantitative demand rather than qualitative demand. Nevertheless, quantitative demand is indirectly related to qualitative demand. For example, qualitative demand that is presented in product variety will later be transformed into quantitative demand through customer orders. Quantitative demand is then presented as sale quantity. Finally, sale quantity will be multiplied by the minimum price of unit product.

In summary, providing sustainable demand means providing sustainable sales revenue. Sustainable sales revenue is important, as it is one of the elements in the financial plan (Sheldon, 2006). Sustainable demand means the continual demand received from customers. Continual demand can be created through production capabilities and marketing strategies. In this case, production capabilities specifically refer to the components of re-activeness and pro-activeness. Meanwhile, the sales and marketing unit is responsible for generating demand for current and new products. In other words, both units are responsible for making products saleable.

3.4.3.2 Sustainable production capacity

Capacity in production refers to the operation's capacity that is presented in the same unit of demand. In this study, the production capacity refers to production output and inventory. Both sources of production capacity are considered as available finished goods that are available for delivery to the customers. Accordingly, a sustainable production capacity is essential in this aspect. In this regard, sustainable production capacity is defined as continuous supply to the demand through economic production capacity.

A. Production Output

Capacity by production output relies on the type of production operations: standardized and repetitive for high-volume low-variety; and wide-ranged for low-volume high variety (Slack, 1997). Output measures are preferable for the standardized and repetitive operation, whilst input measures are often considered for the latter type of production operations. In this respect, both types of operation would finally provide the available finished goods to be delivered to customers.

In this study, the production output is defined as produced finished goods that are available for the required demand. Thus, excess quantity and shortage quantity are negative signs for production efficiency. In the meantime, production capacity should be used effectively in order to avoid production from low utilisation.

B. Inventory

In general, inventory is defined as being what a company has purchased with the intention of selling (Slack, 1997). In this study, the production capacity by inventory refers to the finished goods inventory. This inventory plays an important role in a competitive market environment, especially in terms of price and delivery dependability. Specifically, the optimal limit of the finished goods inventory is strongly related to manufacturing strategies (e.g., Make-To-Order (MTO) and Make-To-Stock (MTS)). The optimal inventory limit will increase under the following conditions:

a. The demand rate is higher.

b. The average production time is longer.

c. The price is higher.

d. The holding cost is lower.

(Li, 1992)

In addition, Li's study (1992) concluded that inventory holding strategy can be used as part of the manufacturing company's time-based competitive strategy for delivery reliability. However, it was also found that the inventory holding strategy is not appropriate for the rapid changes in demand due to its inflexibility and costly. As a result, old products would have a reduced value or become obsolete. Thus, a strategic use of inventory is crucial in supplying customer demands especially for competitive price and delivery reliability.

In Production Fitness, the finished goods inventory should remain as minimal as possible. The finished goods inventory can be minimised by increasing production flexibility where smaller batch sizes are manufactured, together with more frequent deliveries (Chhikara and Weiss, 1995). Alternatively, marketing strategies could be used, but this may only be effective for short-term decisions, as the product value is decreased by the inventory holding time. Thus, efficient production and effective strategies of sales and marketing are necessary in order to sustain the minimum inventory.

3.4 Summary

This chapter has presented the essence of leanness, agility, and sustainability in Production Fitness. Earlier, the necessity of the three pillars to the Fit Manufacturing systems was determined through a literature review of LM, AM, and Sustainability concepts. Then, analogical studies on the Human Body System and Human Fitness Components were applied to explain the necessity for leanness, agility, and sustainability as the components of Production Fitness. Results of the analogical studies demonstrate that human fitness components are compatible with the characteristics of competitive manufacturing capabilities. Consequently, the key concepts of leanness, agility, and sustainability in respect of Production Fitness were concluded as:

- Minimum production wastes – Leanness
- Responsiveness to changes – Agility
- Demand-Capacity balance - Sustainability

Finally, the key factors of leanness, agility, and sustainability were clearly justified by evidence from the literature study. The structure of production leanness was developed through the LM concept: "Produce more with less input". Here, the effect of leanness on profit margin was clearly justified from the production pay-in and pay-out amounts.

The structure of production agility was developed through production responsiveness in respect of product mix. The components of production responsiveness have been identified as re-activeness and pro-activeness. Thus, production re-activeness and pro-activeness are related to product variety and volume variety. In this regard, the PFCT diagram represented in the hierarchical product structure was introduced to determine the variety in terms of product and volume. In this way, the PCFT diagram presents a similar list of product preferences provided in the product catalogue for customers. By using the PCFT diagram, agile production benefits from a direct link to customer preferences.

The structure of production sustainability was developed from the balanced demand-capacity concept. Co-ordination between production and marketing is crucial to making products saleable so that overcapacity and shortage capacity can be avoided.

Overall, this chapter has confirmed the components and the key concepts in Production Fitness. In this respect, the performance of a production system is represented by Production Fitness. Thus, Production Fitness measures will be developed based on the fitness components and the key concepts applied.

Chapter 4

Chapter 4
PRODUCTION FITNESS MEASURES

4.1 Preliminaries

Various manufacturing concepts have been introduced since the 1960s with the purpose of enhancing manufacturing performance in terms of capabilities. Manufacturing capabilities can be referred to as the ability of a production system to compete on basic dimensions, such as quality, cost, flexibility, and time (Hsafizadeh, et al., 2000). Thus, the Fit Manufacturing concept was developed through the integration of manufacturing capabilities generated from the LM, AM, and Sustainability concepts. In this regard, Production Fitness represents production capability in respect of leanness, agility, and sustainability.

This chapter defines and justifies the elements of Production Fitness measures based on three relevant aspects: profitability, adaptability, and stability. Determination of Production Fitness measures is presented in six sections:

- Dimensions of Production Fitness measures
- Workflow of Production Fitness measures
- Production profitability measure
- Production adaptability measure
- Production stability measure
- Production Fitness measure

4.2 Dimensions of Production Fitness

In this study, the performance measure for a production system is termed Production Fitness. Production Fitness is constituted by the ultimate outcomes of integrated Leanness-Agility-Sustainability concepts:

(i) *Profitability* represents the Leanness concept: Minimum production wastes.

(ii) *Adaptability* represents the Agility concept: Responsiveness to changes.

(iii) *Stability* represents the Sustainability concept: Demand-Capacity balance.

Accordingly, Production Fitness is defined as production capability to fulfil market demands economically, responsively, and continually. In this case, Production Fitness can only be measured with the presence of demand quantity in the production system. In this study, Production Fitness is measured through the portion of leanness, agility, and sustainability applied by a production system in fulfilling required demand quantity. In this respect, each portion is scaled by using index numbers, which means unit less. Thus, there are four separate indices represented in Production Fitness measures as follows:

- Production Profitability Index (PPI)
- Production Adaptability Index (PAI)
- Production Stability Index (PSI)
- Production Fitness Index (PFI)

4.3 How the Production Fitness Measures Work

In this study, continual improvements of production capabilities can be achieved through a periodical measure of Production Fitness. Monthly basis approach is an appropriate interval for measuring the Production Fitness. This is because, each month, the business planning process within the Sales and Operations Planning confirms profitability as the marketing plans, new product introductions, new customer introductions, and incremental markets are developed, planned, and won (Sheldon, 2006). In this way, production can use the Production Fitness measures: PPI, PAI, PSI, and PFI as production performance indicators in the business planning meeting. In addition, the Production Fitness measures can also be used as a decision-making tool to reduce conflicts between production and marketing. In this case, the Production Fitness measures would be able to indicate the gap between production capabilities and marketing strategies on profitability, agility, and stability.

The Production Fitness measures begin with calculation of Production Waste Index (PWI) for the individual product model. If more than one product model is produced, PWI from different product models would be combined to perform a total PWI of the production system for that particular month. Then, the PPI is calculated based on the total PWI. In this study, PPI ranges from 0.00 to 1.00.

Next, the measure of PAI begins with the determination of effective capacity. Effective capacity is calculated by using data from the production profitability measure, such as production input/output quantity, standard production operating period etc. (refer to Appendix A - Table 4A for the example). Then, the production adaptability measure continues with determination of production re-activeness and production pro-activeness. As has been clearly stated in the previous chapter, the PAI is determined by the elements of production responsiveness, specifically on product mix. Thus, the variety (constituted by product variety and volume variety), Range-flexibility, Response-flexibility, and New Product Introduction (constituted by speed and variety) are the variables for the PAI measure.

High PAI means high production agility in respect of effective capacity, which is correlated to product variety, volume variety, and NPI. PAI would be zero if zero effective capacity resulted from inefficient production or zero demand quantity received from marketing. The lowest PAI is equal to 0.00 whilst the highest PAI depends on effective capacity and variety.

The measure of production stability can be conducted in parallel with the PAI. Similar to the PAI, variables for the PSI measure are based on data from the PPI measure, such as total production output quantity, inventory, and sales quantity. The PSI is measured through the balance between demand quantity and available production capacity. In this distance, the available production capacity is presented by production output quantity and inventory. Thus, the PSI represents the ratio between total demand quantity and total production capacity of the particular period.

The ideal PSI is 1.00, where the available production capacity is equal to the demand quantity. Low PSI (PSI less than 1.00) signals an over capacity. Conversely, shortage capacity occurs when PSI is more than 1.00. The PSI can be equal to 0.00 if zero demand quantity is required from the production system.

Finally, Production Fitness is determined by integrating production profitability, production adaptability, and production stability. The PFI contains a portion of the PPI, PAI, and PSI, where the lowest PFI is equal to 0.00. The PFI does not have a maximum number. Nevertheless, an ideal PFI can be achieved through maximum PPI (PPI equal to 1.00), high PAI, and ideal PSI (PSI equal to 1.00). It is advisable for manufacturing companies to sustain an ideal PFI for internal performance assessment. In the case of high competitive market demands, it is advisable for manufacturing companies to achieve a higher PFI generated from high effective capacity and a wide range of variety through minimum production resources. In the meantime, high PPI and ideal PSI should be maintained. The workflow of Production Fitness measures is shown in Figure 4.1.

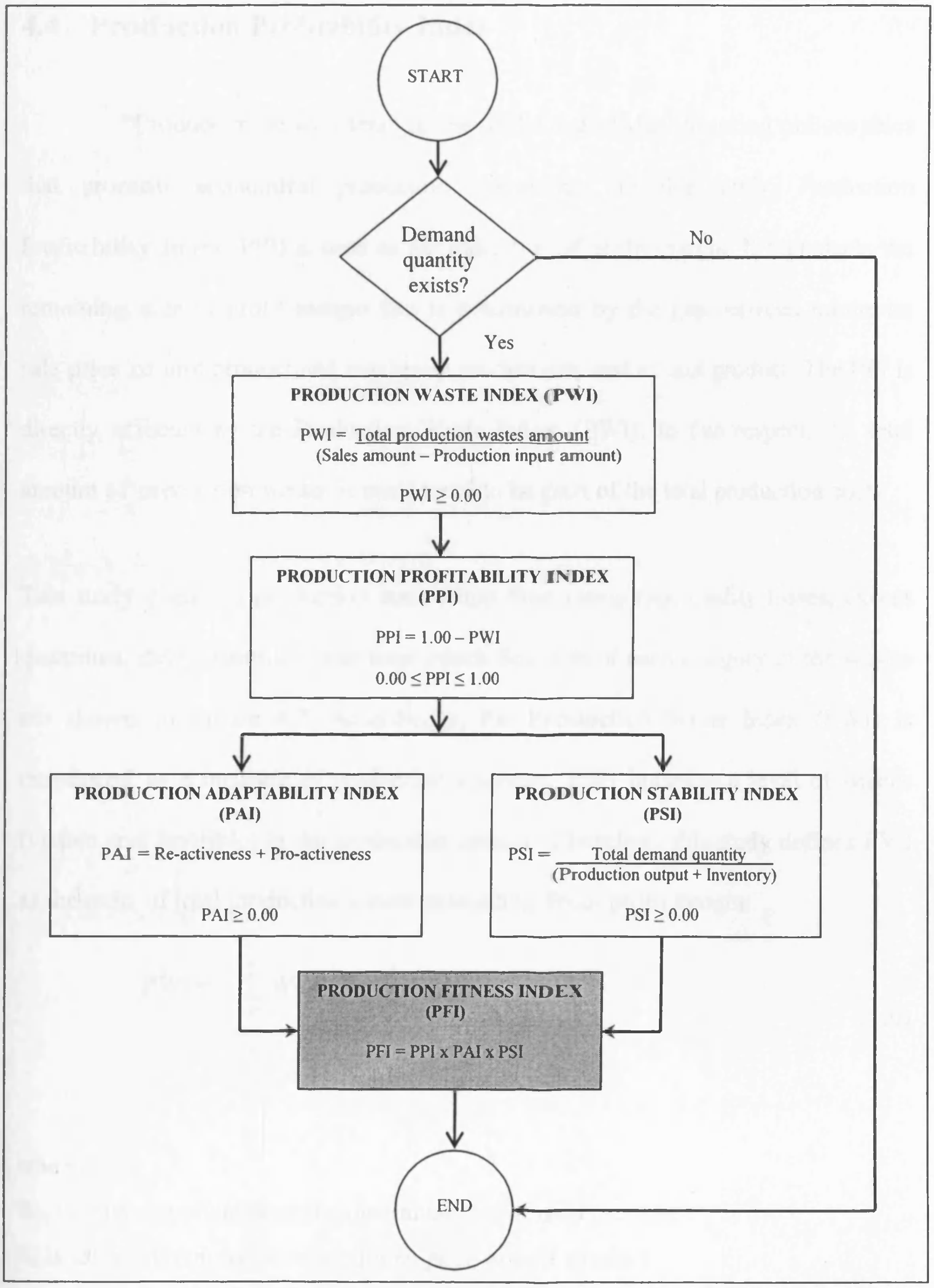


Figure 4.1: Determination of Production Fitness

4.4 Production Profitability Index

"Produce more with less" is one of the Lean Manufacturing philosophies that promote economical production operations. In this study, Production Profitability Index (PPI) is used as the indicator of profit margin. It represents the remaining size of profit margin that is determined by the gap between minimum sale price of unit product and maximum production cost of unit product. The PPI is directly affected by the Production Waste Index (PWI). In this respect, the total amount of production wastes is considered to be part of the total production cost.

This study classifies production wastes into four categories: quality losses, excess quantities, delay quantities, and time losses. Sources of each category of the wastes are shown in Figure 4.2. Accordingly, the Production Waste Index (PWI) is introduced as a measure of production leanness. PWI indicates a level of wastes (visible and invisible) in the production system. Therefore, this study defines PWI as the ratio of total production wastes amounting from profit margin:

$$PWI = \frac{\sum_{k=1}^{n} W_k}{\sum_{k=1}^{n} (S_k - I_k)} \tag{1.0}$$

where,

W_k is wastes amount based on maximum cost of unit product.

S_k is sales amount based on minimum price of unit product.

I_k is production input amount based on maximum cost of unit product.

If,

PWI < 0.00 means sales amount less than input amount

PWI = 0.00 means wastes amount equal to zero

PWI ≥ 1.00 means zero profit for sales amount

Technically, PWI actually represents the efficiency of a production system through the concept of minimum input and maximum output, where high PWI signals low production efficiency. In the meantime, the profit margin is reduced by high total production cost resulting from high production wastes. This means, the lower the PWI, the larger the profit margin would be (as illustrated in Figure 4.3). Thus, the relationship between PWI and profit margin can be written as:

$$\text{Profit margin} = 1.00 - \text{PWI} \tag{1.1}$$

where,

$0.00 \leq \text{Profit margin} \leq 1.00$.

Basically, profit margin is determined by the difference between minimum sale price of unit product and maximum cost of unit product. In this study, the profit margin ranges from 0.00 to 1.00 because PWI determines the ratio of production wastes over profit. In view of this, profit margin is considered to be zero under two conditions:

i. *If PWI is bigger than 1.00*, profit margin will be considered as 0.00 instead of negative value. This is because the amount of production wastes is already more than the profit amount.

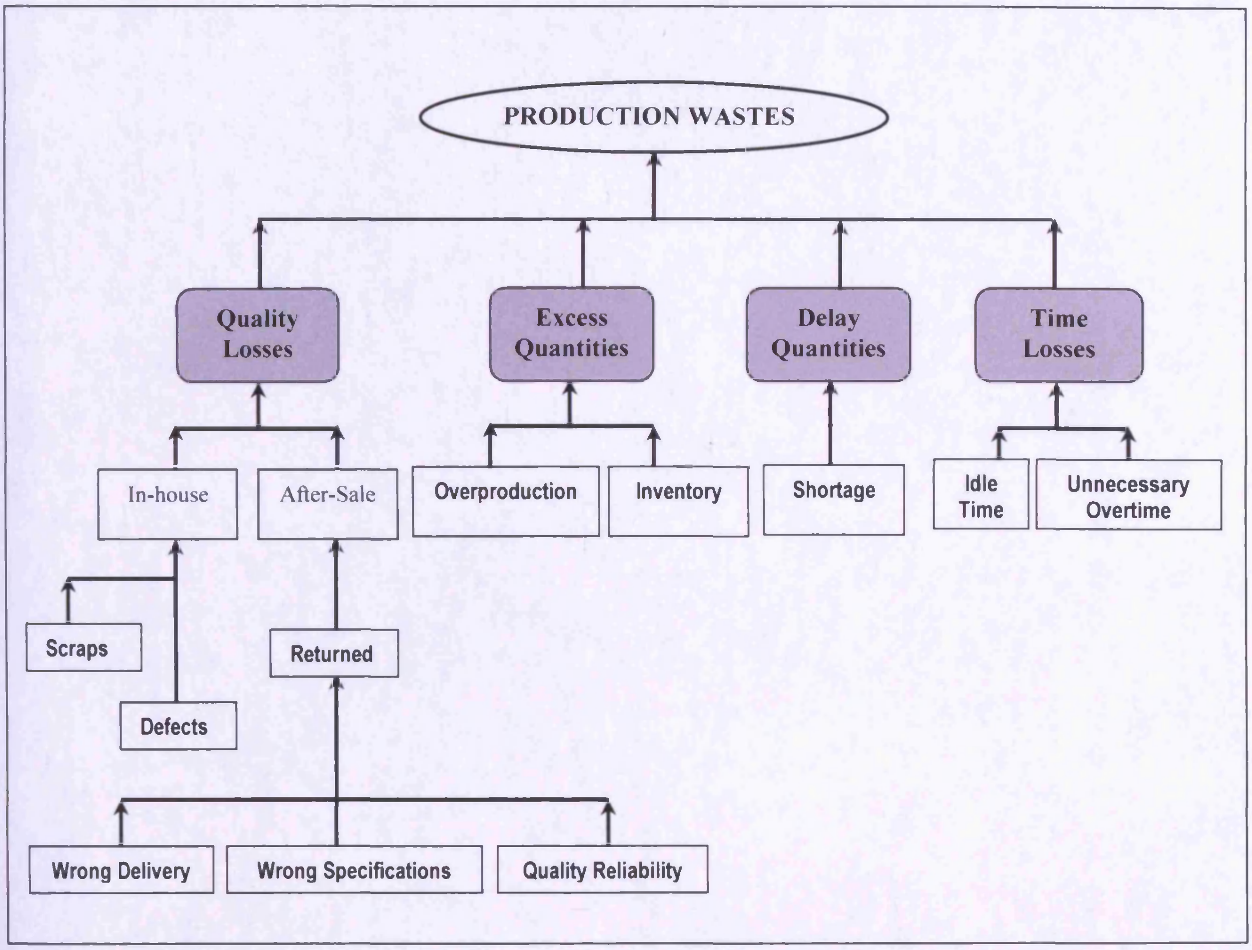


Figure 4.2: Sources of Production Wastes

PRODUCTION WASTE INDEX (PWI)		
OK zone	Alert zone	Critical Zone
0.0 < PWI < 0.35	0.36 < PWI < 0.65	PWI > 0.66
Large Profit Margin	Small Profit Margin	Loss
PROFIT MARGIN		

Figure 4.3: The Relationship between PWI and Profit Margin

ii. *If PWI is smaller than 0.00*, profit margin will be considered as 0.00 instead of more than 1.00. This is because the sales amount is smaller than the total production cost.

As can be seen in Figure 4.3, this study introduces three types of zone based on PWI classification: OK zone (low PWI), Alert zone (medium PWI), and Critical zone (high PWI). The zones are purposely used to indicate the level of production waste amount generated by production operations. Assuming profit margin equal to 1.00, this represents 100% profit. Coloured zones are used to highlight the status of the production waste. Here, the standard colours of traffic lights are adopted to express similar meaning (i.e., green means fine/OK (go), yellow means alert (standby), red means critical (stop)).

The OK zone contains lower PWI where the waste amount consumes up to 35% of profit margin. At this level, manufacturing companies could still absorb the waste amount as consumable items in their budget expenses. Thus, pricing and delivery time strategies could be sufficient for increasing the profit margin. However, it is necessary to keep PWI as low as possible because the pricing and delivery time strategies are regarded as short-term operating decisions (So and Song, 1998). Unfortunately, short-term operating decisions are not reliable for long-term company survival.

In the Alert zone, high PWI index means the waste amount consumes 36% to 65% of the profit margin. The term 'Alert' emphasises the need for a drastic improvement in production operations, and also in current sales and marketing strategies. At this level, the pricing strategies by the marketing unit would not be sufficient. In addition, the marketing unit might be unable to guarantee the delivery time strategy at a high level of PWI in production operations. Therefore, manufacturing companies specifically in the price competitive market environment should avoid their production system moving into the Alert zone.

The Critical zone represents a narrow profit margin remaining, which would bring about profit loss. In this zone, the waste amount consumes at least 66% of the profit margin. There would not be sufficient short-term strategies for increasing the profit margin. Consequently, the only option is continuous long-term production improvement strategy. Accordingly, the term profitability is used to represent the profit margin. In this regard, Equation (1.1) can be written as:

$$\text{Production Profitability Index (PPI)} = 1.00 - \text{PWI} \qquad (1.2)$$

The production system operates fundamentally on the basis of volume and variety characteristics of the manufacturing processes. There are five types of manufacturing process referring to the volume and variety characteristics:

- Project process
- Jobbing process
- Batch process

- Line process
- Continuous process

(Slack, 1997)

A manufacturing company can possibly have more than one type of manufacturing process, depending on how different the product models are from one to another. Thus, calculation of total PWI is based on a similar unit quantity for every product model. For instance, a production system produces two product models with different unit quantities: litre and kilogram. In the PWI calculation, the unit quantity used for each product model has been assumed as a similar unit:

1 litre + 1 kilogram = 2units.

In this study, the total unit quantity is used for determining production input and output quantity, and maximum input quantity (refer to Appendix A – Table 4A for the example). The following examples demonstrate the calculation of PWI and PPI for a production system with a different variety of inputs and outputs:

- Production system with *single-input with multiple-outputs* (Example 4.1).

- Production system with *single-input and single-output* (Example 4.2). In this case, total production PWI is determined by combining the individual PWI from each product model.

- Production system with *multiple-inputs and multiple-outputs* (Example 4.3).

In the following examples, it should be noted that all the paid-out amounts refer to maximum cost of unit product, whilst the paid-in amount refers to minimum sale price of unit product of the particular month.

Example 4.1

Table 4B in Appendix A describes the calculation of PWI and PPI of a plastic film manufacturer by monthly period for the year 2009. The production system applies to the batch process of single-input with multiple-outputs. This example demonstrates the combined PWI of five different product models produced by the same production line.

Example 4.2

Table 4C in Appendix A describes the calculation of PWI and PPI of an agricultural chemical manufacturer by monthly period for the year 2009. The production system applies to the batch process of single-input with single-output. This example demonstrates the combined PWI of four different product models produced by four different production lines.

Example 4.3

Table 4D in Appendix A describes the calculation of PWI and PPI of a cleaning chemical manufacturer by monthly period for the year 2009. The production system applies to the batch process of multiple-inputs with multiple-outputs. This example demonstrates the combined PWI of 13 different product models produced by the same production line.

4.5 Production Adaptability Index

In the context of change, adaptability has been considered a major component of agility that determines responsiveness. From the manufacturing perspective, Bottani (2009) quoted the currently accepted definition relating to agility as *"the ability of companies to respond quickly and effectively to (unexpected) changes in market demand*" (Sharifi and Zhang 2001; Brown and Bessant, 2003, cited in Bottani, 2009, p. 213).

In this respect, response to changes means adaptability to changes. The term is consistent with the description of "adaptation" by ElMaraghy (2009) in his concept of product evolution. He describes "adaptation" as the main driver of evolutionary changes, which can be observed in both nature and manufacturing (ElMaraghy, 2009). The reaction refers to how quickly, economically, and effectively the production system can adapt to the changes. This study, therefore, introduces the Production Adaptability Index (PAI) to represent production responsiveness based on two aspects: *(i) Re-activeness; (ii) Pro-activeness.* As has been defined in the previous chapter, re-activeness refers to production responsiveness to internal changes, which are strongly related to mix flexibility. Mix flexibility is defined as the ability of an organisation to produce different combinations of products economically and effectively given certain capacity (Zhang, et al., 2003).

On the other aspect, pro-activeness refers to production responsiveness to external changes. In this study, the external changes specifically refer to change of product variety and volume variety due to New Products Introduction (NPI). In this regard, the addition of new products into the production system will increase the level of mix flexibility. Furthermore, the frequency of the changes can be presented as the speed of NPI. The NPI speed is regarded as one of the competitive advantages for manufacturing companies (Adeleye and Yusuf, 2006). In this way, measuring production responsiveness through the measure of adaptability in respect of re-activeness and pro-activeness has been clearly justified. This study determines PAI as a combination of re-activeness (Re) and pro-activeness (Pro). In short, the PAI can be determined as:

$$\text{Production Adaptability Index (PAI)} = \text{Re} + \text{Pro} \tag{2.0}$$

Figure 4.4 presents the sources of production adaptability from the two components of agility: *(i) Effective capacity, (ii) High capability.* The effective capacity constitutes time and quantity. In general, the time refers to maximum available production operating time. Meanwhile, the quantity refers to the maximum possible quantity that production is capable of producing within the maximum possible time. High capabilities constitute re-activeness and pro-activeness, of which both components have been clearly justified earlier. The workflow of production adaptability measures is shown at Figure 4.5.

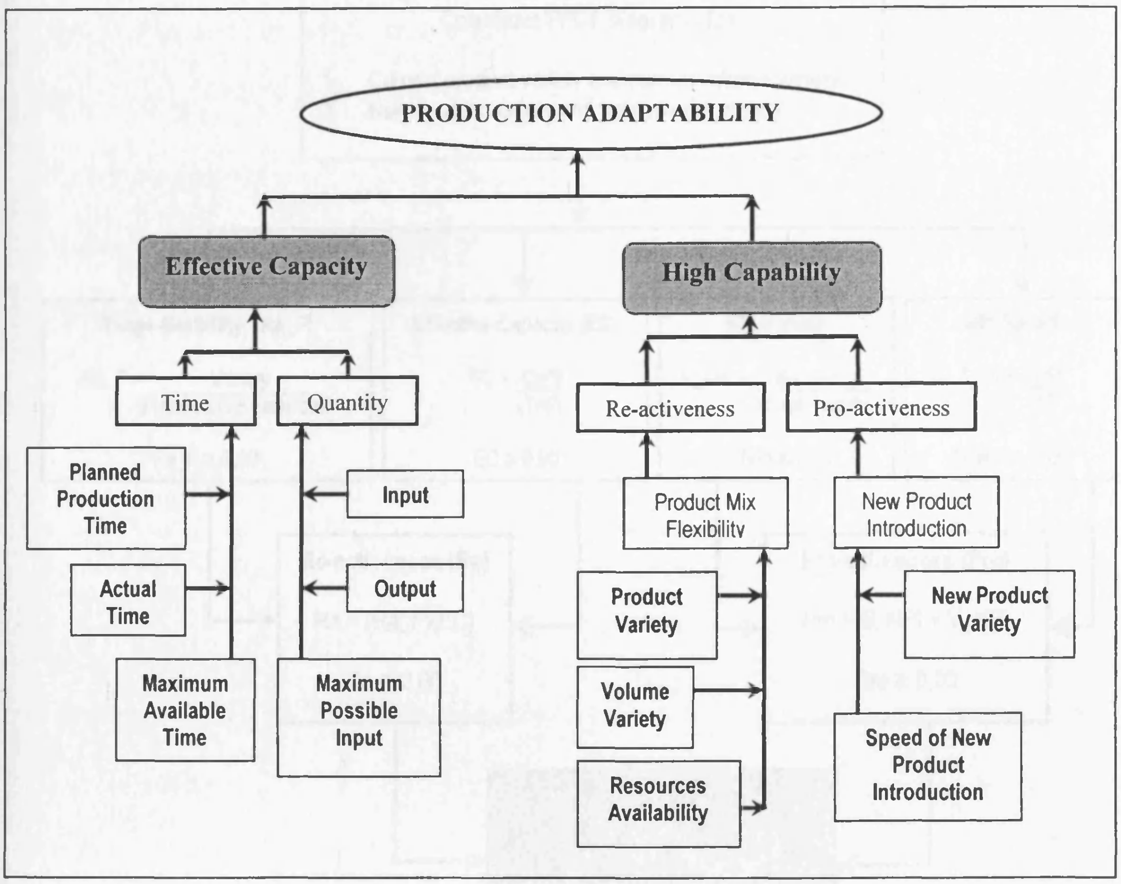


Figure 4.4: Sources of Production Adaptability

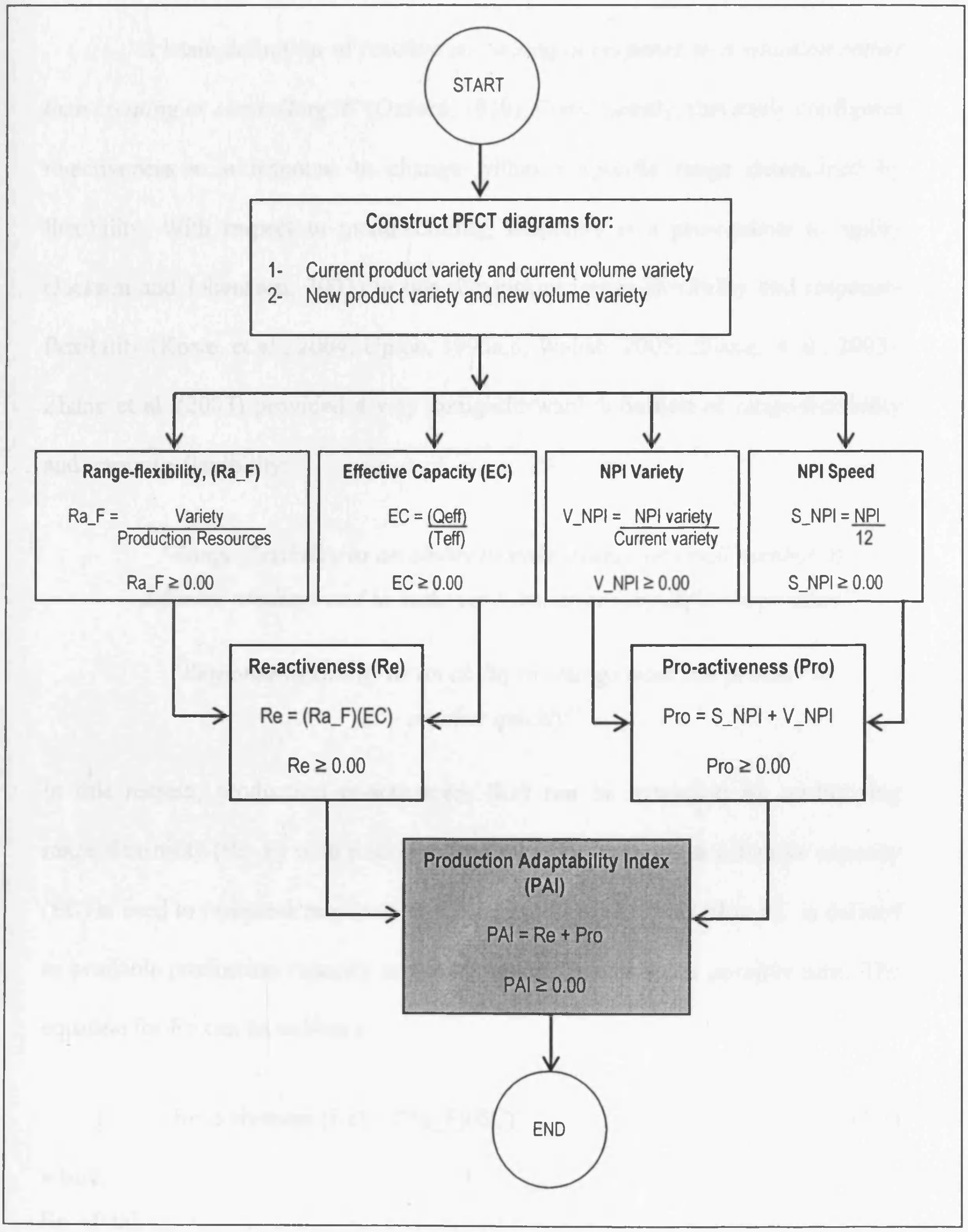


Figure 4.5: Determination of Production Adaptability

4.5.1 Re-activeness Measures

A basic definition of reactive is: "*acting in response to a situation rather than creating or controlling it*" (Oxford, 2010). Consequently, this study configures re-activeness as a response to change within a specific range determined by flexibility. With respect to manufacturing, flexibility is a prerequisite to agility (Jackson and Johansson, 2003) in two dimensions: range-flexibility and response-flexibility (Koste, et al., 2004; Upton, 1995a,b; Wahab, 2005; Zhang, et al., 2003). Zhang et al. (2003) provided a very straightforward definition of range-flexibility and response-flexibility:

> *"Range-flexibility as an ability to make a large or small number of different products and to make very similar or very different product".*
>
> *"Response-flexibility as an ability to change from one product to another quickly".*

In this respect, production re-activeness (Re) can be measured by multiplying range-flexibility (Ra_F) with response-flexibility. Here, the term effective capacity (EC) is used to represent response-flexibility. As a result, production EC is defined as available production capacity produced within the maximum possible time. The equation for Re can be written as:

$$\text{Re-activeness (Re)} = (\text{Ra\_F})(\text{EC}) \qquad (2.1)$$

where,

$Re \geq 0.00$

4.5.1.1 Range-flexibility measure

In this study, range-flexibility (Ra_F) refers to the variety determined through product variety, volume variety, and total number of production resources. Product variety and volume variety account for a number of different items for a product model. Production resources account for the total number of operators, machines, and equipment used to produce the variety. For this reason, the Ra_F index is purposely introduced to indicate how much flexible the changing operations result from product differences (variety) and existing production resources. In this regard, the definition of range-flexibility by Zhang et al. (2003) has been applied. Consequently, Ra_F can be determined as:

$$\text{Ra\_F} = \frac{\text{Variety}}{\text{Production Resources}} \tag{2.2}$$

where,

$\text{Ra\_F} \geq 0.00$

High Ra_F represents high production capability in terms of range-flexibility. In this study, the variety is determined by using the Product Family Classification Tree (PFCT) diagram. Here, the Ratio Scale Measurement approach is applied to weight the ease of changing production operations caused by item differences listed in the PFCT diagram. Thus, changing production operations is defined as any changing operation in manufacturing processes caused by different product instance design, different product specification, different product packaging volume, and different delivery packaging volume.

The idea of weighting has been adopted from the Analytical Hierarchy Process (AHP) technique. Both AHP and PCFT diagram are based on a hierarchical structure. The AHP method is one of the decision making methods introduced by Thomas Saaty through his book published in 1980 (Forman and Gass, 2001). AHP establishes priority weights for alternatives by organising objectives, criteria, and sub-criteria in a hierarchical structure (Berssconi, et al., 2010). AHP allocates the total weight equal to 1.00 for each level. Different weights with a value less than one are then distributed to each item in a particular level. The most important item is determined by the highest weight allocated to the item.

Similar total weight is applied in the PCFT diagram, but instead it is divided by the number of levels. This is because the function of the PFCT diagram is to determine the total variety according to item differences. Therefore, the top level is weighted by 1.00, which represents the least simple change of operations (i.e., changing product family and changing product model). The weight for the lowest level becomes smaller as the total number of levels increases. For instance, a weight equal to 0.5 applies to each item in Level 2. It is determined by dividing 1.00 (maximum weight) by two. Thus, the weight (also known as the ratio scale) for each item in a particular level (L_n) can be determined as:

$$\text{Scale ratio, } L_n = \frac{1.00}{L_{1+n}} \tag{2.3}$$

where,

$n = 0, 1, 2, 3, \ldots. n+1$

Table 4.1 presents the scale ratio applied to each item at a particular level in the Product Variety PFCT diagram. In this regard, items in the lower level carry a smaller scale ratio than items in the upper level, which means the change of operations at a lower level is easier compared to changing operations at upper levels. For instance, changing production operations for different product models in Level 1 will involve the entire units in the company organisation (e.g., design unit, purchasing unit, quality assurance unit, production planning unit, etc.), whereas, changing production operations for different product specifications normally involves a few units in the company organisation (e.g., technical unit, purchasing unit (if necessary), and sales and marketing unit).

Table 4.2 presents the scale ratio applied to each item at a particular level in the Volume Variety PFCT diagram. A similar weight distribution concept is applied here. However, the scale ratio only applies to Level 3 and onward. This is because items in Level 1 and Level 2 present a standard item of product packaging: product model (Level 1), product packaging and delivery packaging (Level 2). The changing operations in product packaging will only be necessary for different packaging instance design (Level 3), packaging specifications (Level 4) and packaging sub-specifications (Level 5). The specified scale ratio (from Table 4.1 and Table 4.2) will be multiplied by each item in the particular level.

Table 4.1: Scale Ratio for Product Variety PFCT Diagram

Level	**Classification**	**Scale ratio, w**	
1	Product model	1.00/1	1.00
2	Product instance design	1.00/2	0.50
3	Product instance sub-design	1.00/3	0.33
4	Product specification	1.00/4	0.25
5	Product sub-specification	1.00/5	0.20
n	Product sub-specification	1.00/n	$w < 0.20$

Table 4.2: Scale Ratio for Volume Variety PFCT Diagram

Level	**Classification**	**Scale ratio, w**	
1	Product model	Not applicable	Not applicable
2	Category of packaging	Not applicable	Not applicable
3	Packaging design	1.00/1	1.00
4	Packaging specification	1.00/2	0.50
5	Packaging sub-specification	1.00/3	0.33
n	Packaging sub-specification	1.00/n	$w < 0.33$

For instance, there are five different items in Level 2 by which the variety for Level 2 can be determined as:

$$
\begin{aligned}
\text{Variety (Level 2)} &= 0.5(5) \\
&= 2.50
\end{aligned}
$$

Then, the total product variety is determined by the sum of the product variety from each level. However, any similar items at the same level will be counted as one item. For instance, in total, there are 17 items present in Level 3 of the Product Variety PFCT (refer to Figure 4.6), but the calculation of variety only considers the number of different items, which count as eight items instead of 17 items. The following example demonstrates the calculation of product variety and production range-flexibility (Ra-F).

Example 4.4

In January 2008, XYZ company, the Instant Noodles manufacturer produced a number of different product models with four different packaging volumes and three different delivery packaging volumes. The company have two production lines, four packaging machines and four sealing machines. The production operates at one shift with 10 operators. The production range-flexibility for January 2008 can be determined by using the following steps:

(i) Construct the Product Family Classification Tree (PFCT)

- refer to Figure 4.6 and Figure 4.7.

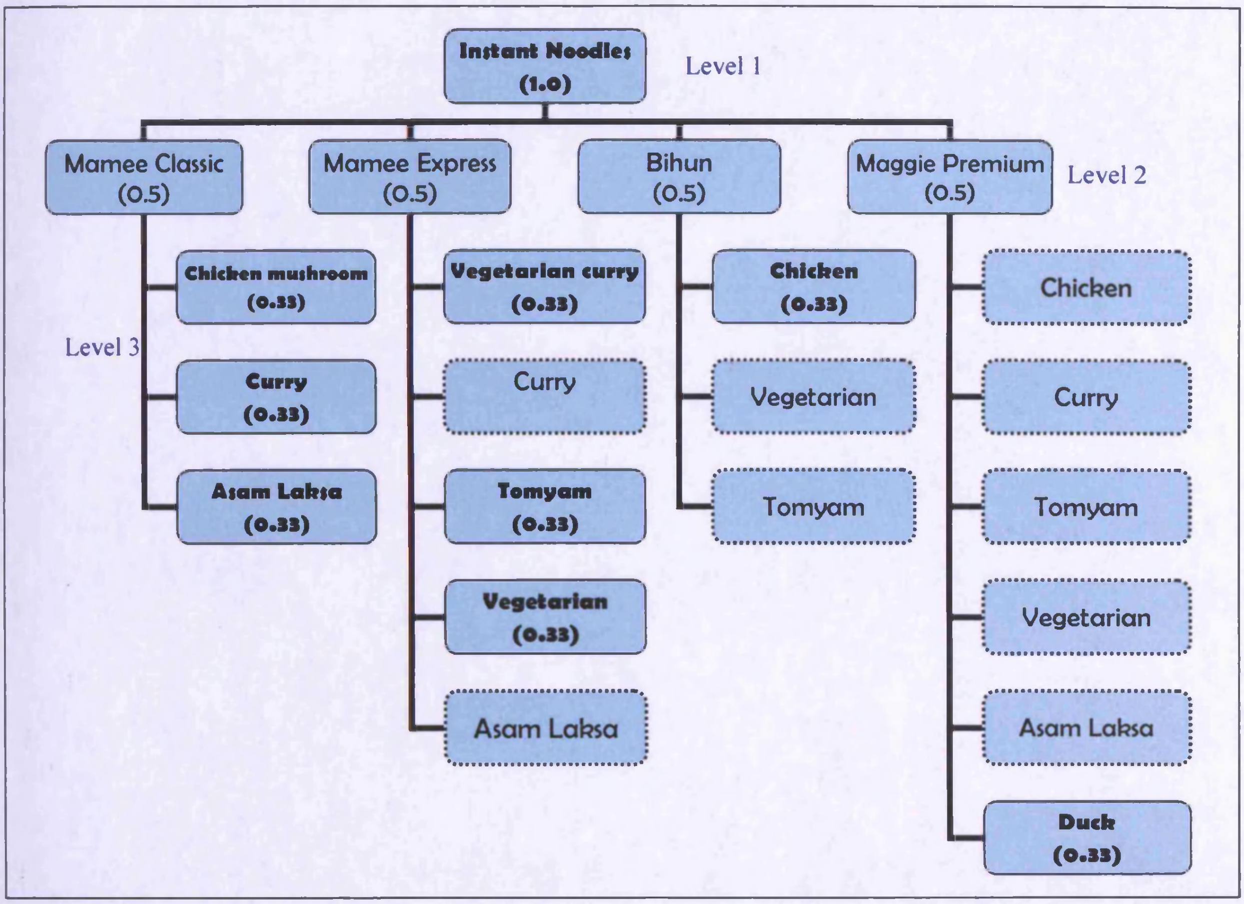


Figure 4.6: The Product Variety PFCT Diagram of Instant Noodles (Foods Product)

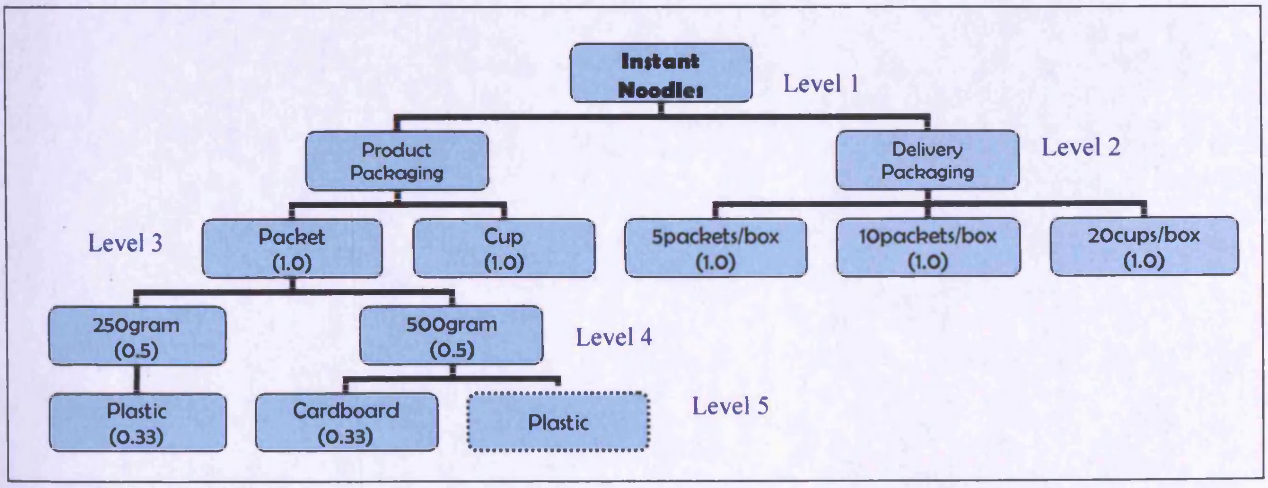


Figure 4.7: The Volume Variety PFCT Diagram of Instant Noodles (Foods Product)

(ii) Calculate:

a. Product variety

b. Volume variety

(a) Product variety (refer to Figure 4.6 for the Product Variety PFCT diagram).

- Product variety $= \sum_{k=1}^{n}$ (Scale ratio)$_k$(Total components)$_k$

  $= 1.00(1) + 0.5(4) + 0.33(8)$

  $=$ **5.64**

Note:

Similar components in the same level are counted as one. In this example, there are eight different components from a total of 17 components.

(b) Volume variety (refer to Figure 4.7 for the Volume Variety PFCT diagram).

- Volume variety $= \sum_{k=3}^{n}$ (Scale ratio)$_k$(Total components)$_k$

  $= 1.00(5) + 0.5(2) + 0.33(2)$

  $=$ **6.66**

(iii) Calculate the variety for the production system.

- Variety = Product variety + Volume variety

  $= 5.64 + 6.66$

  $=$ **12.30**

(iv) Calculate the production range-flexibility.

Production range-flexibility (Ra_F) can be determined by using equation (2.2). Beforehand, production resource is determined by summing up all the number of operators, production lines and equipment.

- Production resources = $\sum_{k=1}^{n}(\text{Operator})_k+(\text{machine})_k+(\text{equipment})_k$

$$= 10 + 2 + 8$$

$$= \mathbf{20}$$

Thus,

$$\text{Ra\_F} = \frac{\text{Variety}}{\text{Production Resources}}$$

$$= \frac{12.30}{20}$$

$$\text{Ra\_F} = \mathbf{0.615}$$

4.5.1.2 Effective Capacity measure

In this study, effective capacity is considered to be one of the contributory factors to production re-activeness. Effective capacity is related to total time consumed and total quantity produced. Thus, this study defines effective capacity (EC) as available production quantity produced within the maximum possible time. EC is, therefore, determined by two factors: *(i) Effective quantity* (Q_{Eff})*; (ii) Effective time* (T_{Eff}).

In this respect, EC can be used as an indicator for production response-flexibility, which also configures the level of production productivity. In other words, it describes production capability in terms of how much quantity could possibly be produced within a minimum possible period.

(i) Effective quantity measure

Effective quantity (Q_{Eff}) is determined by two sources:

- Percentage of available quantity from total production input quantity.

$$\% \text{ Available quantity} = \frac{\text{Total Output quantity}}{\text{Total Input quantity}} \tag{2.4}$$

- Percentage of used quantity from maximum possible input quantity.

$$\% \text{ Usage quantity} = \frac{\text{Total Output quantity}}{\text{Maximum possible input quantity}} \tag{2.5}$$

Q_{Eff} is determined by multiplying the two sources. Therefore, a higher percentage means higher effective capacity is produced. In short, this can be written as:

$$Q_{Eff} = (\% \text{ Available quantity})(\% \text{ Usage quantity}) \tag{2.6}$$

where,

$0.00 \leq Q_{Eff} \leq 1.00$

(ii) Effective time measure

Effective Time (T_{Eff}) refers to total actual production time compared to maximum available time. In this study, the actual production time is the sum of:

- Standard manufacturing lead time of production input quantity.
- Machine downtimes.
- Paid break times for operators.
- Process changeover times (set up time).

This study considers maximum available time as planned production time based on maximum production input quantity. Maximum available time is determined by similar factors of actual production time. However, estimated time is used for machine downtime (based on scheduled maintenance), standard paid break times for operators and standard process changeover time (set up time). In short, T_{Eff} can be determined in unit percentage as:

$$T_{Eff} = \frac{\text{Actual production time}}{\text{Maximum available time}} \tag{2.7}$$

where,

$0.00 \leq T_{Eff} \leq 1.00$

Thus, this study determines effective capacity as the ratio between effective quantity and effective time. This can be written as:

$$EC = \frac{Q_{Eff}}{T_{Eff}} \tag{2.8}$$

where,

$EC \geq 0.00$

High EC means high production productivity in terms of time and quantity. Accordingly, both Q_{Eff} and T_{Eff} contribute to production response-flexibility. As has been stated in section 4.2, an example of monthly EC and its contributing factors can be seen in Appendix A - Table 4A. In this way, high production re-activeness (Re) can be achieved through high production range-flexibility (Ra_F) and high response-flexibility (EC).

4.5.2 Pro-activeness Measures

Pro-activeness is another part of agility (Ren, et al., 2003). As has been stated in the previous chapter, this study refers to pro-activeness in agility in respect of new product introduction. New product introduction (NPI) is defined as any new items added at any level in current Product Variety PFCT diagram and Volume Variety PFCT diagram within the period from January to December. In this case, the term 'any new product introduction' refers to product categories used in the PFCT diagram:

i. New and additional product model
ii. New and additional product instance design
iii. New and additional product specifications
iv. New and additional product sub-specifications
v. New and additional product packaging design
vi. New and additional product packaging specifications
vii. New and additional product packaging sub-specifications

In this study, the measure of NPI is dimensioned by speed and variety. Ren et al. (2003) referred to the speed of New Products Introduction (S_NPI) as one of the sources of production pro-activeness. Apart from how fast the new products can be introduced within one year, new product variety (V_NPI) also contributes to production pro-activeness. The new product refers to how many varieties of a new product the production system is capable of producing. By using a similar method used for determining variety, S_NPI and V_NPI can be determined by applying the scale ratio provided in Table 4.1 and Table 4.2.

Beforehand, a new Product Variety PCFT diagram and Volume Variety PFCT diagram needs to be constructed. A combination of S_NPI and V_NPI perform production pro-activeness.

Following this, production pro-activeness (Pro) can be determined as:

$$Pro = S\_NPI + V\_NPI \qquad (2.9)$$

where,

$Pro \geq 0.00$

4.5.2.1 Speed of new product introduction measure

A study on the impact of product innovativeness found that maximum profitability is higher for product improvements than for line additions (Langerak and Hultink, 2006). This refers to any new items added into the current product structure resulting from product improvements. In this case, the new items introduced by product improvement normally take a shorter development period than the new products introduced by line additions. Therefore, this study defines speed of S_NPI as frequency of new product introduction within a one year period. In this regard, the one year period counts from January to December. Thus, equation (2.9a) below is used to determine (S_NPI):

$$\text{S\_NPI} = \frac{\sum_{k=1}^{n} (\text{Scale ratio})_k(\text{New product})_k + (\text{Scale ratio})_k(\text{New volume})_k}{12} \qquad (2.9a)$$

where,

$\text{S\_NPI} \geq 0.00$

The higher S_NPI means the more frequently new products are introduced. This study considers the objective of new product introduction as a strategy to attract more demand quantity from customers. In this way, it would be possible for production to introduce any new items from lower levels in the PFCT diagram within a 12 month period. With regard to this, the current study allocates S_NPI equal to 1.00 as benchmarking for high S_NPI. The calculation of S_NPI is demonstrated by Example 4.5.

Example 4.5

Extending from Example 4.4 (page 152), company XYZ introduced a new product instance design and new packaging specification in February 2008. Following that, new PFCT diagram for product variety and volume variety were constructed as shown at Figure 4.8 and Figure 4.9. By applying equation (2.9a), the S_NPI for February 2008 can be determined as:

$$S\_NPI = \frac{[0.5(1)+0.33(3)] + [1.00(2)]}{12}$$

$$= \frac{3.49}{12}$$

$$S\_NPI = \mathbf{0.29}$$

4.5.2.2 Variety of new product variety measure

In this study, new product variety (V_NPI) refers to the ratio of new product variety from the current product variety. In this respect, there are usually two objectives of NPI: *to replace* current product and *to increase* the product variety. Thus, the V_NPI would later affect the level of production range-flexibility. Equation (2.9b) is applied to determine the new product variety (V_NPI):

$$V\_NPI = \frac{\sum_{k=1}^{n} (\text{Scale ratio})_k(\text{New product})_k + (\text{Scale ratio})_k(\text{New volume})_k}{\text{Total Variety}} \quad (2.9b)$$

where,

$V\_NPI \geq 0.00$

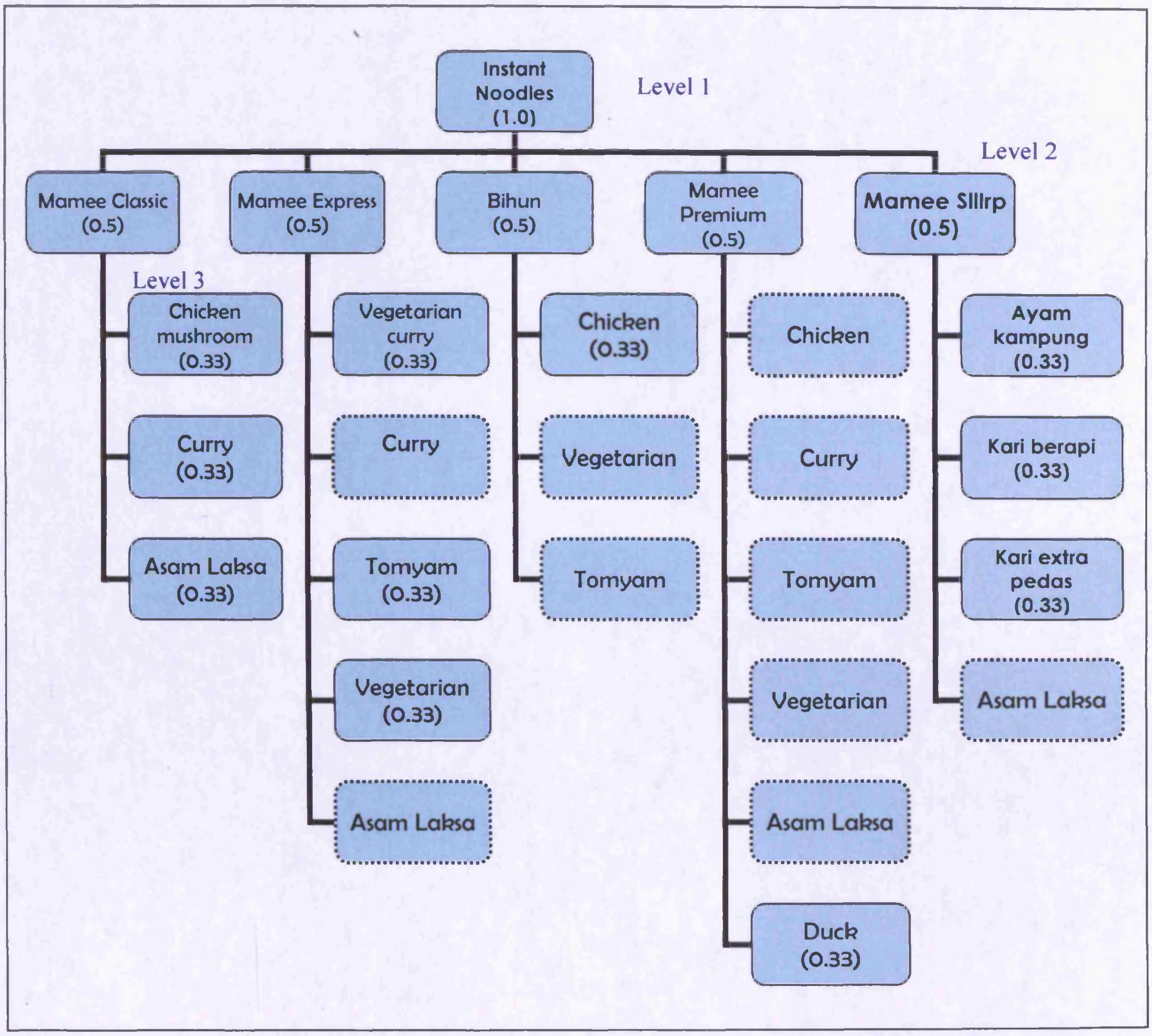


Figure 4.8: The Product Variety PFCT Diagram with Additional New Items

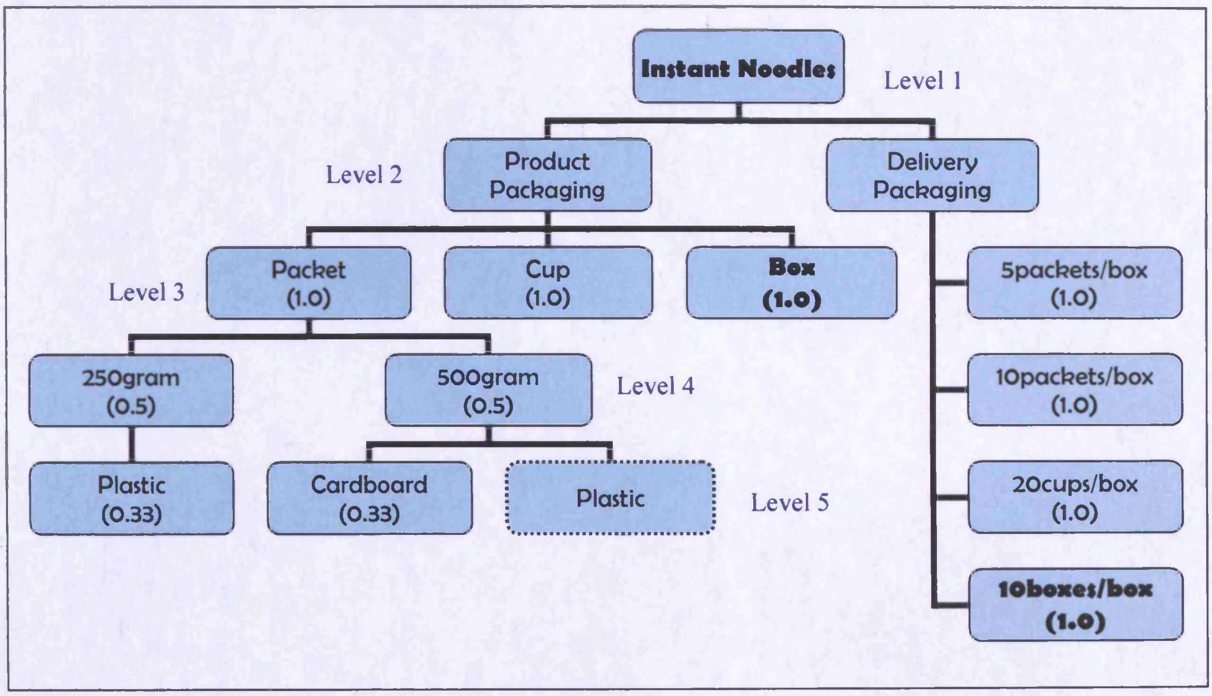


Figure 4.9: The Volume Variety PFCT Diagram with Additional New Items

Example 4.6

By using the result from Example 4.4 (page 153), the current variety is 12.30. From Example 4.5, the new product variety is 3.49. In short, by using equation (2.9b), the ratio of new product variety can be determined as:

$$V\_NPI = \frac{3.49}{12.30}$$

$$= \mathbf{0.28}$$

4.6 Production Stability Index

The concept of balance applies to both static and dynamic circumstances because balance provides stability, sustainability, and continuality. For instance, in static circumstances: a human needs balance while standing; the structure of a building needs to be balanced otherwise the building will collapse; an overloaded boat will sink because of imbalance between the force of the boat's weight and the force of water (buoyant force). Some examples of balance in dynamic circumstances are riding a bicycle, walking, flying an aeroplane etc. Similarly, the concept of balance also applies in Production Fitness.

Balance between supplying demand and production capacity is crucial for sustaining economic production operations. Hence, this study considers production capacity as an important element in fulfilling the required demands promptly and also in contributing to production profitability. Nevertheless, maintaining the balance between production capacity and supplying demand is not always an easy process, specifically in terms of unpredictable market demands. As a result, the production capacity will be in a state of either overcapacity or shortage capacity.

This study refers to production capacity as a combination of production output and current inventory. In this regard, fit production capacity is determined by the Just-In-Time principle from the LM concept where production should only produce required demand quantity. In the meantime, finished goods inventory should be kept as low as possible. Thus, the term stability is used to represent the level of balance between demand quantity and production capacity.

Production Stability Index (PSI) is introduced as the measure of production system stability in respect of production capacity. In this case, other capacity resources, such as outsourcing, sub-contracting, purchasing, are not considered. Here, PSI is determined by three factors: production output quantity, inventory quantity, and demand quantity. Production output quantity refers to finished goods quantity at the final manufacturing process (the packaging process), whilst inventory quantity refers to unsold finished goods of previous months. Demand quantity refers to sales quantity of the current month. Production capacity is normally increased by low demand quantity and/or high inventory quantity. Conversely, high demand quantity and/or low production output quantity will decrease production capacity. Therefore, the equation for PSI can be written as:

$$\text{Production Stability Index (PSI)} = \frac{D_i}{O_i + Inv_i} \tag{3.0}$$

where,

D_i is demand quantity of current month.

O_i is production output of current month.

Inv_i is inventory of current month.

Therefore,

PSI ≥ 0.00

If:

PSI = 0.00 means zero demand quantity.

PSI = 1.00 means production capacity equal to demand quantity.

PSI < 1.00 means overcapacity.

PSI > 1.00 means shortage capacity.

The ideal PSI is 1.00 where low PSI (PSI < 1.00) and high PSI (PSI > 1.00) are disadvantages to company performance. Low PSI means production capacity contains unsold finished goods, which will increase company expenses (pay-out amount), such as cost for holding inventory, penalty on interest etc. In addition, the price of the unsold finished goods would decrease over time, especially for products with a short life span (e.g., frozen foods, beverages, mobile phones, laptops etc.). Within a certain period, these products will become obsolete.

In the case of high PSI, production capacity carries zero available finished goods quantity, resulting in an inability to supply the required quantity. For short-term decisions, the delivery of the required quantity will be delayed upon agreement from the customer. Otherwise, the customer would cancel the order or demand a special discount etc. Even worse, the products delivered might have quality problems due to inefficient production operations resulting from capacity shortage. Poor services in delivery might also occur in this circumstance (e.g., wrong product, wrong quantity, wrong product specifications, wrong product packaging etc). Sooner or later, the company will lose current customer loyalty because of the decrease in customer satisfaction. Therefore, it is important to increase loyalty of current customers because this reflects the company's economic returns through a steady stream of future cash flow (Eugene, et al., 1994, p. 55).

Overall, a balance between production capacity and demand quantity is crucial in the context of sustainable customer satisfaction. An example of monthly PSI measure can be seen in Appendix A – Table 4F.

4.7 Production Fitness Index

In this study, Production Fitness represents the capability of the production system. Thus, Production Fitness is defined as the production capability to fulfil market demands economically, responsively, and continually. Production Fitness is measured through the key components of Fit Manufacturing systems: Leanness, Agility, and Sustainability. Therefore, the Production Fitness Index (PFI) is introduced as an indicator for determining the level of production system performance. The PFI is determined by multiplication of: PPI (leanness concept); PAI (agility concept); and PSI (sustainability concept). In short, the equation for PFI can be written as:

$$\text{Production Fitness Index (PFI)} = (\text{PPI})(\text{PAI})(\text{PSI}) \qquad (4.0)$$

where,

$\text{PFI} \geq 0.00$

PFI equal to zero can be caused by: zero demand quantity or zero profit. Zero demand quantity causes zero effective capacity, whilst zero profit relates to PWI more than 1.00. Furthermore, zero demand also causes zero PPI and zero PSI. Ideal PFI can be estimated through maximum PPI, high PAI, and ideal PSI.

At this stage, the production system produces zero production wastes and zero inventory, which means production capacity relies on current production output. In this respect, PFI is generated by the PAI through high production re-activeness and pro-activeness. In short, in the event of a sudden rise in the demand quantity, then a large amount of variety, reliable production resources, highly effective capacity, and frequent NPI with high variation are the factors of PAI that will generate high profit and demand-capacity stability.

In conclusion, the ideal PFI is applicable for assessing production performances internally where the continuous improvement strategies are necessary to production and marketing. In the face of high competitive market demands, ideal PFI at a high level is essential for manufacturing companies to be competitive. Thus, the PFI must be kept ideal and far from 0.00 for the long-term survival of a manufacturing company.

4.8 Demand Change Ratio

Customer demands normally exist in the form of either quantitative demand or qualitative demand. Quantitative demand refers to product quantity whilst qualitative demand is subject to product quality, product features, product packaging etc. However, both types of demand will finally affect production capabilities. As has been mentioned in the previous chapter (Chapter 3, page 125), this study specifically focuses on quantitative demand. The quantitative demand is indirectly related to qualitative demand in respect of product variety.

In this study, quantitative demand is referred to as total sale quantity. It is clearly justified through the logical operating concept of business, "*Sales will only exist after demand*". In the recent manufacturing business environment, unpredictable change in demand quantity will directly affect production capabilities, specifically in terms of profitability, agility, and stability. For instance, increasing demand quantity requires additional production resources (e.g., materials, manpower, extra operating hours etc.), which depend on the level of production productivity.

In the case of a decrease in demand quantity, high production pro-activeness will be required to increase the demand quantity. This can be achieved by allocating a serial NPI to the production system. At the same time, effective marketing strategies are also required for promoting both current and new products. Thus, increase or decrease in demand quantity will certainly affect the functionality of production re-activeness and pro-activeness. Furthermore, it also affects production profitability (production wastes) and production stability (overcapacity and shortage capacity). In view of this, the size of change can also influence production capabilities. Therefore, this study determines the size of demand changes as:

$$\text{Demand change ratio, DCR} = \frac{S_i}{S_{i-1}} \tag{5.0}$$

where,

S_i is sale quantity of the current month.

S_{i-1} is the sale quantity of previous month.

Thus,

$DCR \geq 0.00$

If,

DCR = 0.00 means zero demand quantity.

DCR < 1.00 means demand quantity of current month decreased.

DCR > 1.00 means demand quantity of current month increased.

$S_{i-1} = 0$, this must be replaced by S_{i-2} or earlier month.

When $S_{i-1} = 0$, Equation (5b) below should be applied instead.

$$\text{Demand change ratio, DCR} = \frac{S_i}{S_{i-p}} \tag{5.1}$$

where,

p = 2, 3, ...n earlier month.

$S_{i-p} \neq 0$

In Fit Manufacturing systems, Production Fitness can only be measured with the existence of demand quantity. Therefore, high DCR (DCR $\geq$ 1.00) indicates a positive sign for a sustainable flow of demand quantity into the production system. It is importance to plot the pattern of DCR over time so that it can be compared with PPI, PAI, PSI, and PFI of the specific period. An example of DCR is shown at Appendix A - Table 4E. Overall, the pattern of DCR is useful for short-term and long-term business plans.

4.8 Summary

The dimensions of Production Fitness have been clearly justified through literature studies and logical concepts. Hence, the Production Fitness measures are developed through the relationships between the specified variables. For production profitability (leanness concept), the PPI is measured through the relationship between production costs and sale price, where the production wastes are considered part of the production costs. In this respect, the PPI represents profit margin that should remain close to one.

For production adaptability (agility concept), the PAI is measured through relationships between effective production capacity and production responsiveness. In this regard, variety, available production resources, and NPI are the key components of production adaptability. Thus, high PAI is generated by high effective capacity, wide variety, minimum production resources, and frequent NPI.

For production stability (sustainability concept), the PSI is measured through the ratio between total demand quantity and available production capacity. The short-term and long-term effects resulting from instability demand-capacity have been discussed. The indication here is that, the ideal PSI should be maintained to avoid instability effects.

For Production Fitness (integration of leanness, agility, and sustainability), the PFI is measured by multiplication of PPI, PAI, and PSI. The ideal PFI has been determined as PPI and PSI equal to 1.00. It is important for a manufacturing company to have consistently ideal PFI to survive. In highly competitive market demands, high PFI is essential for manufacturing companies to be competitive.

Finally, changes in demand quantity affect Production Fitness. The demand change ratio is introduced to represent the indicator of sustainable demand flow into the production system. Thus, the pattern of DCR over time is important for business plans.

Overall, the Production Fitness measures are applicable as a support decision-making tool for production and marketing, especially in Sales and Operations Planning functions.

Chapter 5

Chapter 5
STRATEGIES FOR IMPROVING PRODUCTION FITNESS

5.1 Preliminaries

Production Fitness can be enhanced through modifications in production profitability, adaptability, and stability. Initially, Production Fitness is determined through relationships with capabilities, strategies, and competitiveness in terms of: manufacturing, marketing, and business. Thus, the foundations of Production Fitness are developed on the basis of the strategic process choice, strategic investments, strategic key drivers, and applicable tools and techniques.

In this chapter, strategies for improving Production Fitness are proposed based on four measures: PPI, PAI, PSI, and PFI. Empirical evidence from relevant studies is used to validate the improvement strategies for Production Fitness. This chapter contains six major sections. Relationships in Production Fitness are explored in the first section. Subsequently, strategies for improving indices in the Production Fitness measures are proposed in the following sections. In the final section, significant links within the Production Fitness measures are identified as the key functional elements in integration of the LM, AM, and Sustainability concepts.

5.2 Relationships in Production Fitness

The Production Fitness Index (PFI) is purposely derived for use as a periodical performance measure of the production system. The PFI indicates how fit the production system is in terms of uncertain demand, particularly in product variety and volume variety. In this study, PFI is determined through the integration of PPI, PAI, and PSI, which are the indices of production profitability, production adaptability, and production stability.

Figure 5.1 illustrates the foundation of Production Fitness, which represents the production system performance. The PPI, PAI, and PSI are determined through the manufacturing capabilities. In this regard, manufacturing capabilities are basically developed through strategic process choice, strategic investments, strategic key drivers, and applicable tools and techniques.

Overall, Production Fitness is measured from the basis of production operations performance, which is specifically linked to:

- business performance in respect of profit margin
- manufacturing strategy
- manufacturing capabilities
- competitive priorities
- marketing strategy

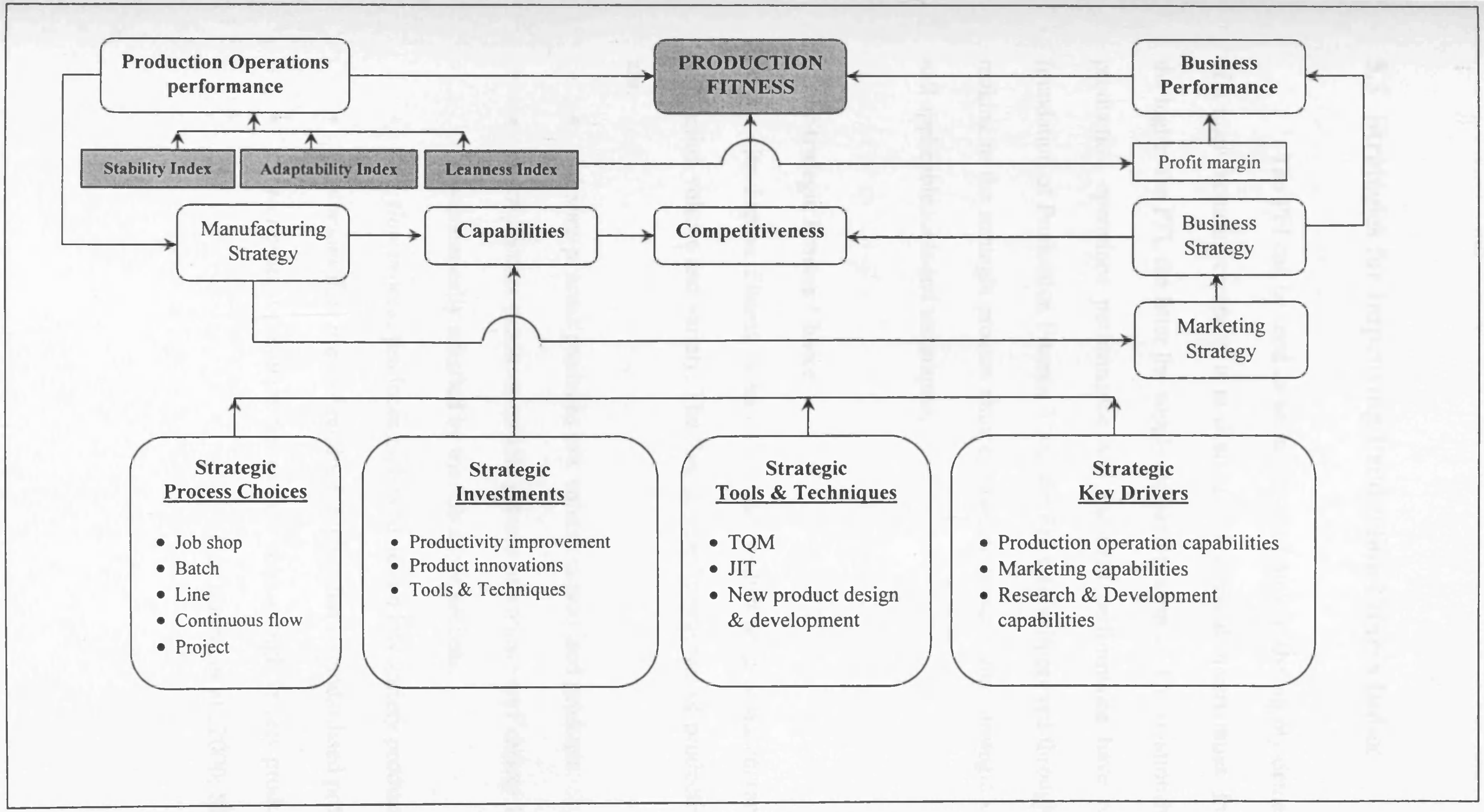


Figure 5.1: The Foundation of Production Fitness

5.3 Strategies for Improving Production Fitness Index

The PFI can be used as an indicator of how fit the supply-demand system of a manufacturing company is in dealing with demand uncertainties. In this case, the higher the PFI, the fitter the supply-demand system is. The relationships within production operations performance and business performance have formed the foundation of Production Fitness. Thus, the PFI can be improved through decision-making in the strategic process choice, strategic investments, strategic key drivers and applicable tools and techniques.

5.3.1 Strategic Process Choice

Production Fitness is based on the production process characterised by production volume and variety. The five standard categories of production process are:

- *Job shop process* produces low volume customised products.
- *Batch process* produces middle ground of volume and variety that cannot be economically satisfied by the Job shops process.
- *Line flow process* produces high volume and low variety products.
- *Continuous flow process* produces high volume standardised products.
- *Project process* produces one-off low volume high variety products.

(Hsafizadeh, et al., 2000; Slack, 1997)

Thus, a decision on the process choices is critical to new product development, especially to products that are new to the company and market. Two important issues are involved in the strategic decisions on process choices: Structural and Infrastructural. The structural issue (e.g., human resources policy, quality systems, organisation culture, and information technology) sets the process and technology for operations, whereas the infrastructure provides long-term competitive edge through persistent day-to-day use and commitment of top management and teamwork at all level (Dangayach and Desmukh, 2001).

Manufacturing capabilities are derived from the manufacturing structure and infrastructure. In fact, manufacturing capabilities derive less from specific technologies or manufacturing facilities but more from manufacturing infrastructure, such as people, management, information systems, learning and organisational focus (Swink and Hergaty, 1998). Moreover, the manufacturing infrastructure has been a major contributor to manufacturing capabilities since the strategic intent and strategic architecture are fundamental to the cultivation and administration of achieving core competencies (Vic and Kaussar, 2001).

A manufacturing company can possibly have more than one type of production process. However, it would depend on the manufacturing capabilities derived from the manufacturing structure and infrastructure. Otherwise, the capability trade-off concept might be the only option for dealing with customer demands. In this case, the trade-off between manufacturing capabilities appears to be both process choice and capability specific. For instance, the trade-off between cost and delivery occurs in batch process, while trade-off between quality and customisation occurs in continuous flow process (Hsafizadeh, et al., 2000). Thus, in the case of PFI, two companies can have equally competent manufacturing, even if their strengths or weaknesses in each capability are considerably different (Kim and Arnold, 1993, p. 6).

5.3.1 Strategic Investments

In the Production Fitness, investment has been determined as the function of sustainable profit so that the company will be able to survive continuously. For manufacturing companies, profit is mainly generated through production and marketing. To improve the profit margin, cost minimisation and production improvement strategies (e.g., productivity and efficiency) are commonly used by production, whilst pricing strategies, warranty and return policies are part of marketing strategies. Thus, investments for profit improvement are necessary in general, however, the strategic investments are sufficient for manufacturing competitiveness. For instance, a negative relationship between investment and production competence is evident in job shop process and flow line process:

- More investments in JIT and SPC have negative impacts on competitiveness in manufacturing lead time, delivery reliability, and delivery speed. *Note that the impacts only apply to line flow process.*

- Investments in MRP negatively influence manufacturing unit costs. *Note that the impacts only apply to Job shops process.*

- More investments in CM do not seem to have a positive effect on delivery reliability, product and volume flexibility. *Note that the impacts only apply to job shop process.*

- Investments in productivity improvements are not generally associated with improvements in delivery performance.

(Schmenner and Vastag, 2006)

Similarly, strategic investments in marketing are also important in improving the profit, which refers to the investments that have contributed to production productivity. For instance, the recent study showed evidence of the relationships between types of investment in return processing and company performance (refer to Table 5.1). The study was based on the two types of product differentiation:

(i) *Functional product*, which is defined as commodity type product with low margins and high price sensitivity,

(ii) *Innovative product*, which is defined as new products that have high margins and low price sensitivity.

(Ketzenberg and Zuidwijk, 2009)

The study concluded that for both product types, investments in increasing recovery speed, reducing the return rate, and reducing market uncertainty are considerably more profitable than reducing the recovery cost and returns uncertainty.

Table 5.1: Types of Investment to Improve Performance
(Ketzenberg and Zuidwijk, 2009)

Type	Description
Speed of recovery	Decrease the recovery lead time so that more returns can be recovered prior to the end of the selling season.
Cost of recovery	Reduce the cost of recovery, perhaps through better systems or improved training.
Rate of returns	Reduce the rate of returns through higher quality service or by investing in software to protect against return fraud.
Market information	Reduce demand uncertainty by investing in additional market information, e.g. market research.
Return information	Reduce return uncertainty by investing in additional return information, e.g. return forecasting.

The study concluded that for both product types, investments in increasing recovery speed, reducing the return rate, and reducing market uncertainty are considerably more profitable than reducing the recovery cost and returns uncertainty.

In summary, Production Fitness can definitely be improved through strategic investments in production operations and marketing strategies. Figure 5.2 presents the relationships between the two categories of investment and competitive advantages. In this regard, strategic investments in production operations depend on the types of production process, whilst investments in marketing strategy, particularly product return processing, has contributed to improvement in production productivity through reduction in the rate of return.

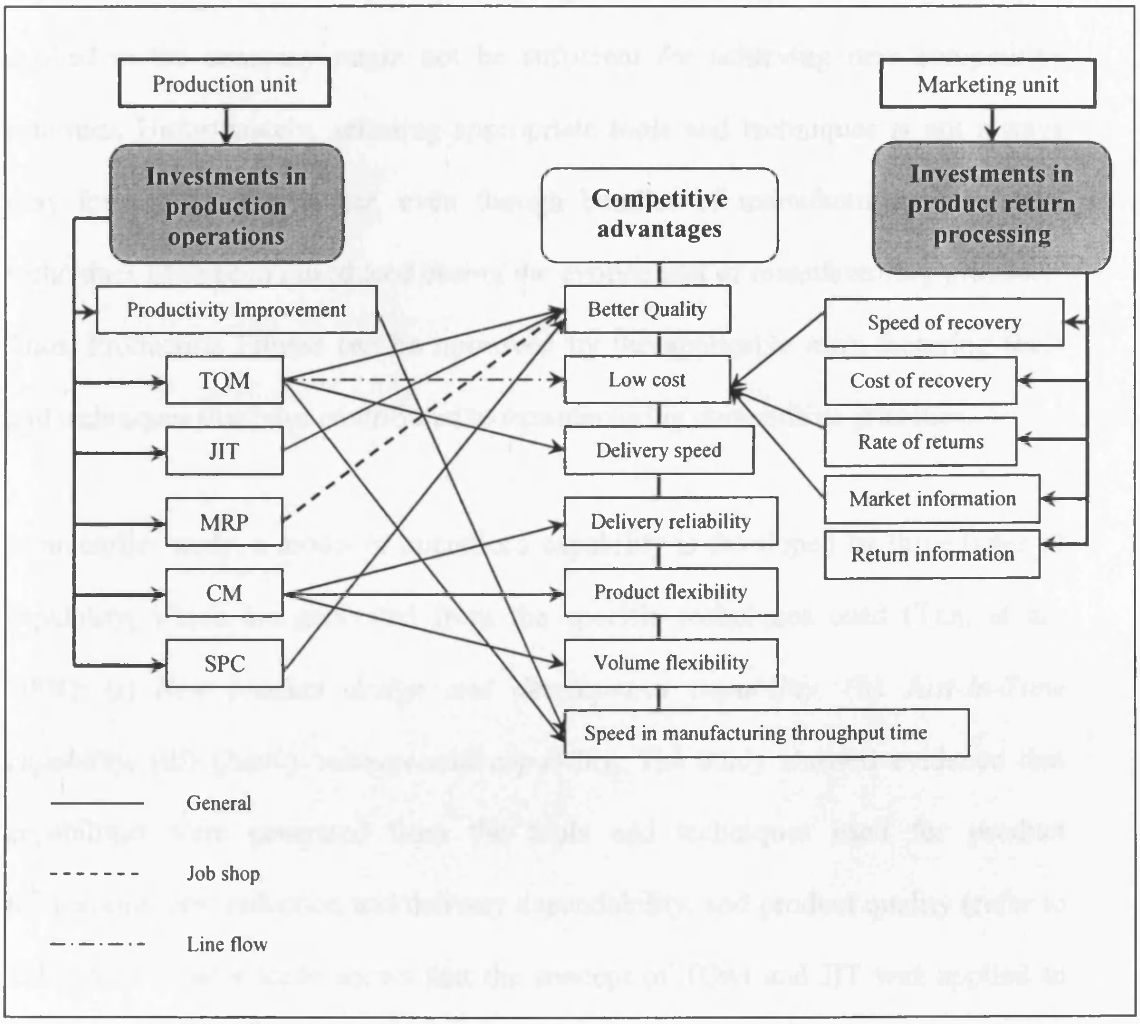


Figure 5.2: Relationships between Strategic Investments and Competitive Advantages

5.3.3 Strategic Manufacturing Tools and Techniques

As market demand changes rapidly in some industries (e.g., automotive and electronics), the competitive priorities of a manufacturing company will also change accordingly. Consequently, existing manufacturing tools and techniques applied in the company might not be sufficient for achieving new competitive priorities. Unfortunately, selecting appropriate tools and techniques is not always easy for the decision-maker, even though bundles of manufacturing tools and techniques have been introduced during the evolvement of manufacturing practices. Thus, Production Fitness can be improved by the applicable manufacturing tools and techniques that have contributed to manufacturing competitive priorities.

In an earlier study, a model of operations capability is developed by three types of capability, which are generated from the specific techniques used (Tan, et al., 2004): (i) *New product design and development capability,* (ii) *Just-In-Time capability,* (iii) *Quality management capability.* The study showed evidence that capabilities were generated from the tools and techniques used for product innovations, cost reduction and delivery dependability, and product quality (refer to Table 5.2). A later study shows that the concept of TQM and JIT was applied to new product development and supply chain management while the companies developed their core competencies and included them in their business processes (Kleindorfer, et al., 2005). In short, strategic manufacturing tools and techniques are purposely used to develop manufacturing capabilities and new products.

Table 5.2: The Generated Capabilities Resulting from Quality Management, JIT, and New Product Design and Development

Quality Management	**JIT**	**New Product Design and Development**
• Process improvements	• Set up time reduction	• Concurrent Engineering
• Design quality into product	• Lot size reduction	• Value Analysis/Engineering
• Statistical Process Control	• Inventory reduction	• Simplification of parts
• Communication of quality goals	• Increasing delivery frequency	• Standardisation of parts
• Employee training in quality	• Preventive maintenance	• Modular design parts
• Employee empowerment		• Early supplier involvement

5.3.4 Strategic Key Drivers

Strategic key drivers are used to determine the fundamental capabilities for developing Production Fitness. Keeping the production fit ensures continuity of the demand-supply process through the generation of demands and development of new products. Hence, the strategic key drivers for Production Fitness are an integration of research and development capability, production operations capability, and marketing capability. Research and development capability innovates new products where production operations capability manufactures current and new products. In the meantime, marketing capability generates demand for the products manufactured.

Recent studies show a positive impact of the strategic key drivers on company performance (Krasnikov and Jayachandran, 2008; Nath, et al., 2010). Both studies concluded that marketing capabilities have dominated company business performance. However, they have not neglected the positive impact of research and development capability, and production operations capability on company performance.

In general, the key drivers depend on the capabilities of the manufacturing structure and infrastructure. Therefore, it is important to recognise that a company's resource capabilities must evolve over time in response to, or in anticipation of technological change, marketplace changes, and competitive forces (Gaimon, 2008).

Relatively, competing on an infrastructural issue is vital, since it is difficult to imitate where Japanese strategy has concentrated on infrastructural issues (Dangayach and Deshmukh, 2001). More specifically, to achieve sustainable operations management, firms must integrate employee health and safety metrics with key business processes, measure results, and obtain the commitment of top management (Kleindorfer, et al., 2005).

In summary, the strategic key drives towards competitive capabilities are supported by a competent structure and infrastructure in which a qualified competency is characterised by being inimitable, superior, and valuable (Vic and Kaussar, 2001).

5.4 Strategies for Improving Production Profitability Index

In spite of the fact that profit is necessary to companies, it is, nevertheless, insufficient for competitiveness, which is crucial for companies in order to survive continuously in their industry. In the case of manufacturing companies, profit can also be improved by minimising manufacturing costs. Hence, the Production Profitability Index (PPI) is introduced as part of the Production Fitness measure. In Production Fitness, the PPI is determined by the Production Waste Index (PWI).

As previously detailed in Chapter 4, the PWI is determined by three categories of production waste: Quality problems (scraps and defects), Inventory (excess or shortage quantity), Idle time (production resources). The costs generated from production wastes have been considered as part of total manufacturing cost. Thus, the higher the cost generated from production wastes, the smaller the remaining profit margin. In this case, the PPI can be improved through production unit improvement strategies, particularly the waste elimination strategy.

The PPI can be further improved by coordinating the strategies of production and marketing in terms of return policies and warranty length. In respect of production strategies, improvements in product quality and reliability contribute to reduction in product return quantity and warranty length. Turning to marketing strategies, the return policies and warranty length depend on product quality and reliability. Thus, the PPI can certainly be improved by strategic production operations and marketing strategies.

5.4.1 Strategic Production Operations

Strategic production operations in Production Fitness refer to efficient production generated from LM practice, particularly the wastes elimination concept. However, the decision to adopt LM practice is quite difficult because of the substantial differences between a traditional production system and the LM system, particularly in employee management, plant layout, material and information flow systems, and production scheduling/control methods.

5.4.1.1 Lean Manufacturing in cross-industry

The literature on LM contains more empirical studies of implementations in the automotive industry, specifically in the U.S.A., U.K. and Europe, which are compared to the Japanese automotive industry. Therefore, the LM practice is very well established in the automotive industry compared with other industries.

With regard to Production Fitness, LM practice can be applied to all types of industry. For instance, a range of industry sectors within the sample of 72 manufacturing companies has been used in a study of Lean production implementation among Australian organisations, such as (Sohal and Egglestone, 1994): Consumable goods (29%), Metal processing (20%), Chemical industry (12%), Automotive and transport (10%), Building products (10%), Electrical and electronic (6%), Rubber (4%), Metal fabrication (2%), Pulp and paper industry (2%), Plastic industry (2%) and Packaging (2%).

The study reveals the most common tools and techniques used in Lean production implementation are TQM and JIT. Although, the Kanban technique (also known as Pull system) accompanies JIT, the Kaizen tool (also known as Continuous Improvement activities) has received a higher adopted percentage than the Kanban technique. This is because the Kaizen method is more generic than the Kanban technique. Quality Circles and Flexible Manufacturing Systems (FMS) received a similar percentage to the Kanban technique. Group Technology (GT) received the lowest percentage. The key important point from the study is the consistency of TQM and JIT as applicable tools and techniques across the manufacturing industries.

The study also reveals the benefits of LM practice across the industry, mainly in market competitive positioning, customer relationships, and quality constraints. Other common benefits of LM practices appeared in the cross-industry, such as increased flexibility, lowering cycle times, greater sensitivity to market changes, higher productivity levels, stronger focus on performance, improved supplier bonds, and changed from reactive to proactive organisation.

In summary, LM practice can be applied in the cross manufacturing industry. Therefore, the PPI can certainly be improved through LM practice.

5.4.1.2 Lean Manufacturing in Discrete Industry

LM practice originates from the Toyota Production System, which operates in discrete manufacturing processes. Discrete industry is determined through discrete manufacturing processes, which include job shop process and batch process. The job shop is commonly applied in fabrication processes and assembly processes where the production capacity depends on material flow. Conversely, the production capacity of the batch process depends on the size of production batch. In both cases, total manufacturing lead time relies on production capacity. In general, lead time is defined as the total time required to manufacture an item (Burcher, et al, 1996). Thus, production capacity and manufacturing lead time are the most important factors of productivity in discrete industry.

Productivity of the job shop process can be improved by increasing the rate of material flow. For instance, LM practice uses a combination of Cell Manufacturing technique and One-piece Flow technique in the assembly process (Detty and Yingling, 2000, p. 434;Motwani, 2003, p. 344). For the batch process, productivity can be improved by reducing manufacturing lead time. More specifically, Burcher et al. (1996) introduced five elements of lead time as Planning time, Set-up time, Run time, Move time, and Queue time. Consequently, high production productivity is determined by high production capacity, resulting in short manufacturing lead time. Overall, lead time reduction is the key productivity improvement strategy in discrete industry, which uses the Bottleneck strategy as a substitute strategy.

A. <u>Lead time reduction strategy</u>

Being competitive in delivery dependability and delivery speed offers no better option to manufacturers than reduction in lead time. In the case of repetitive batch process, the lead time reduction strategy is based on the reduction in batch size and set up time. Although the small batch sizes reduce the queue time that is proportional to the amount of work in progress (WIP), more frequent set-ups are involved (Burcher, et al., 1996). Therefore, the set-up time reduction is also necessary for minimising manufacturing lead time.

Lead time reduction strategy also applies to assembly processes, especially for a high volume consumer electronic product (Detty and Yingling, 2000). In this case, the terms lot size and changeover time are used instead of batch size and set up time.

B. **Bottleneck strategy**

In the case of production of high product variety with low volume, a variety of set-up tools normally need to be used (Burcher, et al., 1996). Thus, allocating an appropriate processing sequence is crucial in determining the minimum manufacturing lead time. Here, the Bottleneck strategy is used to determine a processing sequence with minimum lead time. The term 'Pacemaker' is used in a later study to represent the Bottleneck strategy (Abdulmalek and Rajgopal, 2007).

In summary, the lead time reduction strategy is the best strategy for improving production profitability through high productivity performance in discrete industry. For instance, overtime is unnecessary as demand capacity can be met promptly where the PPI has been improved through cost reduction in overtime and idle time.

5.4.1.3 Lean Manufacturing in Process Industry

LM practice originated from the discrete industry, resulting in being less attractive to the process industry. This is because the structure of the process industry is designed for high volume production. However, many industries in the process sector actually have a combination of continuous and discrete elements (Abdulmalek and Rajgopal, 2007).

In fact, the concept of Lean Thinking has been applied within the process industries, notably chemicals and pharmaceuticals, to great effect in releasing working capital, increasing supply chain speed, and reducing manufacturing costs (Melton, 2005). A later study reveals that the application of hybrid production system (push-pull system) with Total Productive Maintenance (TPM) can have enormous effects on reducing both lead times and WIP inventory (Abdulmalek and Rajgopal, 2007, p. 235). The study shows the applicability of tools and techniques in LM practice, such as Pacemaker process (also known as Bottleneck), Value Stream Mapping (VSM), Kanban system (also known as Pull system), Continuous flow, Production levelling and TPM. However, the study found the set up reduction technique did not have a positive effect on performance.

In summary, the LM practice offers similar benefits to the process industry as to discrete industry, specifically in the reduction of manufacturing costs. Thus, production profitability can be improved through LM practice.

5.4.1.4 Strategic Lean Manufacturing tools and techniques

The applicability of tools and techniques from LM practice relies on the types of manufacturing industry (discrete or process). Therefore, the strategic LM tools and techniques refer to the necessary and sufficient tools and techniques which have contributed to LM benefits.

A. **Key important tools and techniques (sufficient)**

Total Productive Maintenance (TPM) programme is the most sufficient tool and technique providing the greatest impact on manufacturing process improvements (Abdulmalek and Rajgopal, 2007; Brah and Chong, 2004; Swanson, 2001). Total manufacturing lead time relies on the capability of machines and equipment to operate with less interruption and high productivity. Effective maintenance extends equipment life, improves equipment availability and retains equipment in a proper condition (Swanson, 2001). In fact, TPM programme is the most effective tool and technique for maintaining equipment fit and safe to operate (Duffuaa, et al., 2001).

In general, the aim of the effective maintenance system is to maximise production equipment effectiveness in terms of economic efficiency and profitability (Saridakis and Dentsoras, 2007). Therefore, the TPM programme is designed to prevent breakdowns, set up and adjustment loss, idling and minor stoppage, reduced speed, defects and rework, and start up, and yield loss (Brah and Chong, 2004, p. 2384; Chan, et al., 2005, p. 73).

The TPM programme has a positive impact on company performance, particularly in operational, financial and managerial functions (Brah and Chong, 2004). For instance, three large global companies showed evidence of an improvement in their performance resulting from the TPM programme (Ireland and Dale, 2001). In some respects, the TPM programme was adopted because of business difficulties and brought-in culture from Japanese stakeholders. Another case study has proved the TPM contribution in production costs reduction (Swanson, 2001). The TPM benefits evident from empirical studies are shown in Table 5.3.

Table 5.3: Evidenced TPM Benefits to Production Profitability Index (PPI)

TPM Benefits	Empirical studies
1- Increase productivity	Ireland and Dale (2001), Brah and Chong (2004), Chan et al. (2005)
2- Reduce overtime cost	Ireland and Dale (2001)
3- Reduce absenteeism	Ireland and Dale (2001), Brah and Chong (2004)
4- Reduce defects	Ireland and Dale (2001), Swanson (2001), Brah and Chong (2004)
5- Reduce production costs	Swanson (2001)
6- Reduce inventory costs	Brah and Chong (2004)
7- Increase sale	
8- Increase cost savings (material & energy conservation)	
9- Increase delivery dependability (reduce returned products)	

B. **Basic tools and techniques (necessary)**

The basic tools and techniques are referred to as essential tools and techniques to support LM practice and the TPM programme. For instance, 5S technique is a good place to start LM practice (Melton, 2005, p. 669; Motwani, 2003, p. 435). Kaizen technique works with the concept of continuous improvement (Melton, 2005; Sohal and Egglestone, 1994).

Tools, such as Pareto diagram, Ishikawa diagram, Quality circle, Failure Mode and Effects Analysis (FMEA), Poka-Yoke, and Heijunka, are particularly used in lead time reduction strategy (Burcher, et al., 1996; Detty and Yingling, 2000). Table 5.4 presents the strategic tools and techniques used in empirical studies on LM practice.

5.4.1.5 Benefits of Lean Manufacturing practices

Results from empirical studies show the benefits of LM practice favour both discrete industry and process industry (Abdulmalek and Rajgopal, 2007). A summary of the lean benefits to discrete industry and process industry is shown in Table 5.5.

Table 5.4: Strategic Tools and Techniques of Production Operations for Improving Production Profitability Index (PPI)

Tools and Techniques	Applicability		Empirical studies
	Discrete Industry	Process Industry	
Key Important			
TPM	Yes	Partially	Motwani (2003), AbdulMalek and Rajagopalan (2007)
Basic Necessary			
5S	Yes	Yes	Detty and Yingling (2000), Motwani (2003), Melton (2005), AbdulMalek and Rajagopalan (2007)
Small batch sizes	Yes	No	Burcher et al. (1996), Detty and Yingling (2000), Motwani (2003), AbdulMalek and Rajagopalan (2007)
Set up reduction	Yes	Partially	Burcher et al. (1996), Detty and Yingling (2000), Motwani (2003), AbdulMalek and Rajagopalan (2007)
Bottleneck/Pacemaker	Yes	Partially	Burcher et al. (1996)
Value Stream Mapping	Yes	Yes	Motwani (2003), AbdulMalek and Rajagopalan (2007)
Pull system (Kanban)	Yes	Partially	Detty and Yingling (2000), Motwani (2003), Melton (2005), AbdulMalek and Rajagopalan (2007)
Continuous Improvement (Kaizen)	Yes	Yes	Detty and Yingling (2000), Melton (2005),
Visual systems (Jidoka)	Yes	Yes	Detty and Yingling (2000), Motwani (2003), Melton (2005), AbdulMalek and Rajagopalan (2007)
One-piece-flow	Yes	Partially	Detty and Yingling (2000), Motwani (2003), Melton (2005)
Standardised work (Poka-yoke)	Yes	Partially	Burcher et al. (1996), Detty and Yingling (2000), Motwani (2003)
Production levelling (Heijunka)	Yes	Partially	Burcher et al. (1996), Motwani (2003), AbdulMalek and Rajagopalan (2007)
Cellular Manufacturing	Yes	No	Detty and Yingling (2000), AbdulMalek and Rajagopalan (2007)

Table 5.5: Evidenced Benefits of Lean Manufacturing Practice to Production Profitability Index (PPI)

Benefits of Lean Manufacturing Practice	**Empirical studies**	
	Discrete Industry	**Process Industry**
1- Reduction in inventory	Sohal and Egglestone (1994), Burcher et al. (1996), Detty and Yingling (2000),	Melton (2005), AbdulMalek and Rajagopalan (2007)
2- Higher productivity level	Sohal and Egglestone (1994), Burcher et al. (1996), Detty and Yingling (2000), Motwani (2003)	Sohal and Egglestone (1994), Melton (2005), AbdulMalek and Rajagopalan (2007)
3- Increases in customer satisfaction (reduce number of returned product)	Sohal and Egglestone (1994)	Melton (2005)

5.4.2 Strategic Marketing Operations

Profit is most sensitive to price, return policy, maximum return rate and purchase cost (Ketzenberg and Zuidwijk, 2009). Hence, the PPI can also be improved by marketing strategies, particularly pricing strategies, warranty length strategy, and return policies. In this case, these strategies affect the finished goods inventory. In general, warranty length strategy and return policies are purposely used to minimise the rate of product returns, whilst the impact of pricing strategies is used to increase sales quantity so that the profit margin can be maintained or increased.

Failure to deliver products promptly results in customer dissatisfaction and lost sales (Crittenden, et al., 1993; Ketzenberg and Zuidwijk, 2009). Therefore, pricing strategies have commonly correlated to delivery dependability and quick delivery strategy. Similarly, warranty length has a long-term effect on sales (Menezes and Currim, 1992) because customers usually predict the quality of a product based on its warranty (Wu, et al., 2006). The warranty length is related to product quality and reliability, where the maximum return rate has significantly affected return policies (Ketzenberg and Zuidwijk, 2009).

5.4.2.1 Strategic return policies

The effect of return policies on the PPI is shown in the rate of product return, which is due to quality problems and delivery mistakes (e.g., wrong specification, wrong quantity, wrong product, wrong packaging style etc.). Therefore, strategic return policies are necessary for sustainable profitability. In the case of low marginal production cost and not too great demand uncertainty, manufacturers should accept returns (Padmanabhan and Png, 1997). In a recent study, an optimal return policy is defined as one that is somewhere between accepting no returns and accepting all returns unconditionally (Ketzenberg and Zuidwijk, 2009) .

5.4.2.2 Strategic warranty length

Product warranty is closely related to product life cycle where warranty length depends on product quality and reliability. Returned products that are still in the warranty period are classified into three types (Menezes and Currim, 1992): (i) *Replacement,* (ii) *Repair,* (iii) *Pro-rata* . In this case, the manufacturer has to pay the majority of warranty costs of returned products. Despite this, Menezes and Currim (1992) have proved that longer warranty length yields higher sales.

A later study reveals a significant relationship between price and warranty length, where the warranty length strategy is good for products with low profit margin and short life cycle (Kleindorfer, et al., 2005). Thus, the impact of warranty length on the PPI is measured by the decrease in the number of returned products and increases in sales quantity. Table 5.6 presents the strategic warranty length in different circumstances.

Table 5.6: Strategic Warranty Length for Improving Production Profitability Index (PPI)

Category	Strategic Warranty Length	Empirical studies
Replacement	A firm with lower failure rate can offer a longer warranty.	Menezes and Currim (1992)
Repair	When repair cost equals the manufacturing cost, the optimal warranty length is equal to optimal warranty length for replacement.	
Pro-rata	• Economical for items that wear out and must be replaced at failure rather than items that must repaired. • The warranty cost depends on when the product fails and its price.	
General		
"Static" sale rate function (*sale depends only on price and warranty length, but not the cumulative sales volume*)	1- Shorter warranty length with lower price for competitive price situation.	Wu et al. (2006)
	2- Longer warranty length with higher price for competitive warranty length situation.	
	3- Shorter warranty length with higher price for increased unit cost situation.	
"Separable" sale rate function (*sale depend on price-warranty length effect and cumulative sales effect*)	1- Warranty length does not significant effect the profit in the increased price elasticity of the market.	
	2- Unnecessary to increase the warranty length and to lower the price in the increased warranty length elasticity of the market.	
	3- Declining/remaining warranty length but higher price in the increased unit cost with the increased warranty length elasticity of the market.	
	4- Unnecessary to change the warranty length and price in the increased warranty length elasticity of the market.	
	5- Increasing/remaining warranty length but higher price in the increased unit cost with the increased price elasticity of the market.	

5.5 Strategies for Improving Production Adaptability Index

The Production Adaptability Index (PAI) is used as the measure of production agility, which is purposely derived to answer a simple question: "*What makes agility necessary in production systems?*" Therefore, the PAI is measured based on two key reasons for the need for agility in the production system, which are identified as product variety and demand uncertainty. In a highly competitive market environment, production agility is driven by rapid changes in demand. The changes in demand become uncertain as a result of the emergence of ranges of product variety, frequent new product introductions, speed delivery services, and lower price. Thus, the production system has been challenged for producing higher product variety and more new products with lower price and quicker delivery services. In this case, the PAI refers to production agility as:

> "*The continual readiness of an entity to rapidly or inherently, proactively or reactively, embrace change, through high quality, simplistic, economical components and relationships with its environment*"
>
> (Kieran and Brian, 2004, p. 40)

The term 'adaptability' is used to represent the ability of the production system to adapt to rapid changes in demand. Thus, the PAI is determined by the components of re-activeness and pro-activeness. As has been explained earlier in Chapter 4, re-activeness refers to production responsiveness to the demand for product volume-variety, whilst pro-activeness refers to production responsiveness to the demand for new product introduction. However, the total number of product variety depends on the capabilities of the production system to produce quality products economically with competitive delivery services. Ultimately, Production Fitness can be improved through the strategic product variety and strategic new product introductions.

5.5.1 Strategic Product Variety

Responsiveness to product volume-variety relies on the capability of production mix flexibility. In Production Fitness, production mix flexibility is determined by effective capacity, variety, and total number of available production resources (operators, machines and equipment). Thus, re-activeness represents the production mix flexibility, which is structured by range-flexibility and response-flexibility.

The relationship between range-flexibility and effective capacity is formed by the integration of LM concept (referring to effective capacity) and AM concept (referring to flexibility). Effective capacity determines production productivity in terms of quantity and time, which relies on the total number of available production resources. Similarly, Range-flexibility also relies on the total number of available production resources to produce the given variety. The variety is determined by a combination of the product variety and the volume variety (packaging volumes).

Thus, a high production Range-flexibility is generated from a large variety but with a small number of available resources.

However, this is not always the case as the demand of product variety depends on factors such as industrial types (discrete or process), characteristics of product variety, supplier independence, applicability of tools and techniques in managing product variety, and coordination product variety strategy between production and marketing.

5.5.1.1 Product variety and industrial types

In the case of high Production Waste Index (PWI) resulting from production operations, a large variety will not be sufficient for improving Production Fitness. This is because of the incapability of production operations to cope with the large variety, especially with low volume demand. For instance, a study of the impact of product variety on manufacturing performance concluded that the high volume designed process is not economical for small batch sizes (Berry and Cooper, 1999). In contrast, high product variety has a positive impact on performance in the context of discrete industry (MacDuffie, et al., 1996). Therefore, the product variety strategy should be used institutively according to process capabilities and market demands.

5.5.1.2 Characteristics of product variety

Product variety is generated from product characteristics (product structure). The product variety offered to customers (catalogue based) is normally smaller than the variety for manufacturing the product itself (product components). As the customers and the manufacturer have different views on a product family, they should be consistent because a change in one view is normally accompanied by a change in the other view (Erens and Hegge, 1994). A high product variety can be achieved by linking the *external variety* (variety offered to customer) and the *internal variety* (variety involved in creating the product (Pil and Holweg, 2004).

Thus, Production Fitness determines the variety based on the Product Family Classification Tree (PFCT) diagram. The product variety and volume variety is presented in a separate PCFT diagram. The items in both PFCT diagrams are based on the external variety where each item is weighted according to operational changes. For instance, more operational changes are involved in changing the product model to another product model compared to a change in product specifications.

Therefore, the hierarchical structure of the PFCT diagram represents the link between customer preferences (external variety) and manufacturing preferences (internal variety).

The PFCT diagram also shares some of the values of the generic bill-of-material (GBOM) concept with the following characteristics:

- *Functional characteristics* best describe the commercial viewpoint on a product family and its variant.
- *The product variety of a product family* originates from the product variety at lower levels of the product structure.
- *The customer and manufacturer view* on a product are different, but can be linked in a shared product model.

(Erens and Hegge, 1994)

5.5.1.3 Supplier independency

Supplier independence is another important factor that has to be considered in determining the strategic variety. In this regard, the optimal number and type of module-options acquired by the OEM is impacted by whether or not the suppliers are independent or wholly owned subsidiaries of the OEM (Chakravarty and Balakrishnan, 2001). The OEM that offers high product variety would have smaller profit due to a high price from the independent suppliers. Therefore, moving to subsidiary suppliers would be the best option if the companies have the capability to assess Return-on-Investment (ROI) in product development, additional production and marketing strategy.

5.5.1.4 Tools and techniques for managing product variety

Production with high product variety needs specific tools and techniques for managing the variety to reduce complexity in operations (e.g., Component/part Commonality, Modularity, Postponement/Delayed Product Differentiation/Late Configuration, Option Bundling and Mutable Support Structure). However, the effectiveness of the tools and techniques depend on the optimal number of product variety to generate profit. For instance, a study by Jans, et al, (2008) has found the optimal number of common parts in determining product variety contributed to profit maximisation through a reduction in product costs and development costs. An earlier study found the choice of module-options (Modularity technique) affects product variety, module option commonality, total sales, product development cost and company profit (Chakravarty and Balakrishnan, 2001).

The effectiveness of the tools and techniques also depends on the order fulfilment strategy used, such as Make-to-Order, Make-to-Stock and Make-to-Assembly (Pil and Holweg, 2004). For instance, Delayed Product Differentiation (also known as Postponement/Late Configuration) is commonly used in Make-to-Order (MTO) operations. The Delayed Product Differentiation technique is claimed as a key strategy that has been adopted to achieve high variety to customer but with low variety in products manufacturing methods (ElMaraghy, et al., 2009). Table 5.7 presents the tools and techniques of product variety management, which are based on the order fulfilment strategy.

Table 5.7: Strategic Tools and Techniques for Increasing Variety

Category	Tools and Techniques	Description	Empirical studies
Make-to-stock system	• Option bundling	Bundle or package options to reduce external variety.	(ElMraghy, et al., 2009; Jans, et al., 2008, p. 803; Pil and Holweg, 2004)
	• Late configuration/Postponement/ Delayed Products Differentiation	Product customisation is delayed until close to the order point.	
Make-to-order system	• Modularity	Modular architecture in product design used to create a one-to-one mapping between a set of physically proximate components, or subassemblies, and particular functions.	
	• Mutable support structures	Any component designed to support multiple product configurations.	
	• Parts commonality	Common parts used in the product range of a product family.	

5.5.1.5 Coordination between production and marketing

Product variety is generated from either market demands or product innovations. Inconsistency between sales order to production and production variety commonly occurs in high product variety management (Erens and Hegge, 1994). While production is responsible for manufacturing the products as demanded, marketing is responsible for creating demand from the product variety offered by production. In this regard, coordination between production and marketing is crucial in the competitive product variety environment.

For instance, marketing must provide price sensitivity information and determine the price level if the production decision concerns a redesign and range split (Jans, et al., 2008). Pricing strategies are important to generate profit for high product variety in the process industry (Berry and Cooper, 1999). In the case of high product variety with low reliability product, profit can still be generated from warranty length strategy (Murthy, et al., 2009). Moreover, the same product structure should be used by production and marketing to promote consistency in the ordering system, such as the PFCT diagram.

In summary, Production Fitness is affected by the strategic variety, which relies on the capability of production mix flexibility. The key points of the strategic product variety are listed in Table 5.8.

Table 5.8: Important Notes for Achieving Strategic Product Variety

General (Jans, et al., 2008; Murthy, et al., 2009; Pil and Holweg, 2004)	**Discrete Industry** (Chakravarty and Balakrishnan, 2001; MacDuffie, et al., 1996)	**Process Industry** (Berry and Cooper, 1999)
• Linking the external variety (the variety offered to customer) and internal variety (the variety involved in creating the product).	• Profit maximisation is necessary for acquiring higher product variety through module-options technique (Modularity).	• Necessary investments in process and infrastructure to improve alignment between process choices options and market requirements.
• Optimal split of product range into families, where all the models in the same family share the same version of a component.	• *Independent supplier:* OEM should be willing to pay a higher unit price to the supplier to maximise its profit in high competitive market.	• Pricing strategies to provide adequate margins for increased product variety.
• *Competitive product market:* Product variety depends on the variations in the usage rate. In turn, product reliability decreases as the usage rate increases. Thus, warranty costs rely on product reliability.	• *Wholly owned supplier:* OEM's product development cost increased by the number of module-option.	• Necessary investment in inventory for cycle stock to enable longer production run resulted from extended production order sizes strategy.
• *Monopoly product market:* Product variety is not important if the variations in the usage rate very small.		
• When product reliability varies significantly, manufacturing strategy is to build a variety of product instead of single product.		

5.5.2 Strategic New Product Introduction

New product introduction is regarded as one of the pro-active strategies in a highly competitive manufacturing environment. A study on the impact of new product strategies concludes that firms with a high overall performance are particularly pro-active in identifying market needs (Cooper, 1983). Moreover, the speed of new product development is vital to company finance, reaffirming that companies cannot depend solely on their current product offerings to meet their sales and profit objectives (Langerak and Hultink, 2005).

However, the positive impact of new products on company performance depends on product innovativeness and speed to market. Innovative new products attract more competitive reaction than radically new products (Debruyne, et al., 2002). A study on success factors of the new product concludes that being first to the market is not necessarily a performance advantage for selling a new product in high-technology markets (Henard and Szymanski, 2001).

Therefore, production pro-activeness in Production Fitness accounts for new product strategy, which is a combination of new product variety and speed of new product introduction. The PFCT diagram is used to determine the new product variety across product innovativeness. The speed of new product introduction refers to the frequency of new products introduced per year.

5.5.2.1 Product innovativeness

Product innovativeness relates to product newness, where the level of product innovativeness refers to how new the new product is to the market and to the company. Kleinschmidt and Cooper (1991) define product innovativeness in three categories: (i) *highly innovative products* (new to market and new to the company), (ii) *moderately innovative products* (new to the company but not new to the market, and new items in existing product lines for the company), (iii) *less innovative products* (modified and/or redesigned for improvements, e.g., cost reductions). This was followed by a later study, in which product innovativeness was divided into two categories (Debruyne, et al., 2002): *radically new products* (new to market and new to the company) and *innovative new products* (new to the company but not new to the market).

In this regard, items in the PFCT diagram represent all categories of product innovativeness, which is based on product newness. For instance, a new product model in the existing product family is classified as a moderately innovative product or innovative new product since it is new to the company but not new to the market. However, if the new product model is a new product family (e.g. new technology) to the market and the company, it can be classified as a highly innovative product or radically new product.

Product innovativeness has a U-shape relationship with company performance, where high and low product innovativeness contribute to higher profit, sales, ROI and market share than moderate product innovativeness (Kleinschmidt and Cooper, 1991). In addition, a new product related to the company's existing products (i.e., same end use, fit into an existing line, same product class) has a higher success rate (Cooper, 1984). Thus, through innovations in packaging, promotion, and by making small modifications in the product to better suit customer tastes, existing products can prove to be highly profitable (Chaney, et al., 1991). In addition, continuous new product introduction and high product innovativeness contribute to a larger market value of companies in their industry.

To marketing, the impact of new product introduction on sales management strategies depends on the types of product innovativeness (Micheal, et al., 2003). Thus, strategic new product introduction not only refers to product innovativeness, but also to dynamic sales management strategies.

5.5.2.2 Speed to market

A positive impact on speed to market strategy in company performance depends on the demand for new products, since product development speed has an inverted U-shape relationship with new product profitability. This implies that an initial increase in development speed boosts new product profitability, but that additional increases become detrimental after a certain point (Langerak and

Hultink, 2006). In addition, results from an earlier study on the impacts of new product speed reveal that speed is not universally appropriate in all industrial contexts (Kessler and Chakrabarti, 1996). A later study found the trade-off concept between speed to market and new product performance (Bayus, 1997; Langerak and Hultink, 2005). Speed to market is less important when market uncertainty is low (Chen, et al., 2005). In particular, the speed to market strategy is affected by:

- *Economic competitiveness, technological dynamism, demographic dynamism, regulatory restrictiveness* (Kessler and Chakrabarti, 1996).
- *Competition scenario, catch the competition or beat the competition* (Bayus, 1997).
- *Market uncertainty and technological uncertainty* (Chen, et al., 2005).
- *Type of company: pioneer, fast follower, late follower, and laggard* (Langerak and Hultink, 2005).
- *Product innovativeness* (Langerak and Hultink, 2005).

In general, high development speed contributes to high financial performance through high new product profitability (Langerak and Hultink, 2005). Adopted from Bayus (1997), Figure 5.3 presents a summary of optimal speed to market based on sales growth, window of market opportunity, development time-cost trade-off curve and strength of competitor.

In summary, product innovativeness strategy and speed to market strategy contrast with each other in relation to both product success and company performance (e.g. profit, sales, ROI). Most innovative and less innovative products contribute to a better company performance, whilst new product profitability is decreased by high development speed after the optimal point. Table 5.9 presents a summary of relationships between product innovativeness, customer interest, speed to market and applicability.

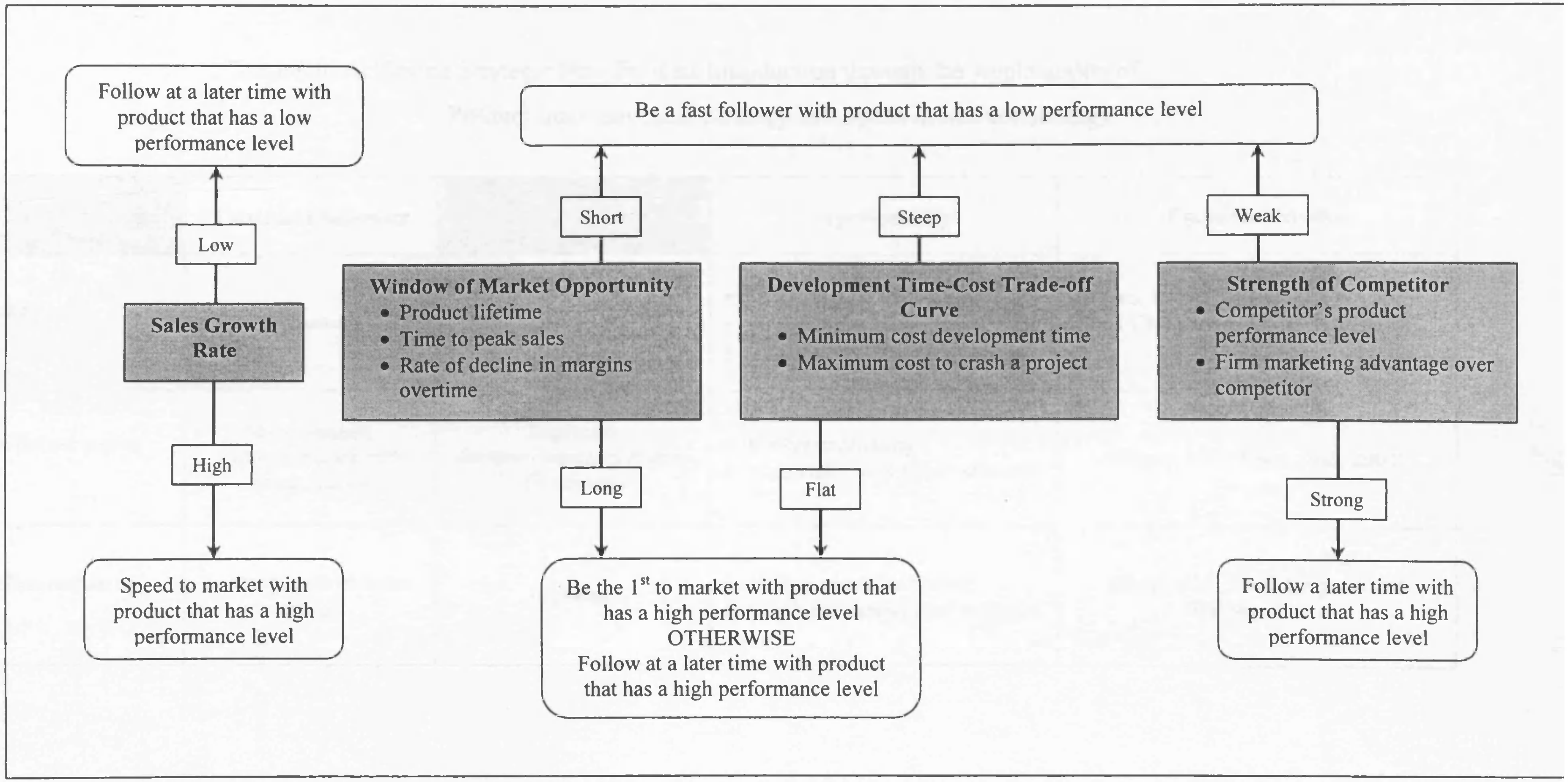


Figure 5.3: Summary of Optimal Speed-to-Market (Bayus, 1997)

Table 5.9: Achieving Strategic New Product Introduction through the Applicability of Product Innovativeness Strategy and Speed to Market Strategy

Product Innovativeness	Customer interests	Speed to Market	Applicability	Empirical Studies
1- New to market	Uniqueness	Important	• Technological uncertainty • Pioneer firms • 'Beat the competition' scenario	(Bayus, 1997; Chen, et al., 2005; Kessler and Chakrabarti, 1996; Langerak and Hultink, 2005)
2- New to firm but not new to market	More features, reasonable price with better quality	Important (to new customers & new distributers)	• Market uncertainty • 'Catch the competition' scenario	(Bayus, 1997; Chen, et al., 2005)
3- Not new to firm neither to market	Lower price with better quality	Important	• High competitive market • 'Catch the competition' scenario	(Chen, et al., 2005; Langerak and Hultink, 2005)

5.6 Strategies for Improving Production Stability Index

A balance between demand and supply is important for the economic sustainability of manufacturing companies. Shortage in supply will decrease potential future demand resulting from unsatisfied customers on delivery services. However, a high finished goods inventory is also not economical to the manufacturing company due to additional costs, especially storage cost. For perishable products, value depletes over time and becomes obsolete if too long in stock. Therefore, the Production Stability Index (PSI) is used to present the level of equilibrium between demand quantity and production capacity. Demand quantity is determined by sales quantity, whilst production capacity is determined by total quantity from production output and inventory. Thus, the PSI determines the ratio between demand and supply.

However, 'overcapacity' is necessary for uncertain market demand, which is commonly presented as optimal capacity. This is because, since the cost of being short of demand is much larger than the cost of having excess inventory, the stochastic case safety stock is used to hedge against uncertainty (Ketzenberg and Zuidwijk, 2009). The term safety stock is used to represent optimal capacity for the finished goods inventory. As a result, a manager faces two critical decisions in balancing the demand-supply system: (i) *When to produce a unit?; (ii) How many units need to be produced?*. Managers have to ensure the stability of the demand-supply system since stability has been affected by demand uncertainties and production capacity limitation. Therefore, strategic production-inventory control system is required to consider both demand uncertainty and production capacity limitation for the stability of the demand-supply system.

5.6.1 Strategic Production-Inventory Control System

The production-inventory control system represents the integration between production control system and inventory control system. A study of the integrated production inventory system shows that the optimal production policy is state-dependent base-stock policy, where the optimal inventory policy depends on the status of the demands in the system (ElHafsi, et al., 2010). Thus, the strategic production-inventory control involves four critical decisions in managing demand uncertainty with limited production capacity:

- Order fulfilment strategy
- Queuing priority (e.g., First-In First-Out, (FIFO))
- Optimal safety stock
- Pricing strategy
- Return policy

Order fulfilment strategy and queuing priority correspond to production control on the capacity of product flow that determines the total quantity of finished goods inventory. Make-to-Stock (MTS), Make-to-Order (MTO) and Hybrid strategy (combination of MTS and MTO) are the most common types of order fulfilment used in general. Other fulfilment strategies, such as Assembly-to-Order (ATO) and Engineering-to-Order (ETO), have been applied in more specific manufacturing processes (e.g., assembly based and project based). The capacity of product flow is also controlled by queuing priority. For instance, First-Come First-Served (FCFS) queuing priority is often used for products with MTO operations.

The ultimate outcome of production control on the particular subjects has been formed in the finished goods inventory. In this section, inventory management is responsible for controlling the total quantity of current stock to sustain the stability of the demand-supply system. Optimal inventory level (also known as safety stock) is used to avoid shortage capacity and over capacity in the demand-supply system. Apart from safety stock, pricing strategies and return policies have also been used as inventory control mechanisms.

5.6.1.1 Strategic order fulfilment strategy

Uncertainties in market demands and production processes require strategic order fulfilment to achieve economic sustainability of the manufacturing firm. The company has to decide for each item whether it is MTS or MTO periodically, and also what type of inventory policy for the MTS items (Rajagopalan, 2001). The decision on the choice of order fulfilment strategy becomes more complicated because of the disadvantages of MTS and MTO. For instance, MTS becomes more costly than MTO in the case of high inventory cost.

Unfortunately, MTO is unsuitable for a quick response scenario due to long order lead time. MTS also becomes costly when the number of products is large and also risky for products in high demand, variable and short life cycle, whilst MTO usually means longer customer lead time and large order backlogs (Diwakar and Saif, 2004).

The applicability of MTS and MTO system is affected by queuing priority, limited production capacity, optimal point of product delayed differentiation, accuracy of demand information, holding costs, set up times and batch sizes (Diwakar and Saif, 2004; Karaesmen, et al., 2002; Rajagopalan, 2002; Soman et al., 2004). For instance, maintaining some items in stock (refers to MTS) was seen as a safe and flexible strategy when both demand and production processes were somewhat uncertain (Rajagopalan, 2002). Summary of the applicability of MTS and MTO in different scenarios is presented in Table 5.10.

In short, the implication of order fulfilment strategy on production stability in respect of demand-supply system is linked to the PAI, since the choice of either MTS or MTO or both is driven by uncertainties in product volume and variety.

Table 5.10: Applicability of MTS and MTO

SCENARIO	APPLICABILITY			Empirical studies
	MTS	MTO	Hybrid (MTO and MTS)	
With FCFS/FIFO queuing priority		✓		
High demand quantity	*✓	✓		(Diwakar and saif, 2004; Mapes, 1993; Rajagopalan, 2002; Soman, et al., 2004)
Uncertain demand		✓	**✓	
Uncertain production capacity	✓		**✓	(Soman, et al., 2004)
Short lead time	✓			(Mapes, 1993; Rajagopalan, 2002)
High set up time	✓			
Small batch size		✓		(Rajagopalan, 2002; Soman, et al., 2004)
High holding costs		✓		
Advance demand information		✓		(Karaesmen, et al., 2002)
High valuable products without Vendor Managed Inventory contract		✓		(ElHafsi, et al., 2010)

Notes:

* Applicable for food production system

** Applicable for high product variety

5.6.1.2 Strategic inventory control system

The inventory control system functions to determine the optimal inventory level so that the stability of the demand-supply system can be sustained. However, the optimal inventory level has to be dynamic over time, especially when uncertain demands are involved. The optimal inventory level of product depends on both demand distribution and substitution probability (Chen and Plambeck, 2008). A recent study shows limited production capacity directly affects the optimal inventory level (ElHafsi, et al., 2010). In addition, other relevant factors, such as pricing strategies and product returns, have been considered in determining the optimal inventory (Fleischmann and Kuik, 2003; Petruzzi and Dada, 2002). In Production Fitness, particularly in respect of non-recycle products, product returns refers to the product returns regarding quality problem and wrong delivery.

Thus, the strategic inventory control system considers all these factors simultaneously in determining the optimal inventory level especially in the aspects of demand control, limited production capacity, pricing strategy, and product returns.

A. <u>Demand distribution</u>

Demand is generally uncertain and may even vary with time, especially in the case of demand for new products, spare parts, or style goods (Kamath and Pakkala, 2002). Products sensitive to economic conditions, products subject to obsolescence, and new products are among the examples of the nature of a fluctuating demand environment (Song and Zipkin, 1993).

Results from empirical studies reveal that the operation costs increase as variation in the mean demand increases (Kamath and Pakkala, 2002; Li and Zeng, 2006). In the case of unknown demand distribution, the Bayesian approach is recommended for incorporating demand information and updating demand distribution to determine the optimal policy (Kamath and Pakkala, 2002).

B. Limited production capacity

One of the objectives of most manufacturing systems is to operate as closely as possible to full capacity utilisation, so that when demand is higher than expected, most of this demand can be met from current production where less safety stock is needed (Mapes, 1993). Unfortunately, the maximum production capacity varies stochastically because of production process uncertainties, such as unexpected breakdowns, manpower shortage etc. (Tetsuo, 2002). Consequently, production capacity becomes limited in the case of unexpected large demand. Unlike limited production capacity, the effect of a large demand on unlimited production capacity in one period can be corrected immediately in the next period (Federgruen and Zipkin, 1986).

As a solution, advance demand information proved to be more valuable for a system with tight capacity, so that a continuous capacity shortage can be avoided (Ozer and Wei, 2004). The study shows that, with zero fixed costs resulting from capacity increase, the full capacity is optimal if the modified inventory position is below the threshold. In contrast, increasing capacity with positive fixed costs does not necessarily reduce inventory and related costs and the policy is to produce either full capacity or nothing.

Table 5.11 presents the highlighted points in developing a strategic inventory control in respect of demand uncertainties and limited production capacity.

C. <u>Pricing strategies</u>

The relationship between demand and price can be observed through ongoing sales, where the characterisation of demand uncertainty can also be updated. In the case of unexpected large demand, stock-out avoidance motive is critical in order to sustain future demand. Hence, the selling price will be adjusted to close the gap between:

- demand and stocking quantity
- production output and sales quantity

Table 5.11: Important Notes for Achieving Strategic Inventory Control in Uncertain Demand and Limited Production Capacity

Uncertain Demand and Limited Production Capacity	Empirical studies
• The effect of production capacity limitations is to increase significantly the amount of safety stock.	(Mapes, 1993)
• In the case of zero fixed cost, an increase of n units in demand does not increase the base stock level for current period for more than n units.	(Elhafsi, et al., 2010; Karaesmen, et al., 2002; Ozer and Wei, 2004)
• In the case of positive fixed cost, producing full capacity may not be enough to reduce future shortage costs.	
• Advance demand information is necessary for setting planned release times and underlines the strong interaction between planned release times and order information availability. In short, it is used to reduce the variability of the order inter-arrival time.	
• In the case of demand increasing-decreasing, the demands should be considered further into the future because of the possibility that shortages may occur (due to the fact that capacity is less than mean demand in some periods).	(Tetsuo, 2002)
• The system with uncertain yield will have a lower optimal mean demand where the lower the demand, the higher the cost will be.	(Elhafsi, et al., 2010; Li and Zheng, 2006)
• In the case of low demand items with wide variation (e.g. new products, spare parts, style goods), the loss increases as variation in the mean demand increases.	(Kamath and Pakkala, 2002)
• *Perishable inventory*: the myopic inventory level is equal to Bayesian optimal inventory level with unobserved lost sales.	(Chen and Plambeck, 2008)
• *Non-perishable inventory*: the Bayesian optimal inventory level increase with unobserved lost sales.	
• Not suitable for standard static control policies such as the static re-order point and the static order-up-to-level policies.	(Babai and Dallery, 2009)
• The dynamic inventory control policies; (r_k, Q) and (T, S_k) applicable for high demand variability with small forecast uncertainty.	
• The production-inventory control system operates in lower operation costs with Vendor Manage Inventory (VMI) contract.	(Elhafsi, et al., 2010)

Increased variation in sales reflects increased variation in prices, where the variation in sales depends on the degree to which marginal production cost is increasing (Maccini and Zabel, 1996). In the case of uncertain demand, optimal selling price and optimal stocking quantity increases over the period of stock-out for additive demand, but it decreases over the period of stock-out for multiplicative demand (Petruzzi and Dada, 2002).

Thus, the dynamic optimal selling price contributes to reducing the amount of uncertainty if a stock-out again occurs in the subsequent period. In fact, demands in different periods are independent and distribution is based on product price, whilst the product price depends on initial inventory at the beginning of the period (i.e., the higher the inventory holding and shortage cost, the lower the optimal selling price (Chen and Simchi-Levi, 2006).

D. <u>Product returns</u>

Returned products will certainly increase total inventory quantity if the returned products can be used as a finished goods product. As demand and return rates are probabilistic, there is a chance that the on-hand inventories exceed the predefined limits (Korugan and Gupta, 1998). The distribution of product returns is difficult to predict as return flows are often characterised by considerable uncertainty regarding time and quantity (de Brito and van der Laan, 2009).

In the case of independent stochastic product returns, the return flow has a mild impact on the optimised expected average costs, unless the return ratio is close to one, resulting in high on-hand inventory (Fleischmann and Kuik, 2003). Thus, with respect to imperfect information about the return rate, it is better to underestimate, the return rate rather than to overestimate, since stock-outs are usually much more costly than overstocks (de Brito and van der Laan, 2009).

In summary, the case of capacity shortage (also known as stock-out) has a large negative impact on manufacturing company sustainability compared to the case of overcapacity. This is because the shortage capacity has a long-term effect on future demands. Thus, the optimal inventory level is adjusted by either production strategy (capacity) or marketing strategy (pricing strategy and return policy), depending on demand distribution. In turn, the PSI is improved through the dynamic optimal inventory level.

5.7 Significant Links between the Production Fitness Measures

The Production Fitness measures are based on the integration of leanness, agility, and sustainability concepts where Production Fitness is determined through the measures of production profitability, adaptability, and stability. An earlier study clarifies a connection between LM, AM, and Sustainability concepts (Pham, et al., 2008c). The study concludes that satisfying the criteria for LM and AM should lead to sustainability resulting from integration of LM, AM, and 'Energetic system'. In Production Fitness, the 'Energetic system' is referred to as a sustainable demand-supply in production system.

Subsequently, indices in the Production Fitness measures are linked to each other through key functional elements. A key functional element is defined as a shared strategy of the two integrated concepts in Production Fitness, which is affected accordingly by improvements in the Production Fitness measures. The following are the key functional elements identified from the integration concepts:

- *Warranty length* (link between production profitability and adaptability)
- *Return policies* (link between production profitability and stability)
- *Order fulfilment* (link between production adaptability and stability)
- *Effective capacity* (link between production profitability, adaptability and stability)

Effective capacity is identified as the core element of Production Fitness because it is affected by improvements in all three measures: Profitability-Adaptability-Stability. Figure 5.4 illustrates the model of Production Fitness equipped with the core element, the key functional elements and the dedicated elements. The structure of Production Fitness model expresses symbolically how the stability of the demand-supply system depends on sustainable coordination between the three pillars of Fit Manufacturing systems. The sustainability concept has been positioned as the base section of the structure to illustrate the symbol of stability between the integration of LM, AM, and Sustainability concepts.

5.7.1 Significant Link between Production Profitability and Adaptability

Production profitability has been linked to production adaptability through warranty length strategy, which is commonly used in a highly competitive product variety. New product introductions resulting from production adaptability are guaranteed by warranty length. The warranty length depends on product quality and reliability, which is determined from production profitability. Warranty length is related to product life cycle, which is determined from production adaptability. The longer the warranty length, the more attractive the products are to customers, and this later contributes to production profitability through more sales. Therefore, warranty length is determined as the key functional element for production profitability and adaptability.

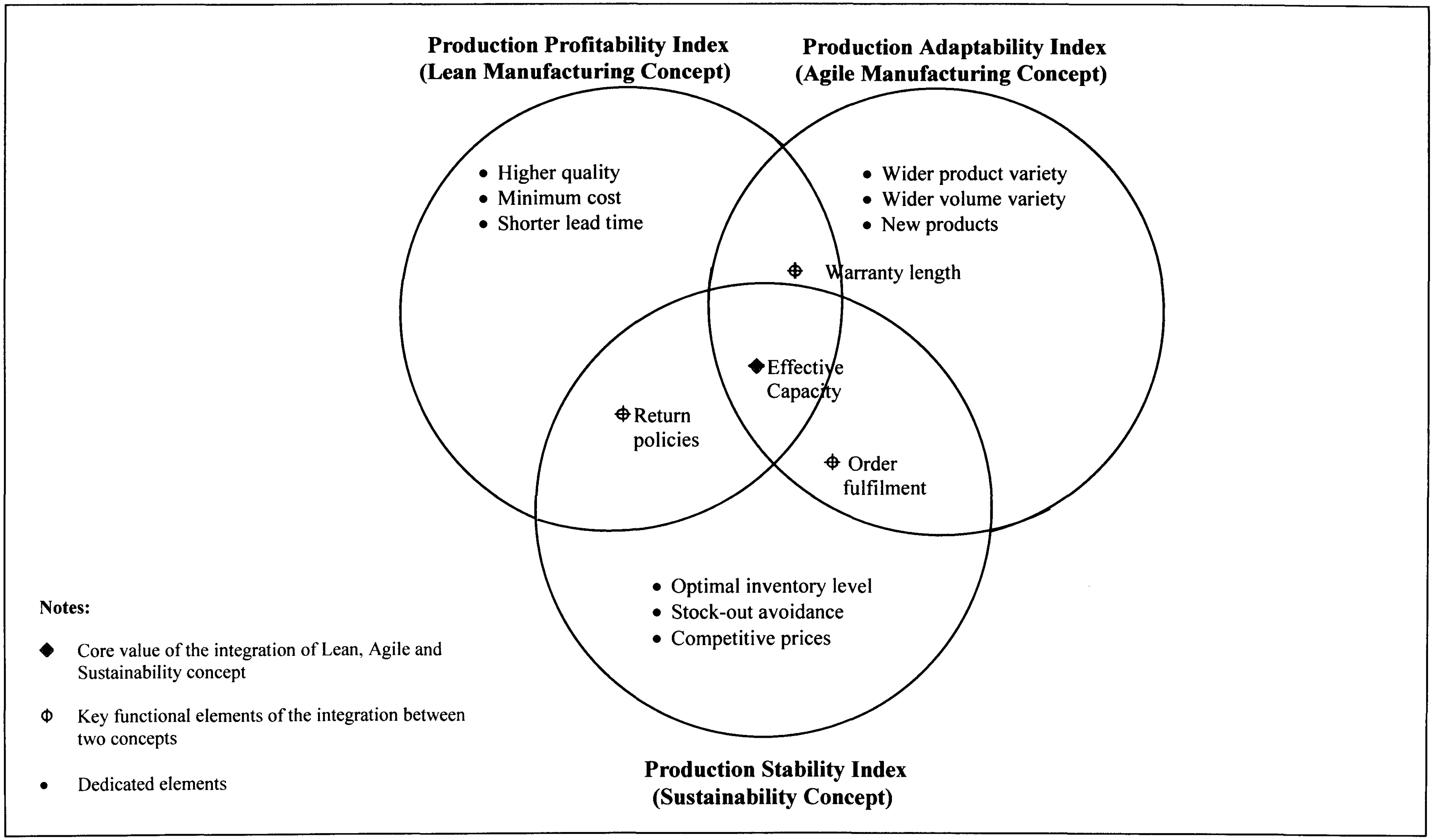


Figure 5.4: The Model of Production Fitness

5.7.2 Significant Link between Production Profitability and Stability

Production stability is linked to production profitability through return policies. Returned products that are due to quality problems will be repaired or replaced where the rate of product returns affects the optimal inventory level. In some cases, the products are returned because of poor delivery services (e.g., wrong product, wrong specification, packaging problems etc.). In the case of a high return rate, the return policies are commonly used by the inventory control system to improve the profit margin. In the meantime, improvements in production operations are also used to improve production profitability. Thus, the return policies are affected by product quality and services. Therefore, the return policies are determined as the key functional element for production profitability and stability.

5.7.3 Significant Link between Production Adaptability and Stability

Production adaptability is linked to production stability through the order fulfilment strategy, particularly the Make-to-Stock, Make-to-Order or a combination of the two. A decision on the order fulfilment has a huge impact on production adaptability and stability, especially in the case of uncertain market demands. While production adaptability is challenged by rapid changes in demand of product variety, volume, and new products, production stability struggles in determining the optimal inventory level. Therefore, the order fulfilment strategy is determined as the key functional element for production adaptability and stability.

5.7.4 Significant Link between Production Profitability, Adaptability, and Stability

Effective capacity is the measure of production productivity in terms of quantity and time. In Production Fitness, effective capacity is generated from LM concept, which contributes to production profitability. At the same time, effective capacity corresponds to responsiveness on product variety and new product introductions in respect of production adaptability. Ultimately, effective capacity affects the current optimum inventory level in respect of production stability. In short, effective capacity is a function of production profitability (idle time and overtime), production adaptability (mix flexibility and new products) and stability (optimum inventory level). Thus, effective capacity is determined as the core value of Production Fitness improvement strategies.

5.8 Summary

This chapter has presented the foundation of Production Fitness and the key functional factors for the integration of LM, AM, and Sustainability concepts. The foundation Production Fitness is identified from the factors that have contributed to manufacturing capabilities, particularly in achieving competitiveness in rapid changes demand.

In general, Production Fitness can be improved by strategic key drivers, strategic process choices, strategic investments, and strategic tools and techniques. The PFI is the measure of Production Fitness that is determined from the PPI, PAI, and PSI. Thus, the PFI improves as the PPI, PAI, and PSI improves. The improvements of the PPI are based on strategic implementation of the LM practice, which depends on the type of manufacturing industry (Process or Discrete) and applicability of the tools and techniques used. Thus, the benefits of LM practice can be achieved.

The strategic improvements of the PAI refer to the need for agility in respect of variety (product and volume) and new products. Similarly, the two aspects also depend on the type of manufacturing industry and applicability of the tools and techniques used. Supplier independence and characteristics of product variety (product structure) are other aspects that have contributed to improvement in the PAI. Interestingly, strategic new product introduction cannot be fully based on product innovativeness and speed to market because it depends on which type of manufacturing industry the company belongs to.

The PSI improvements refer to the optimal inventory level, pricing strategies, and return policies that are required for a strategic production-inventory control system. The strategic improvements of PPI, PAI, and PSI are also referred to as coordination strategies between production and marketing, all of which are responsible for ensuring that profitable supplies correspond to demands.

Finally, significant links between the PPI, PAI, and PSI are identified through the key functional elements and the core element, which originate from the strategic improvements strategies. These elements are important in sustaining the integration of leanness, agility, and sustainability concepts in Production Fitness.

Chapter 6

Chapter 6
RESULTS AND DISCUSSION

6.1 Preliminaries

The Production Fitness measures can be applied to any manufacturing company since common data of production and sales are used to determine PPI, PAI, PSI, and PFI. Consequently, case studies of manufacturing companies in micro-SMEs within four different industries are used to validate the dimensions of the Production Fitness measures. This chapter presents and discusses the results and discussion of the case studies and is divided into three major sections. The details of the case studies and data collection are explained in the first section.

The results of PPI, PAI, PSI, and PFI are discussed in the second section. Since archival data have been used in the Production Fitness measures, it is important to clarify the pattern of PPI, PAI, PSI, and PFI over the five-year period. Therefore, the discussion is based on two types of result: (i) *Monthly results,* (ii) *Annual results*. Both types of result are presented in graphical figures and appendices are also attached for detailed information. For the monthly results, the discussion is focused on the effects of Demand Change Ratio (DCR) to the Production Fitness measures.

For the annual results, particularly the PPI, PAI, and PSI, the results are analysed based on relationships between the Production Fitness measures and variables used, such as PWI, effective capacity, variety, total number of production resources and NPI. The analysis is extended to more generic factors to further justify the results in respect of company characteristics and production characteristics. For the PFI, relationships with PPI, PAI, and PSI, and the results of SWOT analysis are used instead.

In the final section, a summary of the findings is presented in a table so that the factors influencing Production Fitness can be clearly identified. In addition, the unimportant factors are also illustrated in the table. Thus, this chapter provides important information of how Production Fitness has increased, decreased or remained steady.

6.2 Case Studies and Data Collection

The PPI, PAI, PSI, and PFI can be determined over various timescales (e.g., daily, weekly, monthly, and annually). In this study, Production Fitness is measured on a monthly basis. In this case, monthly data of production and sales are needed for the Production Fitness measures. Furthermore, data of administration are also necessary (e.g., total number of production labour, wages of operator based on number of years employed, additional machines/equipment, etc.). This information is especially used for the PWI measure. Table 6.1 presents the lists of archival data during the five-year period from 2005 to 2009 provided by production, marketing, and administration.

In this study, the process of data collection was time-consuming as three approaches were used: *(i) Tracking the archival data; (ii) Interviews* (with top and middle management, and operators); (iii) *Observations* (manufacturing process, production work flow). Therefore, 27 manufacturing companies in various industries and of different size were contacted for the purpose of industrial visits and data collection.

Unfortunately, only one company agreed, as the others were reluctant to become involved for reasons of confidentiality. As a result of recommended walk-in visits, five manufacturing companies agreed to become involved, all of which are from the SME sector in Malaysia, particularly in the Melaka region. Thus, six manufacturing companies have been used as case studies for the Production Fitness measures.

- Case Study 1: Semi-finished Goods Manufacturer
  (Rubber and Plastic Products Industry)

- Case Study 2: Consumer Goods Manufacturer
  (Chemical Industry)

- Case Study 3: Consumer Goods Manufacturer
  (Food Products Industry)

- Case Study 4: Consumer Goods Manufacturer
  (Chemical Industry)

- Case Study 5: Consumer Goods Manufacturer
  (Beverages Industry)

- Case Study 6: Consumer Goods Manufacturer
  (Beverages Industry)

Proof of the industrial visits is shown in Appendix B-1.

Table 6.1: List of Required Data for the Production Fitness Measures

Production unit	Marketing unit	Administration unit	Key Person
Process flow and process cycle time	Sale quantity of individual product	Total number of production labour	**Production unit:** • Production Manager • Supervisor **Marketing unit:** • Marketing Manager • Accountant **Administration unit:** • Managing Director • HR Manager
Batch sizes	Minimum price per unit product	Standard working hours per day	
Set up times	Distribution methods (contractual agreement, distributors & direct consumer)	Employment record	
Scraps/defectives yield		Wage per hour (normal hour and overtime hour)	
Frequency of machine breakdowns		Overtime policy	
Maximum storage capacity		Total public holidays taken per year (2005~2009)	
Safety stock quantity		Product portfolio	
Product returns quantity			
Record on additional machines/equipment			
Total number of operators per process			
Queuing priority system			
Average cost per unit product			
Cost of material (per batch)			
Number of product variety			
Number of volume variety (packaging volumes)			

6.2.1 Data Limitation

Since the archival data for five years are required, there is a possibility of missing some data, especially in respect of hardcopy data. In the case studies, some data are unfortunately not available, such as production input and output quantities. These data are a requisite of PWI, particularly time loss which refers to total idle time and overtime. Idle times normally occur when there are small quantities of sales and high finished goods inventory. Conversely, the overtimes normally occur in the case of large quantities of sales and zero finished goods inventory. As an alternative, the unavailable data have to be constructed by using other relevant data. In this case, the production input and output quantity can be determined through the sales quantity and inventory, where:

$$\textit{Sales quantity} = \textit{Production output quantity} + \textit{Inventory}$$

The production output quantity is the result of production input quantity, which is restricted by three factors:

(i) Available production lead time within the standard operating hours
(ii) Maximum storage capacity (finished goods inventory)
(iii) The rate of scraps, and/or defectives

Thus, the production input quantity is determined based on these three factors. For the batch processes, the production lead time is defined as the processing time for a batch being equal to a set up or changeover time plus the time required for producing a batch (Rajagopalan, 2002, p.203). In this study, machine downtimes are included in the production lead time.

6.2.2 Assumptions

Since some of the companies were unable to provide the required archival data, assumptions have been used to measure Production Fitness, particularly in measuring the PWI and production lead time.

A. PWI

The amount of individual production waste is estimated based on the following assumptions:

(i) Any *unsatisfied demand* is backordered (Fleischmann and Kuik, 2003; Karaesmen, et al., 2002). In this regard, the demand quantity (sales quantity) of the current month is assumed to have already been included with the backordered quantity.

(ii) For the *wrong delivery products*, the returned products are assumed to be added to the inventory.

(iii) For the *returned products* which occur because of the quality problems, the cost of the returned product is assumed to be similar to the current cost per unit product in a particular month. In this case, returned products are related to unsatisfied demand which it is not penalised but results in lost sales (Krasnikov and Jayachandran, 2008).

(iv) The *scraps and defectives* are assumed to be as the loss of finished goods. In this respect, the cost is based on the current cost per unit product in a particular month.

(v) The *raw material and WIP inventories* are ignored as the process is continuous and one primary raw material is common to all items (Rajagopalan, 2002).

(vi) The *set up costs* are assumed to be negligible so that production lot sizing issues can be avoided (Karaesmen, et al., 2002).

B. <u>Production lead time</u>

The actual production lead time and maximum production lead time have been estimated based on the following assumptions:

(i) It is assumed that the *fractional lot sizes* can be rounded up without significant loss of optimality (Rajagopalan, 2002).

(ii) *Absence of manpower* is assumed negligible so that the production operations are only interrupted by machine breakdowns and unpaid break times.

(iii) For Companies B, D, and F, the *machine downtimes* are assumed to have been caused by the decrement of motor reliability over time (Schump, 1989). In this case, a new motor is assumed to have replaced the old motor as soon as the rate of machine downtimes reached 15% of the process time in a particular month.

(iv) The *maximum possible production input quantity* is assumed to have a higher rate of machine downtimes in the particular month.

(v) The *FIFO queuing priority* is assumed to have been applied for the production facilities with limited capacity (Rajagopalan, 2002).

Apart from numerical data, information on company characteristics and production characteristics are essential in order to determine the other factors which might influence the results of the Production Fitness measures. Table 6.2

and Table 6.3 present the summary of company characteristics and production characteristics. In addition, a brief SWOT analysis is held through observation and discussions with the Managing Director and Production Manager. Samples of the questionnaire used for the general information of the company are shown in Appendix B-1.

6.2.3 Company Characteristics

In this study, the case studies are focused on independent manufacturing companies from micro-SMEs in Malaysia, specifically in the same region. An independent company is defined as a company which is not a partner or linked to another company (Verheugen, 2005, p. 16). As can be seen from Table 6.2, this study considers 10 relevant aspects in company characteristics which might influence the results of Production Fitness measures.

Table 6.2: Summary of Company Characteristics

Characteristics	Case Studies					
	1	2	3	4	5	6
Company name	A	B	C	D	E	F
1- Year established	2004	2000	1998	2005	2005	2007
2- Industry classification	Plastic	Chemical	Food	Chemical	Beverage	Beverage
3- Product classification	Semi-finished goods	Consumer goods	Consumer goods	Consumer goods	Consumer goods	Consumer goods
4- Market status	National	International	National	National	National	National
5- Market position	Leader	Leader	Follower	Follower	Leader	Leader
6- Product distribution method	Direct-to-consumer	- Direct-to-consumer - Distributor	- Direct-to-consumer - Distributor	- Direct-to-consumer - Distributor	Direct-to-consumer	- Direct-to-consumer - Distributor
7- Approximate annual turnover, (RM)	2 million	1.5 million	0.1 million	0.5 million	0.05 million	0.2 million
8- Total number of production labour (2009)	4	3	3	3	2	8
9- Standard operating days	Monday-Sunday	Monday-Saturday	Monday-Saturday	Monday-Saturday	Monday-Friday	Monday-Saturday
10- Annual Public holidays taken (day)	15	15	15	15	15	15

6.2.3.1 Year established

From a business perspective, the year established represents the age of a company. Assuming the older company is more experienced than the new company, the results of Production Fitness measures could be influenced by the age of the company. The case studies contain different years of establishment, ranging from 1998 to 2007. In this regard, the oldest company has been established for 12 years, whilst the youngest company has been established for just three years. Thus, the six companies are divided into two groups: *(i) Old companies* (established for 6 to 12years), *(ii) New companies* (established less than 5years).

6.2.3.2 Industry classification

The capability-performance relationship could be stronger in studies that focus on one industry than studies with multi-industry data (Krasnikov and Jayachandran, 2008). However, application of the Production Fitness measures is not limited to certain industries. Thus, the case study on manufacturing companies from various industries is used to compare the level of Production Fitness across industries. In this regard, the UK Standard Industrial Classification (SIC) codes are used to classify the six companies accordingly (Prosser, 2009).

The case studies contain four different industries with:

- two companies from the *Chemical Industry* (SIC 20.14: Fertilisers, and SIC 20.41: Soap and detergents, cleaning & polishing preparation),
- two companies from the *Beverages Industry* (SIC 11.07),
- one company from the *Food Products Industry* (SIC 10.20: Processing and preserving of fish, crustaceans and molluscs),
- one company from the *Rubber and Plastic Products Industry* (SIC 22.21: Plastic plate, sheets, tubes and profiles).

6.2.3.3 Product classification

In general, manufactured products can be classified into three types: *(i) Raw material; (ii) Semi-finished products; (iii) Consumer products*. In the manufacturing supply chain, manufacturers of semi-finished products are positioned as either second or third tier whilst manufacturers of consumer products are positioned at the second end of the chain. Product classification is related to the patterns of demand, such as seasonal demand and uncertain demand. Thus, product classification could influence the results of Production Fitness measures. The case studies contain five manufacturers of consumer products and one manufacturer of semi-finished products.

6.2.3.4 Market status

Market status can be simply divided into two categories: *(i) National market; (ii) International market.* It is common to expect high performances from companies that are involved in the international market. Thus, the market status of a company could influence the results of Production Fitness measures. The case studies contain only one company involved in the international market.

6.2.3.5 Market position

Market Leader and Market Follower determine the market position of a manufacturing company in terms of product newness. Adopted from Langerak and Hulting (2005), this study refers to the Market Leader manufactures as 'First to market (pioneer)' and the Market Follower manufacturers as 'Fast or Late follower'. The market position illustrates company responsiveness to the demands of new product introduction, where the Market Leaders are expected to have higher performances than the Market Followers. Thus, the market position of a company could influence the results of Production Fitness measures. The case studies contain four Market Leader companies and two Market Follower companies.

6.2.3.6 Product distribution method

Two common methods are commonly used by manufacturers to distribute their products: *(i) Direct-to-Consumer; (ii) Distributor*. The Direct-to-Consumer method distributes the products directly from the manufacturer to the consumers without involving any third party. The method is applicable for semi-finished products and consumer products. The second method uses third parties who formally appointed by the manufacturer, to distribute the products. Most manufacturers of consumer products use the Distributor method, especially for branded products. In this way, the product distribution method contributes to the generation of demand quantity. Thus, product distribution methods could influence the results of Production Fitness measures, particularly with respect to the PPI. The case studies contain two companies that use the Direct-to-Consumer method and four companies with the Distributor method.

6.2.3.7 Company size

The term Small-Medium Enterprise (SME) has been used to differentiate medium and small companies from large companies. The European Commission defines SMEs according to staff headcount, annual turnover or annual balance sheet, where the three sizes of SME are defined as follows:

(i) *Medium-sized SME* – between 50 to 250 employees with approximately 50 million annual turnover or approximately 43 million annual balance sheet.

(ii) *Small SME* – between 10 to 50 employees with approximately 10 million annual turnover or approximately 10 million annual balance sheet.

(iii) *Micro SME* – between 1 to 10 employees with approximately 2 million annual turnover or approximately 2 million annual balance sheet.

(Verheugen, 2005)

Thus, the six companies in the case study are in the micro-SME category with different numbers of production labour and different annual turnover. Although the companies are micro-SMEs, the differences could influence the results of Production Fitness measures. In this respect, companies with a higher number of production labour are expected to have high performances.

6.2.3.8 Standard operating days

The average production capacity has been affected by the total number of operating days per week. The total number of public holidays taken per year also affects the annual production capacity. In this regard, overtime is commonly used to increase production capacity in short-term decisions. Thus, the standard operating days could affect the results of Production Fitness measures as overtime increases the cost of production labour.

6.2.4 Production Characteristics

The types of manufacturing process are used to differentiate manufacturing companies in respect of production characteristics. In view of this, it is rational to compare Production Fitness within the same types of manufacturing process. Thus, the case studies are focused on batch processes. Table 6.3 presents a summary of production characteristics in respect of production input and output classification, operational based, order fulfilment based, standard operational hours, and product design and specification changes based.

6.2.4.1 Production input-output classification

Production input-output variety in the Batch processes can be divided into three categories: (i) *Single input with single output,* (ii) *Single input with multiple output,* (iii) *Multiple input with multiple output*. It is closely related to production flexibility in terms of product mix. Thus, the production input-output classification could influence the results of Production Fitness measures. The case studies contain two companies in the first category, one company in the second category, and three companies in the third category.

Table 6.3: Summary of Production Characteristics

Characteristics	Manufacturing companies					
	A	B	C	D	E	F
Input classification	Single	Single	Multiple	Multiple	Single	Multiple
Output classification	Multiple	Single	Multiple	Multiple	Single	Multiple
Production Operations based	Technology intensive	Technology intensive	Labour Intensive	Technology intensive	Labour Intensive	Technology intensive
Level of automation process	Semi-auto	Semi-auto	Manual	Semi-auto	Manual	Semi-auto
Order fulfilment based	MTO	MTS (majority) MTO	MTS (majority) MTO	MTO (majority) MTS	MTO	MTS
Standard operating hours (per day)	24 hours (two shifts)	8 hours (Mon-Fri) 5 hours (Sat.)	8 hours (Mon-Fri) 5 hours (Sat.)	8 hours (Mon-Fri) 5 hours (Sat.)	8 hours (Mon-Fri)	8 hours (Mon-Fri) 5 hours (Sat.)
Design/specification changes based	Customer-oriented (customisation)	Self-oriented (innovation)	Self-oriented (innovation)	Market-oriented (competition)	Self-oriented (innovation)	Self-oriented (innovation)

6.2.4.2 Production operations based

Process automation in manufacturing technologies contributes to better performance in production operations, especially in quality and productivity. Thus, production operations can be classified into two types: *(i) Labour Intensive operations; (ii) Technology Intensive operations.* The Labour Intensive operations refer to the rate of production output, which depends on the number of operators per process. In this case, production productivity relies on the working efficiency of the operators.

With regard to Technology Intensive operations, the rate of production output depends on machine performance, where skilled operators are normally required. In this case, the higher the technology, the higher the level of skilled operators required. Thus, production operations based could influence the results of Production Fitness measures, especially in respect of the PAI and PPI. The case studies contain two companies with Labour Intensive operations and four companies with Technology Intensive operations.

6.2.4.3 Order fulfilment based

Make-to-Stock (MTS) and Make-to-Order (MTO) are the strategies used to fulfil the demand. In the case of uncertain demand, the MTS strategy risks over capacity, whilst the MTO strategy risks a shortage in capacity. Thus, order fulfilment based could influence the results of Production Fitness measures, especially with regard to the PSI and PPI. The case studies contain two companies using MTO strategy one company using MTS, and three companies using a majority of MTS with also some MTO.

6.2.4.4 Standard operating hours

For manufacturing companies, production capacity is estimated by standard operating hours. Low production productivity often requires for additional operating hours to meet high demand. However, overtime hours directly increase the cost of production labour. Therefore, shift working hours are normally applied for high production capacity, which is more economical. Thus, standard operating hours could influence the results of Production Fitness measures.

6.2.4.5 Design/Specification changes based

Changes in product design and specification can occur for many reasons (e.g., product innovation, changes in raw materials/parts specification, quality improvements, and product cost reduction etc). In this regard, the sources of such changes are simplified into three categories: *(i) Customer-oriented; (ii) Innovation-oriented; (iii) Market-oriented.* Changes caused by customer-oriented normally occur in customised-products, whereas changes caused by innovation-oriented occur in innovated products. In the case of market-oriented, the changes of product design and specification refer to product competitiveness such as low price, new features, etc. Despite changes being necessary for greater product variety, frequent changes in product design and specification affect production productivity. Therefore, design/specification changes based could influence the results of Production Fitness measures, especially the PAI and PPI.

6.3 Results and Discussion

The results of the Production Fitness measures are based on a case study of six independent manufacturing companies in micro-SME with batch processes. Archival data of production and marketing over a five year period (from 2005 to 2009) have been used on a monthly basis. In view of this, the discussion of the results is divided into two sections: Monthly results and Annual results.

The monthly results will be compared to the Demand Change Ratio (DCR) so that the impact of changes in demand quantity on the Production Fitness measures can be seen from the graphs. Despite the changes of PPI, PAI, and PSI, the impacts are also viewed based on the constancy of the three indices over the five year period. In this way, the capability of the companies to sustain Production Fitness can be clarified from the monthly results.

Annual results are used to overview production performances in respect of the Production Fitness measures based on the average of the monthly results. Here, the effects of used variables (e.g., PWI, variety, etc.) to the PPI, PAI, and PSI can be clearly identified. Thus, the relationships between the PFI and the three indices can be justified accordingly. In addition, comparisons of the PFI between the six companies are used to further justify the PFI where the results of SWOT analysis are part of the discussion.

6.3.1 Production Profitability Index

As has been explained in Chapter 4, this study introduces the three types of zone to determine the level of PWI: *(i) The Green Zone ($0 \leq PWI \leq 0.35$); (ii) The Alert Zone ($0.36 \leq PWI \leq 0.65$); (iii) The Critical Zone ($0.66 \leq PWI \leq 1.00$).* The PWI zones can be used by the Production unit as a visual tool in controlling production wastes.

As the PPI is equal to 1- PWI, the levels of PPI are classified in contrast to the PWI zones. In this respect, the PPI zones also contain Green Zone ($0.66 \leq$ PPI $\leq$ 1.00), Alert Zone ($0.36 \leq$ PPI ≤ 0.65) and Critical Zone ($0 \leq$ PPI ≤ 0.35). In this way, the PPI zones can be used by the Marketing unit as a visual tool in controlling the profit margin of products after considering the PWI where the minimum price per unit product can be decided appropriately.

In short, the PPI can be continuously improved through improvement strategies from production and marketing.

6.3.1.1 Monthly results

Figure 6.1 presents the results of PPI versus DCR for the six manufacturing companies namely A, B, C, D, E and F which are referred to as Case Study 1, 2, 3, 4, 5, and 6 respectively. The effects of DCR on the PPI are observed through the constancy of the PPI during the five-year period and the changes in the PPI in a particular month.

From the graphs, it can be noted that the DCR of Companies B, C, D and F has constantly fluctuated, whilst Companies A and E have a fairly constant DCR. Despite the inconsistent changes of DCR, Companies B, D and F have managed to maintain a constant PPI close to 1.00 which is in the Green zone unlike the PPI of Companies A, C and E which have varied from 0.00 to 1.00. In particular, the results show the PPI has either increased or decreased as a result of the change of DCR.

In this way, the results illustrate the uncertain relationship between PPI and DCR. In this respect, the constancy of PPI is caused by the capability of the companies to sustain the profit margin, especially through pricing strategies. In the meantime, these companies have sustained production wastes at minimum costs.

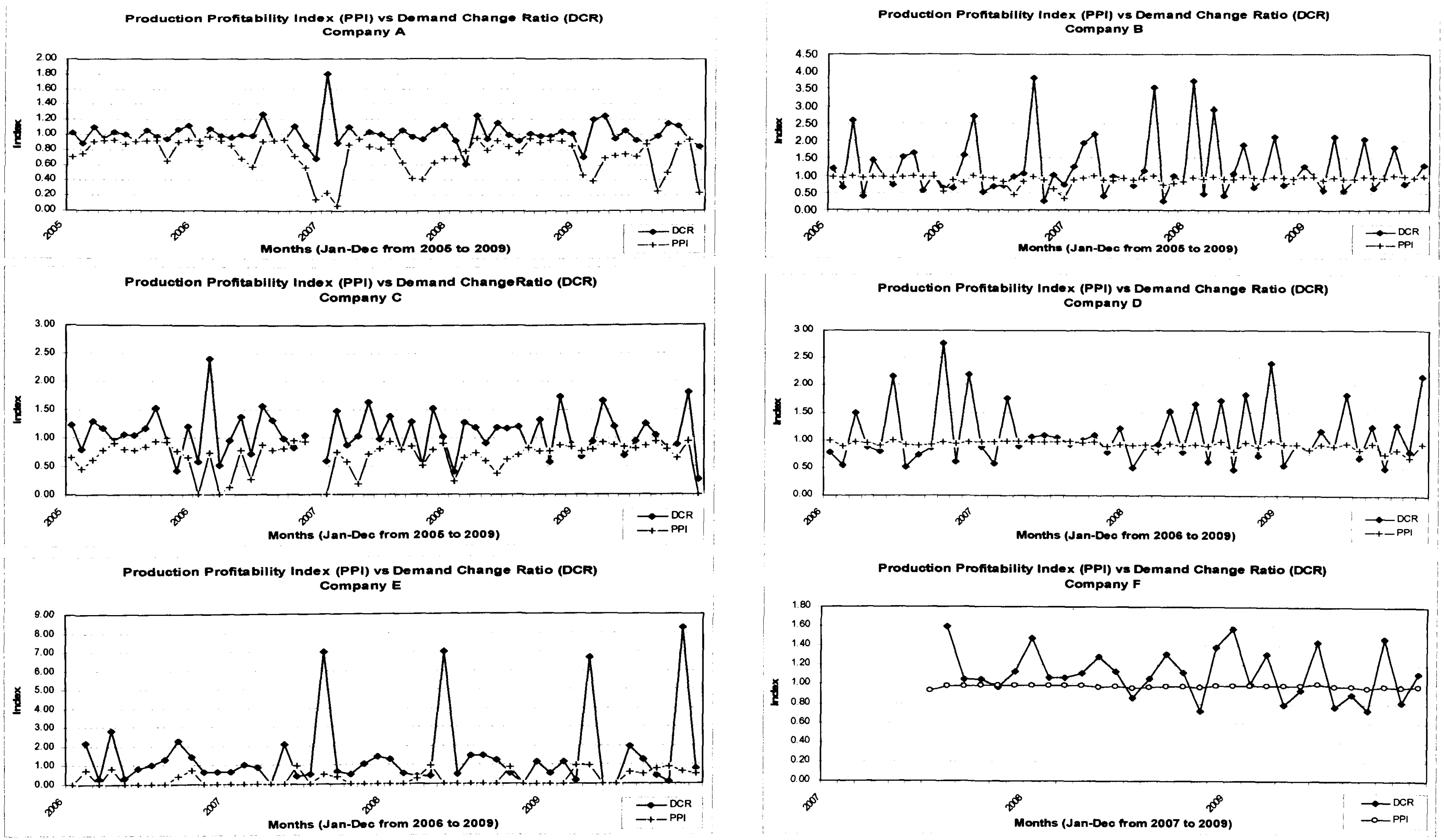


Figure 6.1: Monthly Production Profitability Index (PPI)

In the case of inconstant PPI, first, the PPI decreases as the DCR decreased because of low production capacity usage. As a result, the highly idle time and inventory have contributed to a high PWI. Second, the PPI decrease as the DCR increased because of high production capacity usage. In this regard, the total production cost has been increased as the overtimes are applied to increase production capacity.

Therefore, the results prove that the PPI is not strongly affected by the DCR. It can be concluded that the PPI has been directly affected by production productivity and pricing strategies. The results are consistent with the concept of profitability, where good profitability results are likely to be achieved through high profit margins (Olhager and Selldin, 2007). In fact, the DCR is related to the pricing strategies, for instance, the additive demand resulting in inconsistent price over time (Maccini and Zabel, 1996).

6.3.1.2 Annual results

The annual results of PPI are used to further justify the PPI of the six companies based on the specified criteria of company characteristics and production characteristics. From the annual results, the relationships between PPI and the following variables of Production Fitness can be identified;

(i) PWI
(ii) Effective capacity

(iii) Variety
(iv) NPI
(v) Number of production resources (man, machines and equipment)

In the context of the relationship between PPI and PWI, Figure 6.2 presents the average annual PWI of the six companies. The annual results show five out of the six companies are able to maintain the PWI in the Green zone ($0 \leq PWI \leq 0.35$). Company E has the highest PWI, ranging from 0.60 to 5.10, which is in the Critical zone.

Figure 6.3 presents the annual PPI emerging from the results of annual PWI. As can be seen from the graphs, Companies A, B, C, D and F have an annual PPI of more than 0.65 which is in the Green Zone. Company E, on the other hand, has the lowest annual PPI, which reached 0.00 in 2007 and 2008. The company has been in the Critical zone since it was first established. Overall, it can be concluded that it is possible to have a PPI close to 1.00 as the PWI close to 0.00.

In the context of the relationship between PPI and effective capacity, the effective capacity is affected by time losses. In this respect, the PWI increases as the time losses increase, while the PPI will decrease. The results show that the PPI increases as the effective capacity is increased. Details of the results are shown in Appendix C-1a.

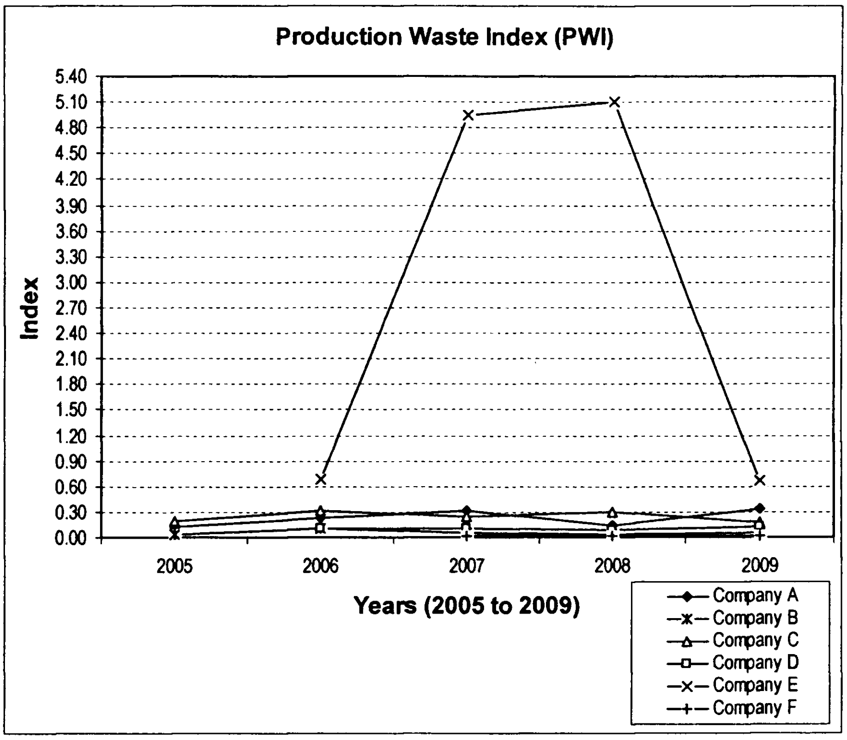


Figure 6.2: Annual Production Waste Index (PWI)

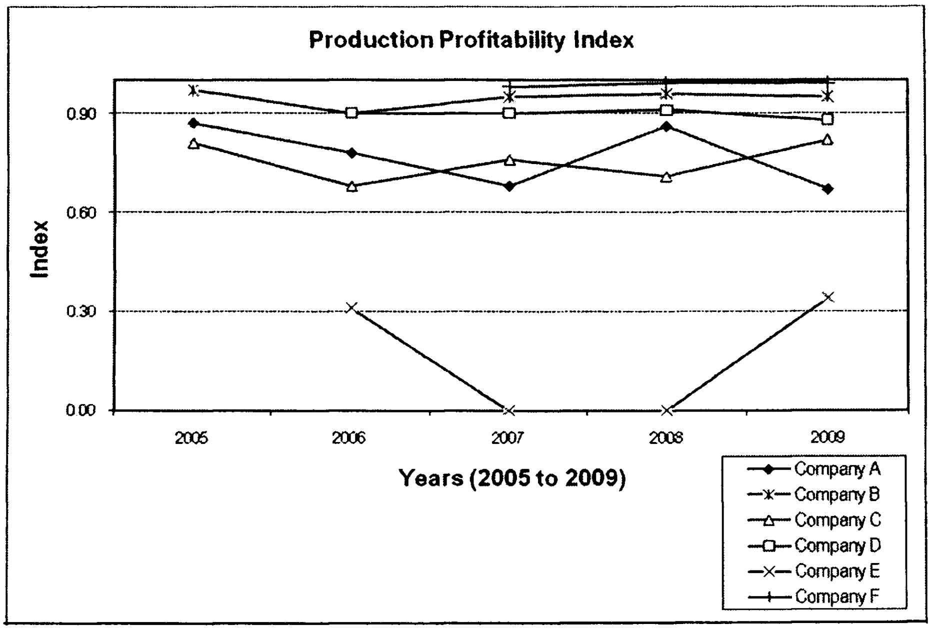


Figure 6.3: Annual Production Profitability Index (PPI)

With regard to the relationship between PPI and variety, an increment in the variety results from NPI. Hence, the relationship between PPI and NPI can be based on the relationship with the variety. The results indicate that four out of the six companies have an increment in PPI after the variety has increased. The PPI of Company E remained at 0.00 as the variety increased. However, it increased in the following years as the variety increased.

Thus, it can be concluded that the relationship between PPI and the variety is uncertain. In this regard, Langerak and Hutlink (2005) have concluded that the relationship between NPI speed and profitability is uncertain, depending on the approach used for the acceleration of New Product Development (NPD). Details of the results are shown in Appendices C-1b and C-1c.

In terms of the relationship between PPI and the number of available production resources, the addition or reduction of product resources, particularly operators, machines, and equipment affects production productivity. The results show that three out of the six companies have an increment in PPI after the number of production resources increased. However, the PPI of Company E only increased a year later. Two companies retained the same number of available production resources in which the PPI is fairly constant. Thus, it can be concluded that the number of available production resources has not strongly affected the PPI. Details of the results are shown in Appendix C-1d.

Since the PPI is closely related to the company's profit, the results of PPI need to be further justified based on company characteristics and production characteristics. In this respect, the company characteristics might have influenced the total sales quantity. On the other hand, the production characteristics might have influenced the PWI. The results from the following aspects of the company characteristics show the PPI is not strongly influenced by:

- *Industry classification*
  - the companies do not produce similar products. However, Companies E and F could have similar customers as both companies are beverage manufacturers.

- *Market status*
  - Company F (national market) outperforms Company B (international market). However, Company B is able to maintain an average annual PPI above 0.90.

- *Annual turnover*
  - Company A (highest turnover, app. 2.0 million) has lower PPI compared to Companies B, C, D and F (smaller turnover, ranging from 0.2 million to 1.5 million). However, Company E (the lowest turnover) has the lowest PPI.

- *Product classification*
  - Company A is the only company that manufactures semi-finished goods.

Following are the results of the PPI based on a comparison between the two categories defined by company characteristics and production characteristics.

A. **Comparison between two categories in company characteristics**

The detailed results are shown in Appendix C-1e.

i. Old companies versus new companies (company age)

The results show that the PPI is not affected by the company age. In fact, the new company has higher PPI than the old company. In this case, the youngest company (Company F) has performed the highest PPI of all.

ii. Market Leader versus Market Follower (market position)

The results show neither Market Leader nor Market Follower influence the PPI. Company E (Market Leader) has the lowest PPI because of the very low sales quantity. In this case, marketing strategies, such as product promotions, pricing etc. have a high impact on PPI. The results support the findings from previous studies that marketing capabilities have a strong impact on business performance (Krasnikov and Jayachandran, 2008; Nath, et al., 2010). However, production improvement strategies are also required to improve manufacturing competitiveness, especially for the Market Follower.

iii. Direct-to-Consumers versus Distributor (product distribution method)

From the results, it may be concluded that those companies which use both Direct-to-Consumer and Distributor methods would have a higher PPI compared to those that use only the Direct-to-Consumer method. This is because more demand quantities can be generated through the Distributor method. In view of this, manufacturers could use return policies and warranty length to improve the profit margin (Ketzenberg and Zuidwijk, 2009, p. 348; Menezes and Currim, 1992, p. 185; Padmanabhan and Png, 1997).

iv. Total number of production labour

From the results, it can be noted that either a large or small difference in the size of the production labour force is capable of sustaining the PPI in the Green Zone. Thus, it can be concluded that the total number of production labour has no significant influence on the PPI.

v. Standard operating hours

The results indicate that the standard operating hours do not strongly influence the PPI. For instance, two of the three companies with an eight hour operation have a higher PPI than the company with a 24 hour operation. Meanwhile, the company with an eight hour operation for only five days per week has the lowest PPI.

B. Comparison between two categories in production characteristics

The detailed results are shown in Appendix C-1f.

i. Technology intensive versus Labour intensive

The results show that the Technology intensive companies managed to achieve a higher PPI than the Labour intensive companies. The results support the theoretical concept of technology as an important tool for improving manufacturing performance, in particular quality, cost, delivery, and flexibility (Schemenner and Vastag, 2006; Small, 1999; Thomas and Barton, 2010).

ii. Production input-output classification

The results show that the production input-output variety does not strongly influence the PPI, particularly in the case of machines/equipment that have been shared by different products. This justification is based on:

- *Comparison among the productions with multiple input-output.*
  Company F manufactures two different products compared to Company D which manufactures 17 different products. The results indicate that Company F has higher PPI than Company D. In this case, Company F has fewer process changes, e.g. machine set-up. Thus, the results prove that PPI can be improved by having fewer process changes.

- *Comparison of production with single input-output to the others.*
  Production with single input-output is expected to have a higher PPI as the changes in the process are not required. However, this is not always the case: Company B has a lower PPI than Company D (production with

multiple input-output) and Company A (production with single input and multiple output). In this case, the low PPI is because of the low sales quantity.

iii. Order fulfilment based

The results show that a company with MTS strategy is capable of maintaining the highest PPI among the companies with MTO and MTS-MTO strategy. In particular, the company with MTS-MTO has managed to keep the PPI in the Green Zone. The results also indicate that the company with MTO strategy could have a lower PPI because of the demand uncertainty. Thus, it can be concluded that the order fulfilment basis has influenced the PPI.

iv. Product design/specification changes based

The results reveal that the PPI is not strongly influenced by changes in product design/specification. Three out of four companies with self-oriented products have a higher PPI than those companies with market-oriented and customer-oriented products. However, this is not always the case. Despite uncertain demands, the company with market-oriented products is able to maintain the PPI in the Green zone. Unfortunately, one of the four companies with self-oriented products has the lowest PPI in the Critical Zone.

6.3.2 Production Adaptability Index

The PAI represents production responsiveness, which is measured in respect of re-activeness and pro-activeness. In this way, the production re-activeness is determined through production effective capacity, variety, and total number of production resources. With regard to production pro-activeness, this is determined through NPI in terms of speed and variety. Thus, the PAI is used as an indicator of production responsiveness.

6.3.2.1 Monthly results

Figure 6.4 presents the monthly results of PAI for the six companies compared to DCR. The graphs show the uncertain relationship between the PAI and DCR. The effects of DCR on the PAI are observed through the constancy of the PAI over the five-year period and the changes of the PAI in a particular month.

Constancy in production responsiveness indicates consistency in production operations to changes in demand quantity. In this respect, consistency is observed through changes of effective capacity, variety, and the number of available production resources. As can be seen from Figure 6.4, despite the DCR fluctuations, Companies A, C, D, E and F have a relatively constant PAI over the five-year period whereas Company B was unable to maintain constant production responsiveness. Thus, it can be concluded that Companies A, C, D, E and F have more consistent production operations compared to Company B.

In the case of high DCR, the PAI has been increased by effective capacity where a higher production capacity is needed to adapt the high DCR in a particular month and/or the following month. In this respect, it can be noted that the MTS strategy has been applied to the production system. Thus, the results show that the larger batches result in higher productivity, and lower productivity occurs during the peak season (Berry and Cooper, 1999).

High PAI means high production responsiveness. The PAI of Companies A and D has slightly increased in recent years. In this case, the PAI increased as the result of additional variety, where the total number of production labour remained the same. Meanwhile, despite the additional variety, the PAI of Companies B, C, and F decreased because of the additional number of production resources. The PAI of Company E fluctuated over the five year period.

Therefore, the results confirm that the PAI has been strongly affected by the effective capacity. However, the PAI has also been affected by the variety, but only if the total number of production resources remains the same.

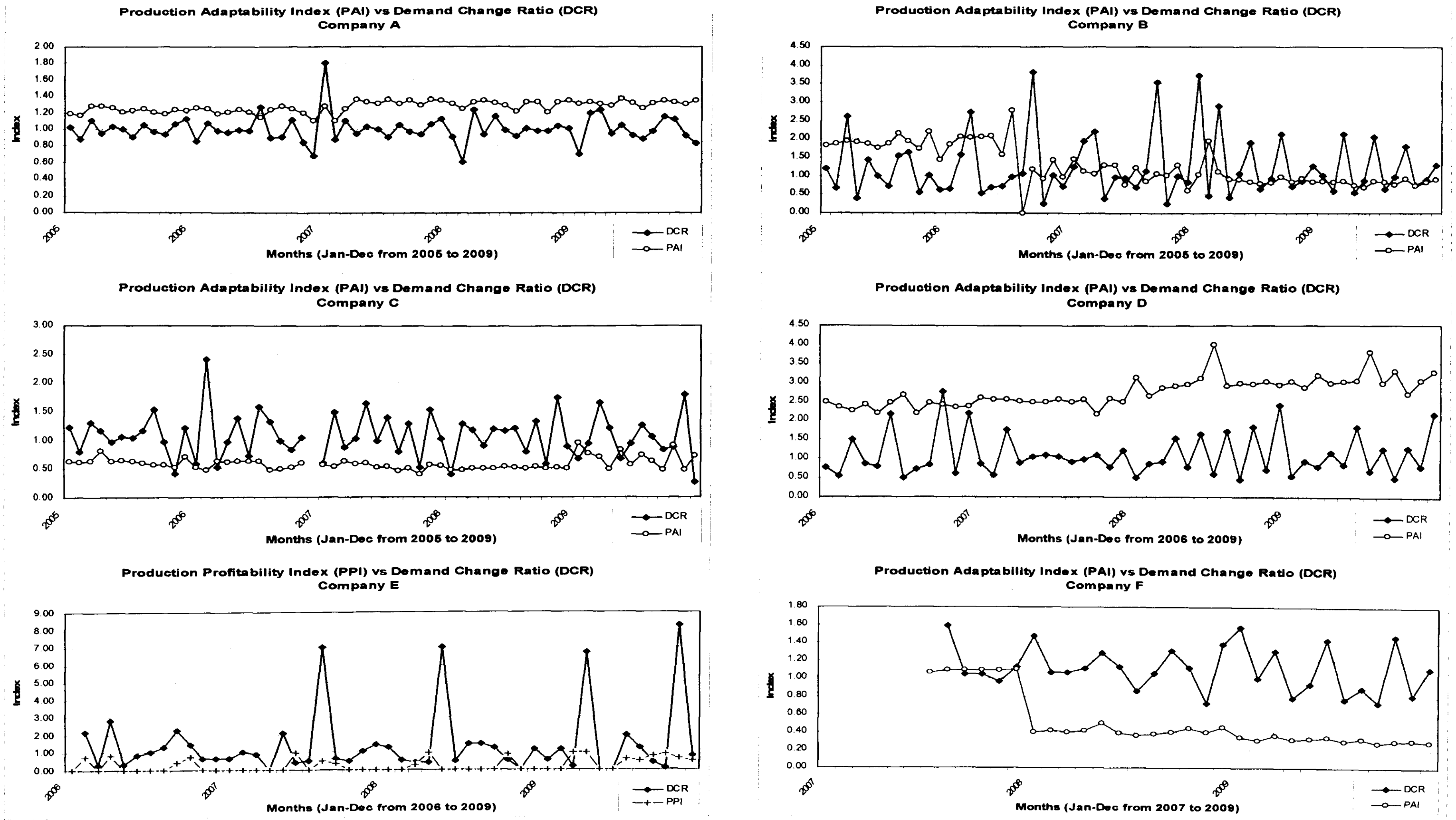


Figure 6.4: Monthly Production Adaptability Index (PAI)

6.3.2.2 Annual results

In this section, the monthly results of PAI are further justified through the annual results. The relationship between PAI and the following variables of Production Fitness can be clarified;

(i) Range-flexibility
(ii) Re-activeness
(iii) Pro-activeness
(iv) NPI

Figure 6.5 presents the changes in the variety and production range-flexibility over the five year period, where production re-activeness has been measured in respect of product mix flexibility. In this respect, the production range-flexibility represents the capability of production resources to respond to changes of demand quantity. Thus, the smallest the number of production resources, the higher the range-flexibility production could achieve.

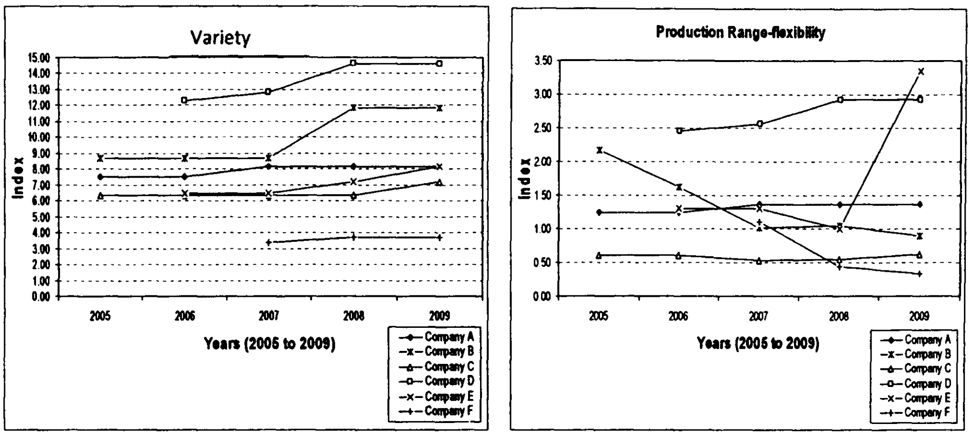
Figure 6.5 (ii) shows that production range-flexibility is not strongly influenced by the variety (as has been shown in Figure 6.5 (i)). For instance, the range-flexibility of Companies B and F has dropped since the increment in variety. However, the range-flexibility of Companies A, C, D and E increased as the variety increased. Overall, Company D continues to have the highest range-flexibility and the largest variety among the six companies.

Figure 6.6 presents the factors of PAI in respect of re-activeness (response-flexibility) and pro-activeness (NPI). As can be seen from Figure 6.6 (i), effective capacity has significant influence on production re-activeness. For instance, the production re-activeness of Company E becomes the lowest among the six companies even though the company has a larger amount of variety and a higher range-flexibility compared to Companies C and F.

Figure 6.6 (ii) presents the level of production pro-activeness in terms of NPI variety and NPI speed. The results show that Company B has the highest production pro-activeness whilst Company D has the lowest. In general, all six companies have NPI at least once within the five-year period. According to Cooper (1983), 36.5 % of current sales are derived from NPI over five years. Thus, in respect of micro-SMEs in particular, it can be concluded that the NPI occurs at least once in a five-year period. This finding is consistent with the findings of an earlier study where small-sized companies in Malaysia, especially younger companies were shown to be more likely to innovate (Lee and Lee, 2007).

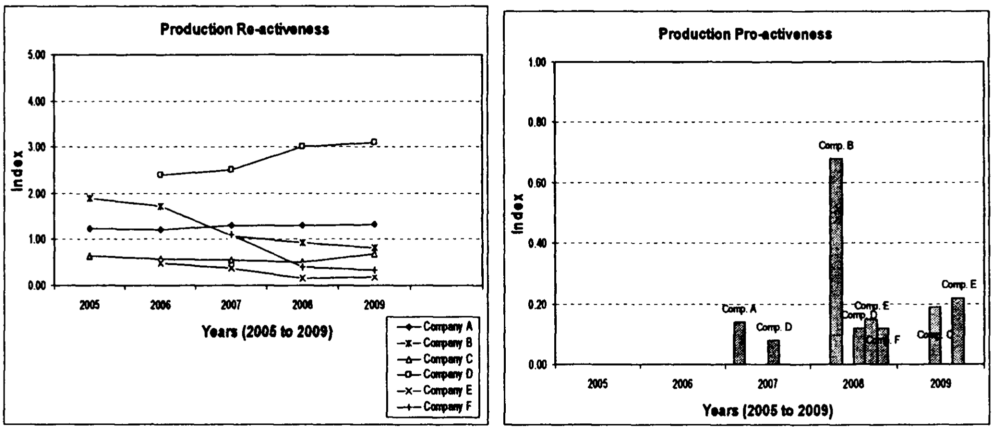
The results show the uncertain relationship between PAI and NPI. In this case, the PAI of Companies A, C, D, and E is increased by the NPI. However, the PAI of Companies B and E is decreased by the NPI. In the case of Company D, despite the low NPI, the company has the highest PAI. Thus, it can be concluded that NPI is necessary but not sufficient for increasing the PAI. These results support the conclusion from an earlier study that the ability to manufacture a new product with current existing facilities is not the key, but the fact that the product fits well with the existing production skill is clearly tied to overall performance (Cooper, 1983).

Figure 6.7 presents the annual PAI for six companies. In general, the results prove the effects of production effective capacity, variety and total number of production resources on the PAI. From Figure 6.6 (i) and Figure 6.7, it can be concluded that production re-activeness is a major influence on production agility. Note that the relationships between PAI and range-flexibility, re-activeness, and NPI are shown in Appendices C-2a, C-2b, and C-2c.



(i) (ii)

Figure 6.5: The Factors of Production Re-activeness



(i) (ii)

Figure 6.6: The Variables of Production Adaptability Index (PAI)

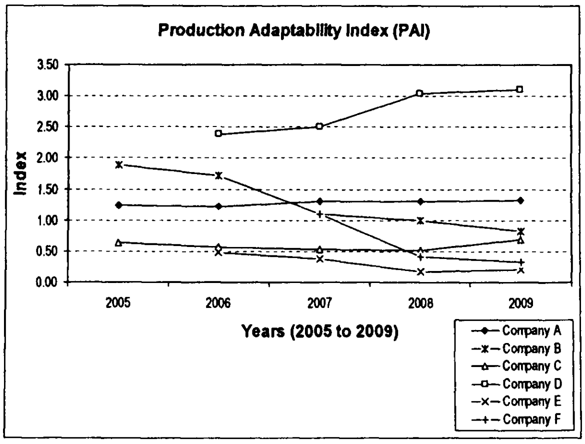


Figure 6.7: Annual Production Adaptability Index (PAI)

Apart from the above factors, the PAI is possibly influenced by the nature of company characteristics and production characteristics. In terms of company characteristics, the results show that the PAI is not strongly influenced by:

- *Industry classification.*
  - the companies in the Chemical industry show the highest PAI, however, one of the companies has a decrement in PAI which is slightly lower than the PAI of the company in the Plastics industry.

- *Product classification*
  - the companies which manufacture consumer products could have higher or lower PAI than the semi-finished goods company.

- *Market status*
  - one of the five companies involved in the national market show the highest PAI. The PAI of the international market company is the second highest but has decreased in recent years.

- *The product distribution method*
  - the companies with the Distribution method could have higher or lower PAI than the companies with the Direct-to-Consumer and Distribution method.

- *Annual turnover*
  - The company with only 0.5 million annual turnover shows the highest PAI compared to companies with larger annual turnover. Meanwhile, the company with the smallest annual turnover show the lowest PAI.

Following are the results of the PAI based on comparison between the two categories defined in the company characteristics and production characteristics.

A. <u>Comparison between two categories in company characteristics</u>

The detailed results are shown in Appendix C-2d.

i. Old companies versus new companies (company age)

The results indicate that the PAI is not strongly influenced by the company age. In fact, the new companies show variations in PAI as one new company has far higher PAI than the old companies, while the other two new companies have slightly lower PAI.

ii. Market Leader versus Market Follower (market position)

The results show that being Market Leader or Market Follower is not a guarantee for higher PAI. Thus, it is proved that the market needs newness and differential advantages, in particular quality and superiority, but relies more on uniqueness of product (Debruyne, et al., 2002).

iii. Total number of direct-labour

As expected, the number of production labour influences the PAI, especially in the case of increment in size of variety. With the smallest variety, Company F which operates with the highest number of production labour has the lowest PAI.

iv. Standard operating hours

The results show that companies with eight hours operations per day are able to have higher PAI compared to companies with 24 hour operations. Consequently, this indicates that the standard operating hours have no influence on the PAI.

B. <u>Comparison between two categories in production characteristics</u>

The detailed results are shown in Appendix C-2e.

i. Technology intensive versus Labour intensive

The results prove that the Technology intensive category provides higher PAI compared to the Labour intensive. In this case, the semi-auto processes are applied purposely to increase productivity and the variety. For instance, Company D is able to produce 17 different products after upgrading the packaging process to semi-auto process. In turn, Company D has the highest PAI among the six companies.

ii. Order fulfilment based

The results show that the company with the MTS strategy has the lowest PAI. Meanwhile, the companies with MTO-MTS strategy have higher PAI than the companies with MTO strategy. Since the demand quantity of Company F is uncertain, the result disproves the concept of using MTS strategy for flexibility (Rajagopalan, 2002). In the meantime, the results support the concept of MTO-MTS strategy which is applicable for production involved in the competitive market of high product variety (Diwakar and saif, 2004; Soman, et al., 2004).

iii. Production input-output variety

As expected, the production with multiple input-output has higher PAI than the production with single input-output. In this regard, the PAI is closely related to the number of changes in set up times which correlates to the production input-output variety.

iv. Product/specification changes based

The results indicate that the product/specification changes through market-oriented have a higher PAI compared to self-oriented and customer-oriented. In this regard, a higher PAI would be expected from the companies which are involved in rapid changes in market demand. The ability of the firm to adapt to change is one of the capabilities of the market-driven organisation (Day, 1994).

6.3.3 Production Stability Index (PSI)

Production capacity, inventory and demand are the three factors which determine the PSI. Over capacity and shortage capacity are signs of imbalance in the demand-supply system which has a negative impact on production costs. Thus, the PSI represents production stability in respect of changes in demand quantity. In this respect, the ideal PSI is equal to 1.00 which indicates perfect production stability.

6.3.3.1 Monthly results

Figure 6.8 presents the results of monthly PSI for the six companies. The graphs show the uncertain relationship between PSI and DCR. The effects of DCR on the PSI are observed through the constancy of the PSI over the five year period and the changes of the PSI in a particular month.

The graphs in Figure 6.8 indicate the uncertain relationship between PSI and DCR. Constancy in production stability indicates the capability of production to constantly supply the required demand quantity with a minimum possible inventory and zero shortage quantity. Despite fluctuations in demand quantity, Companies C and F prove that the constancy of ideal PSI can still be achieved, unlike Companies A, B, D, and E where the PSI fluctuated with the fluctuation of the DCR.

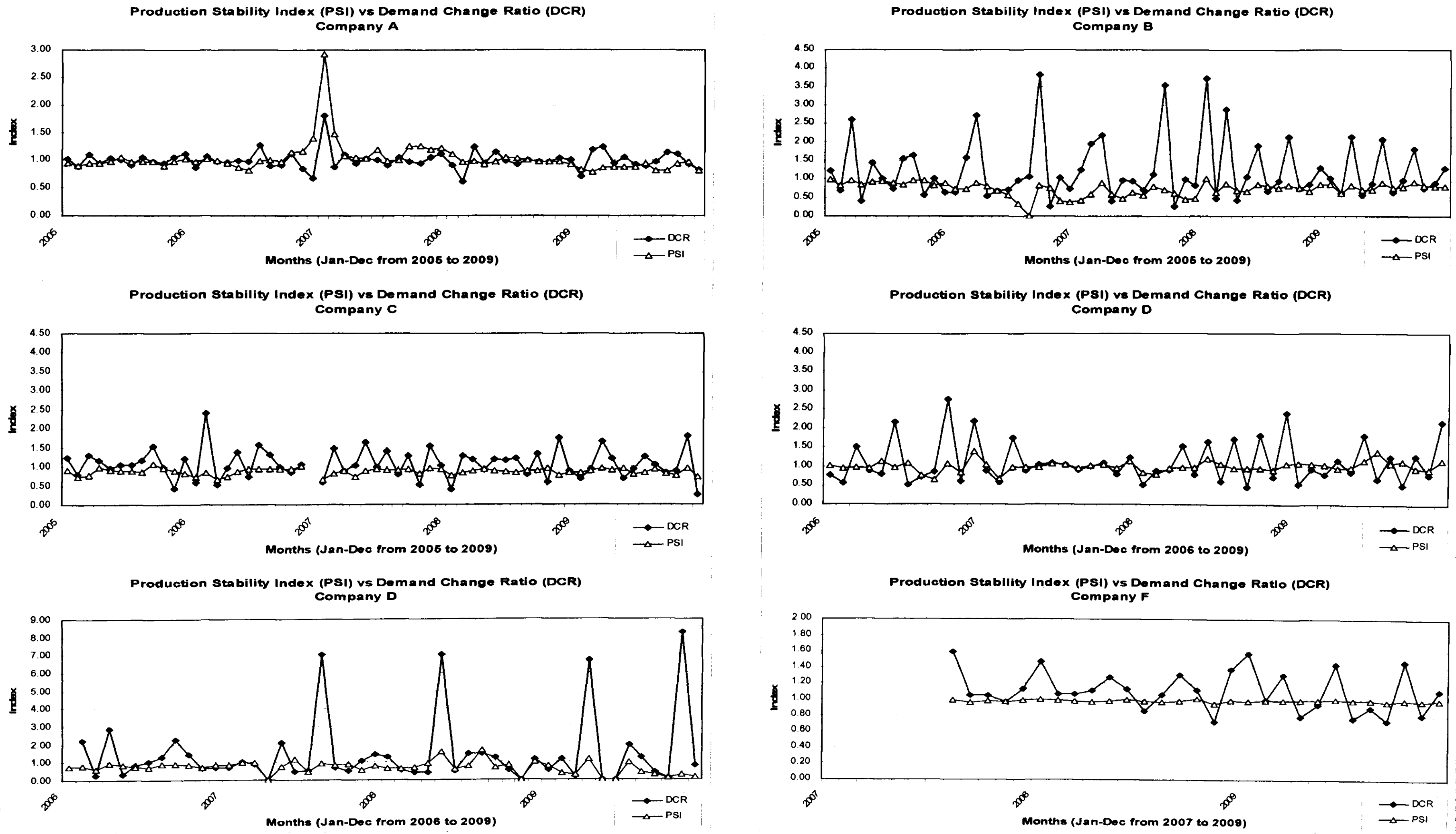


Figure 6.8: Monthly Production Stability Index (PSI)

Overall, it can be seen that the six companies managed to avoid a massive over capacity (PSI < 0.5) and shortage capacity (PSI > 1.5) over the five year period. In early 2007, Company A had the highest PSI because of a major flood in the region. Production was severely shutdown during which time most of the demand quantity had to backlog. Thus, it can be concluded that the PSI is not strongly influenced by the DCR.

6.3.3.2 Annual results

In this section, the monthly results of PSI are further justified through the annual results. The relationships between PSI and the following variables of Production Fitness can be clarified:

(i) Effective capacity

(ii) Variety

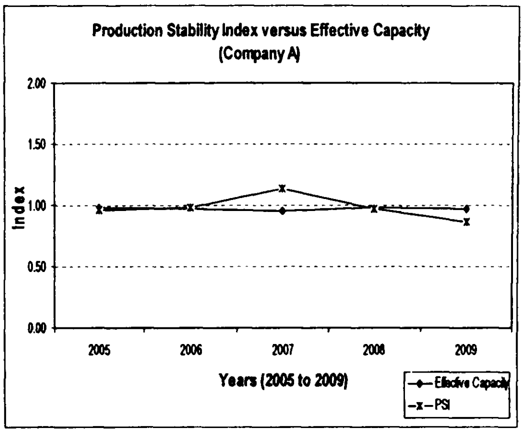
Figure 6.9 represents the relationship between PSI and effective capacity for the six companies. Production capacity and inventory are generated from the effective capacity. As can be seen from the graphs, the PSI is decreased by the increment in effective capacity. Here, the decrement in PSI means that the production capacity is more than the demand quantity, which is known as over capacity. However, the increment in effective capacity is sometimes necessary to recover the shortage capacity in the previous period. In this case, as illustrated in Figure 6.9 (c), the

PSI is likely to be unaffected by the effective capacity. Thus, the results prove the inverse relationship between the PSI and effective capacity in general.

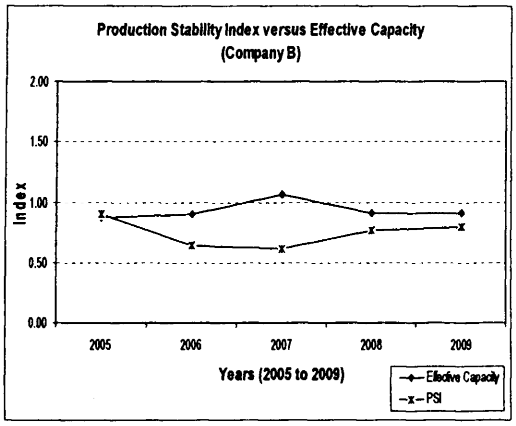
In terms of the variety, the relationship between the PSI and variety is justified based on two aspects: *(i) Comparison between the companies; (ii) The changes in variety.* In the first aspect, the results show that the variety has not affected the PSI. Thus, it can be concluded that the company which has the larger variety would be able to achieve the ideal PSI.

In the second aspect, the result shows that the PSI increased as the variety increased. In this respect, the increment of PSI contributed to both positive and negative impact on production stability. The increment of PSI is considered positive to production with over capacity, but not to production with shortage capacity. Thus, it can be concluded that the variety has not strongly influenced the PSI. As the variety is increased by the NPI, the PSI has a similar relationship with NPI. Details of the results are shown in Appendices C-3a and C-3b.

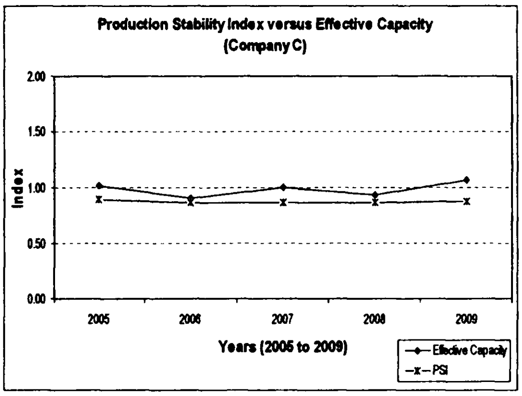
Figure 6.10 presents the PSI for the six companies. In general, the results show that three of the companies have a PSI relatively close to 1.00 while the other three have a PSI ranging from 0.6 to 0.8. Thus, it can be noted that the micro SME is likely to have more capacity than the required demand.



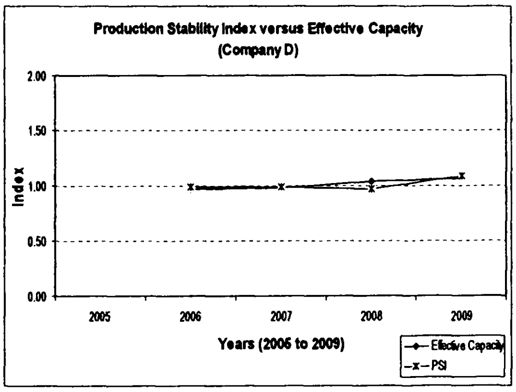
(a)



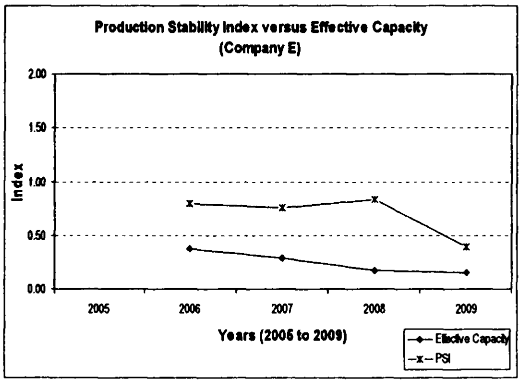
(b)



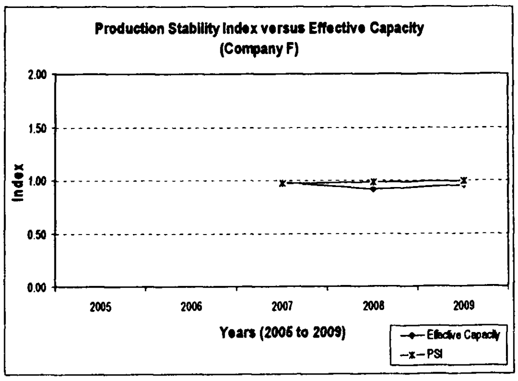
(c)



(d)



(e)



(f)

Figure 6.9: Relationship between PSI and Effective Capacity

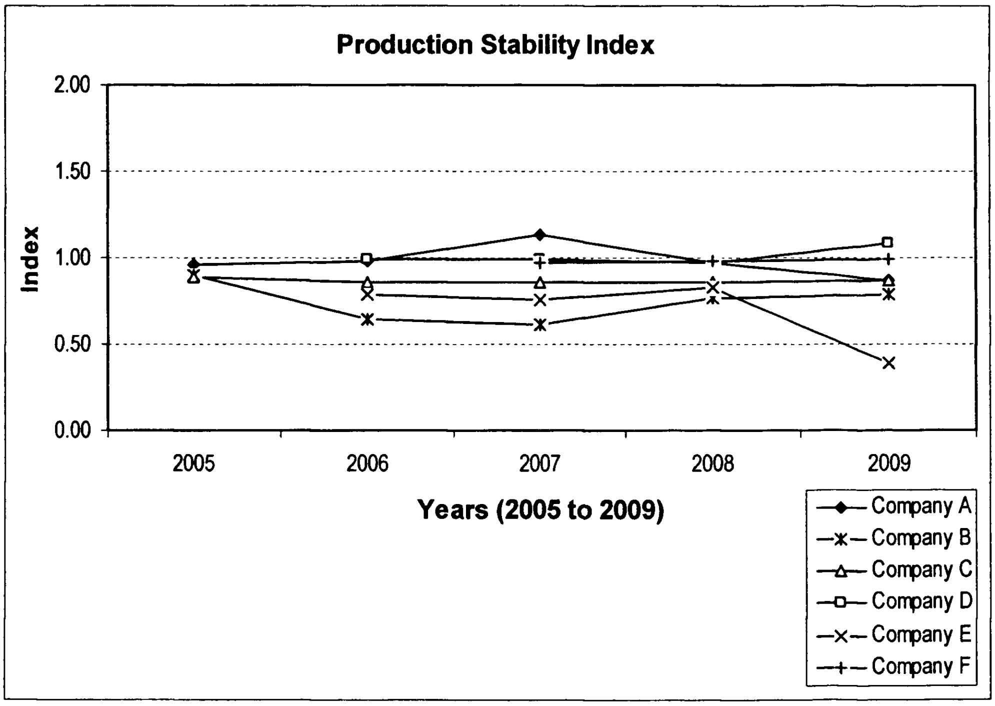


Figure 6.10: Annual Production Stability Index (PSI)

To further justify the results of the PSI, the specified criteria of company characteristics and production characteristics are used accordingly.

In the aspect of company characteristics, the results show that the PSI is not influenced by:

- *Industry classification.*
  - the results do not show any significant relationship between the types of industry and the PSI. For instance, the company in the Chemical industry has a PSI as close to 1.00 as companies in the Plastics and Beverage industries.

- *Product classification*
  - the results indicate that the consumer-product manufacturers and the semi-finished goods manufactures have a PSI close to 1.00.

- *Annual turnover*
  - the results show the company with higher annual turnover (1.5 million) has lower PSI than the company with the smallest annual turnover (0.05 million).

In the aspect of market position, the results show the lowest PSI from the company with an international market. In the case of micro-SMEs, companies involved in the international market might prefer to keep a higher inventory for more flexible delivery.

A. **<u>Comparison between two categories in company characteristics</u>**

The detailed results are shown in Appendix C-3c

i. Old companies versus new companies (company age)

The results show that two of the three new companies have a better PSI than the old companies. In fact, the old companies are likely to have a smaller PSI which is a sign of over capacity. Thus, it can be concluded that the PSI is not strongly influenced by company age.

ii. Number of production labour

The results illustrate that the company with four production labour forces has PSI close to 1.00 which is also achieved by the company with eight production labour forces. It can be concluded that the PSI is not influenced by the number of production labour.

iii. Market Leader versus Market Follower

The results indicate that neither Market Leader nor Market Follower influence the PSI. In this regard, it can be concluded that product innovations are not related to the PSI.

iv. Direct-to-Consumers versus Distributor (product distribution method)

The results show no difference in PSI between the two types of product distribution method. Thus, it can be concluded that the PSI is not influenced by the method of product distribution.

B. <u>Comparison between two categories in production characteristics</u>

The detailed results are shown in Appendix C-3d

i. Technology intensive versus Labour intensive

From the results, it can be seen that the companies with Technology intensive characteristics have better PSI at close to 1.00. The companies with Labour-intensive characteristics are likely to prefer to use over capacity to cope with demand changes.

ii. Production input-output variety

The results show that production with single input-output has the lowest PSI. In contrast, production with multiple input-output has a PSI close to 1.00. In the case of single input-output, a large size of production batch is normally used. Thus, the results show the impact of a large volume batch on the inventory, especially in low demand quantity.

iii. Order fulfilment based

The results show the order fulfilment strategy does not strongly influence the PSI. The PSI of companies with both MTO and MTS strategy ranges from 0.6 to 1.10. In the case of MTO strategy, Company E has a lower PSI than Company A in fact, it is the lowest among the six companies. This is because of the inconsistent demand on Company E's products. Conversely, Company A has managed to maintain the PSI close to 1.00 as demand is relatively constant. In general, the company with MTS strategy is expected to have a low PSI because of the inventory. However, it is not always the case as the PFI of Company F is relatively close to 1.00.

iv. Standard operating hours

The results indicate that the standard operating hours has not influenced the PSI. In particular, Company A and Company F has managed to have PSI relatively close to 1.00.

v. Design/specification changes based

The results show that the design/specification changes based characteristic does not influence the PSI. The companies involved in design/specification changes by customer-oriented and market-oriented products have better PSI than companies with self-oriented products. In this respect, the companies with self-oriented products are likely to keep inventory for the products which are new to the market.

6.3.4 Production Fitness Index

In this study, Production Fitness has been referred to as the capabilities of production operations to achieve manufacturing competitiveness. Integration of LM, AM and Sustainability concepts is applied to improve production operations. In this regard, the PFI is used to determine Production Fitness based on the PPI, PAI and PSI. In short, a constant increment in PFI is necessary for manufacturing companies to survive, especially in a highly competitive market.

6.3.4.1 Monthly results

Figure 6.11 presents the PFI of the six companies compared to DCR. In this case, the monthly results are used to observe the trend of PFI over the five-year period. The trend is significant to production performance in terms of constancy. Therefore, it is important to sustain the PFI at more than 0.00 where the higher PFI means the fitter the production system to the changes of demand.

As can be seen from the graphs, the trend of PFI is slightly similar to the trend of DCR. However, there are points where the PFI is against the DCR. In this case, the points illustrate the adjustability of the production system towards sustainability. Overall, the results show five of the six companies have managed to sustain Production Fitness at a different PFI which Company D has the highest PFI. Meanwhile, Company E has failed to sustain the PFI at more than 0.00 on several occasions. Thus, it can be concluded that the PFI has occasionally been affected by the DCR.

To further justify the results of the PFI, the annual results are used to observe the relationships between the PFI and PPI, PAI, and PSI. Furthermore, the results from the SWOT analysis are also used to support justification of the PFI.

6.3.4.2 Annual results

The relationships between the PFI and PPI, PAI, and PSI can be clarified from the annual results. In addition, the annual results are used to view the PFI from different manufacturing industries. Meanwhile, the changes in PFI can also be observed within the five-year period.

Figure 6.12 presents the relationship between the PFI and PPI, PAI, and PSI. As seen from the graphs, it can be noted that the PFI is relatively closed to the PAI when the PPI and PSI is equal to 1.00. In this case, the ideal Production Fitness has been achieved through the following factors:

- continuous demand flows into the production system.
- efficient production operations..
- dependable production capacity.

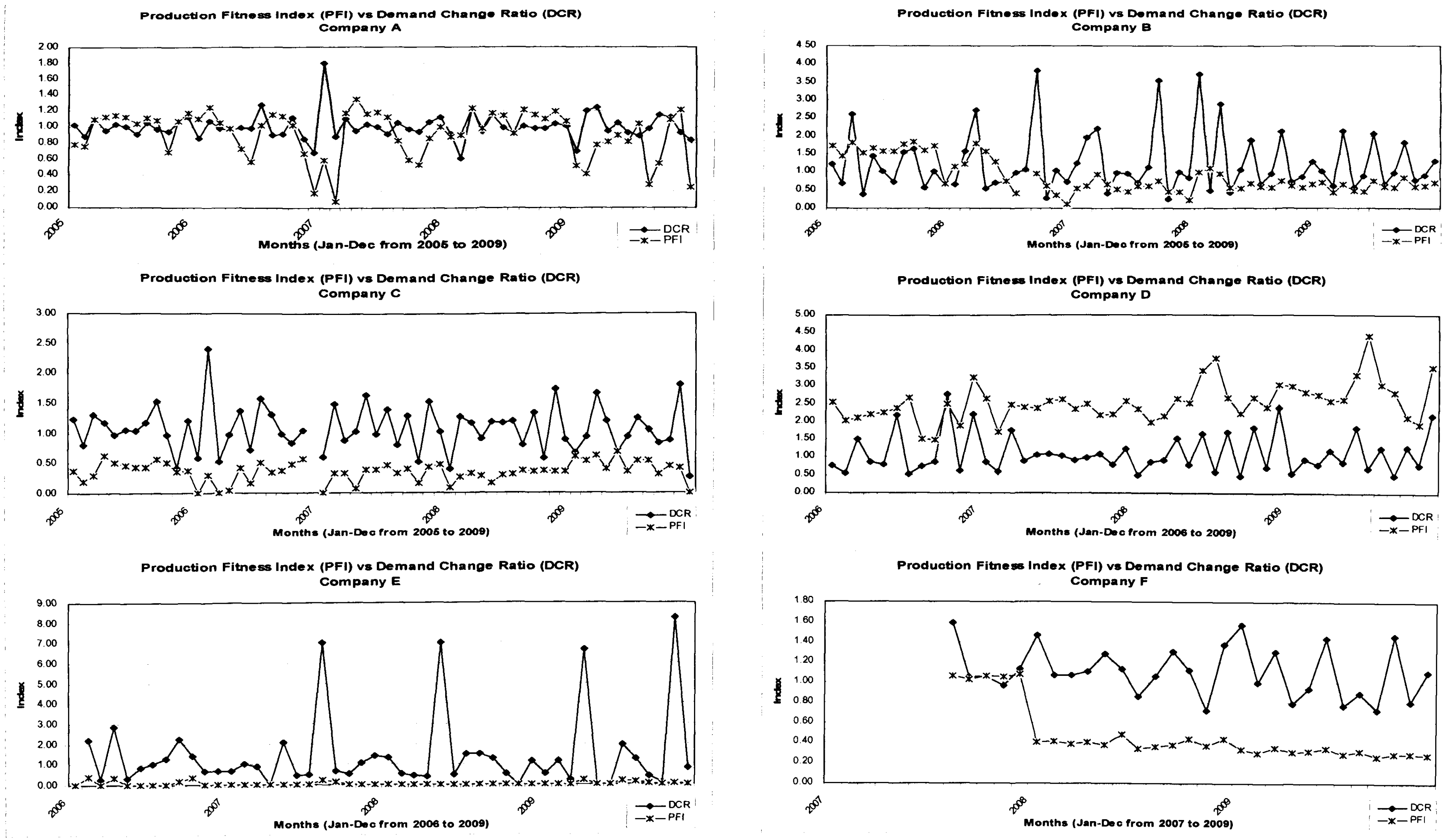
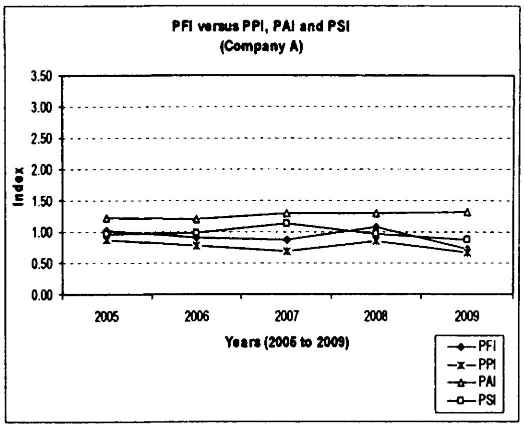
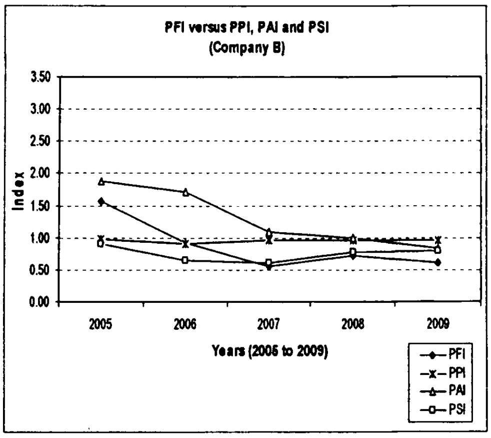


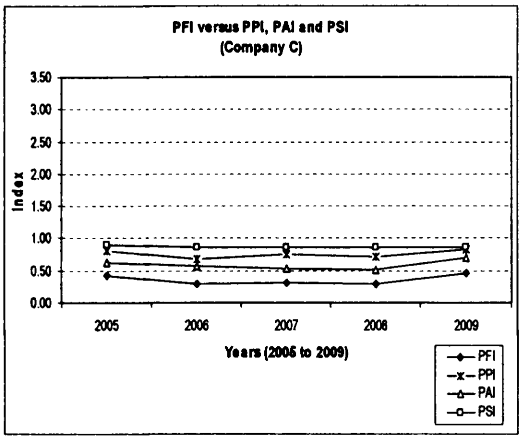
Figure 6.11: Monthly Production Fitness Index (PFI)



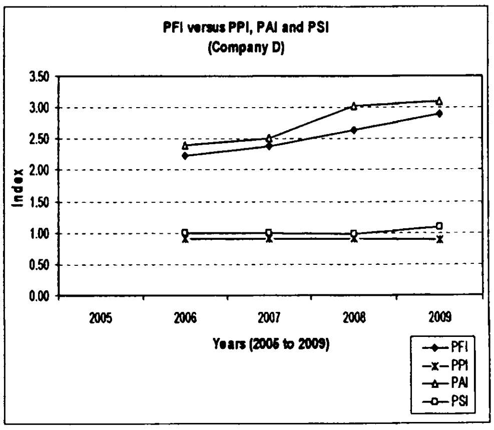
(a)



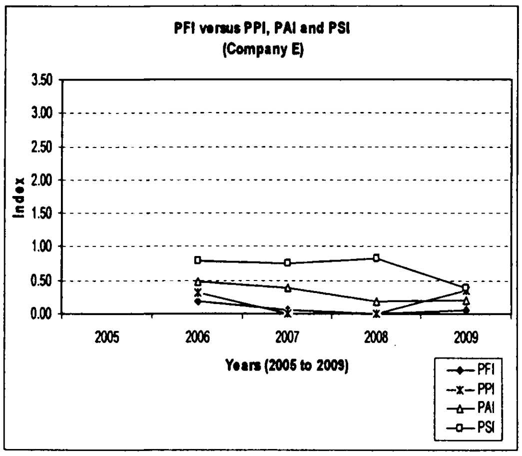
(b)



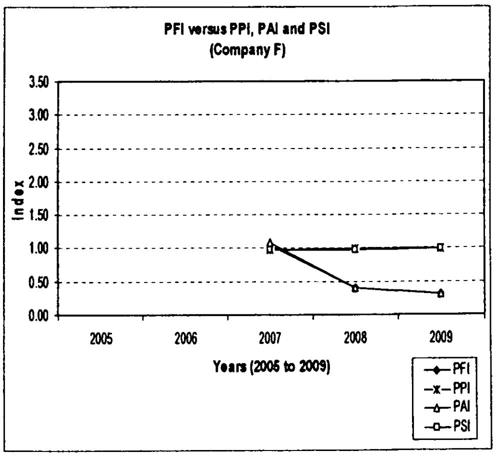
(c)



(d)



(e)



(f)

Figure 6.12: Relationship between PFI and PPI, PAI and PSI

From the results, it can be seen that Companies D and F have achieved the ideal Production Fitness. Since Company D and Company F are from different manufacturing industries, their PFI is not comparable to one another. In this regard, the ideal Production Fitness can be used for self-competitiveness. Self-competitiveness refers to continuous improvements in production operations towards the constancy of the PFI.

However, being competitive is crucial to manufacturing companies which are in the same industry. In this respect, competition in the PFI between manufacturing companies is necessary. For instance, both Companies E and F are beverage manufacturers located in the same region. From Figure 6.13, the results indicate that Company E has far a lower PFI than Company F. It can also be noted that Company E has the worst Production Fitness of all. In this case, Company F has fitter production operations than Company E.

As can be seen from the graphs in Figure 6.13, Company D has the highest PFI which ranges from 2.00 to 3.00. Companies A and B have PFI ranges between 0.50 and 1.50. Meanwhile, Companies C, E, and F have lower PFI which ranges from 0.00 to 0.50. Thus, the annual PFI of different manufacturing industries is viewed from the highest to the lowest:

(i) 2.00 – 3.00: Chemical industry - Soap and detergents, cleaning & polishing preparations

(ii) 0.50 – 1.50: Rubber and Plastic Products industry
Chemical industry – Fertilisers

(iii) 0.00 – 0.50: Beverages industry
Food Products industry

From the graphs of Companies B and F, it can be noticed that the PFI has dropped drastically. In this case, the PFI of Company B has fallen because of the low effective capacity. For Company F, the PFI dropped after the number of production labour increased, whilst the variety remained steady. Thus, it can be concluded that the PFI has been strongly affected by the components of Production Fitness.

However, the PFI could be affected by the company's strengths, weaknesses, opportunities, and threats. For instance, environmental regulations and international trade regulations could be threats for manufacturing companies from the Chemical industry to expand the variety. Therefore, the results of the PFI are further justified by using the results of SWOT analysis. Table 6.4 presents the results of the SWOT analysis for the six companies.

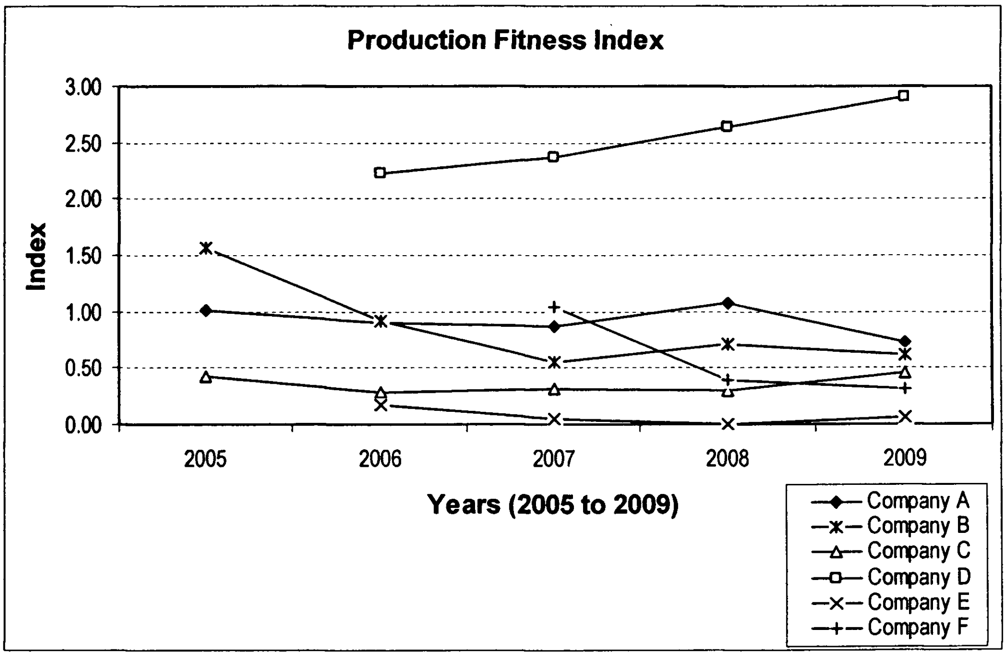


Figure 6.13: Annual Production Fitness Index (PFI)

Table 6.4: Summary of the SWOT Analysis Results

SWOT Analysis	Manufacturing Companies					
	A	B	C	D	E	F
Strengths						
Quality		✓	✓	✓	✓	✓
Low price				✓		✓
On-time delivery	✓	✓	✓	✓		
Product variety				✓	✓	
Innovative products		✓	✓	✓	✓	✓
Market leader	✓	✓			✓	✓
Others	Largest market share	Unique products			Unique products	Unique products
Weaknesses						
Limited capacity (time and space)	✓	Limited space		Limited space	Limited space	
Lack of marketing strategies		✓		✓	✓	✓
Skilled workers (production management or/and marketing)	Production management	✓		✓	✓	
Others	High rate of scraps		Manual operations		Manual operations	Negative cash flow
Opportunities						
New market		✓			✓	✓
Growth market (domestic)	✓	✓	✓	✓	✓	
Growth market (International)		✓				✓
Capacity expansion				✓	✓	✓
Others	New product model		Product variety	Training services		
Threats						
Environmental regulations	✓	✓		✓		
Worker retentions	✓		✓			
Customised machines					✓	
Raw materials			✓	✓	✓	Packaging materials
International trade regulations		✓			✓	✓
Others		Long-term customer approval		Price competition		Competing with unoriginal products

CASE STUDY 1 - Company A (*Rubber and Plastic Products Industry*)

The PFI of Company A was the third highest among the six companies in the first three years. In 2008, the PFI increased from 0.87 to 1.08, resulting from the NPI. However, the PFI dropped to the lowest point (PFI = 0.72) in the following year. In this case, the PFI was affected by the low demand quantity resulting from new environmental regulations in respect of PVC products. As a result, the PPI was affected by the low demand quantity in respect of time losses. In the meantime, the PSI was also affected in that the company carried a high inventory.

Based on the result of the SWOT analysis, by 2015, the production of PVC plastic film in Malaysia will be terminated. Therefore, the production of PVC products needs to be reduced gradually. Thus, the new environmental regulations threaten the company from expanding the variety for PVC plastic film to enhance the PFI. In this regard, the company is in the planning stages of shifting to the production of PET plastic film. Consequently, the company needs to overcome the weaknesses in order to improve the PFI. With the company opportunities, the PFI can be further improved.

CASE STUDY 2 - Company B (Chemical Industry – Fertilisers)

The PFI of Company B continually dropped over the first three year period. Even though Company B was able to sustain the PPI close to 1.00, the PAI of the company decreased for the following reasons:

- 2006 – the packaging process was upgraded to semi-auto, which resulted in more production capacity than demand quantity.
- 2007 – additional total number of production labour.
- 2008 – additional new lines for new products.

In this case, the PFI of Company B was affected by range-flexibility where more production resources were used for the same variety. Unfortunately, the demand quantity has slightly decreased in recent years resulting in a high inventory. This is consistent with the claims of Sohal and Egglestone (1994), "*The consumer goods industry had the highest inventory turnover*".

With current strengths and opportunities, the PFI of Company B can certainly be improved through more effective capacity and sales quantity. In addition, the company has to overcome its weaknesses and threats.

CASE STUDY 3 - Company C (Food Products Industry)

Company C is considered to have low PFI ranging from 0.30 to 0.46. In this regard, the low PFI is mainly caused by the small variety. However, the company has fairly constant PFI resulting from constant PPI, PAI, and PSI (as is shown in

Figure 6.12 (c)). According to Soman et al. (2004), the food processing industries is part of a very competitive supply chain and has to cater for an increasing number of products and stock keeping units (SKUs) of varying logistical demand (e.g., specific features, special packaging and short due dates).

In this case, it is crucial for Company C to sustain the constancy of the PFI in order to remain competitive. Results from the SWOT analysis show unsustainable raw materials and worker retentions are critical threats which would affect the constancy of the PFI. The company also needs to improve the weaknesses and increase the number of strengths in order to increase the PFI.

CASE STUDY 4 - Company D (Chemical Industry - Soap and detergents, cleaning & polishing preparation)

Company D had the highest and ideal PFI over the five-year period. Variety is the main factor of high PFI and the company has the largest variety among the six companies. The company managed to achieve a consistent PPI and PSI relatively close to 1.00 which is necessary for long term survival. As can be seen from Figure 6.12 (d), the PFI of Company D increased as the PAI increased. Thus, the results prove that the PFI can be enhanced by increasing the variety as long as the PPI and PSI remain close to 1.00. In order to enhance the PFI and retain the consistency of the PPI and PSI, Company D has to overcome threats and weaknesses.

Based on the results of the SWOT analysis, price competition is a critical threat to the company. According to Melton (2005), the price imposes continuing pressure on the cost base. Meanwhile, variations in consumer preferences cause productivity differences in the soap and detergent business (Lewis, et al., 1993). In this case, more sales quantity can be generated from the company's opportunity by providing training services to customers. To achieve a sustainable flow of demand quantity, Company D has to maintain current strengths in order to win customer loyalty.

CASE STUDY 5 - Company E (Beverages Industry)

Despite a higher variety than Companies C and F, Company E had the lowest PFI. Even worse, the company reached a PFI equal to 0.00 several times. In this case, the major problem of the company is ineffective capacity due to the very low sales quantity. However, the company has managed to improve the PFI in recent years, when the PFI increased from 0.00 to 0.06.

Based on the results of the SWOT analysis, Company E has to compete with Company F in terms of price. In this regard, the company lacks marketing strategy and has failed to generate a continuous flow of demand quantity. Therefore, the company has to improve the PFI with stronger marketing strategies. To improve the PPI, PAI, and PSI, the company needs to improve other weaknesses, such as manual processes and limited space for capacity expansion. In this case, the PFI can also be further enhanced through sustainable strengths and opportunities.

CASE STUDY 6 - Company F (Beverages Industry)

Company F managed to have a constant PFI with ideal Production Fitness over the five year period. However, the PFI has decreased in recent years because of low range-flexibility after an increase in production labour. In this case, Company F is considered insufficiently competitive with a low PFI. In order to be competitive, the company has to increase the PFI through expansion in the variety. In the meantime, the current PPI and PSI have to be sustained.

Based on the results of the SWOT analysis, the company has to overcome the threats as well as the weaknesses, especially the copyright issue (competing with unoriginal product) and the inconsistent supply of packaging materials.

6.4 Summary

In general, the monthly and annual results show the effects and relationships involved in the PPI, PAI, PSI, and PFI. A summary of the results is presented in Table 6.5. The results are justified based on the factors of Production Fitness. The factors are divided into four categories: *(i) Demand* *quantity;(ii) Specific variables; (iii) Company characteristics, (iv) Production characteristics.* The SWOT analysis results have been used to further justify the Production Fitness measures, especially the PFI.

In the first category, the changes in demand quantity strongly affect the PAI and PFI. The DCR does not strongly affect the PSI, whilst the PPI is not affected at all. As dynamic environments lead to poor operational performance (Olhager and Selldin, 2007), the constancy of the PAI and PFI is necessary for company survival.

Moving on to the second category, effective capacity is proved to be the core factor of Production Fitness as it affects the PPI, PAI, and PSI. In this respect, the PPI, PAI, and PSI are proved to be functions of the PFI, where a large amount of variety with a minimum number of production resources contributes to a high PFI. However, the NPI would be insufficient if the high PPI had not been sustained where a high PPI is generated from a low PWI. In this regard, a higher PFI is necessary for the highly competitive market.

In the third category, the product distribution method strongly influences the PPI where the distributor method contributes to a higher PPI. For the PAI, the amount of production labour influences the PAI, which affects production range-flexibility. The PSI is relatively influenced by market status.

Table 6.4: Summary of the Results of Production Fitness Measures

Influential Factors	The Fitness Measures (Index)				Remarks
	Lean	Agile	Sustainable	Fit	
Demand Quantity	**PPI**	**PAI**	**PSI**	**PFI**	
Demand Change Ratio (DCR)	No	**Yes**	Not strongly	**Yes**	
Specific Variables					
1- PWI	**Yes**	na	na	na	PPI, PAI, and PSI are the function of PFI.
2- Effective capacity	**Yes**	**Yes**	**Yes**		
3- Variety	Not strongly	**Yes**	Not strongly		
4- Total number of production resources	Not strongly	**Yes**	na		
5- NPI	Not strongly	Not strongly	Not strongly		
Company characteristics					
1- Year established	No	Not strongly	Not strongly	na	PFI has been further justified by using SWOT analysis
2- Industry classification	Not strongly	Not strongly	No		
3- Product classification	Not strongly	Not strongly	No		
4- Market status (National/International)	Not strongly	Not strongly	**Yes**		
5- Market position (Leader/Follower)	No	No	No		
6- Product distribution method	**Yes**	Not strongly	No		
7- Annual turnover	Not strongly	Not strongly	No		
8- Number of production labour	No	**Yes**	No		
9- Standard operating days	Not strongly	No	No		
Production Characteristics					
1- Production input-output variety	Not strongly	**Yes**	**Yes**	na	
2- Production Operations based	**Yes**	**Yes**	**Yes**		
3- Order fulfilment based	**Yes**	**Yes**	Not strongly		
4- Standard operating hours	Not strongly	No	No		
5- Design/specification changes based	Not strongly	**Yes**	**Yes**		

In this case, the company involved in the international market is likely to have a low PSI. This finding is consistent with the conclusion of an earlier study that the new products market, including export and world markets, does not show a significantly better performance than companies with a domestic focus (Debruyne, et al., 2002).

For the fourth category, production operations based on intensive technology strongly influence the PPI, PAI, and PSI. The MTO strategy negatively influences the PPI, but has a positive influence on the PAI. Production with multiple input-output positively influences the PAI, whilst the single input-output production negatively influences the PSI. Changes in design/specification based on market-oriented characteristics positively influence the PAI. However, changes due to self-oriented characteristics negatively influence the PSI.

Overall, the ideal PFI has been achieved by two of the six companies, which are Company D and Company F. The results of the PFI are further justified, based on the SWOT analysis, where the company's strengths, weaknesses, opportunities and threats are related to the constancy of the Production Fitness components.

In summary, the significance of the Production Fitness measures to production performance is determined by the ideal PFI and the constancy of the PPI, PAI, and PSI. In this regard, a high PFI is not necessarily ideal. Companies operating in the same market segment using similar functional strategies can have dramatically different levels of performance (Grewal and Slotegraaf, 2007). Thus, the PFI is comparable between manufacturing companies in the same industry.

Chapter 7

Chapter 7
CONCLUSION

7.1 Contributions

This research introduces a model for measuring production operations performance, known as Production Fitness measures. The aim is to provide a measure for the Production Fitness Index that can be applied as a decision support tool for production and marketing. The main contributions of this research are:

(i) *A distinct approach to measuring production operations performance.* The model of performance measure has been designed based on integration of the concepts of leanness, agility, and sustainability. Leanness, agility, and sustainability have been clarified as the dimensions of Production Fitness. Thus, research objective (i) has been achieved.

(ii) *A thorough analysis of Production Fitness dimensions.* Analogical study of the human body system and human fitness components are proved to be compatible with the manufacturing system. In general, leanness, agility, and sustainability concepts determine survival, especially in competitive environments. The components of

Production Fitness have been clearly identified. Thus, research objective (ii) has been achieved.

(iii) *A simple architecture for the Production Fitness measurement system.* This has been developed from the structure of leanness, agility, and sustainability based on fundamental production operations system. The functions of leanness, agility, and sustainability in production system have been identified. Thus, research objective (ii) has been achieved.

(iv) *A simple objective measure for production operations performance.* An index has been used as an indicator of the Production Fitness measures, which apply common production data and sales data for the measurement inputs. In this way, it is more practical for industrialists to adapt the measures to their current system. The relationship between demand changes and the Production Fitness components has been clearly defined. Thus, research objective (iii) has been achieved.

(v) *A method for measuring variety (constituting product variety and volume variety).* A measure of variety has been proposed using the Product Family Classification Tree (PFCT) diagrams. External variety (customer preferences) and internal variety (manufacturing preferences) are linked through the PFCT diagram. The ideal Production Fitness has been clearly defined. Thus, research objective (v) has been achieved.

(vi) *A thorough analysis of integrated manufacturing concepts.* The leanness (LM), agility (AM), and sustainability concepts have been integrated to form a set of production capabilities, termed Production Fitness. Effective capacity has been shown to be the core element of production profitability, adaptability, and stability. The factors influencing Production Fitness have been identified and the strategies for improving indices in the Production Fitness measures have also been proposed. Thus, research objectives (iv), (vi) and (vii) have been achieved.

7.2 Conclusions

In this research, the production capability is measured based on the concept of leanness, agility, and sustainability. The components of Production Fitness are determined through the structure of these concepts. Measuring indices are determined from the leanness measure, agility measure, sustainability measure, and fitness measure, which are defined as:

- Production Profitability Index, PPI (leanness)
- Production Agility Index, PAI (agility)

- Production Stability Index, PSI (sustainability)
- Production Fitness Index, PFI (combination of leanness, agility, and sustainability)

The pattern of the indices over a five-year period is generated by monthly production and sales data from six case studies. Changes in the pattern are compared to the Demand Change Ratio (DCR). Influence factors from the aspect of company characteristics and production characteristics are identified by comparison within the six companies. A summary of the results is presented in Table 7.1. In summary, the key conclusions for this research are:

- The Production Fitness components are part of the manufacturing mission, objective, policy, and competition. Table 7.2 presents the production fitness components compared to the elements of manufacturing strategy.

- The Production Fitness components are part of business competitive. Table 7.3 presents the Production Fitness components compared to the elements of business competition.

Table 7.1: Summary of Influence Factors that Affect the Indices in Production Fitness Measures

Company characteristics	PPI	PAI	PSI
1- Year established	No	Not strongly	Not strongly
2- Industry classification	Not strongly	Not strongly	No
3- Product classification	Not strongly	Not strongly	No
4- Market status (National/International)	Not strongly	Not strongly	**Yes**
5- Market position (Leader/Follower)	No	No	No
6- Product distribution method	**Yes**	Not strongly	No
7- Annual turnover	Not strongly	Not strongly	No
8- Amount of production labour	No	**Yes**	No
9- Standard operating days	Not strongly	No	No
Production characteristics			
1- Production input-output variety	Not strongly	*Multiple input-output	**Yes**
2- Production Operations based	**Yes**	**Yes**	**Yes**
3- Order fulfilment based	**Yes**	**Yes**	Not strongly
4- Standard operating hours	Not strongly	No	No
5- Design/specification changes based	Not strongly	*Market oriented	**Yes**

Notes:

* The PAI is strongly affected by the particular characteristic.

Table 7.2: The Components of Production Fitness as Part of Manufacturing Strategy

Manufacturing Missions	**Production Fitness components**	**Manufacturing Objectives**	**Production Fitness component**	**Manufacturing Policies**	**Production Fitness components**	**Distinctive competence**	**Production Fitness components**
Quality & reliability	✓	Quality	✓	Quality of the product	✓	Consistent quality & delivery	✓
Customer service (delivery, warranty, field service)	✓	Delivery performance	✓	Management of the work force		Short turnaround & high quality assurance	✓
Economic performance (efficiency, productivity, unit cost)	✓	Flexibility to change volume	✓	Treatment of suppliers & vendors		Very knowledgeable work force	
Flexibility (volume, product)	✓	Flexibility to change product	✓	Professional & managerial development		Flexible to change	✓
Resource & equipment utilisation (capacity, output)	✓	Employee relations		Inventory & distribution levels	✓	Highly efficient & volume oriented	✓
Technology (product, process)		Inventory turnover		Development of new process technology			
Organisational development		Equipment utilisation	✓	Focus of facilities			
Employee & community relations				Facilities location			
Inventory control	✓			Vertical integration			

Notes:

1- Elements of manufacturing mission, objective, policy and distinctive competence refer to (Dangayach and Deshmukh, 2001, p. 910, Schroeder, et al., 1986, pp. 410-412).

2- The elements of manufacturing mission are in rank order of priority and importance.

3- The elements of manufacturing objective are in rank order of highest to lowest.

4- The elements of manufacturing policy are in rank order of highest to lowest % of response by manufacturing managers.

5- *The elements of distinctive competence are some examples of what managers saw as distinctive competencies in manufacturing.*

Table 7.3: Production Fitness Components as Part of Business Competitiveness

Competitive Priorities		Production competence (Choe, et al., 1997)	Core competency (Vic and Kaussar, 2001)	Core capabilities (Swink and Hegarty, 1998)	Production Fitness Components
(Kim, et al., 1993)	(Schmenner and Vastag, 2006)				
Low defective rate	*Product performance feature*	*Quality*	*Quality*	*Quality*	**Quality**
Dependable delivery	*Quick & reliable delivery*	*Dependability of supply*	*Dependable delivery*	*Quick delivery*	**Dependable delivery**
Mix change	*Flexibility*	*Flexibility of volume*	*Flexibility*		**Flexibility**
Price	*Low cost product*	*Cost efficiency*		*Cost*	**Low Cost**
	Rapid new product introduction	*Design of product*	*New product uniqueness*		**New product**
	Product customisation				**Product variety**
			Sustainable demand		**Demand continuity**

Φ The PPI:

- is not affected by the DCR.
- is directly affected by production productivity and pricing strategy.
- can be equal to 1.00 when the PWI is equal to 0.00.
- increases as the effective capacity is increased.
- has an uncertain relationship with the size of variety, which means the NPI does not guarantee a better PPI.
- is not strongly affected by the number of available production resources.
- is strongly influenced by product distribution method, production operation based, and order fulfilment based.

Thus, the production waste measure is applicable for improving production productivity, which ultimately improves the production profitability.

⊕ The PAI:

- has an uncertain relationship with the DCR.
- is strongly affected by effective capacity.
- will only be affected by the variety if the number of available production resources remains the same.
- is strongly affected by production re-activeness.
- is strongly influenced by the amount of production labour, production operation based, and order fulfilment based.

Thus, the production agility can be measured through adaptability to changes in demand quantity. In this respect, the amount of available production resources is crucial to ensure high adaptability to changes in demand quantity.

- The PSI:
  - has an uncertain relationship with the DCR.
  - has an inverse relationship with effective capacity.
  - has an uncertain relationship with variety.
  - is strongly influenced by market status (national/international), production input-output variety, production operation based, and design/specification changes based.

Thus, the stability measure of demand-capacity is applicable for improving sustainability of production capacity. Available production capacity is crucial to ensure a continual supply to demand since a shortage capacity has a negative impact on customer loyalty and also company image.

- The PFI:
  - is occasionally affected by the DCR.
  - is considered ideal when there is: (i) *a continual demand flowing into the production system*, (ii) *an efficient production operation*, (iii) *a dependable production capacity*.

- is strongly affected by the production fitness components.
- can be affected by company's strengths, weaknesses, opportunities, and threats.

Thus, ideal PFI can be used for internal competition, particularly for assessing production operations improvement. On the other hand, high PFI can be used for external competition, especially for the purpose of order winning and order qualifying. Ideal PFI and high PFI can be achieved simultaneously, provided that manufacturing companies respond to exploit their strengths, weaknesses, opportunities, and threats.

- In micro-SMEs, NPI occurs at least once in a five-year period. Although NPI is necessary, it is not sufficient for increasing the PAI.

- Micro-SMEs are likely to have more capacity than the required demand.

- Based on the empirical evidence studied to propose strategies for improving Production Fitness, significant links between Production Fitness (integration of leanness-agile-sustainability concepts), profitability (leanness concept), adaptability (agility concept), and stability (sustainability concept) are identified through the core element and key functional elements:

    - Effective capacity is the core element for Production Fitness.

- Warranty length is the key functional element for production profitability and adaptability.
- Return policies is the key functional element for production profitability and stability.
- Order fulfilment method is the key functional element for production adaptability and stability.

7.3 Suggestions for Future Research

Possible extensions that can be made to the work presented in this thesis include:

- Application of Production Fitness measures for batch process in small SMEs, medium-sized SMEs, and large manufacturing companies (multinational).

- Application of Production Fitness measures in other types of manufacturing process (e.g., job shop, line flow, continuous flow, and project). Calculation of time losses should be further analysed to be fitted into the PWI measure. For instance, project process commonly involves product customisation where a standard production lead time would be difficult to establish. In addition, application of the PCFT diagrams should be further analysed for measuring the variety.

- Development of a standard template for calculating Production Fitness measures, using the Microsoft Excel Software Application. The template should be designed based on the types of manufacturing process.

- Analysis of the relationships between Production Fitness, profitability, adaptability, and stability through empirical study, particularly in respect of the functional elements of Production Fitness: *(i) Warranty length; (ii) Return policy; (iii) Order fulfilment methods.*

- Application of Production Fitness measures in large manufacturing companies.

Table 6.5: Summary of the Results of Production Fitness Measures

Influential Factors	The Fitness Measures (Index)				Remarks
	Lean	Agile	Sustainable	Fit	
Demand Quantity	**PPI**	**PAI**	**PSI**	**PFI**	
Demand Change Ratio (DCR)	No	**Yes**	Not strongly	**Yes**	
Specific Variables					
1- PWI	**Yes**	na	na	na	PPI, PAI, and PSI are the function of PFI.
2- Effective capacity	**Yes**	**Yes**	**Yes**		
3- Size of variety	Not strongly	**Yes**	Not strongly		
4- Total number of production resources	Not strongly	**Yes**	na		
5- NPI	Not strongly	Not strongly	Not strongly		
Company characteristics					
1- Year established	No	Not strongly	Not strongly	na	PFI has been further justified by using SWOT analysis
2- Industry classification	Not strongly	Not strongly	No		
3- Product classification	Not strongly	Not strongly	No		
4- Market status (National/International)	Not strongly	Not strongly	**Yes**		
5- Market position (Leader/Follower)	No	No	No		
6- Product distribution method	**Yes**	Not strongly	No		
7- Annual turnover	Not strongly	Not strongly	No		
8- Number of direct labour	No	**Yes**	No		
9- Standard operating days	Not strongly	No	No		
Production Characteristics					
1- Production input-output variety	Not strongly	**Yes**	**Yes**	na	
2- Production Operations based	**Yes**	**Yes**	**Yes**		
3- Order fulfilment based	**Yes**	**Yes**	Not strongly		
4- Standard operating hours	Not strongly	No	No		
5- Design/specification changes based	Not strongly	**Yes**	**Yes**		

REFERENCES

A

Abdel-Maksoud, A., Dugdale, D. and Luther, R. 2005. Non-financial performance measurement in manufacturing companies. *British Accounting Review.* 37(3), pp. 261-297.

Abdulmalek, F. A. and Rajgopal, J. 2007. Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *Intl J Production Economics.* 107(1), pp. 223-236.

Adeleye, E. O. and Yusuf, Y. Y. 2006. Towards agile manufacturing: Models of competition and performance outcomes. *Intl J Agile Systems And Management* 1(1), pp. 93-110.

Agarwal, A., Shankar, R. and Tiwari, M. K. 2006. Modeling the Metrics of Lean, Agile and Leagile supply chain: An ANP-based approach. *European Journal of Operational Research.* 173(1), pp. 211-225.

Aitken, J., Christopher, M. and Towill, D. 2002. Understanding, implementing, and exploiting agility and leanness *Intl J Logistics* 5(5), pp. 59-74.

Al-Yousfi, A. B. 2004. Cleaner production for sustainable industrial development: Concept and applications. *J Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management.* 8(4), pp. 265-273.

Amika, S. S., Marijke, J. M., Chin, A. P., Ruud, J. B. and Willem, V. M. 2006. Cross-sectional relationship between physical fitness components and functional performance in older persons living in long-term care facilities. *J BMC Geriatics.* 6(6), pp. 1471-2318.

Arteta, B. M. and Giachetti, R. E. 2004. A measure of agility as the complexity of the enterprise system. *J Robotics and Computer-Integrated Manufacturing.* 20(6), pp. 495-503.

Azapagic, A. 2004. Developing a framework for sustainable development indicators for the mining and minerals industry. *J Cleaner Production.* 12, pp. 639-662.

Azapagic, A. and Perdan, S. 2000. Indicators of sustainable development for industry: A general frameweork. *Trans. IChemE (Proc. Safety Envir. Prot.) Part B.* 74(B4), pp. 243-261.

B

Babai, M. Z. and Dallery, Y. 2009. Dynamic versus static control policies in single stage production-inventory systems. *Intl J Production Research.* 47(2), pp. 415-433.

Banks, J. ed. 1998. *Handbook of Simulation.* Engineering & Management Press.

Bateman, N., Stockton, D. J. and Lawrence, P. 1999. Measuring the mix response flexibility of manufacturing systems. *Intl J of Production Research.* 37(4), pp. 871-880.

Barlow, C. 2003. Towards industrial sustainability. *IET Manufacturing Engineer.* 82(6), pp. 36-37.

Baykasoglu, A. and Ozbakir, L. 2008. Analysing the effect of flexibility on manufacturing systems performance. *J Manufacturing Technology Management.* 19(2), pp. 172-193.

Bayou, M. E. and de Korvin, A. 2008. Measuring the leanness of manufacturing systems: A case study of Ford Motor Company and General Motors. *J Engineering and Technology Management.* 25(4), pp. 287-304.

Bayus, B. L. 1997. Speed-to-market and new product performance trade-offs. *J Product Innovation Management.* 14(6), pp. 485-497.

Bhasin, S. and Burcher, P. 2006. Lean viewed as a philosophy. *J Manufacturing Technology Management.* 17(1), pp. 56-72.

Bernard, M. and Gianni, S. 2003. Business performance measurement: Past, present and future. *Management Decision.* 41(8), pp. 680-687.

Bernasconi, M., Choirat, C. and Raffaelo, S. 2010. The analytic hierarchy process and the measurement. *Management Science.* 6(4), pp. 699-711.

Berry, W. L. and Cooper, M. C. 1999. Manufacturing flexibility: methods for measuring the impact of product variety on performance in process industries. *J Operations Management.* 17(2), pp. 163-178.

Bi, Z. M., Lang, S. Y. T., Shen, W. and Wang, L. 2008. Reconfigurable Manufacturing Systems: The state of the art. *Intl J Production Research.* 46(4), pp. 967-992.

Biddle, S. 1987. *Foundations of Health-Related Fitness in Physical Education.* Ling Publishing House.

Bititci, U. S., Carrie, A. S. and McDevitt, L. 1997. Integrated performance measurement systems: A development guide. *Intl J Operations and Production Management.* 17(5), pp. 522-534.

Bititci, U. S., Turner, T. and Begemann, C. 2000. Dynamics of performance measurement systems. *Intl J Operations and Production Management.* 20(6), pp. 692-704.

Bottani, E. 2009. On the assessment of enterprise agility: Issues from two case studies. *Intl J Logistics Research and Applications.* 12(3), pp. 213-230.

Brah, S. A. and Chong, W. K. 2004. Relationship between total productive maintenance and performance. *Intl J Production Research.* 42, pp. 2383-2401.

Brown, S. and Bessant, J. 2003. The manufacturing strategy-capabilities links in Mass Customisation and Agile manufacturing: An exploratory study. *Intl J Operations and Production Management.* 23(7-8), pp. 707-730.

Bryant, L., Jones, D. A. and Widener, S. K. 2004. Managing value creation within the firm: An examination of multiple performance measures. *J Management Accounting Research* 16(1), p. 107

Buchan, I. E., Bundred, P. E., Kitchiner, D. J. and Cole, T. J. 2007. Body Mass Index has risen more steeply in tall than in short 3 years old: Serious cross-sectional surveys 1988-2003 *Intl J Obesity.* 31, pp. 23-29.

Burcher, P., Dupernex, S. and Relph, G. 1996. The road to lean repetitive batch manufacturing: Modelling planning system performance. *Intl J Production and Operations Management.* 16, pp. 210-220.

C

Calvo, R., Domingo, R. and Sebastin, M. A. 2008. Systemic criterion of sustainability in Agile Manufacturing. *Intl J Production Research.* 46(12), pp. 3345-3358.

Carbonell, P. and Rodriguez, A. I. 2006. The impact of market characteristics and innovation speed on perceptions of positional advantage and new product performance. *Intl J Research in Marketing.* 23(1), pp. 1-12.

Causey, G. C. 1999. *Elements of Agility In Manufacturing.* PhD Thesis. Case Western Reserve University.

Chakravarty, A. and Balakrishnan, N. 2001. Achieving product variety through optimal choice of module variations. *IIE Transactions.* 33(7), pp. 587-598.

Chan, F. T. S., Lau, H. C. W., Ip, R. W. L., Chan, H. K. and Kong, S. 2005. Implementation of total productive maintenance: A case study. *Intl J Production Economics.* 95(1), pp. 71-94.

Chaney, P. K., Devinney, T. M. and Winer, R. S. 1991. The impact of new product introductions on the market value of firms. *J Business.* 64(4), pp. 573-610.

Chhikara, J. and Weiss, E. 1995. JIT Savings: Myth or Reality? *Business Horizons.* 38(3), pp. 73-78.

Chen, J., Reilly, R. R. and Lynn, G. S. 2005. The impacts of speed-to-market on new product success: The moderating effects of uncertainty. *IEEE Engineering Management.* 52(2), pp. 199-212.

Chen, L. and Plambeck, E. L. 2008. Dynamic inventory management with learning about the demand distribution and substitution probability. *Manufacturing and Service Operations Management.* 10(2), pp. 236-256.

Chen, X. and Simchi-Levi, D. 2006. Coordinating inventory control and pricing strategies: The continuous review model. *Operations Research Letters.* 34(3), pp. 323-332.

Choe, K., Booth, D. and Hu, M. 1997. Production competence and its impact on business performance. *J Manufacturing Systems.* 16(6), pp. 409-421.

Christopher, M. and Towill, D. 2001. An integrated model for the design of agile supply chains. *Intl J Physical Distribution And Logistics Management.* 31(4), pp. 235-246.

Cooper, R. G. 1983. The impact of new product strategies. *Industrial Marketing Management.* 12(4), pp. 243-256.

Cooper, R. G. 1984. How new product strategies impact on performance. *J Product Innovation Management.* 1(1), pp. 5-18.

Crittenden, V. L., Gardiner, L. R. and Stam, A. 1993. Reducing conflict between marketing and manufacturing. *Industrial Marketing Management.* 22(4), pp. 299-309.

Cross, K. F. and Lynch, R. L. 1988. The "SMART" way to define and sustain success. *National Productivity Review.* 8(1), pp. 23-33.

D

Dangayach, G. S. and Deshmukh, S. G. 2001. Manufacturing strategy: Literature review and some issues. *Intl J Operations and Production Management.* 21, pp. 884-932.

Davis, J. P., Eisenhardt, K. M. and Bingham, C. B. 2007. Developing theory through simulation method. *Academy of Management Review.* 32(2), pp. 480-499.

Day, G. S. 1994. The capabilities of market-driven organizations. *J Marketing.* 58, pp. 37-52.

de Brito, M. P. and van der Laan, E. A. 2009. Inventory control with product returns: The impact of imperfect information. *European Journal of Operational Research.* 194(1), pp. 85-101.

Debruyne, M., Moenaertb, R., Griffinc, A., Hartd, S., Hultinke, E. J. and Robben, H. 2002. The impact of new product launch strategies on competitive reaction in industrial markets. *J Product Innovation Management.* 19(2), pp. 159-170.

Detty, R. B. and Yingling, J. C. 2000. Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. *Intl J Production Research.* 38, pp. 429-445.

De Vos, D., Van Landeghem, H. and Van Hoof, K. 2006. A knowledge discovery method to predict the economical sustainability of a company. *J Concurrent Engineering Research and Applications.* 14(4), pp. 293-303.

Dimitropoulos, G. P. 2009. Agility Index of Automatic Production Systems: Reconfigurable logic and open source as agility enablers. *Computers in Industry.* 60(4), pp. 248-256.

Diwakar, G. and Saif, B. 2004. Make-to-Order, Make-to-Stock, or Delay Product Differentiation?: A common framework for modeling and analysis. *IIE Transactions.* 36, pp. 529-546.

Dixon, J. R., Nanni, A. J. and Vollmann, T. E. 1990. *The New Performance Challenge: Measuring Operations for World-Class Competition.* Homewood Dow Jones-Irwin.

Dove, R. 1991. *21st Century Manufacturing Enterprise Strategy.* Bethelem: Iacocca Institute.

Duffuaa, S. O., Ben-Daya, M., Al-Sultan, K. S. and Andijani, A. A. 2001. A generic conceptual simulation model for maintenance systems. *J Quality in Maintenance Engineering.* 7, pp. 207-219.

E

ElMaraghy, H. A. 2005. Flexible and Reconfigurable Manufacturing Systems paradigms. *Intl J Flexible Manufacturing Systems.* 17(4), pp. 261-276.

ElMaraghy, H. A. 2009. Changing and Evolving Products and Systems – Models and Enablers. In: D. T. Pham ed. *Changeable and Reconfigurable Manufacturing Systems.* Springer London, pp. 25-45.

ElMaraghy, H., Azab, A., Schuh, G. and Pulz, C. 2009. Managing variations in products, processes and manufacturing systems. *CIRP Annals - Manufacturing Technology.* 58(1), pp. 441-446.

ElHafsi, M., Camus, H. and Craye, E. 2010. Managing an integrated production inventory system with information on the production and demand status and multiple non-unitary demand classes. *European Journal of Operational Research.* 207(2), pp. 986-1001.

Erens, F. J. and Hegge, H. M. H. 1994. Manufacturing and sales co-ordination for product variety. *Intl J Production Economics.* 37(1), pp. 83-99.

Eugene, W. A., Claes, W. F. and Donald, R. L. 1994. Customer satisfaction, market share and profitability: Findings from Sweden. *J Marketing.* 58(3), pp. 53-66.

F

Federgruen, A. and Zipkin, P. 1986. An inventory model with limited production capacity and uncertain demands: The Average-Cost criterion. *Mathematics of Operations Research.* 11(2), pp. 193-207.

Fleischmann, M. and Kuik, R. 2003. On optimal inventory control with independent stochastic item returns. *European Journal of Operational Research.* 151(1), pp. 25-37.

Fliedner, G. and Vokurka, R. J. 1997. Agility: Competitive weapon of the 1990s and beyond? *J Production and Inventory Management.* 38(3), pp. 19-24.

Forman, E. H. and Gass, S. I. 2001. The analytic hierarchy process: An exposition. *Operations Research.* 49(4), pp. 469-486.

Fullerton, R. R. and Wempe, W. F. 2009. Lean Manufacturing, Non-financial performance measures, and financial performance. *Intl J Operations and Production Management.* 29(3), pp. 214-240.

G

Gaimon, C. 2008. The management of technology: A production and operations management perspective. *Production and Operations Management.* 17(1), pp. 1-11.

Geyer, A. 2003. The future of manufacturing in Europe 2015-2020: The challenge for sustainability.*FuTMaN Final Report.* Research Industrial Technology, EU FP6 Funded Programme. 1-50.

Globerson, S. 1985. Issues in developing a performance criteria system for an organization. *Intl J Production Research.* 23(4), pp. 639-647.

Grewal, R. and Slotegraaf, R. J. 2007. Embeddedness of organizational capabilities. *Decision Sciences.* 38, pp. 451-488.

Griese, H., Stobbe, L., Reichl, H. and Stevels, A. eds. 2005. *Eco-design and beyond: Key requirements for a global sustainable development.* Proceedings of the Asian Green Electronics Conference. 15th - 18th March, Shanghai, China. IEEE Inc., pp. 37-41.

Griffin, A. 1993. Metrics for measuring product development cycle time. *J Product Innovation Management.* 10(2), pp. 112-125.

Griffin, A. 1997. PDMA research on new product development practices: Updating trends, and benchmarking best practices. *J Product Innovation Management.* 14, pp. 429-458.

H

Hallam, C. R. A. 2003. *Lean Enterprise Self-assessment as A Leading Indicator for Accelerating Transformation in the Aerospace Industry* PhD Thesis. Massachusetts Institute of Technology.

Hancock, W. M. and Zayko, M. J. 1998. Lean production: Implementation problems. *IIE Solutions.* 30(6), pp. 38-42.

Helo, P. 2004. Managing agility and productivity in the electronics industry. *J Industrial Management And Data Systems.* 104(7), pp. 567-577.

Henard, D. H. and Szymanski, D. M. 2001. Why Some New Products Are More Successful Than Others. *American Association Marketing.* 38(3), pp. 362-375.

Herron, C. and Braiden, P. M. 2006. A methodology for developing sustainable quantifiable productivity improvement in manufacturing companies. *Intl J Production Economics.* 104(1), pp. 143-153.

Hines, P. and Taylor, D. 2000. *Going Lean.* Lean Enterprise Research Center, Cardiff Business School.

Hines, P., Holwe, M. and Rich, N. 2004. Learning to evolve: A review of contemporary Lean Thinking. *Intl J Operations and Production Management.* 24(10), pp. 994-1011.

Hockey, R. V. 1977. *Physical Fitness: The Pathway To Healthful Living.* 3rd ed. St Louis, USA: C. V. Mosby Company.

Hoffman, J. 2006. *Norms for Fitness, Performance and Health.* Illinois, USA: Human Kinetics, Inc.

Holweg, M. 2007. The Genealogy Of Lean Production. *J Operations Management.* 25(2), pp. 420-437.

Hopp, J. W. and Spearman, M. L. 2004. To pull or not to pull: What is the question? *J Manufacturing And Service Operations Management.* 6(2), pp. 133-148.

Hon, K. K. B. 2005. Performance and evaluation of manufacturing systems. *CIRP Annals - Manufacturing Technology.* 54(2), pp. 675-690.

Hoogenraad, M. S. and Wortmann, J. C. 2007. Changeability of Production Management Systems *Advances in Production Management Systems.* 246(1), pp. 179-187.

Hoque, Z. 2004. A contingency model of the association between strategy, environmental uncertainty and performance measurement: Impact on organizational performance. *Intl Business Review.* 13(4), pp. 485-502.

Hsafizadeh, M., Ritzman, L. P. and Mallick, D. 2000. Revisiting alternative theoretical paradigms in manufacturing strategy. *Production and Operations Management.* 9(2), pp. 111-126.

Hyland, P. W., Mellor, R. and Sloan, T. 2007. Performance measurement and continuous improvement: Are they linked to manufacturing strategy? *Intl J Technology Management.* 37(3-4), pp. 237-246.

I

Ireland, F. and Dale, B. G. 2001. A study of total productive maintenance implementation. *J Quality in Maintenance Engineering.* 7, pp. 183-192.

J

Jack, E. P. and Raturi, A. 2002. Sources of volume flexibility and their impact on performance. *J Operations Management.* 20(5), pp. 519-548.

Jackson, M. and Johansson, C. 2003. An agility analysis from a production system perspective. *J Integrated Manufacturing Systems.* 14(6), pp. 482-488.

Jans, R., Degraeve, Z. and Schepens, L. 2008. Analysis of an industrial component commonality problem. *European Journal of Operational Research.* 186(2), pp. 801-811.

Jayachandran, R. 2006 The design for sustainable manufacturing system: A case study of it importance to product variety manufacturing. *Innovative Production and Machines Systems (I*PROMS)* Cardiff, U.K., 01st -14th July.

Jin-Hai, L., Anderson, A. R. and Harrison, R. T. 2003. The evolution of agile manufacturing. *J Business Process Management.* 9(2), pp. 170-189.

Jusoh, R., Ibrahim, D. N. and Zainuddin, Y. 2008. The performance consequence of multiple performance measures usage: Evidence from the Malaysian Manufacturers. *Intl J Productivity and Performance Management.* 57(2), pp. 119-136.

K

Kaebernick, H., Kara, S. and Sun, M. 2003. Sustainable product development and manufacturing by considering environmental requirements. *J Robotics And Computer-Integrated Manufacturing.* 19(6), pp. 461-468.

Kamath, K. R. and Pakkala, T. P. M. 2002. A Bayesian approach to a dynamic inventory model under an unknown demand distribution. *Computers and Operations Research.* 29(4), pp. 403-422.

Kaplan, R. S. and Norton, D. P. 1996. Using the Balanced Scorecard as a Strategic Management System. *Harvard Business Review* pp. 75-85.

Kara, S., Honke, I. and Kaebernick, H. 2005. An integrated framework for implementing sustainable product development. *Proceedings of the 4th Intl Symposium on Environmentally Conscious Design and Inverse Manufacturing (Eco Design).* 12th - 14th December. Tokyo, Japan. IEEE Explore Digital Library, pp. 684-691.

Karaesmen, F., Buzacott, J. A. and Dallery, Y. 2002. Integrating advance order information in make-to-stock production systems. *IIE Transactions.* 34(8), pp. 649-662.

Karlsson, C. and Ahlstroem, P. 1996. Assessing changes towards lean production *Intl J Operations and Production Management.* 16(2), pp. 24-41.

Keegan, D. P., Eiler, R. G. and Jones, C. R. 1989. Are your performance measures obsolete? *Management Accounting.* 70(12), pp. 45-51.

Kessler, H. E. and Chakrabarti, K. A. 1996. Innovation speed: A conceptual model of context, antecedents, and outcomes. *The Academy of Management Review.* 21(4), pp. 1143-1192.

Ketokivi, M. and Schroeder, R. 2004. Manufacturing practices, strategic fit and performance: A routine-based view. *Intl J Operations and Production Management.* 24(1-2), pp. 171-191.

Ketzenberg, M. E. and Zuidwijk, R. A. 2009. Optimal pricing, ordering, and return policies for consumer goods. *Intl J Production and Operations Management.* 18(3), pp. 344-360.

Khoshsima, G. 2003. A model for measuring organizational agility in Iran television manufacturing industry: A Fuzzy Logic framework. *Proceedings of the Engineering Management Conference (IEMC).* 2nd - 4th November. New York, USA. IEEE Explore Digital Library, pp. 354-358.

Kidd, P. T. 1996. A strategy for the 21st Century. *Proceedings of the IEEE Colloquium on Agile Manufacturing.* 28 Mar. Cranfield, UK. IEEE Explore Digital Library, pp. 1-6.

Kieran, C. and Brian, F. eds. 2004. Toward a conceptual framework of agile methods: A study of agility in different disciplines. *Proceedings of the 2004 ACM*

Workshop on Interdisciplinary Software Engineering Research. 31st Oct. - 5th Nov. Newport Beach, USA. ACM, pp. 37 - 44.
Kim, J. S. and Arnold, P. 1993. Manufacturing competence and business performance: A framework and empirical analysis. *Intl J Operations and Production Management.* 13(10), pp. 4-25.

Kleindorfer, P. R., Singhal, K. and Van Wassenhove, L. N. 2005. Sustainable operations management. *Production and Operations Management.* 14(4), pp. 482-492.

Kleinschmidt, E. J. and Cooper, R. G. 1991. The impact of product innovativeness on performance. *J Product Innovation Management.* 8(4), pp. 240-251.

Kojima, S. and Kaplinsky, R. 2004. The use of a Lean Production Index in explaining the transition to global competitiveness: The auto components sector in South Africa. *Technovation.* 24(3), pp. 199-206.

Kopacek, P. 1999. Intelligent Manufacturing: Present state and future trends. *J Intelligent and Robotic Systems: Theory and Applications.* 26(3), pp. 217-229.

Korugan, A. and Gupta, S. M. 1998. A multi-echelon inventory system with returns. *Computers and Industrial Engineering.* 35(1-2), pp. 145-148.

Koste, L. L., Malhotra, M. K. and Sharma, S. 2004. Measuring dimensions of manufacturing flexibility. *J Operations Management.* 22(2), pp. 171-196.

Krajnc, D. and Glavic, P. 2005. How to compare companies on relevant dimensions of sustainability. *J Ecological Economics.* 55(4), pp. 551-563.

Krasnikov, A. and Jayachandran, S. 2008. The relative impact of marketing, research and development and operations capabilities. *J Marketing.* 72(4), pp. 1-11.

Kritchanchai, D. 2004. Assessing responsiveness of the Food Industry in Thailand. *Industrial Management and Data Systems.* 104(5), pp. 384-395.

L

Labuschagne, C., Brent, A. C. and Van Erck, R. P. G. 2005. Assessing the sustainability performances of industries. *J Cleaner Production.* 13(4), pp. 373-385.

Lamb, K. L., Brodie, D. A. and Roberts, K. 1988. Physical fitness and health-related fitness as indicators of a positive health state. *Intl J Health Promotion.* 3(2), pp. 171-182.

Langerak, F. and Hultink, E. J. 2005. The impact of new product development acceleration approaches on speed and profitability: Lessons for Pioneers and Fast Followers. *IEEE Engineering Management.* 52(1), pp. 30-42.

Langerak, F. and Hultink, E. J. 2006. The impact of product innovativeness on the link between development speed and new product profitability *J Product Innovation Management.* 23(3), pp. 203-214.

Leachman, C., Pegels, C. C. and Shin, S. K. 2005. Manufacturing performance: Evaluation and determinants. *Intl J Operations and Production Management.* 25(9), pp. 851-874.

Lee, C. and Lee, C. G. 2007. SME innovation in the Malaysian manufacturing sector. *Economics Bulletin.* 12(30), pp. 1-12.

Lewis, W. W., Gersbach, H., Jansen, T. and Sakate, K. 1993. The secret to competitiveness: Competition. *The McKinsey Quarterly.* (4).

Li, L. 1992. Role of inventory in delivery-time competition. *J Management Science.* 38(2), pp. 182-197.

Li, L. L. X. 2000. Manufacturing capability development in a changing business environment *Industrial Management and Data Systems.* 100(6), pp. 261-270.

Li, Q. and Zheng, S. 2006. Joint inventory replenishment and pricing control for systems with uncertain yield and demand *J Operations Research.* 54(4), pp. 696-705.

Lin, C. T., Chiu, H. and Chu, P. Y. 2006a. Agility Index in the supply chain. *Intl J Production Economics.* 100(2), pp. 285-299.

Lin, C. T., Chiu, H. and Tseng, Y. H. 2006b. Agility evaluation using Fuzzy Logic. *Intl J Production Economics.* 101(2), pp. 353-368.

Liu, Y. and Zheng, H. 2007. Measuring agility of enterprise using Analytic Hierarchy Process and Bayesian Belief Networks. *Proceeding of the Intl Conference on Management Science and Engineering (ICMSE).* 5th - 7th October, Lille, France. IEEE Digital Library, pp. 551-556.

Liyanage, J. P. 2007. Operations and maintenance performance in production and manufacturing assets: The sustainability perspective. *J Manufacturing Technology Management.* 18(3), pp. 304-314.

M

Malina, M. A. and Selto, F. H. 2004. Choice and change of measures in performance measurement models. *Management Accounting Research.* 15(4), pp. 441-469.

MacKenzie, B. 2008. *The Components of Fitness* [Online]. London, UK: BrianMac Sport Coach. Available at: http://www.brianmac.co.uk [Accessed: 11th April 2008].

Maccini, L. J. and Zabel, E. 1996. Serial correlation in demand, backlogging and production volatility. *Intl J Economic Review.* 37(2), pp. 423-452.

MacDuffie, J. P., Sethuraman, K. and Fisher, M. L. 1996. Product variety and manufacturing performance: Evidence from the international automotive assembly plant study. *Management Science.* 42(3), pp. 350-369.

Mannisto, T., Peltonen, H., Martio, A. and Sulonen, R. 1998. Modelling generic product structures in STEP. *J Computer-Aided Design.* 30(14), pp. 1111-1118.

Mapes, J. 1993. The effect of capacity limitations on safety stock. *Intl J Operations & Production Management.* 13(10), pp. 26-34.

Maskell, B. H. ed. 1991. *Performance Measurement for World-Class Manufacturing: A Model for American Companies.* New York: Productivity Press.

Mason-Jones, R., Naylor, B. and Towill, D. R. 2000. Lean, agile or league?: Matching your supply chain to the marketplace. *Intl J Production Research.* 38(17), pp. 4061-4070.

Mativenga, P. T. 2010. Implementing Technical and Experimental Project/Case Studies. *Lecture Notes.* Cardiff: School of Mechanical, Aerospace and Civil Engineering. 1-5.

Matson, J. B. and McFarlane, D. C. 1999. Assessing the responsiveness of existing production operations. *Intl J Operations and Production Management.* 19(8), pp. 765-784.

Melton, T. 2005. The benefits of Lean Manufacturing: What Lean Thinking has to offer the process industries. *J Chemical Engineering Research and Design.* 83(6), pp. 662-673.

Menezes, M. A. J. and Currim, I. S. 1992. An approach for determination of warranty length *Intl J Research in Marketing.* 9, pp. 177-195.

Meredith, S. and Francis, D. 2000. *Journey towards agility: The agile wheel explored.* The TQM Magazine. pp. 137-143.

Micheal, K., Rochford, L. and Wotruba, T. R. 2003. How new product introductions affect sales management strategy: The impact of type of "Newness" of the new product. *J Product Innovation Management.* 20(4), pp. 270-283.

Motwani, J. 2003. A business process change framework for examining lean manufacturing: A case study. *J Industrial Management and Data Systems.* 103, pp. 339-346.

Muchiri, P. and Pintelon, L. 2008. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. *Intl J Production Research.* 46(13), pp. 3517-3535.

Murthy, D. N. P., Hagmark, P. E. and Virtanen, S. 2009. Product variety and reliability. *Reliability Engineering & System Safety.* 94(10), pp. 1601-1608.

N

Narasimhan, R., Swink, M. and Kim, S. W. 2006. Disentangling leanness and agility: An empirical investigation. *J Operations Management.* 24(5), pp. 440-457.

Nath, P., Nachiappan, S. and Ramanathan, R. 2010. The impact of marketing capability, operational capability and diversification strategy on performance. *J Industrial Marketing Management.* 39(2), pp. 317-329.

Neely, A., Adams, C. and Crowe, P. 2001. The Performance Prism in practice. *Measuring Business Excellence.* 5(2), pp. 6-13.

Neely, A., Gregory, M. and Platts, K. 2005. Performance Measurement System design: A literature review and research agenda. *Intl J Operations and Production Management.* 25(12), pp. 1228-1263.

Neely, A. and Kennerley, M. 2002. *Performance Measurement: Theory and Practice*. Cambridge: Cambridge University Press.

Nightingale, D. J. and Mize, J. H. 2002. Development of a Lean Enterprise Transformation Maturity Model *Information, Knowledge, Systems Management.* 3(1), pp. 15-30.

Norreklit, H. 2000. The balance on the balanced scorecard a critical analysis of some of its assumptions. *Management Accounting Research.* 11(1), pp. 65-88.

O

O'Donnell, F. J., MacCallum, K. J., Hogg, T. D. and Yu, B. 1996. Product structuring in a small manufacturing enterprise. *J Computers in Industry.* 31(3), pp. 281-292.

Okazaki, Y., Mishima, N. and Ashida, K. 2004. Microfactory: Concept, history, and developments. *J Manufacturing Science and Engineering.* 126(4), pp. 837-844.

Olhager, J. and Selldin, E. 2007. Manufacturing planning and control approaches: Market alignment and performance. *Intl J Production Research.* 45, pp. 1469-1484.

Oliver, N., Delbridge, R. and Lowe, J. 1996. Lean production practices: International comparisons in the auto components industry. *British Journal of Management.* 7(1), pp. 29-44.

Olsen, E. O., Zhou, H., Lee, D. M. S., Ng, Y., Chong, C. C. and Padunchwit, P. 2007. Performance Measurement System and relationships with performance results: A case analysis of a continuous improvement approach to PMS design. *Intl J Productivity and Performance Management.* 56(7), pp. 559-582.

Ortega, F. B., Ruiz, J. R., Castillo, M. J. and Sjöström, M. 2008. Physical fitness in childhood and adolescence: A powerful marker of health. *Intl J Obesity.* 32, pp. 1-11.

Oxford. 2009. *Oxford Dictionaries: The world's most trusted dictionaries* [Online]. Oxford: Oxford University Press. Available at: http://oxforddictionaries.com [Accessed: 04th June 2009].

Oxford. 2010. *Oxford Dictionaries: The world's most trusted dictionaries* [Online]. Oxford: Oxford University Press. Available at: http://oxforddictionaries.com [Accessed: 23rd July 2010].

Ozer, O. and Wei, W. 2004. Inventory control with limited capacity and advance demand information. *Operations Research.* 52(6), pp. 988-1000.

P

Padmanabhan, V. and Png, I. P. L. 1997. Manufacturer's return policies and retail competition. *J Marketing Science.* 16(1), pp. 81-94.

Panizzolo, R. 1998. Applying the lessons learned from 27 lean manufacturers: The relevance of relationships management. *Intl J Production Economics.* 55(3), pp. 223-240.

Papadopoulou, T. C. and Ozbayrak, M. 2005. Leanness: Experiences from the journey to date. *J Manufacturing Technology Management.* 16(7), pp. 784-807.

Petruzzi, N. C. and Dada, M. 2002. Dynamic pricing and inventory control with learning. *Naval Research Logistics (NRL).* 49(3), pp. 303-325.

Pham, D. T. and Thomas, A. J. 2005. *Fighting Fit Factories: Making Industry Lean, Agile and Sustainable.* Manufacturing Engineer. April. pp. 24-29.

Pham, D. T., Barton, R., Thomas, A. J., Williams, O., Shamsuddin, T. and Ebrahim, Z. 2007. Fit Manufacturing. *Proceedings of Innovative Production Machines And Systems (I*PROMS) Virtual Conference.* 2nd - 13th July. Cardiff, UK. Elsevier, pp. 136-141.

Pham, D. T., Pham, P. T. N. and Thomas, A. J. 2008a. Integrated production machines and systems: Beyond Lean Manufacturing. *J Manufacturing Technology Management.* 19(6), pp. 695-711.

Pham, D. T., Williams, O., Thomas, A. J., Barton, R., Ebrahim, Z. and Shamsuddin, T. 2008b. Fit Manufacturing: A strategy for achieving economic sustainability. *Proceedings of the Innovative Production Machines And Systems (I*PROMS) Virtual Conference.* 1st - 14th July. Cardiff, UK. CRC Press, pp. 63-68.

Pham, D. T., Ebrahim, Z., Barton, R., Thomas, A. J., Williams, O. and Shamsuddin, T. eds. 2008c. Relationship between Lean Manufacturing, Agile Manufacturing, and Sustainability. *Proceeding of the Innovative Production Machines And Systems (I*PROMS) Virtual Conference.* 1st - 14th July. Cardiff, UK. CRC Press, pp. 69 - 77.

Pil, F. K. and Holweg, M. 2004. Linking product variety to order-fulfillment strategies. *Interfaces.* 34(5), pp. 394-403.

Prosser, L. 2009. UK Standard Industrial Classification of Economic Activities 2007 (SIC 2007). *Structure and explanatory notes.* Palgrave Macmillan. 1-246.

R

Rajagopalan, S. 2002. Make-to-Order or Make-to-Stock: Model and application. *J Management Science* 48(2), pp. 241-256.

Ramasesh, R., Kulkarni, S. and Jayakumar, M. 2001. Agility in manufacturing systems: An exploratory modeling framework and simulation. *J Integrated Manufacturing Systems.* 12(6-7), pp. 534-548.

Ramesh, G. and Devadasan, S. R. 2007. Literature review on the agile manufacturing criteria. *J Manufacturing Technology Management.* 18(2), pp. 182-201.

Ray, C. D., Zuo, X., Michael, J. H. and Wiedenbeck, J. K. 2006. The Lean Index: Operational "Lean" metrics for the wood products industry. *J Wood and Fiber Science.* 38(2), pp. 238-255.

Ren, J., Yusuf, Y. Y. and Burns, N. D. 2003. The effects of agile attributes on competitive priorities: A neural network approach. *J Integrated Manufacturing Systems.* 14(6), pp. 489-497.

Rogers, G. G. and Bottaci, L. 1997. Modular Production Systems: A new manufacturing paradigm. *J Intelligent Manufacturing.* 8(2), pp. 147-156.

Roth, A. V. and Miller, J. G. 1992. Success factors in manufacturing. *Business Horizons.* 35(4), pp. 73-81.

S

Saad, S. M. and Gindy, N. N. Z. 2007. Future shape of the Responsive Manufacturing Enterprise. *Intl J Benchmarking.* 14(1), pp. 140-152.

Sahin, F. 2000. Manufacturing competitiveness: Different systems to achieve the same results. *J Production And Inventory Management.* 41(1), pp. 56-65.

Sanchez, A. M. and Perez, M. P. 2001. Lean indicators and manufacturing strategies. *Intl J Operations and Production Management.* 21(11), pp. 1433-1451.

Saridakis, K. M. and Dentsoras, A. J. 2007. The role of maintenance engineering in sustainable manufacturing. In: *Innovative Production Machines and Systems (I*PROMS) Virtual Conference.* 1st - 15th July, www.iproms.org/iproms2007

Sarkis, J. 2001. Benchmarking for agility *Intl J Benchmarking.* 8(2), pp. 88-107.

Sarmiento, R., Byrne, M., Contreras, L. R. and Rich, N. 2007. Delivery reliability, manufacturing capabilities and new models of manufacturing efficiency. *J Manufacturing Technology Management.* 18(4), pp. 367-386.

Schmenner, R. W. and Vastag, G. 2006. Revisiting the theory of production competence: Extensions and cross-validations. *J Operations Management.* 24(6), pp. 893-909.

Schroeder, R. G., Anderson, J. C. and Cleveland, G. 1986. The content of manufacturing strategy: An empirical study. *J Operations Management.* 6(3-4), pp. 405-415.

Schump, D. E. 1989. Reliability testing of electric motor. *IEEE Transactions on Industry Applications.* 25(3), pp. 386-390.

Seuring, S. A., Koplin, J., Behrens, T. and Schneidewind, U. 2003. Sustainability assessment in the German Detergent Industry: From stakeholder involvement to sustainability indicators. *J Sustainable Development.* 11(4), pp. 199-212.

Shah, R. and Ward, P. T. 2003. Lean manufacturing: Context, practice bundles and performance. *J Operations Management.* 21(2), pp. 129-149.

Shah, R. and Ward, P. T. 2007. Defining and developing measures of lean production. *J Operations Management.* 25(4), pp. 785-805.

Shahbazpour, M. and Seidel, R. H. 2006 Using sustainability for competitive advantage. *13th CIRP Intl Conference on Life Cycle Engineering (LCE).* 31st May - 02nd June, Leuven, Belgium.

Sharifi, H. and Zhang, Z. 1999. Methodology for achieving agility in manufacturing organisations: An introduction. *Intl J Production Economics.* 62(1), pp. 7-22.

Sharifi, H. and Zhang, Z. 2001. Agile manufacturing in practice application of a methodology. *Intl J Operations And Production Management.* 21(5-6), pp. 772-779.

Sheldon, D. H. 2006. *World Class Sales And Operations Planning: A Guide To Successful Implementation And Robust Execution.* J.Ross Publishing.

Sherehiy, B., Karwowski, W. and Layer, J. K. 2007. A review of enterprise agility: Concepts, frameworks and attributes. *Intl J Industrial Ergonomics.* 37(5), pp. 445-460.

Shih, Y. C. and Lin, C. T. 2002. Agility index of manufacturing firm: A fuzzy-logic-based approach. *Proceedings of the Conference Engineering Management (IEMC).* 8th -20th August. Cambridge, UK. IEEE Explore Digital Library, pp. 465-470.

Sikdar, S. K. 2003. Sustainable development and sustainability metrics. *J American Institute of Chemical Engineers (AIChE).* 49(8), pp. 1928-1932.

Small, A. H. 1999. Assessing manufacturing performance: An advanced manufacturing technology portfolio perspective. *Industrial Management and Data Systems.* 99(6), pp. 266-278.

Singh, R. K., Murty, H. R., Gupta, S. K. and Dikshit, A. K. 2007. Development of composite sustainability performance index for steel industry. *Ecological Indicators.* 7(3), pp. 565-588.

Singh, R. K., Murty, H. R., Gupta, S. K. and Dikshit, A. K. 2009. An overview of sustainability assessment methodologies. *Ecological Indicators.* 9(2), pp. 189-212.

Škrinjar, R., Bosilj-Vukšic, V. and Indihar-Štemberger, M. 2008. The impact of business process orientation on financial and non-financial performance. *J Business Process Management.* 14, pp. 738-754.

Slack, N. 1997. The Blackwell Encyclopedic Dictionary of Operations Management. In: C. L. Cooper and C. Argris eds. *The Blackwell Encyclopedia of Management.* Blackwell Business.

So, K. C. and Song, J. S. 1998. Price, delivery time guarantees and capacity selection. *European J Operational Research.* 111(1), pp. 28-49.

Sohal, A. S. and Egglestone, A. 1994. Lean Production: Experience among Australian organizations. *Intl J Production and Operations Management.* 14, pp. 35-51.

Soman, C. A., van Donk, D. P. and Gaalman, G. 2004. Combined make-to-order and make-to-stock in a food production system. *Intl J Production Economics.* 90(2), pp. 223-235.

Song, J.-S. and Zipkin, P. 1993. Inventory control in a fluctuating demand environment. *Operations Research.* 41(2), pp. 351-370.

Sonntag, V. 2000. Sustainability: In light of competitiveness. *J Ecological Economics.* 34(1), pp. 101-113.

Soriano-Meier, H. and Forrester, P. L. 2002. A model for evaluating the degree of leanness of manufacturing firms. *J Integrated Manufacturing Systems.* 13(2), pp. 104-109.

Srinivasaraghavan, J. and Allada, V. 2006. Application of Mahalanobis Distance as a lean assessment metric. *Intl J Advanced Manufacturing Technology.* 29(11-12), pp. 1159-1168.

Svensson, D. and Malmqvist, J. 2002. Strategies for product structure management at manufacturing firms. *J Computing And Information Science In Engineering* 2(1), pp. 50-58.

Swanson, L. 2001. Linking maintenance strategies to performance. *Intl J Production Economics.* 70(3), pp. 237-244.

Swink, M. and Hegarty, W. H. 1998. Core manufacturing capabilities and their links to product differentiation. *Intl J Operations and Production Management.* 18, pp. 374-396.

T

Tan, K. C., Kannan, V. R., Jayaram, J. and Narasimhan, R. 2004. Acquisition of operations capability: A model and test across US and European firms. *Intl J Production Research.* 42, pp. 833-851.

Tangen, S. 2005. Analysing the requirements of Performance Measurement Systems. *Measuring Business Excellence.* 9(4), pp. 46-54.

Tellis, W. 1997. Application of a case study methodology. *The Qualitative Report.* 3(3), pp. 1-17.

Tetsuo, L. 2002. A non-stationary periodic review production-inventory model with uncertain production capacity and uncertain demand. *European Journal of Operational Research.* 140(3), pp. 670-683.

Thomas, A. J. and Grabot, B. 2006 Key technologies and strategies for creating sustainable manufacturing organisation. *Innovative Production and Machines Systems (I*PROMS) Virtual Conference.* Cardiff, UK, 3rd - 14th July.

Thomas, A. J. and Barton, R. A. 2010. Using Technology to Improve The Manufacturing Performance of Companies. *Innovative Production Machines And Systems Virtual Conference*, 15th - 26th November 2010, www.iproms.org/iproms2010.

Treville, S. d. and Antonakis, J. 2006. Could lean production job design be intrinsically motivating?: Contextual, configurational and levels-of-analysis issues. *J Operations Management.* 24(2), pp. 99-123.

Tsourveloudis, N. C. and Valavanis, K. P. 2002. On the measurement of enterprise agility. *J Intelligent and Robotic Systems.* 33(3), pp. 329-342.

U

Upton, D. M. 1995a. Flexibility as process mobility: The management of plant capabilities for quick response manufacturing. *J Operations Management.* 12(3-4), pp. 205-224.

Upton, D. M. 1995b. What really makes factories flexible? *Harvard Business Review.* 73(4), pp. 74-84.

V

van Assen, M. F. 2000. Agile-based competence management: The relation between agile manufacturing and time-based competence management. *Intl J Agile Management Systems.* 2(2), pp. 142 – 155.

Van Hop, N. 2004. Approach to measure the mix response flexibility of manufacturing systems. *Intl J Production Research.* 42(7), pp. 1407-1418.

Vazquez-Bustelo, D., Avella, L. and Fernandez, E. 2007. Agility drivers, enablers and outcomes: Empirical test of an integrated agile manufacturing model. *Intl J Operations and Production Management.* 27(12), pp. 1303-1332.

Vazzquez-Bustelo, D. and Avella, L. 2006. Agile manufacturing: Industrial case studies in Spain. *J Technovation.* 26(10), pp. 1147-1161.

Veleva, V. and Ellenbecker, M. 2001. Indicators of sustainable production: Framework and methodology. *J Cleaner Production.* 9(6), pp. 519-549.

Verheugen, G. 2005. The New SME Definition.*User guide and model declaration.* Enterprise and Industry Publication. 1-52.

Vic, G. and Kaussar, P. 2001. Core competency requirements for manufacturing effectiveness. *Integrated Manufacturing Systems.* 12, pp. 217-227.

Vinodh, S., Sundararaj, G., Devadasan, S. R., Maharaja, R., Rajanayagam, D. and Goyal, S. K. 2008. DESSAC: A Decision Support System for quantifying and analysing agility. *Intl J Production Research.* 46(23), pp. 6759-6780.

Vokurka, R. J. and Fliedner, G. 1998. The journey toward agility *Industrial Management and Data Systems.* 98(4), pp. 165-171.

Voss, C. A. 2005. Paradigms of manufacturing strategy re-visited. *Intl J Operations and Production Management.* 25, pp. 1223-1227.

W

Wahab, M. I. M. 2005. Measuring machine and product mix flexibilities of a manufacturing system. *Intl J Production Research.* 43(18), pp. 3773-3786.

Wahab, M. I. M. and Stoyan, S. J. 2008. A dynamic approach to measure machine and routing flexibilities of manufacturing systems. *Intl J Production Economics.* 113(2), pp. 895-913.

Walden, M. 2008. *Health Related Fitness* [Online]. United Kingdom: TeachPE.com. Available at: www.teachpe.com [Accessed: 16th October 2008].

Wan, H. D., Chen, F. F. and Rivera, L. 2007. Leanness score of Value Stream Maps. *Proceedings of the Industrial Engineering Research Conference.* 21st - 23rd May. Tennessee, USA. Institute of Industrial Engineer, pp. 1515-1520.

Wan, H. D. and Chen, F. F. 2008. A leanness measure of manufacturing systems for quantifying impacts of lean initiatives *Intl J Production Research.* 46(23), pp. 6567–6584.

Wang, W. P. 2009. Toward developing agility evaluation of mass customization systems using 2-tuple Linguistic Computing. *Expert Systems with Applications.* 36(2, Part 2), pp. 3439-3447.

Ward, P. T., Leong, G. K. and Boyer, K. K. 1994. Manufacturing proactiveness and performance. *Decision Sciences.* 25(3), pp. 337-358.

Wiendahl, H. P., ElMaraghy, H. A., Nyhuis, P., Zah, M. F., Wiendahl, H. H., Duffie, N. and Kolakowski, M. 2007. Changeable Manufacturing - Classification, design and operation. *CIRP Annals: Manufacturing Technology* 56, pp. 783-809.

Willmott, H. 2010. The Case Study.*Lecture Notes.* Cardiff: Cardiff Business School. 1-9.

Womack, J. P. and Jones, D. T. 1994. From lean production to the lean enterprise. *Harvard Business Review.* 72(2), pp. 93-103.

Womack, J. P., Jones, D. T. and Roos, D. 1990. *The Machine That Changed The World.* Harper Perennial.

Womack, J. P. 2006. A Measure Of Lean. *J Manufacturing Engineer.* 85(4), pp. 6-7.

Wu, C. C., Lin, P. C. and Chou, C.-Y. 2006. Determination of price and warranty length for a normal lifetime distributed product. *Intl J Production Economics.* 102(1), pp. 95-107.

Y

Yang, S. L. and Li, T. F. 2002. Agility evaluation of mass customization product manufacturing. *J Materials Processing Technology.* 129(1-3), pp. 640-644.

Yusuf, Y. Y., Sarhadi, M. and Gunasekaran, A. 1999. Agile manufacturing: The drivers, concepts and attributes. *Intl J of Production Economics.* 62(1-2), pp. 33-43.

Yusuf, Y. Y., Ren, J. R. and Burns, N. D. 2001 A method for evaluating enterprise agility: An empirical study. *16th Intl Conference on Production Research.* 29th July - 3rd August, Prague, Czech Republic.

Yusuf, Y. Y. and Adeleye, E. O. 2002. A comparative study of lean and agile manufacturing with a related survey of current practices in the UK. *Intl J Production Research.* 40(17), pp. 4545-4562.

Yusuf, Y. Y., Adeleye, E. O. and Sivayoganathan, K. 2003. Volume flexibility: The agile manufacuring conundrum. *J Management Decision.* 41(7), pp. 613-624.

Z

Zhang, Q., Vonderembse, M. A. and Lim, J. S. 2003. Manufacturing flexibility: Defining and analyzing relationships among competence, capability and customer satisfaction. *J Operations Management.* 21(2), pp. 173-191.

Appendix
A

Table 4A: Sample of Effective Capacity Calculation for Four Different Unit Quantity

Month	PRODUCTION CAPACITY (Quantity vs Time) 2009: Maximum input quantity (litre/kg)	Input quantity (litre/kg)	No. of batch	Output quantity (litre/kg)	Production Value-added period (hour)	No. of Changeover (Bottling)	Total Changeover period (hour)	Production period (hour)	Actual Production period (hour)	Std. working period (hour)	Maximum capacity period (hour)	Idle period (hour)	Overtime period (hour)	Quantity Effectiveness (%): Avalaible Quantity	Quantity Effectiveness (%): Used Quantity	Time Effectiveness (%): Used Time	Effective Capacity, EC (%)
Jan	40,987.10	16,365.90	6	18,342.28	53.00	12	6.00	101.41	110.41	165.00	231.57	54.59	0	1.00	0.46	0.48	0.95
		2,000.00	5			10	5.00										
	608.00	608.00	8	605.90													
Feb	37,859.45	10,910.60	4	12,889.92	41.00	8	4.00	74.62	81.88	168.00	212.43	86.12	0	1.00	0.35	0.39	0.91
		2,000.00	5			10	5.00										
	608.00	608.00	8	606.30													
Mar	33,204.15	19,093.55	7	21,065.13	62.00	14	7.00	120.01	131.67	175.50	195.83	43.83	0	1.00	0.64	0.67	0.95
		2,000.00	5			10	5.00										
	684.00	684.00	9	682.06													
Apr	33,204.15	8,182.95	3	12,167.10	38.00	6	3.00	83.87	90.47	175.50	195.83	85.03	0	1.00	0.38	0.46	0.81
		4,000.00	10			20	10.00										
	684.00	608.00	8	605.20													
May	38,259.45	8,182.95	3	9,772.43	34.00	6	3.00	67.31	72.59	160.50	206.86	87.91	0	1.00	0.27	0.35	0.77
		1,600.00	4			8	4.00										
	760.00	760.00	10	757.50													
Jun	38,259.45	19,093.55	7	20,670.20	62.00	14	7.00	118.70	130.66	178.50	223.53	47.84	0	1.00	0.55	0.58	0.94
		1,600.00	4			8	4.00										
	760.00	760.00	10	756.90													
Jul	37,859.45	13,628.35	5	15,616.02	47.00	10	5.00	89.00	97.51	190.50	212.35	92.99	0	1.00	0.42	0.46	0.92
		2,000.00	5			10	5.00										
	760.00	760.00	10	756.10													
Aug	37,859.45	10,910.60	4	12,893.54	43.00	8	4.00	83.10	90.69	168.00	215.25	77.31	0	1.00	0.35	0.42	0.84
		2,000.00	5			10	5.00										
	608.00	760.00	10	757.40													
Sep	30,076.50	21,820.50	8	23,391.27	69.00	16	8.00	130.86	145.86	168.00	189.57	22.14	0	1.00	0.78	0.77	1.02
		1,600.00	4			8	4.00										
	608.00	684.00	9	681.80													
Oct	37,859.45	16,365.90	6	20,340.54	62.00	12	6.00	122.37	136.12	183.00	204.61	46.88	0	1.00	0.55	0.67	0.82
		4,000.00	10			20	10.00										
	760.00	836.00	11	831.20													
Nov	37,859.45	16,365.90	6	17,545.80	55.00	12	6.00	98.39	110.14	168.00	215.19	57.86	0	1.00	0.47	0.51	0.92
		1,200.00	3			6	3.00										
	608.00	608.00	8	606.30													
Dis	38,259.45	21,821.21	8	23,395.27	64.00	16	8.00	119.43	134.55	175.50	221.09	40.95	0	1.00	0.62	0.61	1.01
		1,600.00	4			8	4.00										
	608.00	608.00	8	604.70													
Total	449,603.50	216,625.96	240	216,340.86	630.00	262	131.00	1,209.07	1,332.55	2,076.00	2524.11	743.45	0	1.00	0.61	0.64	0.91

Table 4B: Sample of PWI and PPI Calculation for Single-Input with Multiple-Outputs

Month	Non-Returned Costs (RM)																					
	2009																					
			Production Wastes																			
	Input (ton)	Paid-out cost	Inventory (ton)	Paid-out cost	Excess quantity (ton)	Paid-out cost	Delayed Loss (ton)	Lost paid-in	Scrap (ton)	Paid-out cost	Returned (ton)	Paid-out cost	Time loss (hour)	Paid-out cost	Overtime (hour)	Paid-out cost	Total Wastes Cost	Sale (ton)	Paid-in cost	Production Profit/Loss	Production Waste Index PWI	Produciton Profitability Index PPI
Jan	15.41	90,611	1.40	8,232	1.20	7,056	0	0	0.36	2,045	0.02	118	122.40	814	0	0	18,264	13.85	121,188	12,312	0.60	0.40
Feb	18.47	108,604	2.60	15,288	1.69	9,937	0	0	0.16	909	0.02	118	13.20	88	0	0	26,339	16.62	145,425	10,482	0.72	0.28
Mar	20.10	118,188	3.38	19,874	0	0	0	0	0.39	2,215	0.01	59	3.12	21	0	0	22,169	20.62	180,425	40,068	0.36	0.64
Apr	19.43	114,248	2.62	15,406	0	0	0	0	0.54	3,067	0.02	118	2.88	0	0	0	18,590	19.65	171,938	39,099	0.32	0.68
May	20.77	122,128	2.62	15,406	0.10	588	0	0	0.09	511	0.01	59	0	0	30.48	405	16,969	20.58	180,075	40,978	0.29	0.71
Jun	19.43	114,248	2.72	15,994	0.01	59	0	0	0.25	1,420	0.01	59	2.88	19	0	0	17,550	19.17	167,738	35,939	0.33	0.67
Jul	15.41	90,611	0.88	5,174	0	0	0	0	0.23	1,306	0.01	59	169.92	1,130	0	0	7,670	17.03	149,013	50,732	0.13	0.87
Aug	20.10	118,188	0.88	5,174	3.08	18,110	0	0	0.29	1,647	0.20	1,176	3.12	21	0	0	26,129	16.73	146,388	2,071	0.93	0.07
Sep	20.10	118,188	3.96	23,285	0.66	3,881	0	0	0.12	682	0.15	882	0	0	44.88	597	29,326	19.32	169,050	21,536	0.58	0.42
Oct	18.76	110,309	1.45	8,526	0	0	0	0	0.22	1,250	0.18	1,058	50.88	338	0	0	11,172	21.71	189,963	68,481	0.14	0.86
Nov	19.43	114,248	0.31	1,823	0	0	0	0	0.39	2,215	0.03	176	2.88	19	0	0	4,234	20.18	176,575	58,093	0.07	0.93
Dis	20.77	122,128	0.31	1,823	3.65	21,462	0	0	0.10	568	0.03	176	0	0	44.88	597	24,626	17.02	148,925	2,171	0.92	0.08
Total	228.18	1,341,698	1.93	136,004	0.87	61,093	0	0	3.14	17,835	0.69	4,057	226.80	2,450	120.24	1,599	223,039	222.48	1,946,700	381,963	0.37	0.55

Notes:

Labor costs:

Category	2005	2006	2007	2008	2009
Senior operator (more than three years working experience) = RM4.20 per hour.	1	1	1	1	2
Junior operator (one to two years working experience) = RM3.40 per hour.	0	1	1	1	0
Training operator (less than one year working experience) = RM2.80 per hour	3	2	2	2	2
Total no. of operators	**4**	**4**	**4**	**4**	**4**

Table 4C: Sample of PWI and PPI Calculation for Single-Input with Single Output

Month	Product	Non- Returned Cost (RM) 2009: Input (liter/*kg)	Paid-out cost	Production Wastes: Inventory (liter/*kg)	Paid-out cost	Excess quantity (liter/*kg)	Paid-out cost	Delayed Loss (liter/*kg)	Lost paid-in	Scrap (liter/*kg)	Paid-out cost	Returned (liter/*kg)	Paid-out cost	Time loss (hour)	Paid-out cost	Overtime (hour)	Paid-out cost	Total Wastes Cost	Sale (liter/*kg)	Paid-in cost	Production Profit/Loss	Total Production Profit/Loss	Production Waste Index (individual)	Production Waste Index PWI (overall)	Production Profitability Index PPI (overall)
Jan	BSL	10,910.60	17,566	2,013.47	2,521	0	0	0	0	11.45	12	0	0	54.59	852	0	0	3,385	11,323	97,944	76,993	103,023	0.04	0.04	0.96
	TD	5,455.30	5,237	266.97	211	1,445.71	463	0	0	8.59	3	0	0			0	0	677	4,001	18,405	12,491		0.05		
	EM-S	2,000.00	3,160	481.09	575	0	0	0	0	3.58	4	0	0			0	0	579	2,251	14,632	10,892		0.05		
	*O-B	608.00	1,155	25.20	43	10.90	19	0	0	2.10	4	0	0			0	0	65	595	3,868	2,647		0.02		
Feb	BSL	8,182.95	14,075	2,013.47	2,743	1,964.33	2,298	0	0	10.62	12	0	0	86.12	1,343	0	0	6,397	6,028	52,142	31,671	48,488	0.17	0.14	0.86
	TD	2,727.65	2,619	172.68	183	618.74	204	0	0	5.91	2	0	0			0	0	389	2,103	9,674	6,666		0.06		
	EM-S	2,000.00	4,120	481.09	801	62.85	104	0	0	4.15	7	0	0			0	0	912	1,933	12,565	7,533		0.11		
	*O-B	608.00	1,581	9.00	22	0	0	0	0	1.70	4	0	0			0	0	26	650	4,225	2,619		0.01		
Mar	BSL	13,638.25	22,776	3,654.42	4,480	0	0	0	0	15.63	18	0	0	43.83	684	0	0	5,181	13,946	120,633	92,676	132,306	0.05	0.05	0.95
	TD	2,727.65	2,482	1,148.75	447	0	0	0	0	7.97	2	0	0			0	0	450	6,630	30,498	27,566		0.02		
	EM-S	2,000.00	2,860	543.94	562	15.18	15	0	0	4.82	5	0	0			0	0	582	1,980	12,870	9,428		0.06		
	*O-B	684.00	1,265	23.30	39	60.60	101	0	0	1.40	2	0	0			0	0	142	622	4,043	2,636		0.05		
Apr	BSL	5,455.30	7,910	3,364.91	3,415	0	0	0	0	4.81	4	0	0	85.03	1,326	0	0	4,746	5,740	49,651	36,995	57,116	0.11	0.11	0.89
	TD	2,727.65	2,673	1,289.76	577	0	0	0	0	4.64	2	0	0			0	0	579	2,582	11,877	8,625		0.06		
	EM-S	4,000.00	14,680	559.12	1,835	48.60	159	0	0	6.40	21	0	0			0	0	2,015	3,945	25,643	8,947		0.18		
	*O-B	608.00	1,660	29.10	74	0	0	0	0	2.80	7	0	0			0	0	81	660	4,290	2,549		0.03		
May	BSL	5,455.30	8,947	2,714.13	3,345	0	0	0	0	5.08	6	0	0	87.91	1,371	0	0	4,722	6,101	52,774	39,105	56,001	0.11	0.10	0.90
	TD	2,727.65	2,891	1,289.76	667	37.62	16	0	0	4.03	2	0	0			0	0	685	2,686	12,356	8,779		0.07		
	EM-S	1,600.00	3,440	487.31	860	0	0	0	0	1.41	2	0	0			0	0	862	1,690	10,985	6,683		0.11		
	*O-B	760.00	3,025	29.10	110	33.50	127	0	0	2.50	9	0	0			0	0	247	724	4,706	1,434		0.15		
Jun	BSL	13,638.25	23,049	2,234.24	2,934	0	0	0	0	13.14	78	0	0	47.84	746	0	0	3,758	14,105	122,008	95,202	133,269	0.04	0.03	0.97
	TD	5,455.30	5,019	237.57	195	0	0	0	0	8.11	23	0	0			0	0	218	6,537	30,070	24,834		0.01		
	EM-S	1,600.00	2,016	395.21	347	0	0	0	0	2.10	10	0	0			0	0	357	1,900	12,350	9,977		0.03		
	*O-B	760.00	1,558	59.50	111	0	0	0	0	3.10	14	0	0			0	0	125	760	4,940	3,257		0.04		
Jul	BSL	8,182.95	12,520	1,987.79	2,335	0	0	0	0	9.40	9	0	0	92.99	1,451	0	0	3,795	8,420	72,833	56,518	80,253	0.06	0.06	0.94
	TD	2,727.65	2,782	237.57	216	1,833.77	532	0	0	9.53	4	0	0			0	0	751	3,612	16,615	13,082		0.05		
	EM-S	2,000.00	3,640	395.21	568	96.70	83	0	0	3.30	5	0	0			0	0	656	1,847	12,006	7,709		0.08		
	*O-B	760.00	2,037	34.60	86	0	0	0	0	3.90	10	0	0			0	0	96	781	5,077	2,944		0.03		
Aug	BSL	8,182.95	14,075	1,896.74	2,606	0	0	0	0	8.00	9	0	0	77.31	1,206	0	0	3,822	8,266	71,501	53,605	75,143	0.07	0.07	0.93
	TD	2,727.65	2,646	1,398.30	587	0	0	0	0	3.69	1	0	0			0	0	588	3,397	15,626	12,392		0.05		
	EM-S	2,000.00	4,200	491.91	843	147.63	210	0	0	5.37	9	0	0			0	0	1,062	1,875	12,188	6,925		0.13		
	*O-B	760.00	2,417	34.60	103	19.40	48	0	0	2.60	8	0	0			0	0	160	738	4,797	2,221		0.07		
Sep	BSL	16,365.20	28,803	1,652.12	2,386	0	0	0	0	18.82	23	0	0	22.14	345	0	0	2,754	16,591	143,512	111,955	150,378	0.02	0.02	0.98
	TD	5,455.30	4,855	304.90	205	0	0	0	0	8.70	2	0	0			0	0	207	6,540	30,084	25,021		0.01		
	EM-S	1,600.00	1,920	362.73	294	0	0	0	0	1.81	1	0	0			0	0	295	1,875	12,188	9,972		0.03		
	*O-B	684.00	1,183	20.80	32	0	0	0	0	2.20	3	0	0			0	0	35	715	4,648	3,429		0.01		
Total	NA	147,775.55	236,841	NA	37,361	NA	4,378	0	0	213.36	338	0	0	457.05	9,325	0	0	42,533	154,149	1,124,219	835,977	835,977	NA	0.05	0.95

Table 4D: Sample of PWI and PPI Calculation for Multiple-Inputs with Single-Outputs

Month	Product	Non- Returned Cost (RM)																							
		2008																							
				Production Wastes																					
		Input (liter/*kg)	Paid-out cost	Inventory (liter/*kg))	Paid-out cost	Excess quantity (liter/*kg)	Paid-out cost	Delayed Loss (liter/*kg)	Lost paid-in	Scrap (liter/*kg)	Paid-out cost	Returned (liter/*kg)	Paid-out cost	Time loss (hour)	Paid-out cost	Unnecessary Overtime (hour)	Paid-out cost	Total Wastes Cost	Sale (liter/*kg)	Paid-in cost	Production Profit/Loss	Total Production Profit/Loss	Production Waste Index (individual)	Production Waste Index PWI (overall)	Production Profitability Index PPI (overall)
	MP	3,000	1,290	249.7	41	0	0	0	0	3.9	0.5	0	0					798	3,063	3,982	1,893		0.30		
	HDD	250	100	123.2	16	0	0	0	0	0.8	0.1	0	0					16	312	499	383		0.04		
	*JP	0	0	132.7	12	0	0	0	0	0	0	0	0					12	0	0	-12		ZS		
	CB	1,000	310	359.6	45	38.0	5	0	0	2.0	0.2	0	0					51	960	528	167		0.23		
	MC	0	0	178.0	17	0	0	0	0	0	0	0	0					17	0	0	-17		ZS		
	TBC	1,000	310	173.4	24	0	0	0	0	2.3	0.3	0	0					24	800	1,200	866		0.03		
Jan	LD	500	150	126.5	16	38.8	5	0	0	1.2	0.1	0	0	53.34	757	0	0	21	460	598	427	14,190	0.05	0.10	0.90
	CS	0	0	0	0	0	0	344.1	344	0	0	0	0					344	0	0	-344		ZS		
	DWL	5,500	2,255	556.9	84	0	0	0	0	12.3	1.5	0	0					86	6,720	3,360	1,019		0.08		
	GC	0	0	88.6	10	0	0	0	0	0	0	0	0					10	0	0	-10		ZS		
	LaD	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0		0.00		
	FC	8,000	4,000	430.6	156	2.4	1	0	0	10.6	2.2	0	0					159	7,987	13,977	9,818		0.02		
	FS	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0		ZS		
	MP	1,000	620	249.7	38	155.4	31	0	0	2.6	0.3	0	0					821	842	1,095	-346		1.73		
	HDD	250	155	72.6	15	0	0	0	0	0.6	0.1	0	0					15	300	480	310		LS		
	*JP	0	0	132.7	12	0	0	0	0	0	0	0	0					12	0	0	-12		ZS		
	CB	0	0	0	0	0	0	102.4	56	0	0	0	0					56	500	275	219		0.20		
	MC	500	230	176.7	26	0	0	0	0	1.3	0.2	0	0					26	500	750	494		0.05		
	TBC	0	0	73.4	10	0	0	0	0	0	0	0	0					10	100	150	140		0.07		
Feb	LD	0	0	166.3	21	0	0	0	0	0	0	0	0	52.94	752	0	0	21	0	0	-21	14,855	ZS	0.08	0.92
	CS	3,000	1,890	179.3	35	0	0	0	0	6.6	0.9	0	0					36	3,000	3,000	1,074		0.03		
	DWL	1,000	620	531.6	148	0	0	0	0	6.3	0.8	0	0					149	4,519	2,260	1,490		0.09		
	GC	500	310	82.9	21	28.3	6	0	0	1.7	0.2	0	0					28	970	873	535		0.05		
	LaD	2,000	1,300	229.5	48	0	0	0	0	3.5	0.6	0	0					48	1,767	3,357	2,009		0.02		
	FC	6,500	4,550	0	0	0	0	66.3	116	8.3	1.7	0	0					118	6,991	12,234	7,566		0.02		
	FS	1,500	945	29.1	6	0	0	0	0	2.9	0.4	0	0					6	1,468	2,349	1,398		0.00		
	MP	1,500	1,005	188.1	41	0	0	0	0	3.0	0.5	0	0					1,372	1,714	2,228	-149		1.12		
	HDD	0	0	72.6	15	0	0	0	0	0	0	0	0					15	0	0	-15		ZS		
	*JP	0	0	132.7	12	0	0	0	0	0	0	0	0					12	0	0	-12		ZS		
	CB	1,000	490	0	0	0	0	0	0	2.3	0.4	0	0					0	1,000	550	60		0.01		
	MC	500	250	176.9	33	0	0	0	0	2.5	0.4	0	0					33	500	750	467		0.07		
	TBC	0	0	0	0	0	0	26.6	40	0	0	0	0					40	100	150	110		0.27		
Mar	LD	0	0	166.3	21	0	0	104.7	136	0	0	0	0	93.70	1,331	0	0	157	0	0	-157	6,914	ZS	0.22	0.78
	CS	0	0	149.3	35	0	0	0	0	0	0	0	0					35	0	0	-35		ZS		
	DWL	4,500	2,970	419.0	133	0	0	0	0	7.6	1.3	0	0					134	4,605	2,303	-801		LS		
	GC	0	0	116.9	19	0	0	0	0	0	0	0	0					19	0	0	-19		ZS		
	LaD	0	0	229.5	48	0	0	0	0	0	0	0	0					48	0	0	-48		ZS		
	FC	8,500	6,800	189.7	88	0	0	0	0	9.0	2.8	0	0					91	8,235	14,411	7,520		0.01		
	FS	0	0	29.1	6	0	0	0	0	0	0	0	0					6	0	0	-6		ZS		
Total	NA	19,250.00	30,550	NA	422	NA	11	344	344	33.1	5	0	0	199.98	2,840	0.00	0	4,849	57,413	71,359	35,960	35,960	NA	0.12	0.88

Table 4E: Sample of DCR Calculation

Month	2005		2006		2007		2008		2009	
	External Change		External Change		External Change		Demand		Demand	
	Sale (unit)	Demand Change Ratio, DCR	Sale (unit)	Demand Change Ratio, DCR	Sale (unit)	Demand Change Ratio, DCR	Sale (unit)	Demand Change Ratio, DCR	Sale (unit)	Demand Change Ratio, DCR
Jan	11,464	1.21	4,604	0.64	4,670	1.24	15,485	3.72	18,170	1.01
Feb	7,644	0.67	7,210	1.57	9,082	1.94	7,295	0.47	10,894	0.60
Mar	19,872	2.60	19,631	2.72	19,900	2.19	21,058	2.89	23,178	2.13
Apr	7,809	0.39	10,489	0.53	8,045	0.40	8,833	0.42	12,927	0.56
May	11,169	1.43	7,226	0.69	7,745	0.96	9,368	1.06	11,230	0.87
Jun	11,187	1.00	5,137	0.71	7,243	0.94	17,717	1.89	23,092	2.06
Jul	8,023	0.72	4,909	0.96	5,083	0.70	11,534	0.65	14,713	0.64
Aug	12,394	1.54	5,132	1.05	5,718	1.12	10,753	0.93	14,248	0.97
Sep	20,322	1.64	19,561	3.81	20,255	3.54	22,956	2.13	25,721	1.81
Oct	11,332	0.56	5,155	0.26	5,147	0.25	16,451	0.72	19,555	0.76
Nov	11,494	1.01	5,238	1.02	5,088	0.99	14,057	0.85	17,463	0.89
Dis	7,212	0.63	3,775	0.72	4,165	0.82	17,933	1.28	22,787	1.30
Total	**139,922**	**1.12**	**98,067**	**1.22**	**102,141**	**1.26**	**173,440**	**1.42**	**213,978**	**1.13**

Table 4F: Sample of PSI Calculation

Month	PRODUCTION SUSTAINABILITY							
	2007			Production Stability Index, PSI	2008			Production Stability Index, PSI
	Demand	Capacity			Demand	Capacity		
	Sale (litre)	Output (litre)	$Inventory_{i-1}$ (litre)		Sale (litre)	Output (litre)	$Inventory_{i-1}$ (litre)	
Jan	4,670	5,435.51	5,570.82	0.42	15,485	13,620.16	1,927.09	1.00
Feb	9,082	8,164.23	7,139.23	0.59	7,295	8,387.63	3,091.80	0.64
Mar	19,900	16,339.96	6,221.46	0.88	21,058	20,168.18	4,189.23	0.86
Apr	8,045	10,892.19	2,661.42	0.59	8,833	9,648.87	3,381.81	0.68
May	7,745	10,887.49	5,508.61	0.47	9,368	10,049.12	4,197.68	0.66
Jun	7,243	2,717.03	8,561.10	0.64	17,717	15,898.15	4,878.80	0.85
Jul	5,083	5,437.04	4,125.13	0.53	11,534	11,401.53	3,059.95	0.80
Aug	5,718	2,718.67	4,479.17	0.79	10,753	11,327.13	2,927.48	0.75
Sep	20,255	21,790.51	1,479.84	0.87	22,956	24,946.78	3,501.61	0.81
Oct	5,147	5,448.00	3,015.35	0.61	16,451	16,045.42	5,492.39	0.76
Nov	5,088	8,169.66	3,316.35	0.44	14,057	16,547.54	5,086.81	0.65
Dis	4,165	2,723.63	6,398.01	0.46	17,933	13,824.81	7,577.35	0.84
Total	**102,141**	**100,723.92**	na	**0.61**	**173,440**	**171,865.32**	na	**0.77**

Appendix
B

INDUSTRIAL VISIT
About The Company

A. COMPANY PROFILE

Company name: ______________________

Address: ______________________

____

Date established: __________

Type of industry: ______________________

Total number of employee:

☐ Direct labor

☐ Indirect labor

Business status:

☐ National

☐ International

Business reliance:

☐ Parent company

☐ Stand alone

Product category:

☐ Semi-finished goods

☐ Consumer goods

B. PRODUCT PROFILE

1- Product variety

Total number of Product Family: ________

2- Product range

Total number of Product Model: ________

Product Family	No. of Product Model	Product Family	No. of Product Model

3- Product customization

☐ Yes ☐ No

Total number of customized item (if Yes): _______

Product Family	No. of Customized Item	Product Family	No. of Customized Item

4- Production volume

Total number of standard input volume: ________

Product Family	Total No. of Std. Volume	Product Family	Total No. of Std. Volume

5- Packaging volume

Total number of standard packaging quantity:_______

Product Family	Total No. of Std. Volume	Product Family	Total No. of Std. Volume

6- Packaging customization

☐ Yes ☐ No

Product Family	Total No. of Std. Volume	Product Family	Total No. of Std. Volume

7- Delivery volume

Total number of standard packaging quantity:_______

Product Family	Total No. of Std. Volume	Product Family	Total No. of Std. Volume

8- Delivery customization

☐ Yes ☐ No

Total number of customized packaging quantity:______

Product Family	No. of Customized Quantity	Product Family	Total No. of Customized Quantity

C. MANUFACTURING SYSTEMS

1- Operation-based

- [ ] Made-To-Stock
- [ ] Made-To-Order
- [ ] Made-To-Forecast
- [ ] Engineering-To-Order

2- Operation durability

Total effective operating hours (per day): ________

Total working days (per year): ________

3- Status of demands

- [ ] Seasonal demand
- [ ] Uncertain demand

4- Category of production flow:

- [ ] Product-oriented
- [ ] Process-oriented
- [ ]

5- The MOST changes in Product Design/Specification were oriented by:

- [ ] Customer request
- [ ] Supplier request
- [ ] Parent company
- [ ] Own-innovation

6- Unpredictable changes in production:

- [ ] Yes
- [ ] No

Type of unpredictable changes in customer demands (if Yes):

- [ ] Volume (Order quantity)
- [ ] Variety (Product Family)
- [ ] Range (Product specifications)
- [ ] Delivery schedule

7- Adaption to the unpredictable changes:

- [ ] Production capability
- [ ] Outsourcing

8- **Continuous Improvement practices:**

- [ ] Quality Circle
- [ ] 5S
- [ ] Total Production Maintenance
- [ ] Statistical Process Control
- [ ] Six Sigma
- [ ] Total Quality Management
- [ ] Visual Management
- [ ] Others: ______________________

____

____

- [ ] None

D. SWOT ANALYSIS

Strength

- [ ] Quality
- [ ] Lower Price
- [ ] On-time Delivery
- [ ] Speed Delivery
- [ ] Flexible
- [ ]
- [ ]
- [ ] Others:

____

____

Weaknesses

- [ ] Limited capacity
- [ ] Limited capability
- [ ] Others:

____

____

Opportunities

- [ ] New market
- [ ] Market growth
- [ ] Capacity expansion
- [ ] Others:

____

____

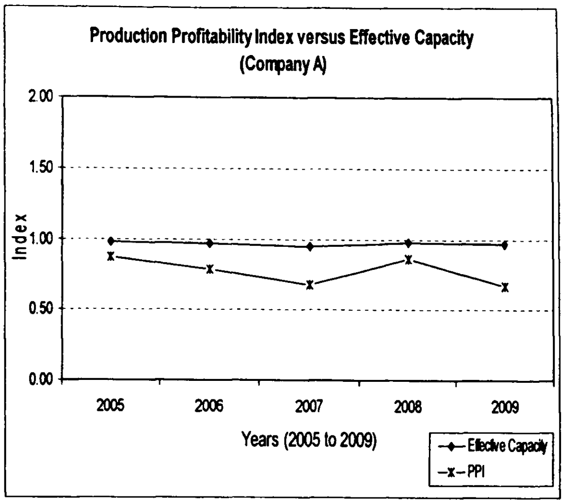
Threat

- [ ] Environmental regulations
- [ ] Multi-skilled labors
- [ ] Others:

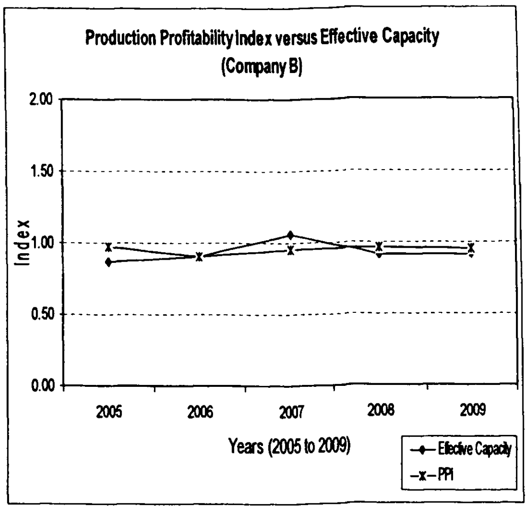
____

____

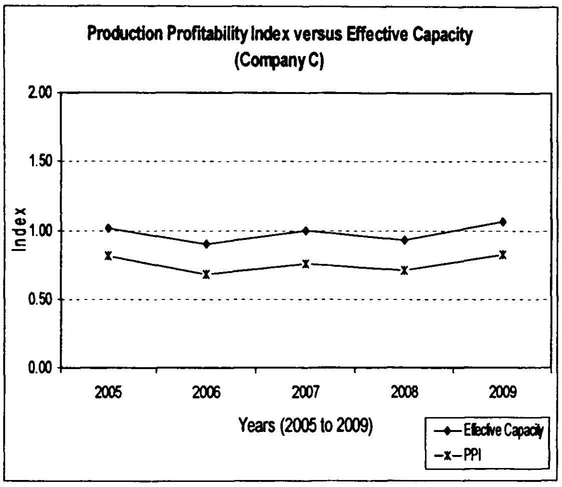
Appendix C



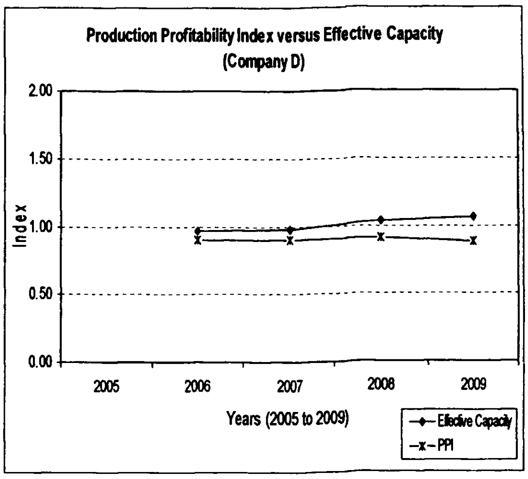
(a)



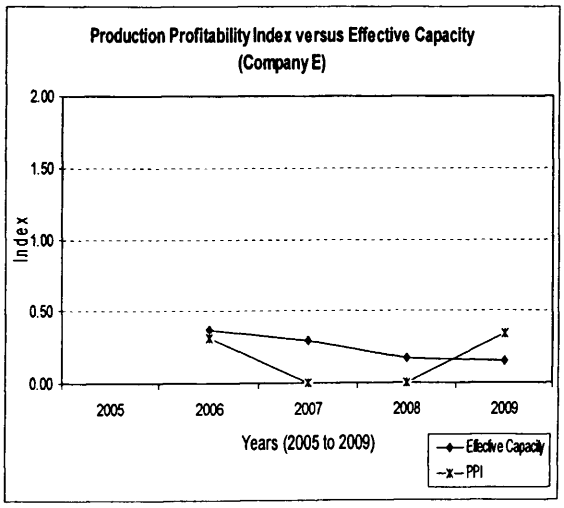
(b)



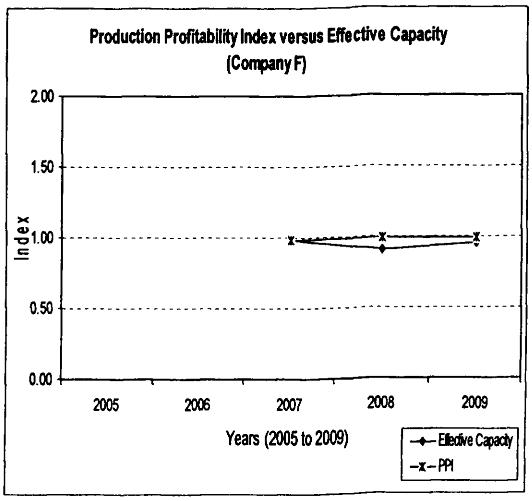
(c)



(d)

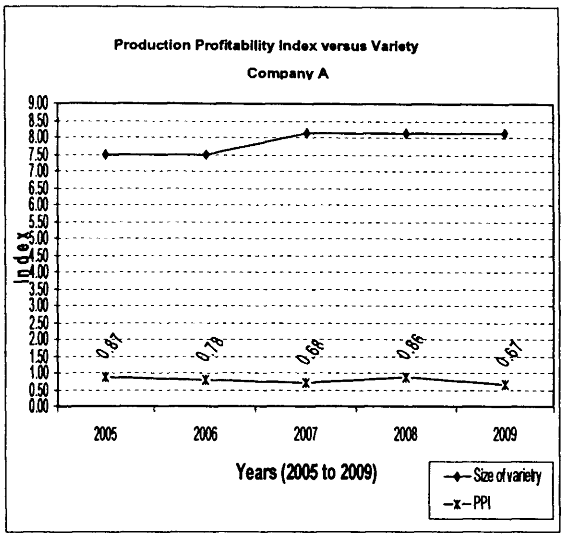


(e)

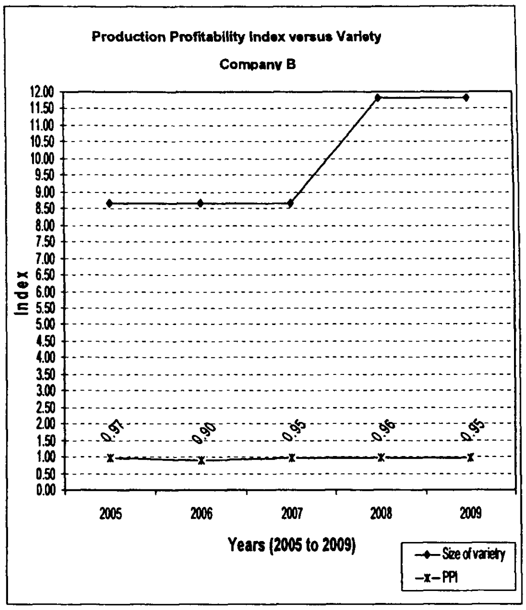


(f)

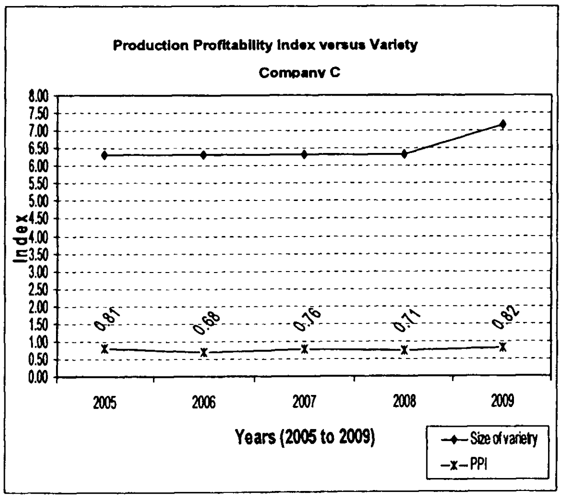
Figure C-1a: Relationship between PPI and Effective Capacity



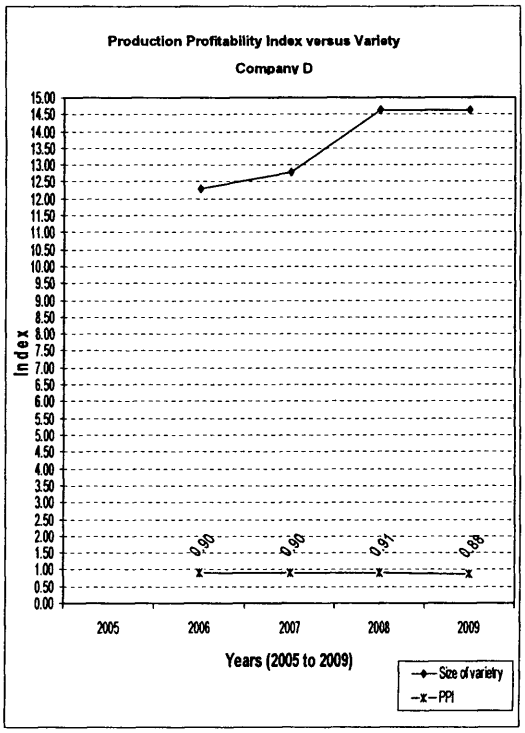
(a)



(b)

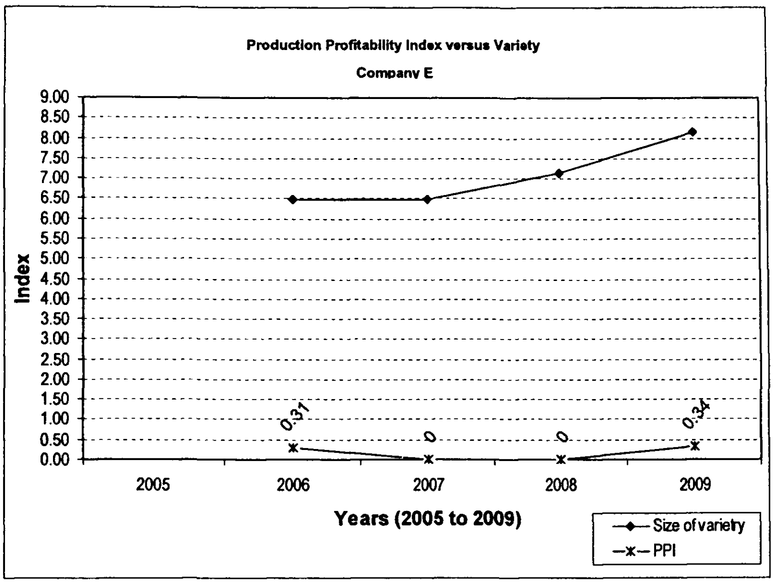


(c)

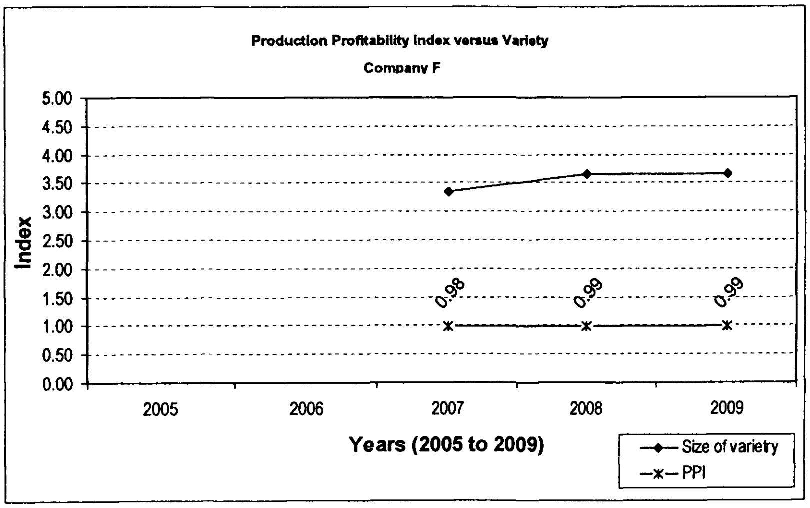


(d)

Figure C-1b: Relationship between PPI and Variety

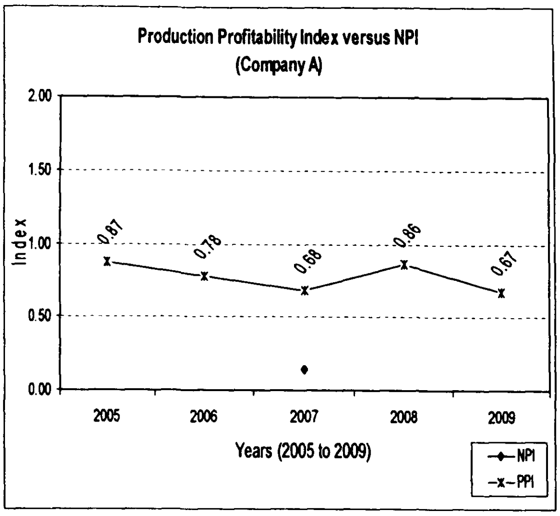


(e)

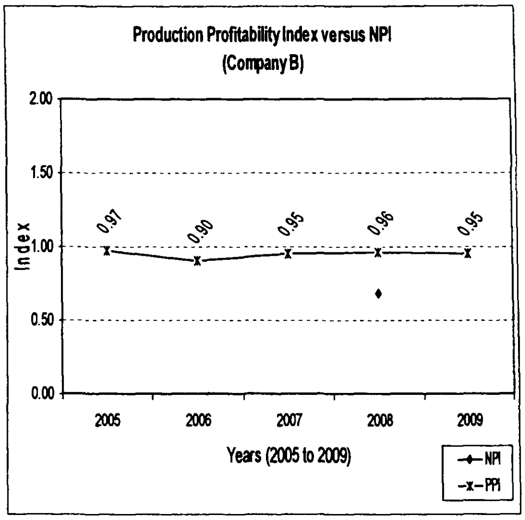


(f)

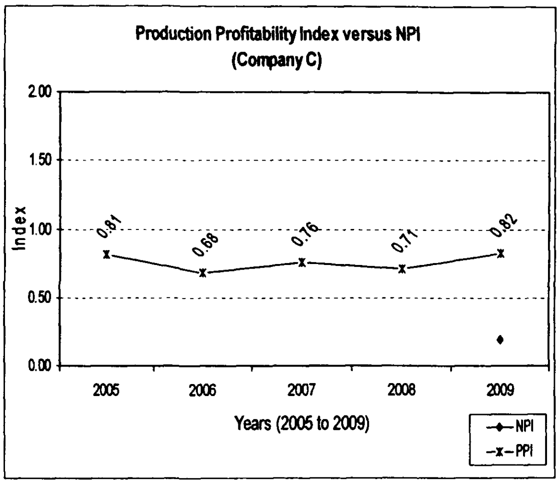
Figure C-1b: Relationship between PPI and Variety (continue)



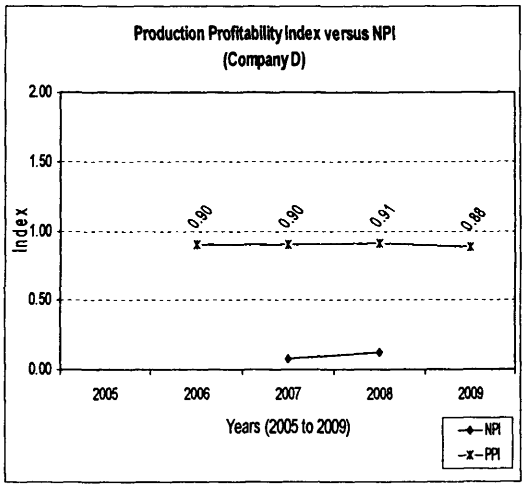
(a)



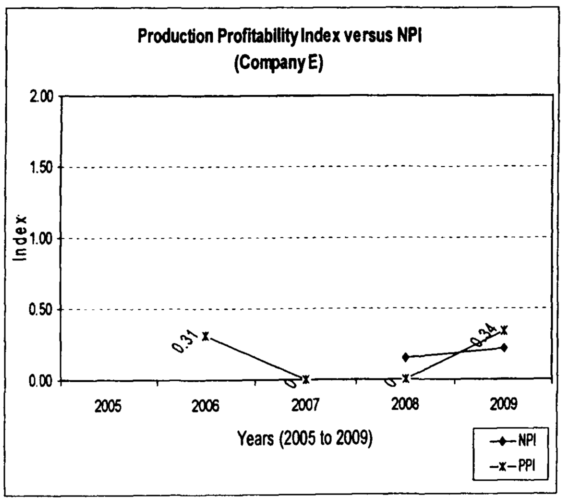
(b)



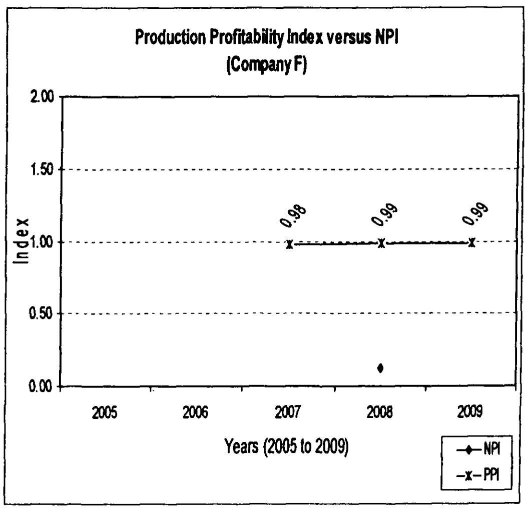
(c)



(d)

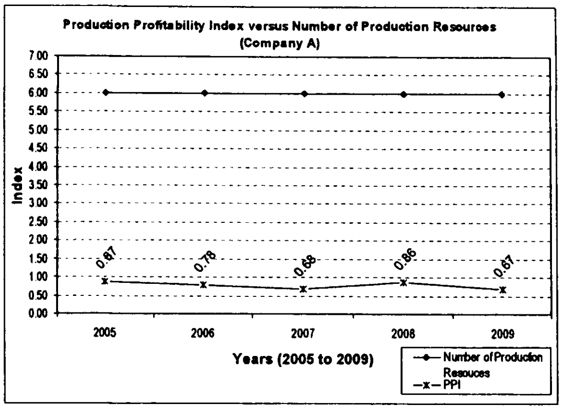


(e)

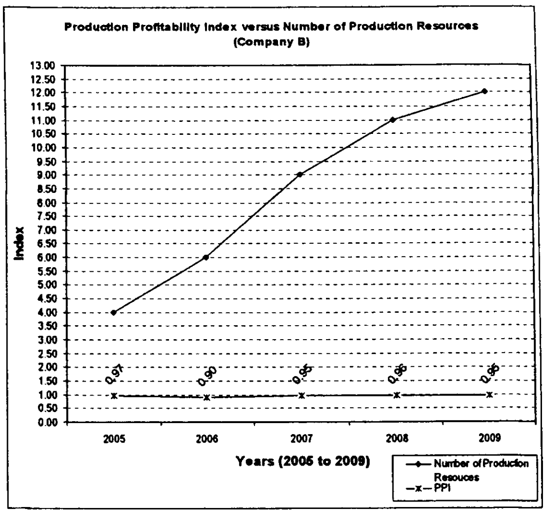


(f)

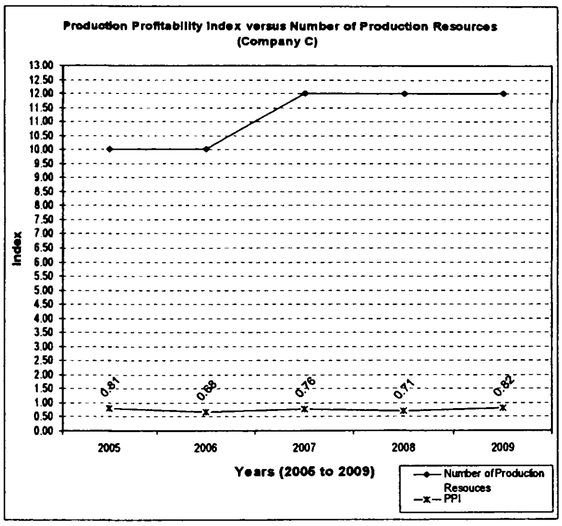
Figure C-1c: Relationship between PPI and NPI



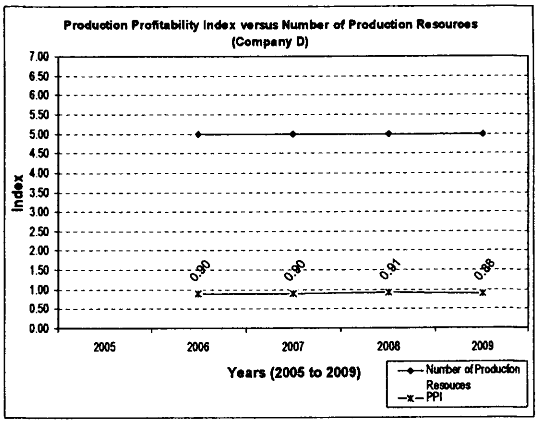
(a)



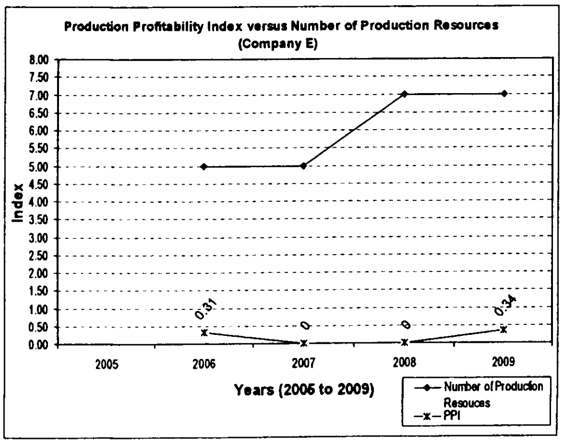
(b)



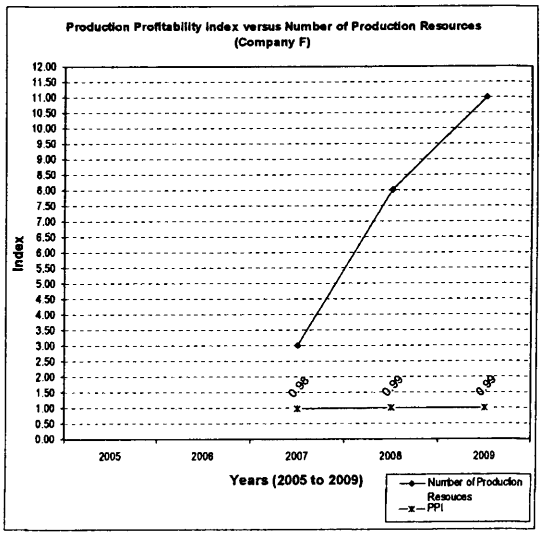
(c)



(d)

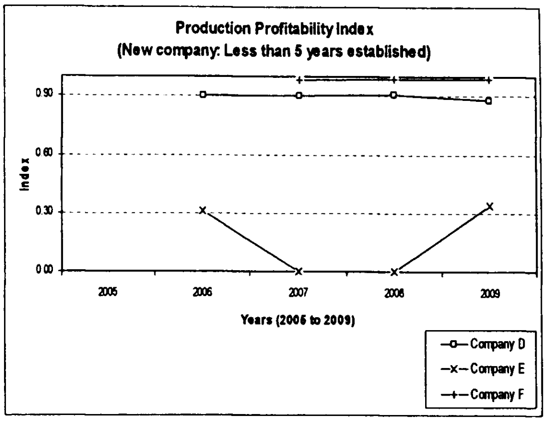


(e)

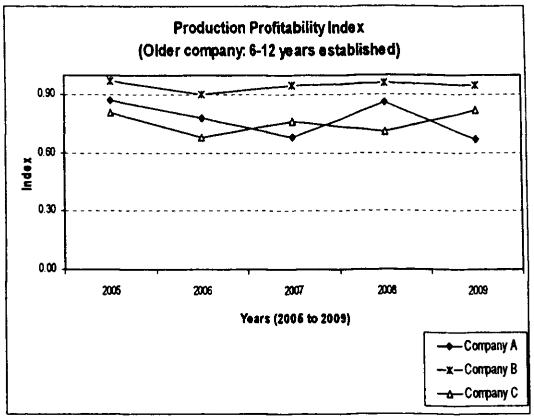


(f)

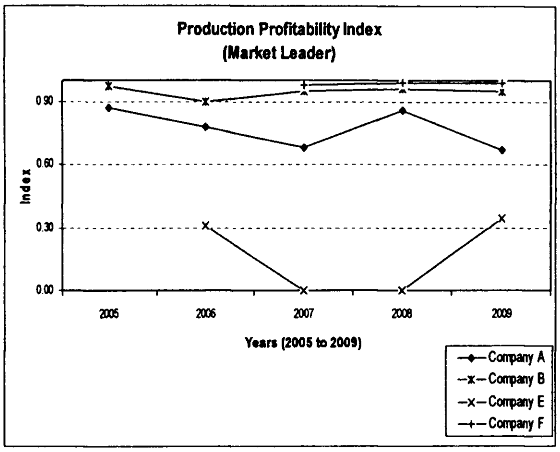
Figure C-1d: Relationship between PPI and Number of Production Resources



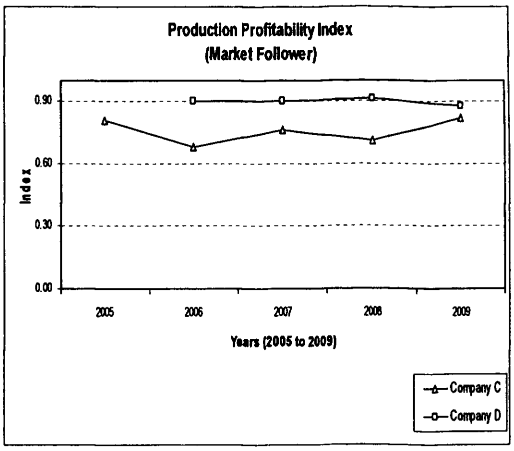
(i)



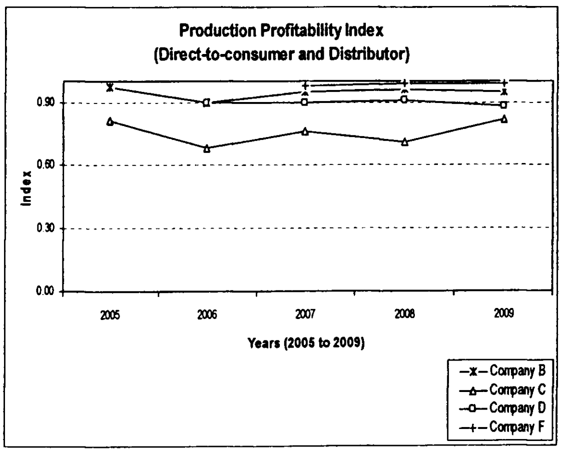
(ii)



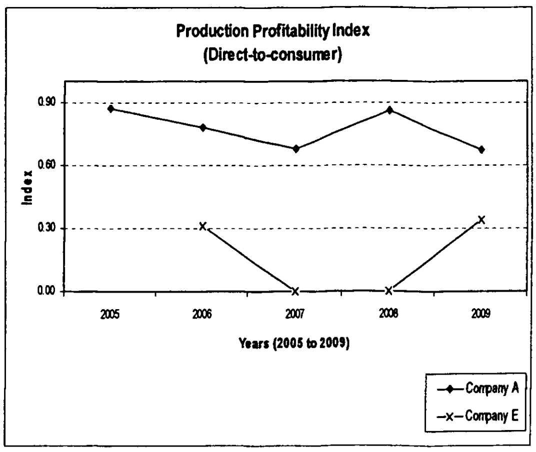
(iii)



(iv)

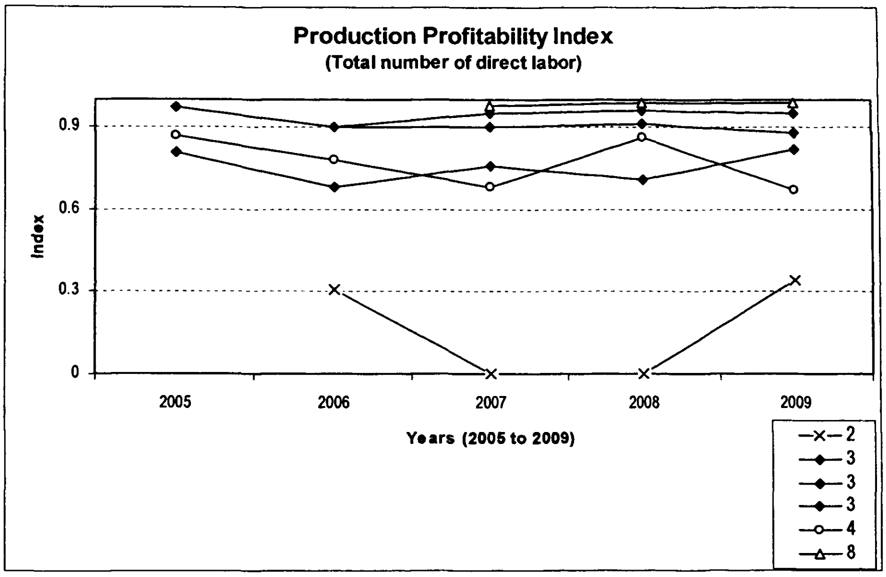


(v)

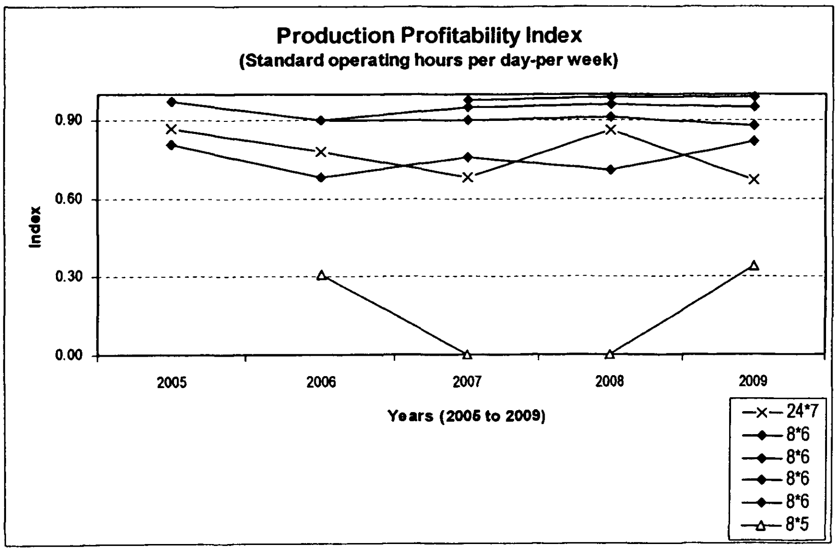


(vi)

Figure C-1e: Annual PPI with Different Company Characteristics

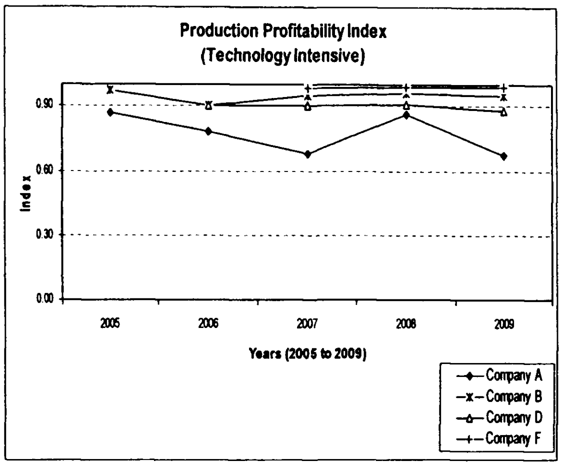


(vii)

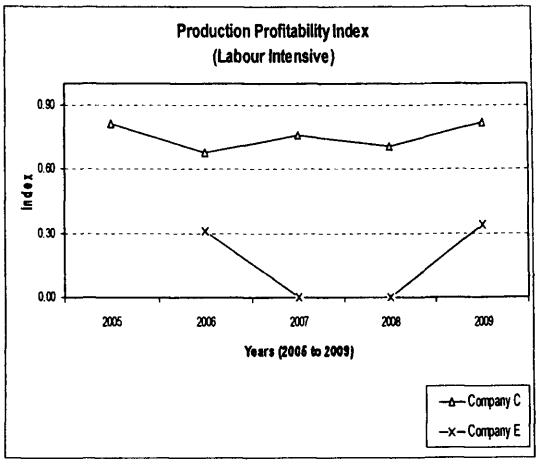


(viii)

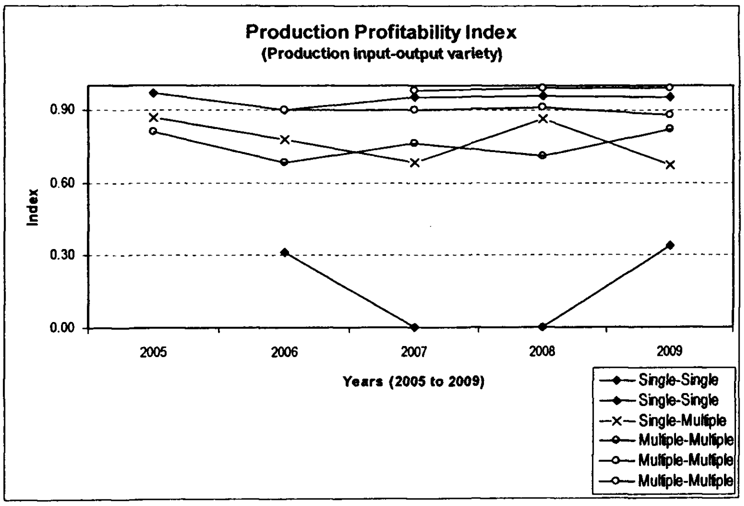
Figure C-1e: Annual PPI with Different Company Characteristics (continue)



(i)

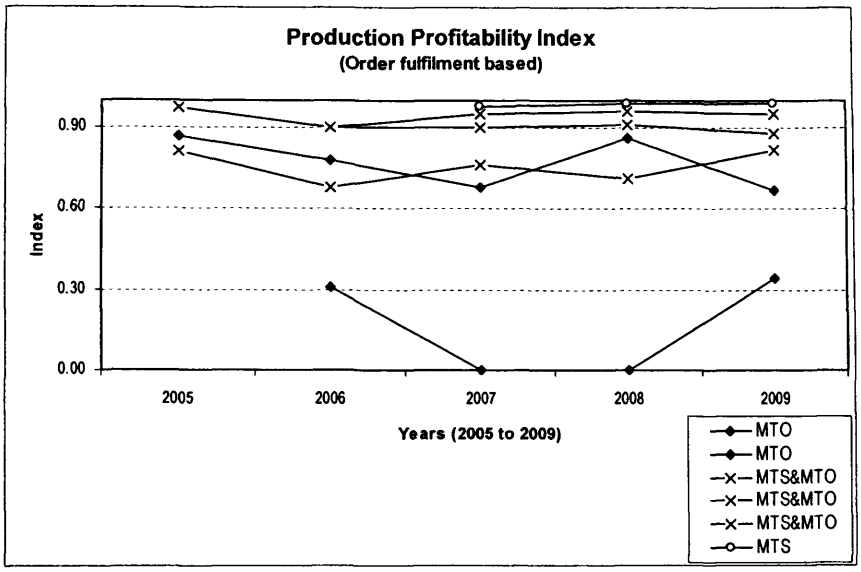


(ii)

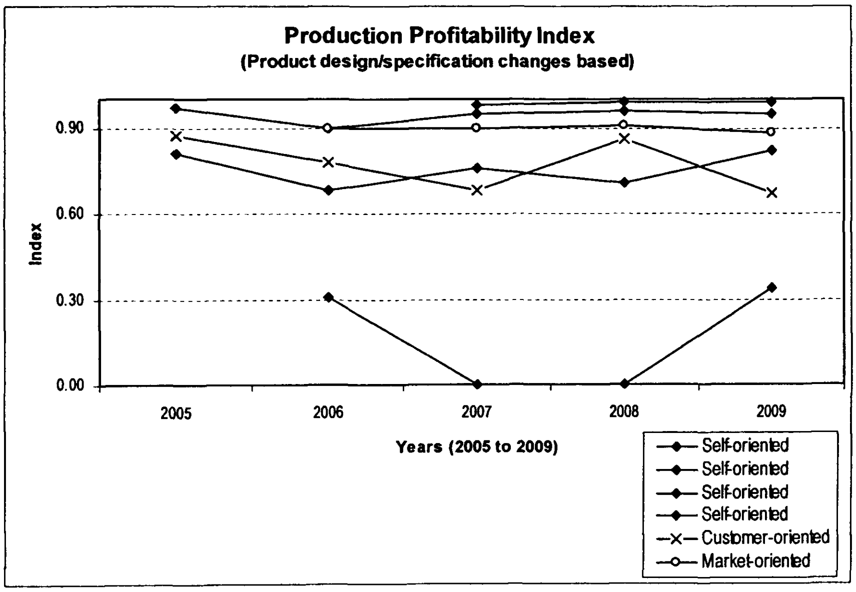


(iii)

Figure C-1f: Annual PPI with Different Production Characteristics



(iv)



(v)

Figure C-1f: Annual PPI with Different Production Characteristics (continue)

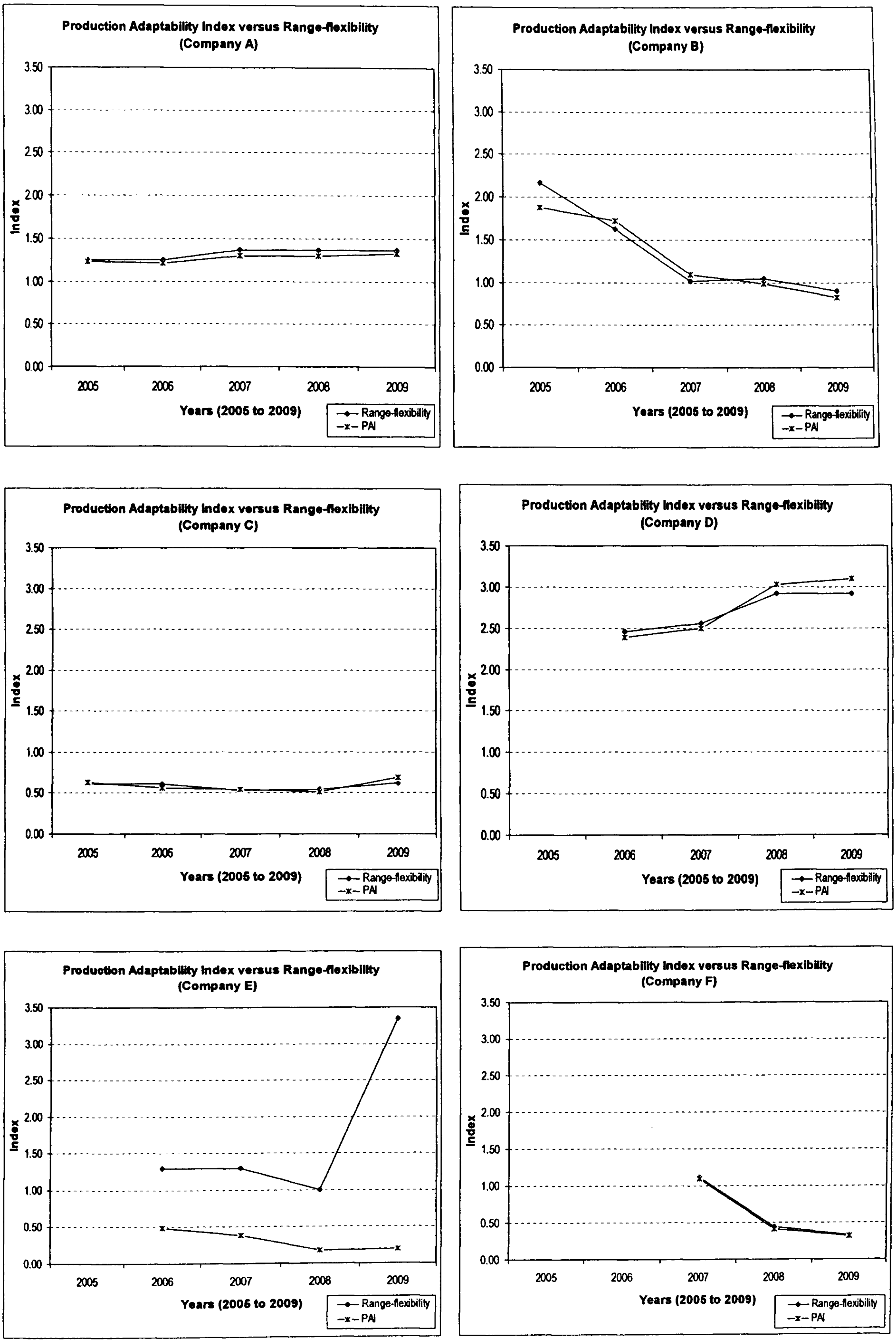


Figure C-2a: Relationship between PAI and Production Range-flexibility

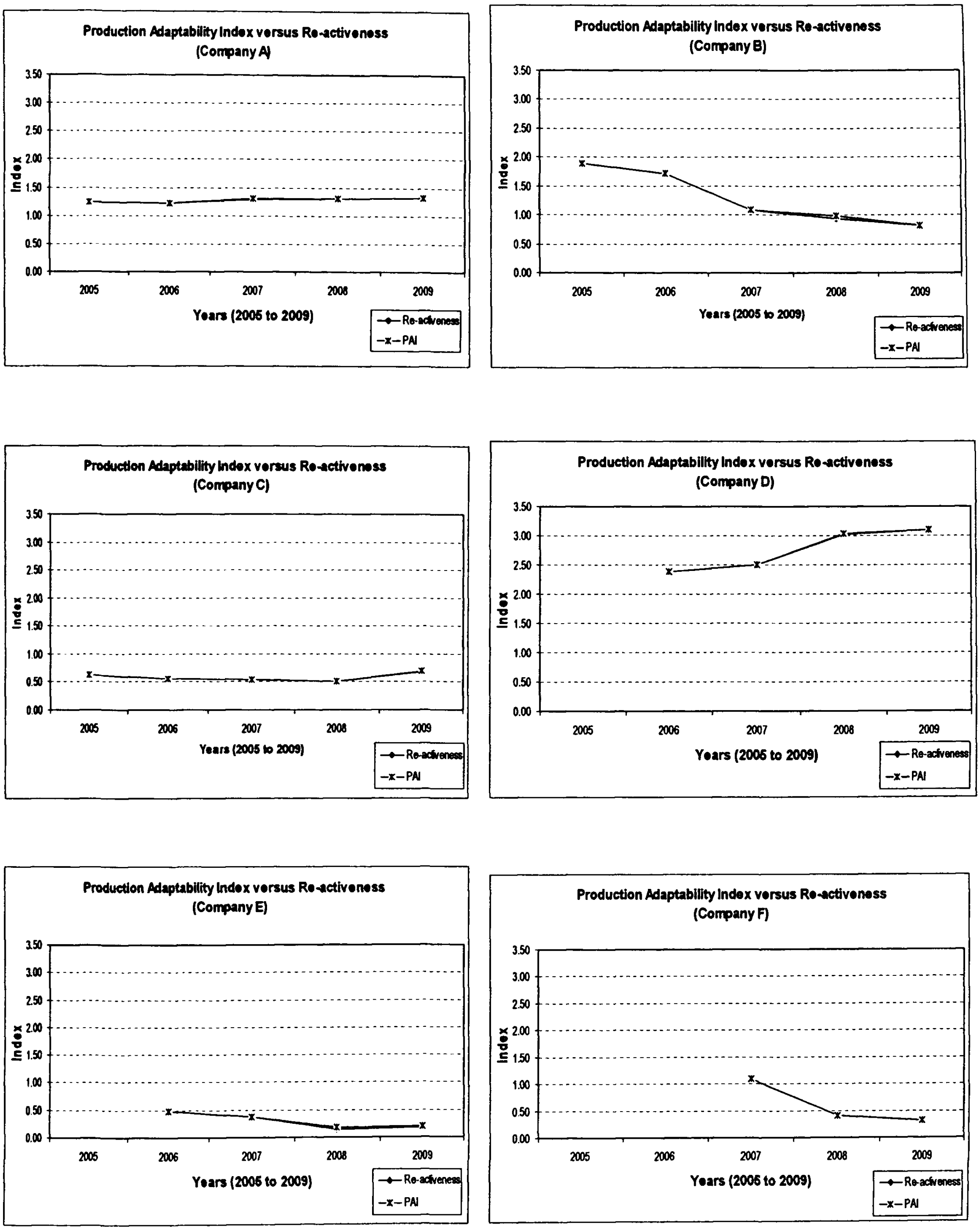


Figure C-2c: Relationship between PAI and Production Re-activeness

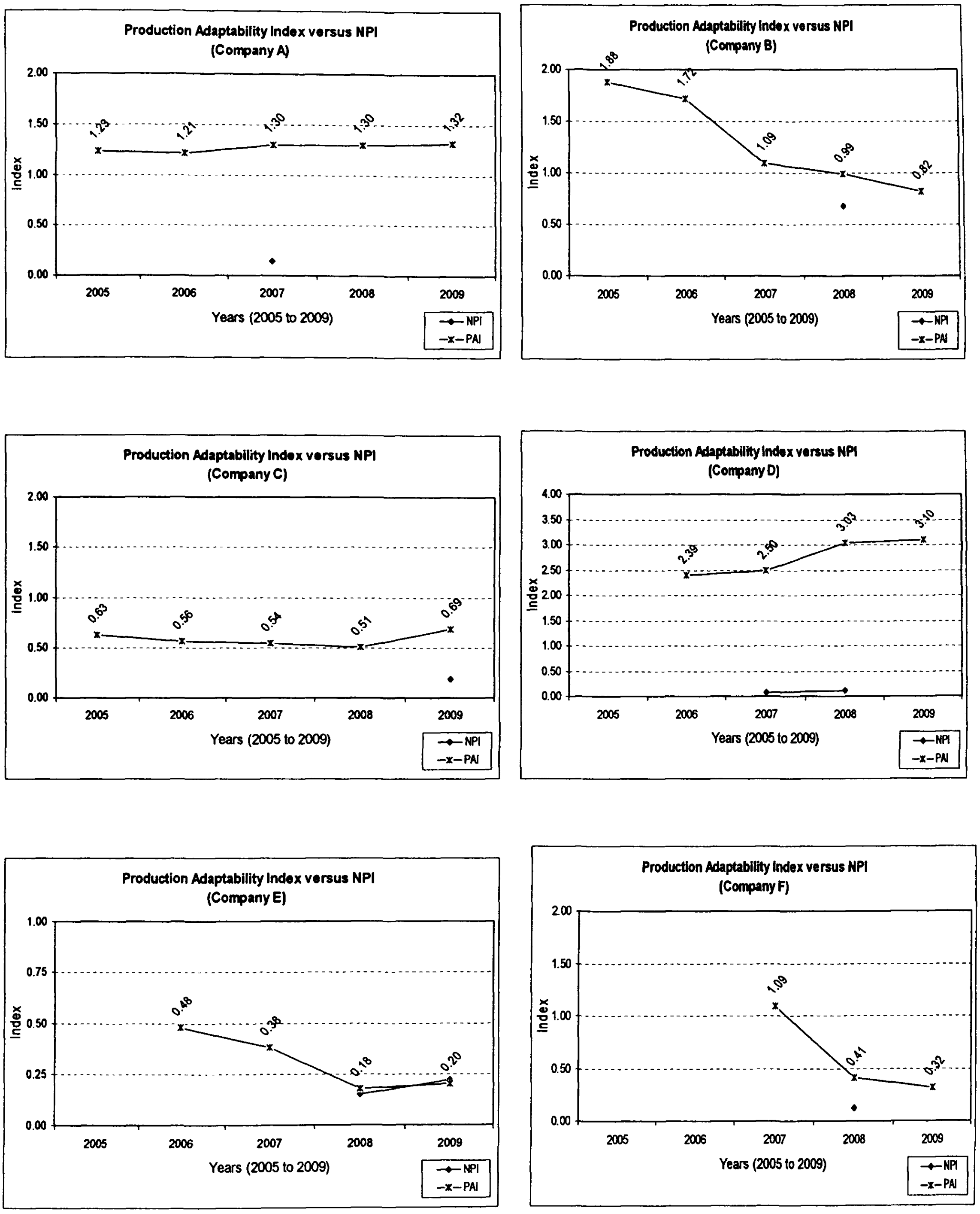


Figure C-2c: Relationship between PAI and NPI

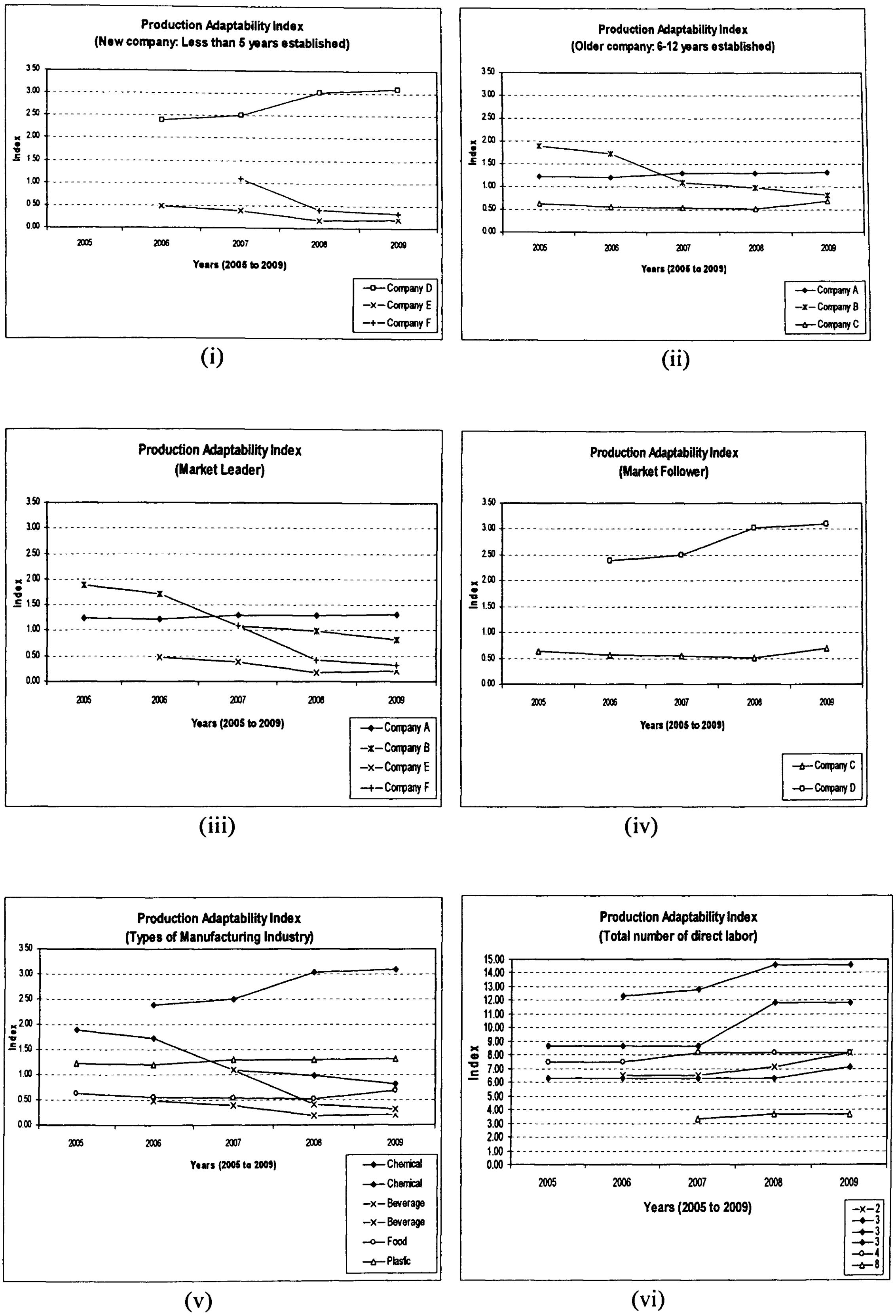
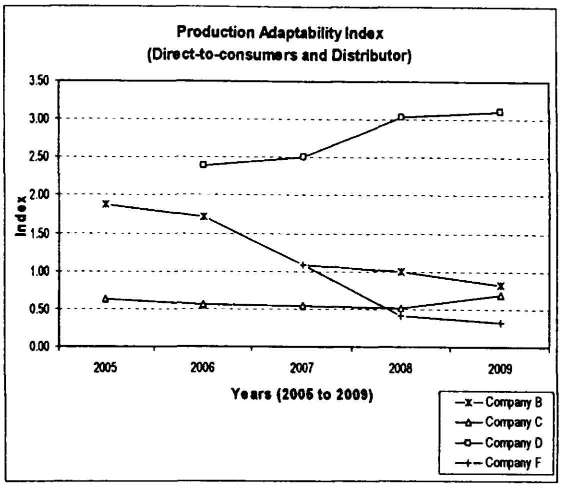
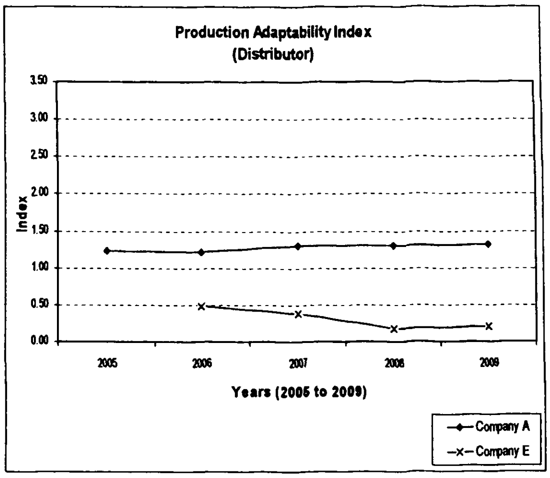


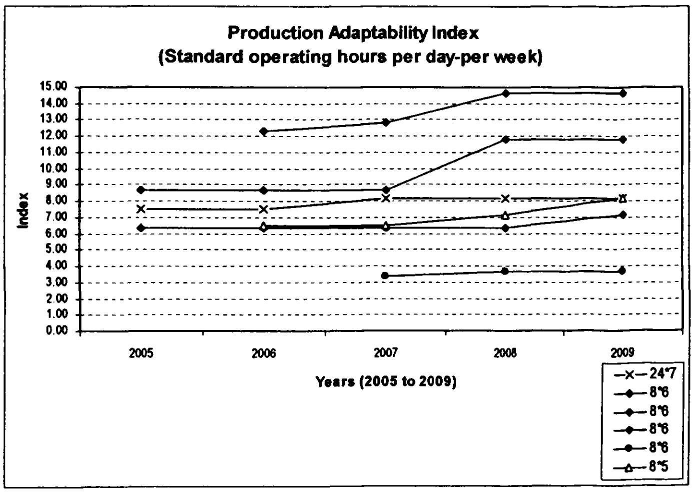
Figure C-2d: The Annual PAI with Different Company Characteristics



(vii)

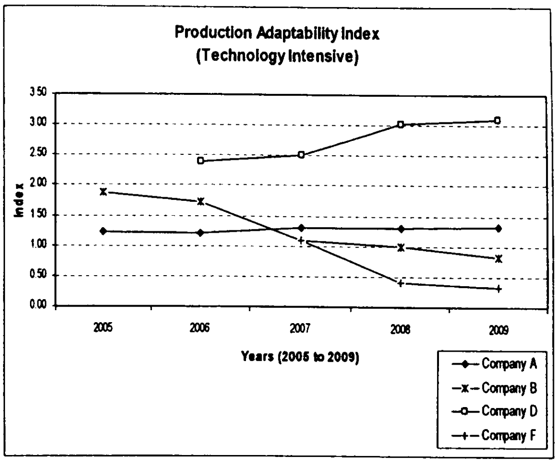


(viii)

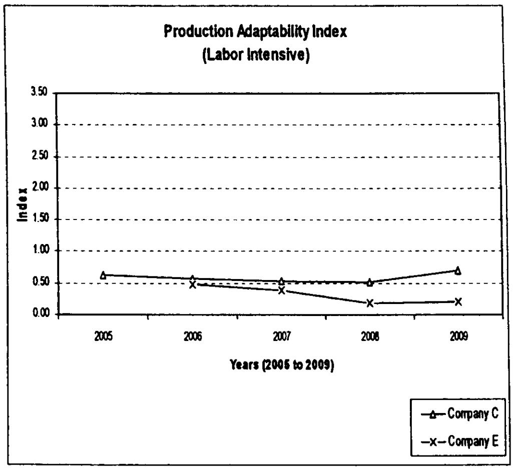


(v)

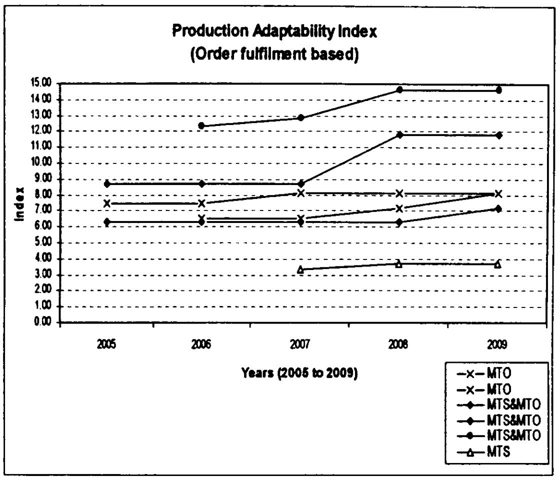
Figure C-2d: The Annual PAI with Different Company Characteristics (continue)



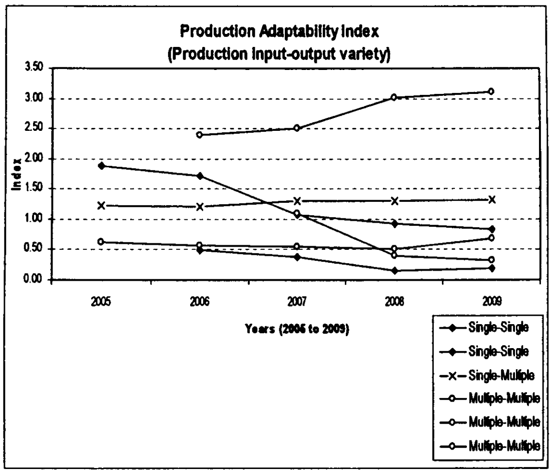
(i)



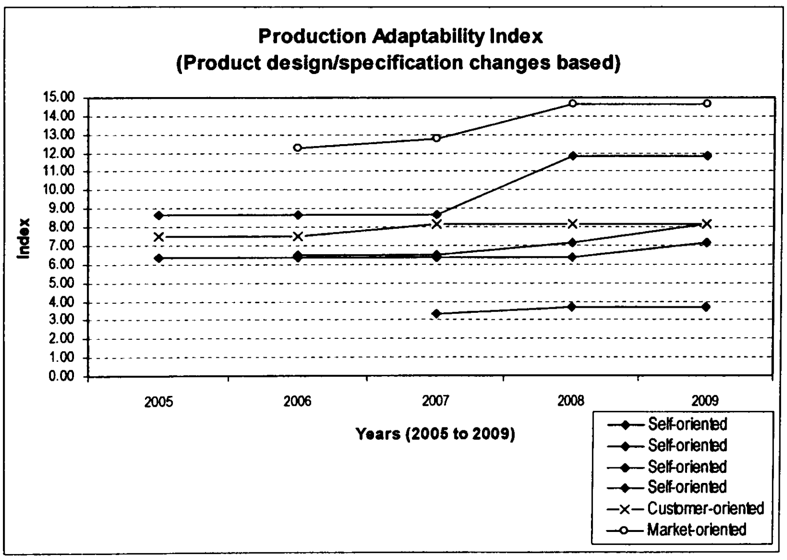
(ii)



(iii)



(iv)



(v)

Figure C-2e: The Annual PAI with Different Production Characteristics

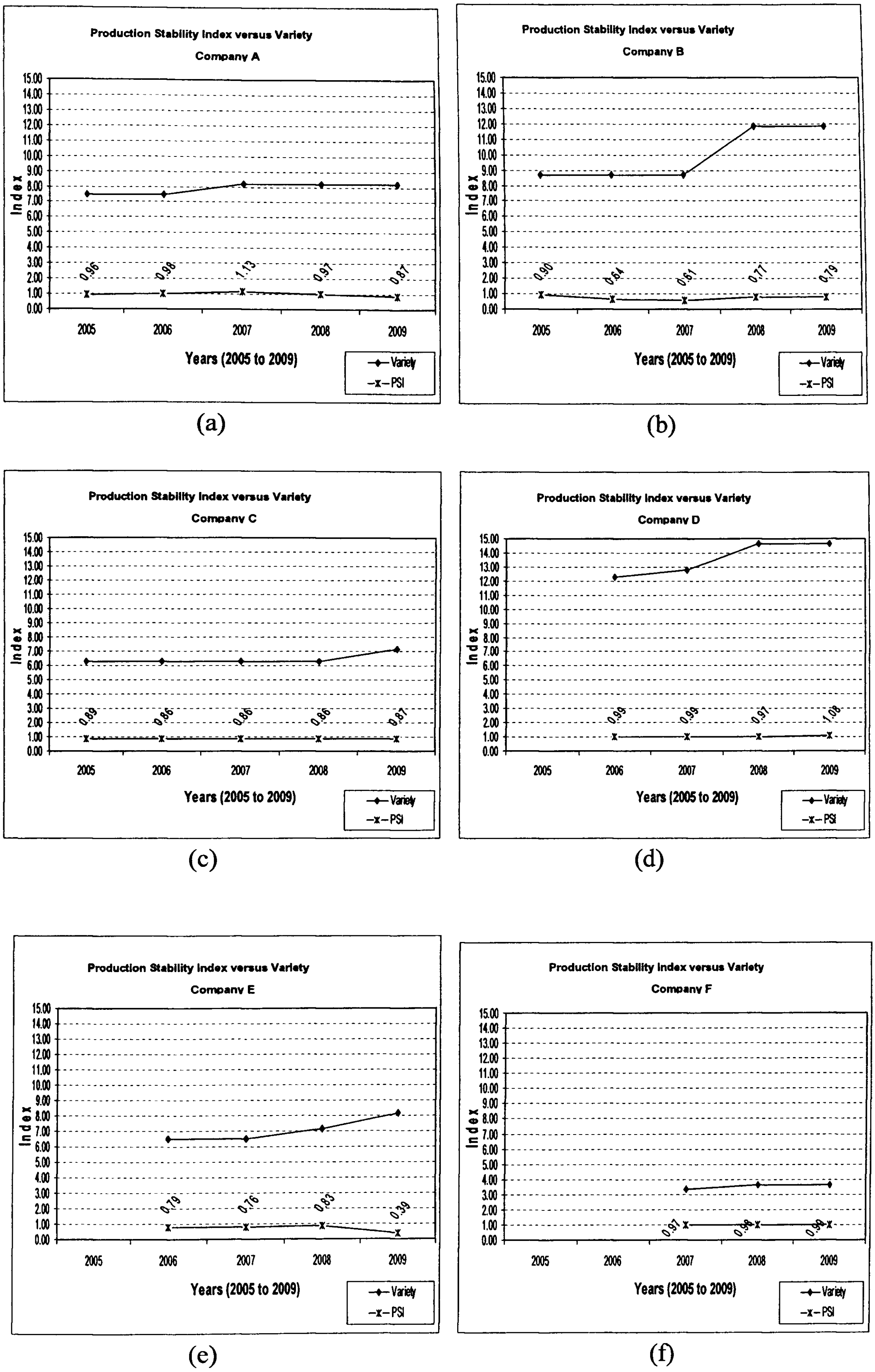


Figure C-3a: Relationship between PSI and Variety

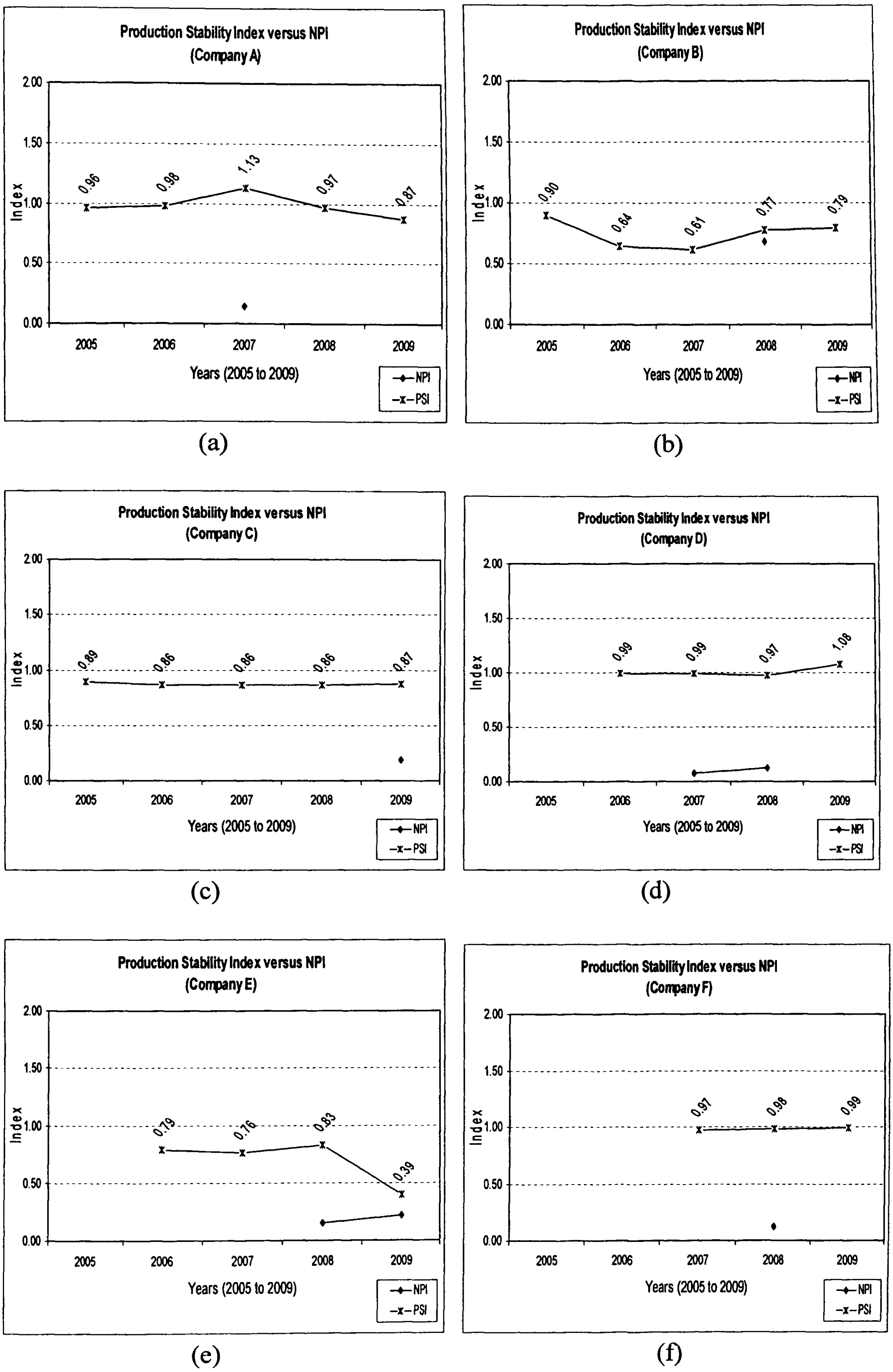


Figure C-3b: Relationship between PSI and NPI

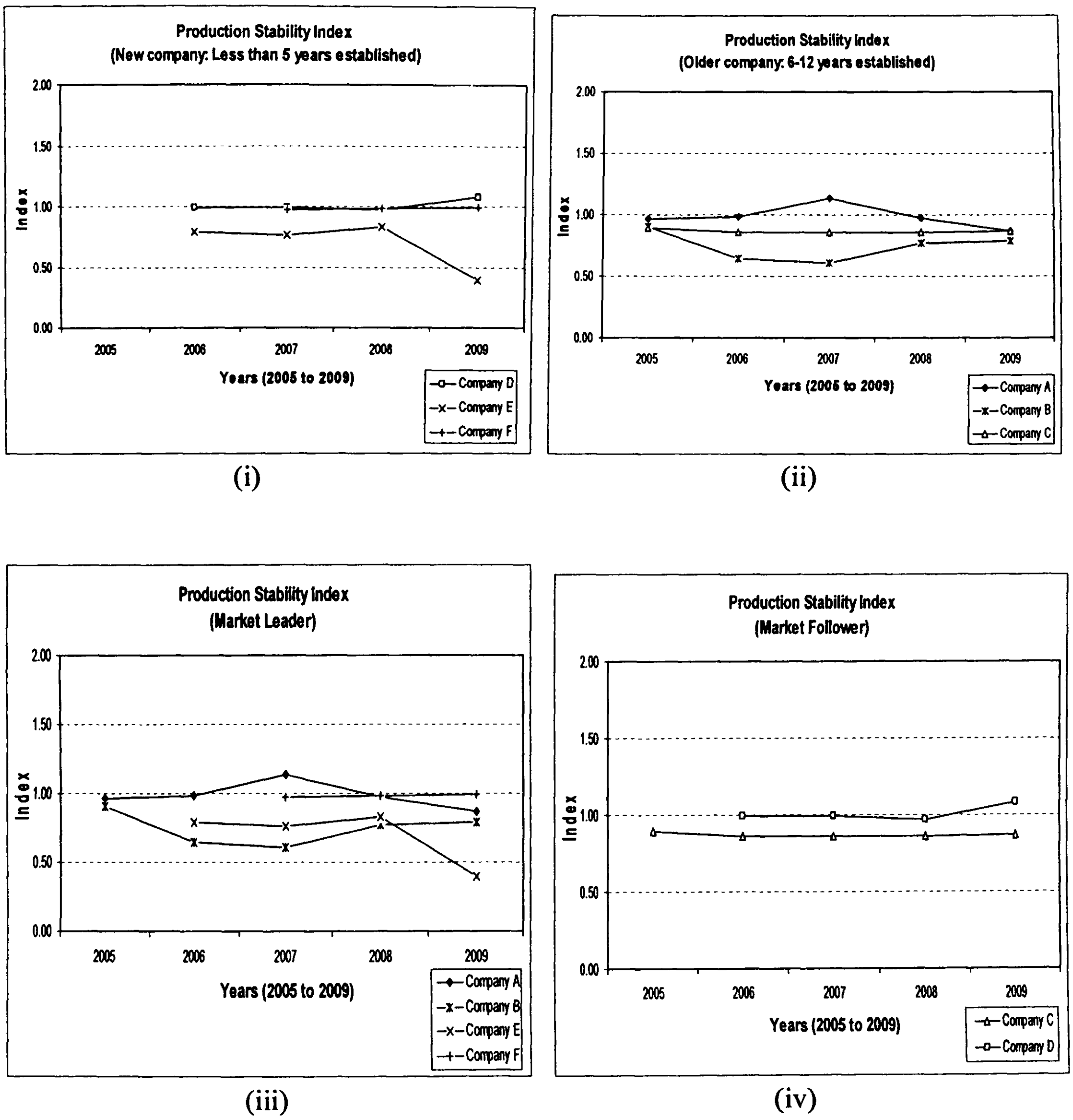
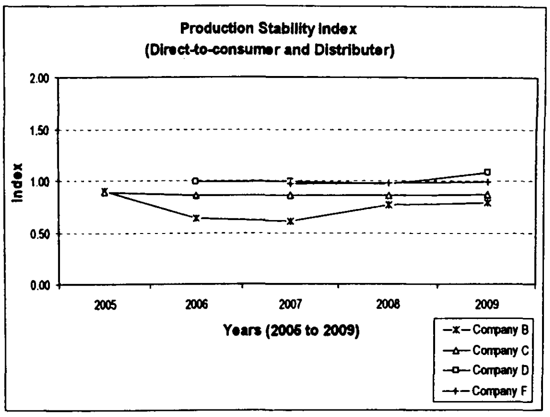
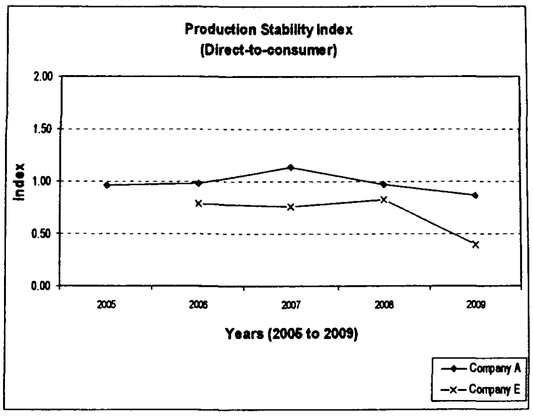


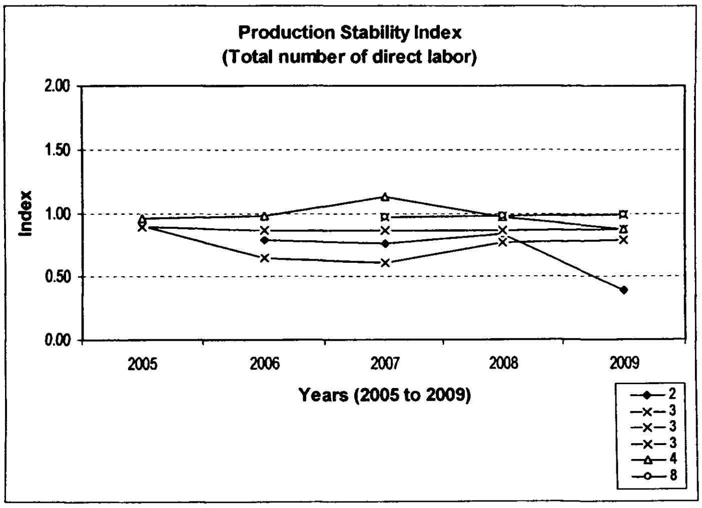
Figure C-3c: Annual PSI with Different Company Characteristics



(v)

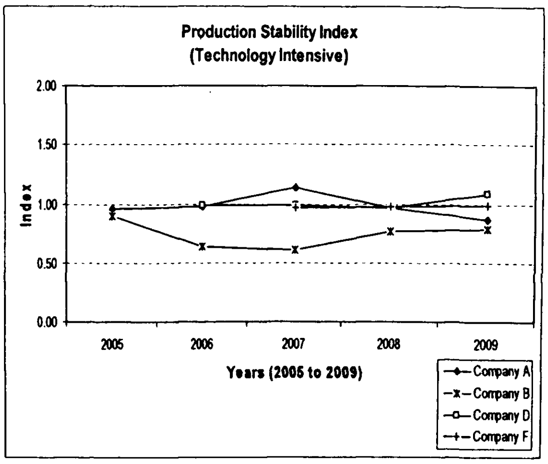


(vi)

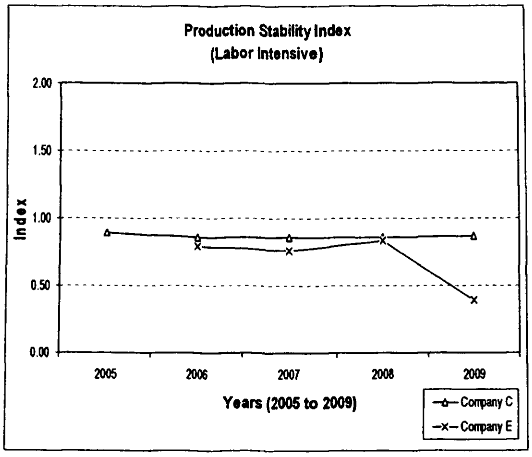


(vii)

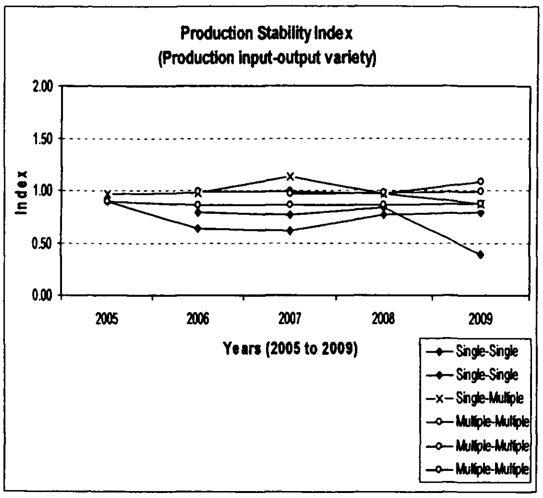
Figure C-3c: Annual PSI with Different Company Characteristics (continue)



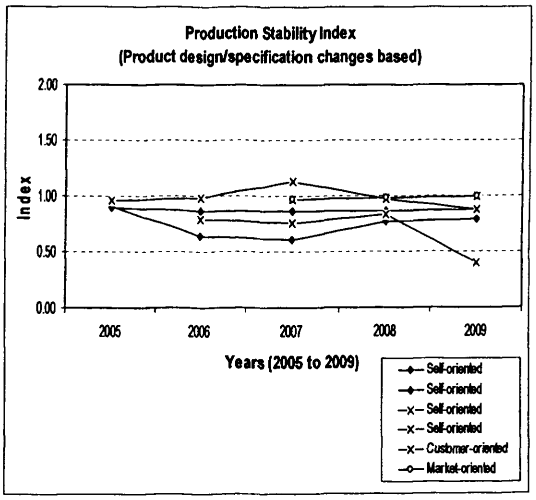
(i)

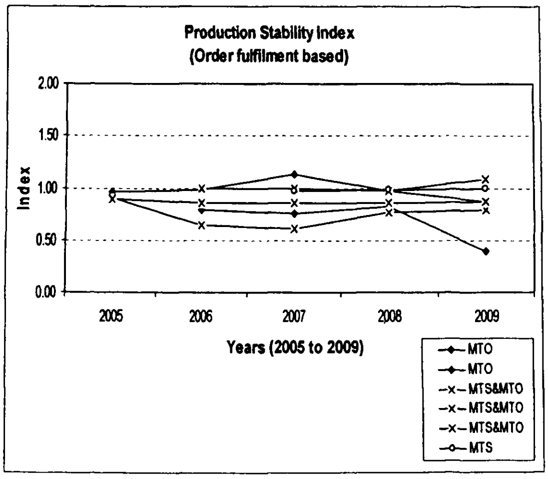


(ii)

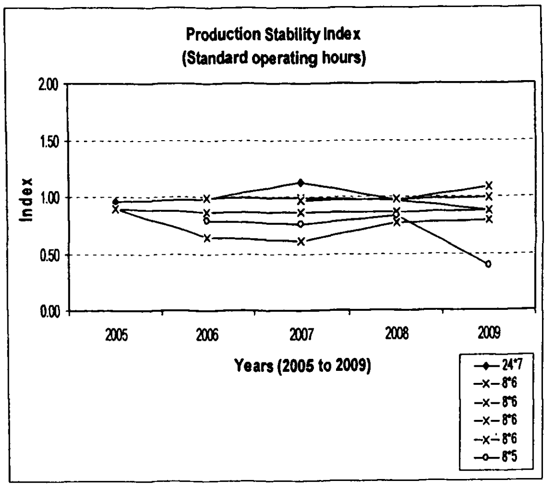


(iii)





(v)



(vi)

Figure C-3d: Annual PSI with Different Production Characteristics