Manufacturing Flexibility Improvement:

Case studies and survey of Thai automotive industry

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ABSTRACT

To deal with dynamic and uncertain business environments, agile manufacturing is of interest to academics and practitioners. However, in order to achieve agile manufacturing, one of its dimensions is of major importance – manufacturing flexibility. It is not possible to achieve agile manufacturing with ineffective management of manufacturing flexibility. Most firms acknowledge how flexibility can be improved but few can successfully implement it to its full potential. In addition, manufacturing firms today tend to improve and implement manufacturing flexibility at a strategic level. This means higher perception of benefits and better awareness of risks.

This research studied the current awareness and practices of manufacturing flexibility improvement in a manufacturing setting, particularly the Thai automotive industry. Through case studies, they can extract more information about the experiences of companies in the planning, implementation and operations of manufacturing flexibility. Thus, the following contributions were made:

First, this research will provide comprehensive overviews and insights on various manufacturing flexibility improvements on aspects of pragmatic management perspectives. Second, this research explored the issues or factors taken into account when manufacturing firms, especially Original Equipment Manufacturers (OEMs), improve their flexibility. Third, the research also explored and validated the major problems in achieving manufacturing flexibility and operating issues critical to manufacturing flexibility performance within manufacturing and supply chain aspects, especially suppliers. The underlying concepts to enhance manufacturing flexibility as well as barriers and enhancers of manufacturing flexibility within individuals and between OEMs and suppliers can be then obtained. In consequence, a framework of manufacturing flexibility improvement incorporating key elements from case studies and surveys was derived.

Finally, the decision-making framework including managerial guidance and strategic evaluation methodology for better evaluating flexibility improvement strategies and achieving manufacturing flexibility were developed and tested. This is sought to create a formal and rational process that guides manufacturers through the strategic evaluation process in relation to manufacturing flexibility improvement. These can be the basis for follow up research in a specific area within flexibility improvement and enhance the development/deployment of flexibility in automotive and other manufacturing enterprises. Overall, an operations strategy can be well established and the highest level of manufacturing flexibility can be achieved. Hence, the firm can maintain or increase its competitive advantages and profitability under uncertain circumstances of manufacturing and supply chain.

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ABBREVIATIONS

AFTA	Asia-Pacific Economic Cooperation Free Trade Area
AHP	Analytic Hierarchy Process
AM	Agile Manufacturing
ANOVA	One-Way Analysis of Variance
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
BSC	Balanced Scorecard
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CBU	Completely Built Unit
CE	Concurrent Engineering
CKD	Completely Knocked Down
CI	Continuous Improvement
CR	Consistency Ratio
CRM	Customer Relationship Management
DM	Decision-Maker
DTI	Department of Trade and Industry
EDI	Electronic Data Interchange
ERP	Enterprise Resource Planning
FMS	Flexible Manufacturing System
FTI	Federation of Thai Industries
GM	General Motor Corporation
IMCT	Isuzu Motor Company Thailand
IPMS	Integrated Process Management System
JIT	Just-In-Time
MAVF	Multi-Attribute Value Function
MCDM	Multi-Criteria Decision Making
MRP	Material Resource Planning
MRPII	Manufacturing Resource Planning
NMC	Nissan Motor Company
NPW	Nissan Production Way
NQC	Necessary Quantity Calculation
OEM	Original Equipment Manufacturer
OM	Operations Management

QCT	Quality-Cost-Time
QFD	Quality Function Deployment
R&D	Research and Development
RBV	Resource-Based View
SAR	Sequence Achievement Ratio
SNA	Siam Nissan Automobile
SPSS	Statistical Package for the Social Sciences
SWOT	Strengths, Weaknesses, Opportunities, and Threats Analysis
TAAP	Thonburi Automotive Assembly Plant
TAPMA	Thai Auto-Parts Manufacturers Association
TAPS	Tool for Action Plan Selection
TMC	Toyota Motor Corporation
TMT	Toyota Motor Thailand
TPM	Total Productive Maintenance
TQM	Total Quality Management
TSA	Thai-Swedish Assembly
VCC	Volvo Car Corporation
WIP	Work-in-Process
WTO	World Trade Organisation

CHAPTER 1 INTRODUCTION TO THE RESEARCH

This chapter provides the outlines of the research including background, aims and objectives of the study, and research scope. The structure of the thesis is presented at the end of the chapter. Section 1.1 describes the background of the study and the motives. The aims and objectives of the research are then presented in Section 1.2. Section 1.3 identifies the scope of the research and, finally, the structure of the thesis is outlined in Section 1.4.

1.1 BACKGROUND OF THE STUDY

In the field of operations management, manufacturing flexibility has been emphasised as a major competitive priority in manufacturing systems. For organisations characterised by customisation, short lead times, changing consumer preferences, and high uncertainty, manufacturing flexibility is not only desired but is quickly becoming a requirement for organisational survival. The desirability of manufacturing flexibility stems from its ability to allow organisations to effectively address uncertainty from a wide variety of sources. There are many examples of the strategic importance of flexibility. For example, in the aftermath of the dot.com's crash and the events of September 11, 2001, the current press is full of stories related to volume flexibility as firms struggle to cope with wide fluctuations in customer demand. Global demand has fallen by more than 50% between 2000 and 2003 for many firms in technology, networking, and telecommunication industries. Even in the airline transportation and hospitality industries, firms are faced with significantly reduced demand and they are struggling to develop approaches that enable them to be more volume-flexible. Some of the strategies deployed for increasing volume flexibility include using overtime and temporary workers, downsizing, cross-training workers, developing complementary product portfolios, creating and maintaining slack resources, using inventory buffers, improving forecasting and planning systems, as well as leveraging the firm's ability to negotiate on volume with suppliers and customers (Jack and Raturi, 2003).

Flexibility improvement becomes an important issue for the managers by which they must evaluate the degree of manufacturing flexibility, implement flexibility, and measure the performances, especially in today's uncertain business environment

(Gerwin 1993). A number of articles have attempted to improve the level of flexibility by various means. The studies of flexibility in manufacturing are mostly concerned with the operational level: the selection from a wide variety of available system configurations and control strategy alternatives in the light of several criteria of flexibility, quality, productivity, costs, etc. Many researchers have studied the manufacturing flexibility in terms of *reactive strategy*, which means providing the production process with the ability to modify itself in the face of uncertainty (Kulatilaka and Marks, 1988). Even though there is a growing body of literature on *proactive strategy* (i.e. the use of flexibility to accommodate uncertainty) to achieve competitive advantage, it has not been clear yet in the field of manufacturing flexibility. Many authors suggested on the shift from operational to strategic level as the full potential of manufacturing flexibility can be obtained when the decision-making process shifts from operational to strategic level or short-term to long-term (Beach et al, 2000). Management needs to have a better understanding of both the operational and strategic issues of manufacturing flexibility in order to be competitive (Swamidass, 1988; Gerwin, 1993).

Typically, managers choose a manufacturing priority and then allocate their scarce resources accordingly when formulating operations strategy. It is known that operations strategy can be defined by the relative weighting of manufacturing capabilities including low cost, quality, flexibility, and delivery. Companies generally make trade-offs between various priorities based on their relative importance (Boyer and Lewis, 2002). Based on this viewpoint, wrong decisions and the problems of strategic fit are sometimes easily made and they are considered as a key issue in decision-making. Especially for flexibility, it is characterised as both multi-levelled and multi-disciplinary and it may result from any of a variety of strategic choices that encompasses both structural and infrastructural elements of the manufacturing organisations. Flexibility is a measure of potential rather than performance, thus the fit between actual flexibility and that required by the environment is likely to easily be imprecise. The failure of flexibility can be caused by; wrong understanding of the definition of flexibility; wrong fit between actual flexibility and required flexibility; identifying and using the wrong source of flexibility; and inappropriately managing the process of flexibility. Despite this, it has been accepted that flexibility can resolve those problems mentioned above. However, the misunderstanding and misuse of flexibility can lead to negative impact to a certain extent. For example, as far as talking about flexibility in automotive manufacturing is concerned, the strategic advantages (i.e. the ability to assemble multiple product lines in a single plant) have been widely discussed over the past decade. Companies that are able to produce a variety of products in their manufacturing plants have a number of advantages. To achieve this, a variety of sources of flexibility are relied upon and strategic decisions play an important role. However, some difficulties that will be described in the following paragraphs can obstruct the use of the right organisational resources and the right decisions.

The management of uncertainty is the primary challenge of top management. One of its approaches is strategic management that can help organisations coping with uncertainty by shaping the competitive environment. This can be enhanced by acknowledging better information and certainty about the environment in order to obtain superior performance (Bluedorn et al, 1994). The study of Parnell and Lester (2000) believed that strategy formulation is to some extent a response to key perceived uncertainties about strategic factors. Following this logic, viable strategic options may be limited by the cognitive and perceptual abilities of an organisation's managers to identify the uncertainty and by objective measures of resources, industry competitiveness, and the like. Hence, the premise that strategy must fit with organisational or environmental factors to be effective may be incomplete.

Anand and Ward (2004) suggested that firms that achieve an appropriate fit between a composite of strategy, organisational attributes, technology, and environmental factors, and manufacturing flexibility would exhibit higher levels of performance. Their point was that in order to be of any use, flexibility in manufacturing technology needed to be congruent with both internal and external contextual factors. In practice, manufacturing managers pursuing flexibility must often choose among multiple investment targets. Choosing how and where to be flexible is a critical issue for manufacturers, particularly as competition becomes more intense and environments become more turbulent. Unfortunately, attempts by scholars to make useful prescriptions remain limited by the fragmented nature of the literature on flexibility as characterised as both multileveled and multidisciplinary and it is a measure of potential rather than performance. For examples, the strategic decisions such as using long-term contracts and buffers (Bourgeois, 1985) and buffering the technical core which enables firms to deal with environmental dynamism (Newman et al, 1993) can be hard to measure in terms of their benefits to firms and ensuring their fit to overall organisational factors.

Most manufacturing flexibility studies have been undertaken in developed countries, such as the United States, Japan, and countries in Western Europe. As flexibility requirements are different in countries with different uncertainty and economic aspects, the study of flexibility in a newly industrialised country such as Thailand is anticipated to address new issues involved and not being recognised in the studies in developed countries. In order to achieve targeted growth, Thai automotive manufacturers have to improve cost, quality, and flexibility vis-à-vis automotive manufacturers in other countries in the region (Laosirihongthong et al, 2003). To respond to global customers and attract more foreign investment, the Thai automotive and supporting industries need to improve existing production systems and current management practices. International standards in quality management systems, low cost production systems, and highly flexible manufacturing systems should enhance competitive advantage. However, the rate of flexibility implementation in the industry is still low because of an absence of appropriate production technology and the difficulty in developing new updated technology or improving the production system. This signifies the interest of conducting the study on flexibility improvement in broader aspects (i.e. not only limited on technological aspects).

Nevertheless, the concept of '*flexible plant*' is growing in practice, and with few studies until now, the evaluation and selection of approaches for manufacturing flexibility clearly requires a further study to provide a framework, or understanding, from which a firm can evaluate its options more precisely. The abilities of firms in capturing uncertainty, understanding production limitations and constraints (i.e. resource-based view), and increasing accuracy of decisions (i.e. applying strategic decision-making process) should receive more focus in order to enhance the effectiveness of flexibility improvement. These key objectives will be presented in the following section.

1.2 RESEARCH OBJECTIVES

This research attempts to develop a framework for flexibility implementation and a decision-making tool for selecting flexibility improvement programme. To achieve this, it starts with examining the different efforts of manufacturing flexibility improvement in various firms to understand the current focus and use of flexibility and investigate the problems they are faced with. A set of criteria imperative to the flexibility success for manufacturing settings is then analysed and developed. The decision-making tool incorporating these key criteria can assist managers making a decision when they are not familiar with flexibility. In summary, the aims of this research consist of:

(1) To provide an empirical study of manufacturing flexibility practices and key problems for not achieving flexibility.
(2) To analyse the mechanisms enhancing the success of manufacturing flexibility implementation (i.e. manufacturing flexibility performance).
(3) To validate the relationship between mechanisms and manufacturing flexibility performance and to provide insights on manufacturing flexibility improvement of the Thai automotive industry.
(4) To develop major criteria to be considered and a decision-making framework for flexibility improvement.
(5) To test and refine the framework and an Analytic Hierarchy Process-based model for assessing flexibility strategies.

1.3 SCOPE OF THE STUDY

This research only covers the issues on volume flexibility and mix flexibility as they are system-level flexibility, which mainly provide firms' competitiveness. However, the issues involving volume and mix flexibility can be sensitive and varied depending on different situations. Thus, the research may be restricted by the sample studied; all variables in this study are referred to in the context of Thai automotive firms and suppliers and the results may not be exactly applied to other industries. The planning and implementation of flexibility are focused in terms of contents. The investigation of successful flexibility implementation is mainly based on the resource-based view. Finally, the framework and decision-making tool developed will facilitate the manufacturing and operations strategy formulation process.

1.4 STRUCTURE OF THE THESIS

This thesis is divided into eight chapters, described as follows:

- Chapter 1 provides an overview and introduction of the research. Research background, motivation, aims and objectives are described.
- Chapter 2 reviews the literature on supply chain management, agile manufacturing, manufacturing flexibility, and strategic management to provide theoretical background to the research including flexibility practices, flexibility management frameworks, flexibility decisions, and factors

associated with flexibility performance. In consequence, the research gaps are identified.

- Chapter 3 describes the research design, explains and justifies the chosen research approach including the method of data collection, selection of sample, and the analysis methods.
- Chapter 4 provides an in-depth empirical study of manufacturing flexibility practices in five automotive companies and suppliers. Their current awareness and practices on manufacturing flexibility were explored as well as the reasons for not achieving flexibility. In consequence, the development of hypothesis regarding key mechanisms for enhancing manufacturing flexibility was then made.
- Chapter 5 examines, tests, and validates the relationships between key mechanisms developed from fieldworks and manufacturing flexibility performance. As a result, flexibility mechanisms are verified and they are used as major criteria for assessing the success of flexibility improvement.
- Chapter 6 refines the flexibility mechanisms and describes the development of manufacturing flexibility improvement framework incorporating flexibility mechanisms, strategic decision-making process, and Multiple Criteria Decision-Making (MCDM) methods.
- Chapter 7 tests and refines the improvement framework with top managers in three automotive companies. The initial test was conducted within the first two companies which provided guidance for further refinement of the framework. The final test was conducted in a third company where the evaluation of the feasibility, usability, and utility of the framework was made. The recommendation and further improvement of the framework are then described.
- Chapter 8 discusses the outcome of the research and the contribution to knowledge. The limitations and future work recommendation are provided.

CHAPTER 2: LITERATURE REVIEW

To maintain a competitive advantage in today's business, manufacturing has to respond quickly to customer needs which are becoming more demanding in terms of order quantities, specifications, and delivery dates. The ability to change the operations to satisfy those requirements, known as '*flexibility*' becomes very necessary and the improvement is increasingly required on a regular basis. This has established an importance of flexibility implementation and structured decision-making process to many manufacturing companies.

This chapter provides the background and overview of manufacturing flexibility researches. It begins with a brief introduction of the concerns on manufacturing and supply chain uncertainties (Section 2.1) and the emergence of agile manufacturing paradigm (Section 2.2). In Section 2.3, the definition and measurement of manufacturing flexibility are presented and followed by an outline of a number of studies on manufacturing flexibility in aspects of flexibility improvement approaches, processes, and frameworks. The factors associated with the decision making on flexibility improvement are summarised from a number of literatures in the fields of supply chain management and operations management. Finally, the focus of this research presented in Section 2.4 is proposed to fill a gap in current manufacturing flexibility literatures by means of providing a strategic decision making framework and tool to facilitate manufacturing flexibility improvement process.

2.1 UNCERTAINTY IN MANUFACTURING AND SUPPLY CHAIN

To provide a better understanding on how supply chain uncertainty can be handled, the following section attempts to outline briefly the importance of uncertainty management within supply chain perspective by describing, firstly, definition and taxonomy of uncertainty, and, secondly, general management of supply chain uncertainty presented in the existing literatures.

2.1.1 Definition and Taxonomy of Supply Chain Uncertainty

A supply chain is defined as 'A network of connected and interdependent organisations mutually and co-operatively working together to control, manage, and improve the flow of materials and information from suppliers to end users' (Scott and Westbrook, 1991). Managing supply chains in today's competitive world is increasingly challenging due to the greater uncertainties in supply and demand, globalisation of the market, shorter and shorter product and technology life cycles, and the increased use of manufacturing, distribution and logistics partners (Christerpher and Lee, 2004). Especially in today's businesses, resource dependency or effect of outsourcing influences higher extent of interorganisational relationships (Paulraj and Chen, 2007). Supply chain management is a very important discipline as it seeks to enhance competitive performance by closely integrating the internal functions within a company (e.g. marketing, product design and development, manufacturing) and effectively linking them with the external operations of suppliers and channel members (Stevens, 1989).

It is a fact that the capabilities of the supply chain can be affected by many types of uncertainties. They can be caused by uncertainties from both internal and external supply chain elements and their effects can be affected to supply and demand chain performances. Hence, one of the main objectives of supply chain management is to reduce the uncertainties. Uncertainty is defined as any unpredictable events which occur during the production process that cannot be planned for (Koh et al, 2002). Supply chain uncertainty can generally be described as any unpredictable events that cannot be planned for during production process in a supply chain or be featured with some levels of fuzziness (Koh and Tan, 2006).

The supply chain, the connected series of value activities concerned with the planning and controlling of raw materials, components and finished products from suppliers to the final customer, has been continually focused on in management field. In the literatures, uncertainties are defined and classified in various ways. Prater (2005) identified uncertainties in supply chain into two level; macro-level and micro-level uncertainty consisting of variable, multiple goal, constraint, amplification, deterministic chaos, long-term planning and, non-deterministic chaos. Paulraj and Chen (2007) described generic types of uncertainties, which are supply uncertainty, demand uncertainty, and technology uncertainty. Koh and Tan (2006) specified manufacturing uncertainty including supply uncertainty, demand uncertainty, new product development uncertainty and technology uncertainty. When considering whole supply chain or system viewpoint, supply uncertainty and demand uncertainty are considered as external uncertainties as they are mainly influenced by customers and suppliers on a regular basis. On the contrary, new product development and technology uncertainty are regarded as internal uncertainties in which sources of uncertainty are mainly embedded within manufacturing functions and they tend to occur in specific activities and time.

According to these views, uncertainties on which this research concentrate are '*supply uncertainty'* and *'demand uncertainty'*. To be able to deal with these uncertainties, there has been an attempt to identify the source of the uncertainty so that solutions can be clearly stated and applied to an individual source of uncertainty. For example, the study of Childerhouse et al (2003) conducted the survey on the source of uncertainty in 23 European automotive value streams. The weaknesses observed included;

- Supply side: short notification of changes to supplier requirements; excessive supplier delivery lead time, adversarial supplier relationships
- Demand side: no customer stock visibility; adversarial customer relationship, continuous product modification causing high levels of obsolescence
- Process side: no measures of process performance; reactive rather than proactive maintenance; random shop floor layout; interference between value streams
- Control side: poor stock auditing, no synchronisation and poor visibility during sub-contracting loop; incorrect supplier lead times in MRP logic; infrequent MRP runs

These sources of uncertainty can be useful data for auditing each uncertainty sources in the supply chain. They can also be considered common sources of uncertainty as being mentioned in a number of literatures. According to this work, the sources of supply uncertainty include; short notification of changes to supplier requirements; excessive supplier delivery lead time; and adversarial supplier relationships. Meanwhile, no customer stock visibility, adversarial customer relationship, and continuous product modification causing high levels of obsolescence are regarded as the sources of demand uncertainty. Once sources of uncertainty have been acknowledged, the efforts on reducing the uncertainties and other methods or techniques relating to supply chain uncertainties will be described in the following section to provide the background on current knowledge for dealing with supply chain uncertainties, especially supply and demand uncertainties.

2.1.2 Managing Uncertainty in Supply Chain

There are a number of efforts to manage supply chain uncertainty from many perspectives such as supply chain management, operations management, strategic management, and knowledge management. Among a number of research works attempting to deal with supply chain uncertainties, broad areas to deal with uncertainty in supply chain can be mainly grouped into; conducting risk assessment (Zsidisin et al, 2004); employing forecasting techniques (Pagh and Cooper, 1998); and minimising sources of uncertainty (Childerhouse et al, 2003; Vorst and Beulens, 2002). Zsidisin et al (2004) suggested that risk assessment techniques facilitate the obtaining of information by purchasing organisations to verify supplier behaviours, promoting goal congruence between buying and selling firms, and reducing outcome uncertainty associated with inbound supply. Childerhouse and Towill (2004) emphasised the importance of uncertainty reduction and enhancing a seamless supply chain for today's business. By putting efforts on such approaches as simplified material flow, supply chain relationship, inventory policy, and information system, uncertainty can be more manageable. Specifically in operational level, short-term planning and decision-making are suggested as means to cope with uncertainty (Wilding, 1998). Among these three areas, it can be seen that conducting risk analysis is considered a key task prior to implementation of a particular action and it allows supply chain uncertainties being treated in more systematic and objective manners. A number of researches have been studied in developing an analysis tools for uncertainty management.

Prater (2005) provided operational strategies and analysis tools for managing various types of uncertainty. Vorst and Beulens (2002) presented a possible list of supply chain redesign strategies in accordance with source of uncertainty and used it for further analysis of uncertainty. Koh and Tan (2006) developed TAPS to aid the decision-making dealing with supply chain uncertainty. With reference to the literatures, it is evident that uncertainty is an important aspect in manufacturing and the supply chain. Through the development of manufacturing practices, there is development of new paradigm within the manufacturing setting in specific response to the supply chain uncertainty; it is *Agile Manufacturing*.

Agile manufacturing (AM) starts as being a business concept in which a company is able to operate profitably in a competitive environment of continually and unpredictably changing customer opportunities. Cooper (1983) delineated that the next generation of process model should be fluid, adaptable, conditional, situational and flexible. AM is not another programme of the month or any other fashionable buzzword (Coronado, 2003). It is recognised as one of the key concerns in modern supply chain management (Teece and Pisano, 1994). It is further described in details in the following section.

2.2 AGILE MANUFACTURING: AN EMERGING PARADIGM

Agility is defined as the ability of an organisation to thrive in a continuously changing, unpredictable business environment (Prater, Biehl, and Smith, 2001). Agility in manufacturing involves being able to respond quickly and effectively to the current configuration of market demand, and also to be proactive in developing and retaining markets in the face of extensive competitive forces (Bessant et al, 2001, p. 31). Guisinger and Ghorashi (2004) suggested the examples of agile practices which are; for instances, systematic procedures for evaluating and responding to customer complaints or concerns; the existence of a quality team to review and make recommendations on quality improvement efforts; utilising flexible process equipment; team work and the formation of reconfigurable teams including members from management, quality, production, and marketing. In terms of manufacturing strategy implementation, it is still unclear as to how precisely manufacturing strategy links with the corporate strategy process (Spina, 1998) and how manufacturing strategy links with agility. Some researches have attempted to investigate this issue. The study of Brown and Bessant (2003) presented the conceptual framework of configurations and tools of agility. Bessant et al (2001) proposed a reference model of agile manufacturing capabilities consisting of four key interlinked parameters; agile strategy, agile processes, agile linkages, and agile people. They suggested that it is necessary to explore the different agile configurations and develop frameworks for facilitating strategic decision-makers in identifying the particular configuration necessary for their sector or product.

Brown and Bessant (2003) suggest that AM combines reactive and proactive behaviour and a high degree of flexibility across several key domains. From this point, the awareness of the term flexibility has been raised as a key element of agility. The next section aims at introducing ‘flexibility’ widely discussed in the literatures as resulting from the concept of AM, followed by the current efforts on improving manufacturing flexibility described by taking automotive industry as an example.

2.2.1 Flexibility: Dimensions of Agile Manufacturing Paradigm

The pressure to improve the agile investments in supply chain has increased as competition expands, product variety grows, and mass customisation trend. Managers are looking for areas they can improve to enhance agility performance. One way to response to uncertainty is to build flexibility into the manufacturing and supply chain. A key dimension of supply chain performance is flexibility; the ability to adapt internal and external capabilities or a reaction to environmental uncertainty. In general, manufacturing flexibility has been classified in many ways. The common way is to classify the flexibility strategies into the three levels, which are operational flexibility, production flexibility, and strategic flexibility. Table 2.1 shows taxonomy of flexibility. Operational flexibility considers technical aspects, process aspects, and human aspects within manufacturing function. Production flexibility considers wider functions including supply chain. These two types of flexibility strategies are meant to focus on operational performance while strategic flexibility tends to have an impact on the organisation in the long run (see Appendix 1 for a summary of flexibility literatures). In spite of this, no consensus has been made on the definition of manufacturing flexibility: in this research, it is defined as *'the ability of a manufacturing organisation to deploy or redeploy its resources effectively in response to changing conditions'*.

Table 2.1: Taxonomy of Flexibility ***(Narasimhan and Das, 1999)***

Level	Manufacturing Flexibility Dimensions	Description
Operational flexibilities (Machine/ shop level)	Equipment flexibility	The ability of a machine to switch among different types of operations without prohibitive effort
	Material flexibility	The ability of equipment to handle variations in key dimensional and metallurgical properties of inputs
	Routing flexibility	The ability to vary machine visitation sequences for processing a part
	Material handling flexibility	The ability of the material handling system to move material effectively through the plant
	Program flexibility	The ability of equipment to run unattended for long periods of time
Tactical flexibilities (Plant level)	Mix flexibility	The ability of a manufacturing system to switch between different products in the product mix
	Volume flexibility	The ability of the manufacturing system to vary aggregate production volume economically
	Expansion flexibility	The ability to expand capacity without prohibitive effort
	Modification flexibility	The ability of the manuafacturing process to customise products through minor design modifications
Strategic flexibilities (Firm level)	New product flexibility	The ability of the manufacturing system to introduce and manufacture new parts and products
	Market flexibility	The ability of the manufacturing system to adapt to or influence market changes

Flexibility improvement is regarded as important activity for increasing competitive advantage and operational performances. Hence, in the next section, efforts on improving manufacturing flexibility will be discussed.

2.2.2 Efforts on Improving Manufacturing Flexibility: Automotive Industry

This attempts to provide broad perspectives in an effort to increase the flexibility level. An automotive industry is chosen as the centre because of its popularity in the OM research. Automotive supply chains are now under concurrent competitive pressure along many axes. Global automotive industry is now facing challenges. The challenge over the next decade is to remove inventory and move to customer order driven stockless supply (Waller, 2004). Another key broad objective of automotive supply chain management is to enhance the ability of suppliers to perform well in the supply chain context (Childerhouse et al, 2003). Seamless supply chain (Towill, 1997) is considered a major concept in the automotive industry. It is the state of total integration in which all players think and act as one. Raw material arrives at the last moment so there is no raw material waiting in stock. Also, there is extreme flexibility and speed, therefore no WIP, and the products arrive in exact sequence and quantity. The study of Childerhouse et al (2003) reported that among 20 automotive supply chains studied, most of them (70 percent) were in various states of transition; many supply chains need to be re-engineered to significantly reduce waste. Some 20 percent of the sample exhibited much good practice in reducing uncertainty and only 10 percent are clear exemplars with little uncertainty from any source. Here, it can be said that improving manufacturing flexibility can help to achieve a seamless supply chain.

According to these factors, this section attempts to provide viewpoints on supply chain and manufacturing flexibility practices currently under focus by automotive firms. It can provide an overview of current strategies and future perspectives towards supply chain and manufacturing investments. It begins with the description of plant configuration with respect to degree of flexibility and follows with the classification of flexibility approaches.

The study of Mair (1994) stated that there is a hierarchy of flexibility in automotive companies; remaining focused-factory: the plant builds and machinery installed for production of a single model so that volume flexibility is preferable for the plant;

changing the mix of existing models; and shifting over time from one product type to a different one.

A focused factory can be characterised as the factory which manufactures products for mass markets. This kind of plant has installed machines and facilities for production of a single model, dedicated machines. Mostly, the assembly process is dedicated to one type of vehicle with varying specifications. The management focus for this kind of plant is likely to be managing demand uncertainty and managing resource utilisation within the plant. The distinct characteristics of this type of plant can be, firstly, it tends to use fixed tooling, semi-automated system and sequencing as methods to deliver various specification (e.g. mix flexibility) to the product. Secondly, the plant invests highly in people and equipment in terms of number of operators, reliable equipments and good incentive as the plant has to satisfy the demand volume of mass markets. Thirdly, buffering the capacity such as overtime, inventory, subcontractor, and so on is generally used in this kind of plant for coping with uncertain demand. It is admitted that the focused-factory retains its own forms of flexibility - in particular the ability to discharge employees during recessions or market slowdowns.

Most automotive companies are no longer manufacturing mass volumes of automobiles as there are several factors involved. Some companies are entering into more niche markets, whose models have a shorter product life, and lower capital investment required for changeover or introduction of new products. These companies then require more flexibility to respond quickly to change, especially changing the mix of existing models. The plant which operates this kind of strategy contains a number of different models in the production line. For example, small-sized, medium-sized, and large-sized passenger cars are assembled in the same production line with relative differences in specification. This kind of plant has more complexity in production processes. The management significantly involves new product development and balancing the model mix within the production process to match customer demand for each model. Key characteristics of this kind of plant are that, firstly, the assembly process needs to operate with various platforms so that equipments are required to be more automated and the workforce must have multi-skills. Secondly, sequencing is required to be more complicated and control systems need to be more sophisticated, otherwise problems resulting from the production of one model can affect that of another.

Mixing of totally different models on single lines is of course no longer a novelty in the world's automobile industry. Declining demand for one model can be counterbalanced with increased demand for others. It is claimed that this kind of strategy is likely to be appropriate for the plant which produces the vehicles for niche markets rather than mass markets. The ability to produce a number of entirely different products in a single production line is increasingly important for automotive plants. The leading automotive plants, especially in North America, are currently improving their production according to this strategy. For example, Chrysler has recently implemented the fully automated welding robots in the production. These robots are programmed to spot different kinds of in-white components for different type of vehicles. Producing a number of different kinds of vehicles certainly cannot be achieved by only using automated robots. Other practices are required as there are several production requirements. Firstly, the development of common platforms and degree of part commonality is necessary but has still found limitations. Secondly, operators have to do various kinds of tasks so that training is necessary to perform multiple tasks, and finally be capable of operating a variety of jobs and deal with uncertainty which may occur in the production process. This plant seems to have some difficulty in adjusting the production volume for each type of product, due to the limitations of automated robots and workforces. However, the plant which operates this kind of strategy exploits the advantages of sharing technology and architectures among plants to minimise the effects of demand fluctuation: this can be called 'chaining'. Chaining requires the plants to build the same product sharing the same technology and architectures. In addition, it requires effective product development strategy and design teams to cope with all process requirements and constraints.

A number of attempts on improving manufacturing flexibility have been presented in both academia and industry. For examples, from the report of the Office of Technology Policy, US Department of Commerce by Fine et al (1996) regarding technology policy for North American automotive industry, manufacturing flexibility is regarded as one of the key performance indicators and it is interesting that there are relative differences among North American, European, and Japanese companies. The comparison of manufacturing flexibility in North American, European and Japanese companies was conducted by (Koste and Malhotra, 2000). It showed that Japanese firms have higher levels of manufacturing flexibility, especially mix flexibility.

Currently, the trend of automotive industry to operate on a global scale in which each plant located around the globe is integrated is the norm, and it is clear that the automotive industry has been increasingly aware of the increasing level of manufacturing flexibility. This is due to the effect of different economic and political factors in each country.

According to literature reviews on the practices employed in automotive industry, in supply chain level, distinct supply chain strategies to increase the level of flexibility that are mostly employed by automotive firms include global manufacturing strategies and postponement strategies. On the manufacturing level, it is seen that increasing manufacturing flexibility involves two core strategies, which are technological and structural investment, and organisational resources development. The latter includes improving production capabilities, buyer-supplier relations, supplier capabilities), and internal practices.

2.2.3 Technological and Organisational Resource Development

Flexible Manufacturing System (FMS) is a distinct area of manufacturing flexibility studies. Mostly, it is focused on the technical design and development of the manufacturing system. However, implementation of such a system is considered to be a key aspect in OM. For instance, Alder (1988) suggested that, to manage flexible automation, the right mix of flexibilities and stabilities must be established by considering the existence of flexibility mechanisms. Some interesting work by Crowe (1992) provided significant insights on the management of FMS. The area of FMS implementation was considered by many researchers for manufacturing to successfully achieve true flexibility within the system.

The literature generally supports the view that advanced manufacturing technology (AMT) is not the only way to achieve different types of flexibility. Suarez et al (1996) identified a number of source factors that make it possible for a firm to implement flexibility. These are production technology, production management techniques, product development process, marketing skills and training, labour policies, suppliers and distributors relationship, and accounting and information systems. With regard to the works of Sethi and Sethi (1990); Jack et al, (2003); Koste et al, (2004), volume flexibility can be improved through the adoption of multipurpose machines, production layouts which are not process-specific, the automation of materials-handling systems and increasing the level of routing flexibility. Enhancing production planning and control systems, and increasing the level of machine flexibility typically are used to increase the level of product flexibility.

Maruca (1993) suggested that plants which managers think are flexible tend to get a lot of practice and get better at it. It is a self-fulfilling belief. This study found that flexibility is determined much more by the people in the plants, their industry experience, and the practice they get, than by the use of a certain type of technology. Anand and Ward (2004) suggested that it is necessary to study more about how to build capabilities that correspond to each type of flexibility that is identified as important. Despite this, some practitioners and researchers appear to consider computer-automated technologies to be synonymous with flexibility: other infrastructural elements are also required to achieve flexibility (Upton 1994; Boyer et al, 1997). To accommodate flexibility, various companies are experimenting with novel organisational structures and management processes including de-layering, team-based network, alliances and partnerships (Gupta and Singh, 2002). Kathuria (1998) investigated the managerial practices of manufacturing flexibility in manufacturing plants in USA. The author reported that managerial practices such as team building, employee empowerment, and relationship-oriented practices can facilitate managing manufacturing flexibility, especially in human aspects.

Following industrial developments, emphasis in academic research has turned to the use of manufacturing flexibility as a response to dynamic environments. Copeland and Weiner (1990) argued that a proactive approach is required of firms that operate in dynamic environments. Newman et al (1993) viewed that buffering the technical core enables firms to deal with environmental dynamism. Bourgeois (1985) empirically demonstrated the pitfalls of using long-term contracts and buffers by showing that reducing the need for flexibility would only be beneficial in stable environments.

Notwithstanding, the study of Kara and Kayis (2004) obviously provided the focus on production systems in building the capability for higher levels of flexibility. It is possible that managers tend to develop other types of strategies that are reducing the uncertainties. The authors believe that this must be included in the lists of potential strategies and should be presented in the other functions such as marketing and sales. In addition, quality and JIT practices can be taken into account as they play an important role in reducing the uncertainties. Thus, not only is technological development required but manufacturing should also focus on building capabilities or developing organisational resources. When considering flexibility techniques and tools (Olhager and West, 2002; Kara and Kayis, 2004), the flexibility techniques can be classified into two main strategic types; reducing uncertainty and building flexibility. In summary, a proposed set of flexibility strategy are classified and shown in Table 2.2.

Table 2.2: A proposed set of flexibility strategy or techniques

Focused strategy (reducing uncertainty)	Flexibility strategy (building source of flexibility)
Design Focus Component reuse Design for manufacturability Cross-functional design teams **Managerial Focus** Project management skills Lean management techniques Lifetime employment Mass production management techniques Standardisation Continuous learning Supplier development Preventive maintenance **Demand/Market Focus** Order processing and forecasting sensitivity Timely and effective information system Real-time acquisition of market knowledge	**Production Control and Technology Focus** Range of process capability Capability of design technology Process change times Scale and integration of process Automatic monitoring device **Workforce Focus** Multi-skilled workers Flexible workforce Subcontracting, Outsourcing Lead time buffers

2.3 ESTABLISHING A CONCEPTUAL BACKGROUND ON MANUFACTURING FLEXIBILITY IMPROVEMENT

Questions have been asked about the extent to which the flexibility strategies implemented are actually needed, and how flexibility problems can be solved for the whole supply chain, not only manufacturing (Ketokivi, 2006). 'How to attain maximum benefits of flexibility?' is becoming important as many various agents and factors are involved in the supply chain. The knowledge of manufacturing flexibility has developed from classification of flexibility, identification of source of flexibility, examination of relationships between contingencies and flexibility performance and, finally, development of model and tool for flexibility implementation. Despite this, the framework for measuring and analysing flexibility has been well developed for decades, the study of manufacturing flexibility remains fragmented; there is inadequate concern on implementation aspects; and an overall decision-making process of manufacturing flexibility is not clear. As a result, flexibility may not be fully achieved.

This section, hence, attempts to provide a conceptual background on key issues contributing to the success of flexibility as presented in the literatures. It starts with understanding the definitions of volume and mix flexibility as they are focused in this research. Next, a planning, implementation processes, and key issues are taken into account as flexibility improvement decisions are described. Finally, the issues significant to the flexibility success in manufacturing and supply chain aspects in relation to key areas of workforce, production control, plant structure, suppliers, and sourcing are summarised through an exploration of existing literatures. In doing so, a broad picture on activities and factors in relation to flexibility improvement efforts can be drawn.

2.3.1 Definition and Measurement of Volume Flexibility and Mix Flexibility

Flexibility is the ability to carry out different works and achieve different objectives with the same facilities (Zhang and Sharifi, 2000). Volume and mix flexibility are the two most important manufacturing flexibility types (Cox, 1989; New, 1996; Oke, 2005). Volume flexibility directly impacts customers' perceptions by preventing out-of-stock conditions for products that are suddenly in high demand. Slack (1991) defined volume flexibility as the ability to change the level of aggregate output. Enhancing capability for volume flexibility has become particularly desirable since the late 1980s. UK manufacturing was faced with disruptions, which resulted in dramatic shortening of product life cycle. Thus, flexible operational capabilities have been instrumental in wading off competition (DTI, 2005). A number of authors have presented the conceptual and empirical works by means to improve volume flexibility. For examples, Oke (2005) identified the generic, fundamental, and shared factors contributing to volume flexibility including supply chains, process technology, information technology, employment terms, and labour skills. The survey of Yusef et al (2003) reported that capability for volume flexibility is constrained at higher levels of adoption of the agility enablers. Market concentration and high-volume contracts limit the need of volume flexibility. Nonetheless, it is necessary to improve capabilities for volume flexibility, especially in the short run.

Mix flexibility is defined as the ability to change the range of products being made by the manufacturing system within a given period. Mix flexibility is the capability of adjusting quickly and economically to changes in the demand mix. Oke (2005) also identified factors contributing to mix flexibility including changeover time, labour skills, and product modularity. Degree of importance of mix flexibility is varied in terms of product offerings. Mix flexibility would probably be important when a plant offers a full-line of products, producing for many different segments of the market. It will probably be less important for a plant focused on a specific market segment. This lends support from many literatures saying that different types of flexibility exist and are important to firms in different competitive situations (Suarez and Cusumano, 1996).

Many authors conducted the studies on flexibility measurement since the last decade. Jaikumar (1984) has discussed three types of flexibility; product, process, and programme flexibility, and suggested measures using stochastic mathematical programming formulation of throughput based on an expected future scenario or on a historical basis of throughput over a defined period. Son and Park (1987) proposed four types of flexibility measures, e.g. equipment, product, process, and demand flexibility, for a given production period and quantified each measure on the basis of related cost. With the help of these partial flexibility measures, total flexibility measure has been defined, which is the reciprocal of the sum of the reciprocals of the individual flexibilities. Gupta and Goyal (1989) had classified the literature on measurement of flexibility into six groups; measures based on economic consequence; measures based on performance criteria; multidimensional approach; Petri-nets approach; the information theoretic approach; and the decision theoretic approach. In another attempt to quantify flexibility monetarily, Son and Park (1990) used four non-conventional costs to describe manufacturing flexibility. These are set-up, waiting, idle, and inventory cost and measure product, process, equipment, and demand flexibility respectively. Each of these non-conventional costs has an opportunity cost, i.e. an economic benefit that is sacrificed when the choice of one action precludes the choice of another. Pyoun and Choi (1994) and Pyoun et al. (1995) made a distinction between potential flexibility and realisable flexibility and developed a procedure for quantifying the realisable flexibility in monetary terms and integrating this value into a financial evaluation model. However, a shortcoming of this model is the difficulty of obtaining the data for calculation of each flexibility value. Malek and Wolf (1991) proposed a single comprehensive indicator that ranks different competing FMS designs according to their inherent flexibility. Extending their work, Malek and Wolf, (1994) developed an index that also includes the technological obsolescence and life cycle cost of the FMS in the evaluation process and quantitatively ranks competing designs.

Flexibility has also been measured on the basis of physical characteristics of the system (Chen and Chung, 1996; Gustavsson, 1984; Kochikar and Narendran, 1992; Zelenovic, 1982). This approach is considered inadequate, however, because flexibility does not come from physical characteristics alone, but is the result of a combination of factors like physical characteristics, operating policies and management practices.

General speaking, the measure of flexibility must include two components; a measure of diversity and a measure of time. Examples of diversity include the number of parts, number of part families, percentage change in volume, and number of set-ups. The time measure includes time between part family switch-overs, percentage change in volume per business cycle, and number of set-ups forecast period. The measures of volume and mix flexibility have been developed by many researchers. Narasimhan and Das (1999) used difficulty in increasing system capacity and time required to vary production to measure volume flexibility. Petroni and Bevilacqua (2002) developed lowest possible volume of parts that still allowing the firm to retain an operating profit. Chenhall (1996) developed measures of materials' throughput time, set-up times, quality of component parts, defect free output, productivity measures related to physical inputs, minimum inventory levels, vendor reliability and responsiveness to measure overall flexibility. Mostly, the measures encompass manufacturing results such as outputs, number of model mix, and measures regarding costs, quality, lead-time incurring from flexibility. However, there are some measures which have not been yet confirmed or included in actual measurements.

2.3.2 Manufacturing Flexibility Improvement Frameworks

Manufacturing flexibility improvement is an effort of the firm to improve organisational abilities to effectively change its operations and processes (e.g. capacity, sequences) to deal with foreseen and unforeseen uncertainties (e.g. demand, internal failure). As earlier mentioned, it is common to classify the flexibility strategies to the three levels, which are operational flexibility, production flexibility, and strategic flexibility. Such improvement is normally laid within these three levels of flexibility strategies. In the author's opinion, the strategies of manufacturing flexibility improvement can basically be further classified by the three following criteria, which are strategic objectives, mode of flexibility, and degree of improvement.

- Strategic objectives include improving customer satisfaction, increasing competitiveness, improving operational performances, and reducing uncertainties in manufacturing and supply chain.
- Modes of flexibility include adaptive, redefinition, banking, and reduction.
- Degree of improvement includes structural investment, process improvement, resource development, and resource planning.

For example, Ndubisi et al (2005) emphasised the importance of supplier selection and supplier management and flexibility which can be improved by adopting such strategy as promoting supplier selection based on technology. This strategy tends to improve operational performances of the plant and it is relied on the reduction of the mode of flexibility in which uncertainty is reduced due to good supplier performances. It is clear that this strategy takes place at the resource planning level. The manufacturing flexibility literature discusses a lot of different flexibility strategies that can be used to improve manufacturing flexibility and, as a result, improve supply chain performance (Sethi and Sethi, 1990). However, it is unclear what strategy should be used in what particular situation. Among the literatures, distinct efforts have been found in attempting to establish rigid procedure to develop strategy concerning the degree of fit to company context, i.e. operations strategy. The following sections will describe the fundamental frameworks that address manufacturing flexibility in the context of manufacturing and operations strategy.

2.3.2.1 Flexibility Process and Frameworks

Manufacturing flexibility is a complex, multi-dimensional and difficult-to-synthesise concept (Sarker et al. 1994). Many researchers have considered definitions, requests, classificatory in dimensions, measurement, choices, and interpretations of manufacturing flexibility (Beach et al. 2000, De Toni and Tonchia 1998, Gupta and Goyal 1989, Sarker et al. 1994, Sethi and Sethi 1990). There also have been some authors focusing on the process of flexibility and suggesting on the analytical framework of flexibility. Upton (1994) proposed a framework for analysing manufacturing flexibility based on different dimensions and is specified by three elements: range, mobility and uniformity. Suarez et al (1991) presented the basic model of manufacturing flexibility shown in Figure 2.1. The main constituents of the model are contextual and organisational factors, flexibility types, and flexibility source factors.

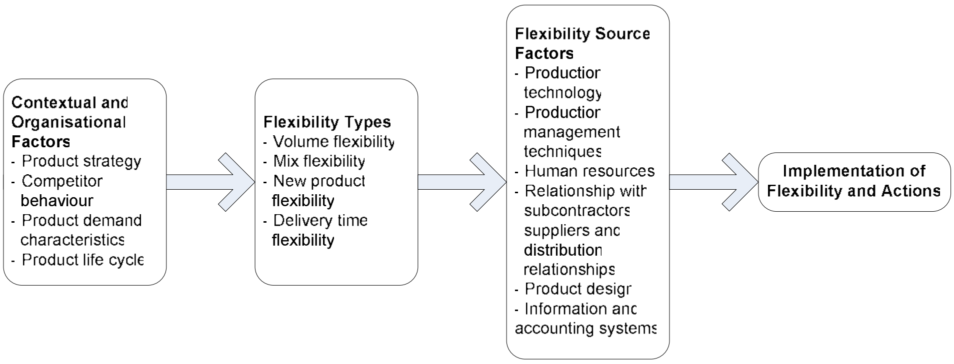

Figure 2.1: Basic Model of Flexibility Implementation ***(Suarez et al, 1991)***

To achieve manufacturing flexibility, a process of flexibility implementation is required to provide guidance for managers. Slack (1988) recommended a three-phase approach consisting of defining flexibility requirements, conducting a flexibility audit, and developing a flexibility action programme. The phase of defining flexibility requirements has been popular and studied by many researchers (Olhager and West (2002); Narain et al. (2000); Nilsson and Nordahl (1995); Gerwin (1993); Suarez et al. (1991) and Slack (1998). The work of Gerwin (1993) provided a comprehensive process to implement flexibility. While most authors put an emphasis on the reactive use of flexibility, his conceptual framework illustrated the use of manufacturing flexibility as a component in a proactive and reactive manufacturing strategy. He proposed the basic framework for flexibility implementation process shown in the Figure 2.2. There are five variables in the framework; environmental uncertainties; manufacturing strategy; required manufacturing flexibility; flexibility methods; and performance measurement.

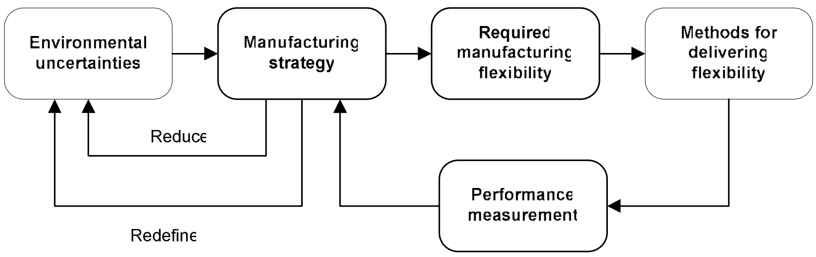

Figure 2.2: Manufacturing Flexibility Process ***(Gerwin, 1993)***

Nevertheless, the frameworks are found to be conceptual and no empirical study supports the feasibility of the framework. The challenge here is to conduct further synthesis and development of existing frameworks to enhance the effectiveness of flexibility implementation. The conceptual background presented in the following section will form the preliminary components and factors for successful flexibility implementation for this research.

In operations, the means of flexibility are encompassed by the terms of efficiency, responsiveness, versatility, and robustness (Chuu, 2005). When an adjustment or change occurs in particular manufacturing processes, flexibility means that the manufacturing system must operate with effective use of resources and provide an efficient output from such change; the system must suddenly respond to such change or within the perfect time; the system must be able to cope with foreseen uncertainties; and the system must be able to deal with unforeseen uncertainties by using its existing capabilities. In an attempt to achieve flexibility, a number of researches have provided fundamental framework to be used in the analysis. For instance, Correa (1994) provided insight into the flexibility of structural manufacturing resources. In structural views, there are three types of structural resource redundancy types, which are redundancy in capability, capacity, and resource utilisation. In order to achieve the appropriate mix of flexibilities required, choices of the adequate configuration of resource redundancies should be made. Harvey et al (1997) presented the framework to manage flexibility in services by reducing variability at the source, dealing with remaining variability at the point of impact, and employing information technology. As mentioned earlier, most of the frameworks have found to be descriptive and there are many efforts to develop flexibility frameworks mainly based on the manufacturing and operations strategy theory. The following sections aim at understanding the factors involving the flexibility implementation (i.e. choices of flexibility improvement programmes and flexibility performance) in aspects of manufacturing and operations strategy theory.

2.3.2.2 Linkages between Business Environment, Business Strategy, Manufacturing Strategy and Flexibility Improvement Programme

The potential to increase flexibility depends on environmental, organisational, and technical factors. Since increasing flexibility may be very costly and can lead to complexity of management and high coordination costs, managers should properly justify whether an increase of flexibility is necessary and suitable for environmental, organisational, and technical factors of the firm (Prater, Biehl, and Smith, 2001). They also revealed that firms successful in supply chain focus on key aspects of their supply chain and do not attempt to provide every feature demanded of the agile firm; only establishing required flexibility types contributes to supply chain success.

Prior to obtaining required flexibility types and the flexibility improvement programme, many authors suggest that a firm has to follow the strategic decision-making process (Gerwin, 1993). For instance, dealing with market saturation, firms often move themselves to a new market. New market expansion strategy has existed in the literature involving market research for an accurate demand of products in the new market, reduced uncertainty and increased resource commitment, decisions on time, place and method of entry to ensure its smooth operations, establishment of new operations, distribution networks and marketing strategies (Cui, 1998). When entering the new market, a manufacturing firm might be taking on board such variables as supply uncertainty, product/market uncertainty, competition uncertainty, and internal uncertainty, and it has to identify numerous business strategies, from time to time, in which they influence firms to a new position. Those business objectives of new operations establishments can be depicted into key manufacturing strategies as ‘Capacity Expansion’ (Bowon and Yoonseok, 2001; Olhager et al, 2001), ‘Demand forecasting’ and ‘Lead-time reduction’. Another example is the shorter product’s life cycle. A firm has to update their product portfolio to retain existing customers and seek new ones so that new product strategy is required. ‘Product-Process Mix’ intuitively appears as manufacturing strategy when adding a new product to the production lines. Thus, the considerations of ‘New technology investment’ and ‘Supplier competency’ are crucial.

Flexibility is required when the firm needs to overcome any particular uncertainty. It is that a firm has to address the uncertainties involved. Referring to the study of Jack and Raturi (2002), the defined uncertainties will be then linked to the sources of volume and product flexibility so that the required variables of volume and product flexibility under key business objectives (e.g. entering new market, launching new product, seeking new sourcing, and evolving the current operations) can be derived. It can be clearly demonstrated that the links between business environment, business strategy, manufacturing strategy, and choices of flexibility improvement programme can be established. In consequence, the manufacturing flexibility improvement process can be illustrated as in Figure 2.3, which is mainly developed from Harrison (1998) and Boyle (2006). Harrison (1998) who suggested the effective strategic decision-making process must possess environmental and organisational assessment; strategic gap analysis; compatibility with operating constraints, optimal amount of information, a high degree of understanding from decision makers at all levels; and open managerial attitudes. Boyle (2006) proposed the manufacturing flexibility framework for implementation consisting of; determining organisational competitive strategy; performing uncertainty analysis; developing manufacturing strategy; identifying flexibility level in aggregate and component level; performing flexibility reconciliation; identifying potential and required flexibility types, tools, levels; implementing flexibility tools; and determining flexibility fit and measuring actual flexibility.

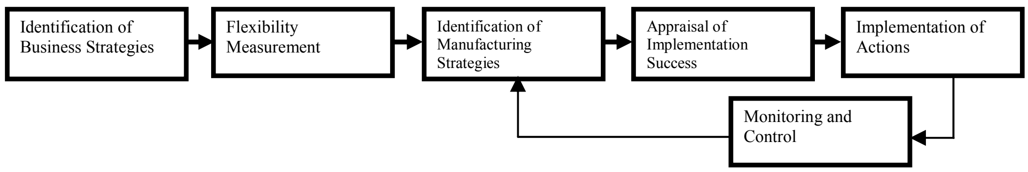

Figure 2.3: A Manufacturing Flexibility Improvement Process (*Adapted from Harrison, 1998; Boyle, 2006*)

As mentioned in the literatures, successful firms have to trade-off their flexibility decisions. Developing a more complex system is not always the answer to deal with uncertainty. Hence, choosing an optimal (i.e. realistic) decision that aligns with current context and capabilities can allow the firm to better deal with the uncertainty of their business environment and successfully achieve profitability (i.e. flexibility outcome) from such decisions. According to operations strategy theory, the alignment between an action and organisational focus and context is crucial in order to achieve the highest benefits from such action (Hill, 1995; Slack and Lewis, 2002). Suarez and Cusumano (1996) proposed a fundamental concept of flexibility decisions relying on these following four factors, which affect the need for flexibility; product-demand characteristics; product strategy of the firm; behaviour of relevant competitors; stage in the life cycle of the industry. They also suggested six factors that affect the implementation of flexibility. In other words, these are the areas which should be considered when a firm decides to invest in a particular type of flexibility; production technology; production management techniques; relationships with subcontractors, suppliers, and distributors; human resources (training and skills of the workforce, employment security, and compensation policies); product design; and accounting and information systems. The studies on factors associated with flexibility decisions, however, have been found to be limited.

Through a number of research works, the summary of factors involving flexibility decisions can be drawn and grouped into three main focuses, which are (a) *business conditions*, (b) *manufacturing objectives*, and (c) *operations conditions*. The first factor is business conditions, i.e. both external and internal business environment. The relationship between uncertainty and flexibility is a critical issue since flexibility is often viewed as an adaptive response to environmental uncertainty (Upton, 1995). Surviving in today's highly competitive and rapidly changing environments often requires firms to develop strategies that provide the right kind of flexibility to succeed in their specific environments (Anand and Ward, 2004). Many literatures of manufacturing flexibility described the importance of the identification of contextual factors (i.e. market, competitors) on the success of manufacturing flexibility and overall firm performance such as the work of Petroni and Bevilacqua (2002) who identified the factors which discriminate between manufacturing flexibility best practice and non-best practice firms. Table 2.3 summarises the strategic factors influencing the adoption and implementation of manufacturing flexibility.

Table 2.3: Strategic Issues Influencing Manufacturing Flexibility Adoption and Implementation

Strategic Issues in Flexibility Improvement	References
Market fragmentation and model proliferation	
Maximise the use of their capacity	
Cut manufacturing costs when under-utilised	de Saint-Seine (2007)
Customer order patterns	Szwejczewski (2007)
Ability to compete	Connelly (2006)
Reduced capital investment and lean die standards	
Efficiency and speed	
Market advantages	Industrial Engineer (2005)
Efficiency and quality gains	
Reduce manufacturing bottlenecks	Kochan (2004)
Different types of products	Vasilash (2004)
Increased competition	
Change of demand	
(i.e. general movement away from cars and into light trucks)	
Under utilised facilities	Wall (2003)
Globalisation	Zald (1994)
Costly buffers of capacity, lead time, inventory	Newman and Sridharan (1993)

The second factor is manufacturing objectives. It has been exposed in the literatures that different business strategies and manufacturing strategies of the firms can affect the need of each flexibility type and thus, result in pursuing different flexibility strategies. For example, the strategic objectives of the firm are to reduce uncertainty from customer orders and to increase competitiveness by focusing on a market in which a firm can do well. An avoidance of smaller and less profitable customer orders and a focus on market concentration are used as key manufacturing strategies. These influence the firm to adopt strategies in relation to product flexibility, rather than volume flexibility (Yusuf et al, 2003). According to these manufacturing strategies set by the firm, improving product flexibility yields higher benefits to the plant than volume flexibility. Taking these viewpoints, firm should adopt the flexibility improvement programme with respect to its overall manufacturing objectives. In short, the considerations of flexibility targets against other objectives such as cost, quality, and delivery should be made in order to minimise such negative effects from flexibility implementation. It is obvious that implementing flexibility can sometimes reduce the quality of final products, reinforce the opportunities to respond to another market requirement or uncertainty, and lower the level of control ability.

The last factor is operations conditions. To successfully implement flexibility strategies, firms must ensure that they conform to the operational context of the firm. The summary of the potential issues significant to the flexibility performance as derived from the current problems and suggested solutions from supply chain management, agile manufacturing, and manufacturing flexibility literatures will be described in more details in the following sections. This will provide a conceptual background on the operational factors affecting the flexibility implementation in terms of flexibility performance.

2.3.3 Flexibility Requirements: Factors Associated with Flexibility Performance

Over the last two decades, several studies have provided evidence for the relationship between flexibility and performance in operations. Swamidass and Newell (1987) found a significant relationship between manufacturing flexibility and growth in sales and profitability in a sample of 35 companies. Fiegenbaum and Karnani (1991) suggested that output (volume) flexibility was associated to extra profit in small firms, especially in industries under strong demand fluctuation. Narasimhan and Das (1999) found a significant relationship between modification (product customisation) flexibility and manufacturing cost reduction in a sample of 68 companies; however, non-significant relationships were found between cost, and volume and new product flexibility. Jack and Raturi (2002) found evidence to the association between volume flexibility, and financial performance and delivery performance. Finally, Pagell and Krause's (2004) replication of earlier studies by Swamidass and Newell (1987) and Pagell and Krause (1999) found evidence that increased flexibility led to improved performance, although this effect could not be linked to the plants' level of response to environmental uncertainty.

Many empirical studies signify the importance of supply chain and manufacturing flexibility on the performances (Vickery et al, 1999; Sanchez and Perez, 2005). However, there are few empirical researches that contribute to investigate the factors significant to the flexibility performance in particular. In other words, there is a lack of understanding of which factors should be taken into account when justifying strategy for improving flexibility, thus resulting in poor agility and business performance. The examples of research works conducted in the areas of manufacturing flexibility are shown in the following paragraph. To provide theoretical background on factors relating to manufacturing flexibility performance, the existing theories involve supply chain management, and manufacturing and operations management are reviewed. Most of the literatures studied the relationship between variables and flexibility performance. The areas which have an impact on flexibility performance are summarised as follows:

Team building, inspiring, recognising, supportive, mentoring, and delegating practices are useful in facilitating management of flexibility (Kathuria, 1998). The right managerial practices would help the accomplishment of the difficult goal of achieving flexibility at the plant level. Wadhwa et al (2006) studied one of popular flexibility practices, postponement strategies. They emphasised an importance of managing knowledge and developing an innovative mindset on the implementation of postponement strategy.

The increased production flexibility creates new challenges regarding assembly line planning and balancing. Klampfl et al (2006) simulated how to allocate stock within the workcells so that non-value added operations such as walking and waiting are minimised. This shows that the layout of a workstation needs to be examined when operating in a flexible environment. Yusuf et al (2003) studied transition from batch to cellular manufacturing. Availability of resources when required or resource redundancy is one of the key concepts of managing flexibility (Correa, 1994). This requires management understanding on how to plan and allocate the resources and being proactive to planned and unplanned changes or variability in manufacturing processes. An importance of information flow is considered as one of the enablers of flexibility (Childerhouse et al, 2003). In addition, process integration can influence the failure or success of flexibility implementation (Boon-itt and Paul, 2006).

Suppliers play a significant role in the manufacturing flexibility of manufacturers. The manufacturers currently utilise supplier strengths and technologies to support their production efforts, and intervene in the production practices of suppliers. (Rutherford et al, 1995). Ndubisi (2005) pointed out that supplier selection and management strategies have an impact on manufacturing flexibility. They concluded that, to achieve manufacturing flexibility, manufacturers need to present suppliers with a technology roadmap and plans of the manufacturers, and to establish a proper inventory management programme with suppliers. Perez and Sanchez (2001) emphasised the role of supplier relations on flexibility through the case study of Spanish automotive industry. They illustrated that strategic partnerships are developed from delivering JIT principles, transferring information and technology, building long-term trust and commitment, to involvement in product design. As a result, the supply chain is more flexible as suppliers are capable of responding to the needs of downstream customers.

Lastly, the supporting structure and infrastructure are also crucial for flexibility success. Manufacturers are seeking ways to reduce the capital investment, and strategic sourcing is one popular alternative. Narasimhan and Das (1999) emphasised the contribution of strategic sourcing to manufacturing flexibilities and performance. They suggested that targeting specific manufacturing flexibilities with appropriate supply base strategies allows firms to create and support competitive order-winning competencies. In short, flexibility performance is relied on to an extent to which manufacturing and supply base strategies are aligned. McCullen et al (2001) described that lean practices can influence the high level of flexibility success. Lack of appropriate infrastructure such as an effective ordering system can reduce the degree to which a manufacturing system can be flexible (Hormozi, 2001). Table 2.5 summarises the factors influencing the manufacturing flexibility performance.

Summarising from these literatures, the key elements for successful manufacturing flexibility and supply chain effectiveness include production control and management, process capabilities and resource redundancy, buyer-supplier relationships, and supporting structure and infrastructure. These four core areas will be further investigated in the fieldworks (Chapter 4).

Table 2.4: Factors Affecting Manufacturing Flexibility Performance

Factors	Reference
- Manufacturing proactiveness	Chang et al (2005)
- Exclusive and overlapping capabilities of the available resources	Gindy and Saad (1998)
- Communication, inter-departmental relationships, supplier flexibility and technology	R.S.M. Lau (1999)
- Customer and supplier participation	Kayis and Kara (2005)
- Entrepreneurial orientation (Innovativeness, autonomy, innovativeness, risk-taking, proactiveness, and competitive aggressiveness)	Chang et al (2007)
- Team building, employee empowerment, and other relationship oriented practices	Kathuria (1998)
- Supplier selection and management strategies	Ndubisi et al (2005)
- Advanced manufacturing technology and operations improvement practices	Zhang et al (2006)
- Component standardisation or component-process interface standardisation	Salvador et al (2007)
- Information systems	Coronado (2003)
- Managers' perceptions	Nordahl and Nilsson (1996)

It is clear from the literatures that firms need to be aware of the degree of fit between such improvement and its strategic viewpoints and internal contingencies (i.e. operational conditions). Also, that they are coherent with the manufacturing flexibility improvement process presented in Figure 2.3. However, the existing frameworks are in the early stage in which strategic and operational factors are still not adequately addressed. Incorporating such factors with the manufacturing flexibility improvement process would provide a clear link between uncertainty and choices of flexibility strategies. This forms the foundation of manufacturing flexibility framework and it will be developed throughout this research. The next section will specify the need for the manufacturing flexibility framework and how to fill the gaps in the existing frameworks.

2.3.4 The Need for Manufacturing Flexibility Improvement Framework

As presented above, the background of manufacturing flexibility improvement was drawn. The manufacturing flexibility improvement process stems from the impact of environmental uncertainties in supply chain, and the firm needs to maintain or increase its competitive advantages and profitability. To formulate such effective improvement strategies, it is essential that such strategies align with business conditions, manufacturing objectives and that they conform to operations conditions. In addition, the analysis requires thorough considerations of contextual factors, operational factors, and flexibility source factors. However, the frameworks presented in the literatures mostly are conceptual and descriptive. There is no specific empirical research on examining factors involved in flexibility decisions and establishing more explicit framework for justifying the approaches for flexibility improvement in order to attain maximum benefits of flexibility from such implemented actions.

The concept of flexibility is essentially a measure of the efficiency of the process of change (Ndubisi et al, 2005). In this sense, '*resource-based view'* can be applied to the context of OM research (Mills, Platts, and Bourne, 2003) – see Appendix 2 for a summary of theoretical perspectives on manufacturing flexibility improvement process. Firm resources are usually passive and fragmented. The value of firm resources usually rests on two fundamental premises: firstly they provide the basic direction for a firm's strategy and secondly they are the primary source of profit for the firm. Whilst the business environment is much more dynamic, firm resources are relatively stable. Therefore, in a fast changing business environment strategic decision-making should consider the resources that a firm possesses, or has access to, rather than exclusively relying upon the market needs factors. Capability is defined as the capacity for a team of resources to perform some task or activity; it results from a complex pattern of actions and a positive synergy among various resources (Grant, 1991). This means that firms need to understand the capabilities of existing resources prior to making the decisions. Consequently, the process of change is considered more effective as change can be made with few or no errors, or deficiencies. The author believes that for further detailed investigation on how to assess flexibility success, resource and capability viewpoints are needed. Currently, decisions about flexibility strategies often seem to be unstructured and lacking a systematic assessment methodology. This may be due to the large number of factors to be considered, with no clear understanding on which factors (i.e. resources and capacities) are indeed critical to flexibility performance. To justify the feasibility of the conceptual framework, the linkages between resource-based theory and flexibility improvement drawn from the literatures are described in the next section.

2.3.5 The Linkages between Resource-Based Theory and Flexibility Improvement

The resource-based view (RBV) has been of interest in economic and management thinking for the past two decades (Foss and Knudsen, 2003). It enables a company to identify and develop its valuable resources by facilitating the identification of business interrelationships and establishing the foundation for strategy formulation (Grant, 1991; Barney and Zajac, 1994). It assumes that a better understanding of a firm's idiosyncratic resources and capabilities leads to an improved understanding of the relationship between a firm's strategy and performance. Ultimately, a competitive advantage can be achieved (Barney, 1991; Vicente-Lorente, 2001). The key characteristics of this theory are that it provides a long-term view, includes the external environment, and focuses on the heterogeneity of firms. Based on the differences of the firms, RBV determines a firm's choice of a particular strategy, and also how successfully the firm is able to implement and execute the strategy (Barney, 1991). Grant (1998) postulated that the number of differences in a firm's resources is better presented in a turbulent environment, and this will enable a company to be responsive to change and anticipate change over time and, in turn, achieve competitive advantage. The RBV is now considered as a strategic tool in that it allows management to exercise "their ability to work creatively with the raw material presented by the firm and their environment; to respond appropriately when their firm's organisational structure finds 'good' strategies; and to create decision structures and procedures that allow a firm to respond to its environment adaptively" (Cockburn et al., 2000, p. 1128). The study on RBV in OM field are summarised in Appendix 3.

In aspects of flexibility, Bruce (1993) presented the main five classes of flexibility resources which underpinned the flexibility approaches or strategies employed in the organisation. He identified and described these as follows:

> ***1. Physical resources***: This class includes tools, machines, energy sources and raw materials under the firm's control.
> ***2. Personnel resources***: This class encompasses the human resources, but goes beyond the labour capacity of available person-hours to accomplish prescribed tasks. This resource class is uniquely distinguished as a result of human attributes (e.g. learning, social motivations, emotional requirements) that do not apply to the other factors of production.
> ***3. Information resources***: The informational resource class contains two subsets: those resources related to the collection, storage and dissemination of information and those concerning the models and

> tools utilised in analysis and summation of information and the support of decision making. It includes the ease and facility with which it can be communicated or accessed. The flexibility of a decision rule or model is closely related to its robustness and range of application.
> ***4. Structural resources***: This refers specifically to the design of the organisation itself. Flexibility replaces procedures, specialisation, task specificity, repetition and formal controls. It also works to reduce obsolescence, improves decision-making validity and reduces the multiple interfaces common in traditional structures.
> ***5. Procedural resources***: This class represents the management processes used in an organisation and in the relationships between an organisation and its environment. Efforts should be directed towards simplifying company policies and procedures.

From the above definition of flexibility resources, it can be seen that the roles of resources are important because of the extent to which flexibility would be achieved and their management is crucial. A number of literatures suggest the various ways to manage such resources as shown in Table 2.5. For example, Gindy and Saad (1998) introduced the roles of exclusive and overlapping capabilities of the available resources in providing flexibility to manufacturing processes. Their work illustrated the importance of leveraging the use of resources, especially in resource redundancy aspects on the flexibility success. The extra resources or capabilities can influence a higher level of flexibility achieved if appropriately managed. Salvador et al (2007) pointed out the aspects of production control and management in achieving flexibility, which is standardisation of component and component-process interface. Ndubisi et al (2005) studied the relationship between supplier selection and management strategies to the flexibility performance. According to this work, the supply chain aspects, especially buyer and supplier relationship, are also considered significant for flexibility improvement. Finally, flexibility can be improved by focusing on the effectiveness of current technology and organisational practices employed by the firm such as information systems (Coronado, 2003), managers' perceptions (Nordahl and Nilsson, 1996), and manufacturing proactiveness (Chang et al, 2005).

As research has evolved, the focus of flexibility study has been shifted from the identification of flexibility resources to examination of factors or set of capabilities associated with successful flexibility implementation, i.e. flexibility performance. This is in accordance with the direction of RBV study in which it has come to encompass not only a firm's resources, but also its capabilities (Helfat and Peteraf, 2003; Henderson and Cockburn, 1994). In this study, the key important aspects described above are the central focus by which to address the question of 'what could be the key capabilities that a firm should be focused on to ensure the successful flexibility implementation?' It will be further explored in Chapter 4.

2.4 ACHIEVING FULL POTENTIAL OF MANUFACTURING FLEXIBILITY IMPROVEMENT AND IMPLEMENTATION

According to frameworks of flexibility presented in the literatures, when focusing on the decision-making process, few studies exist that explore the key constructs necessary for improving manufacturing flexibility. It is crucial to point out some issues, as follows:

1. In literatures, flexibility frameworks are mostly explained by mapping the variables such as contextual factors, flexibility types, and flexibility source factors. Clearly, only a few research works present the linkage between variables within their decision-making process on flexibility. The examples of the key works are Olhaher and West (2002) which link flexibility to market requirements.
2. In practice, the flexibility decisions are complex but the existing frameworks in the literatures seem to be too simple to explain the whole actual decision-making process. It can be argued that, in real situations, the methods for delivering each type of flexibility can be the same and have some linkages. Also, various methods are involved in each flexibility type (Sethi and Sethi, 1990) and there are conflicts between each flexibility type and it has not yet been clearly reported. Thus, it is necessary to ensure that selected flexibility approaches offer the maximum benefits to organisation. However, no such works address this issue.
3. There is no consensus on which criteria should be used; only a number of factors involved are presented (see Olhager and West, 2002; p. 57-62). The criteria taken into account in the flexibility improvement and decision-making process are not yet explored and no empirical evidence is provided. There is still a question on how to ascertain that selected flexibility methods fit the manufacturing conditions (i.e. production technology, human resources, suppliers) at any particular time. In short, there is lack of a comprehensive set of criteria (i.e. success factors) outlining key capabilities

contributing to the flexibility success, which then can guide managers in the decision-making process. The criteria are likely to facilitate, enhance the effectiveness of decision-making process, and thus improve the degree of success on flexibility implementation.

To sum up, it can be seen that most literatures only suggest the approaches, techniques and strategies to enhance manufacturing flexibility, which is now quite clear for academia and practitioners to follow and adopt. The next step is to consider how it can ensure that such strategies being implemented are successful, i.e. delivering the highest potential of flexibility. As such, more understanding of factors critical to flexibility performance and a development of set of decision criteria helpful in justifying the success of flexibility strategy would be a worthwhile investigation. As the results show, the linkage between business environment, business strategy, manufacturing strategy, operations, and flexibility decisions can be clearer. This can help to provide a foundation in management practice when a firm needs to improve manufacturing flexibility.

Summarising from the literatures, the development of flexibility improvement process is feasible and potentially provides the benefits to the manufacturing firms. On the basis of manufacturing and operations strategy theory and resource-based view, the decision-making framework and analytical approach for flexibility improvement can potentially be constructed by incorporating the critical factors (i.e. the set of the firm's capabilities) contributing to successful flexibility implementation. Among the perspectives for justifying a manufacturing flexibility improvement initiatives (i.e. economic perspectives, business strategy perspectives, operations research and decision science perspectives), the techniques of *Multiple Criteria Decision Making (MCDM)* are likely to be able to solve flexibility decisions in practice. A number of factors are required to be taken into account in order to achieve the desired flexibility to satisfy the firm's business conditions, manufacturing objectives and operations conditions or constraints. *Analytic Hierarchy Process* (Saaty, 2000) is a decision method designed to aid in the solution of complex multiple criteria problems. It is employed for a number of decision purposes such as prioritisation, evaluation, aligning, and forecasting. The background of AHP will be described in Appendix 4 and 5. For justifying flexibility decisions such as selection of FMS technology, the evaluation of the flexibility level, there are many research works applying AHP techniques. It can be seen that, however, there is a limited amount of research in developing the selection and evaluation model for broadly dealing with flexibility decisions and for examining the expected success level of such decisions when actually implemented.

Regarding these issues that have not been addressed, a manufacturing flexibility improvement framework and an assessment methodology are found to be useful if developed and they can be helpful for managers to better cope with uncertainty, effectively exploit the resources, make economic investments, and achieve the highest profitability from the improvement.

2.5 CONCLUSION

This chapter reviewed and explored various points of flexibility improvement; general issues of flexibility; process and factors significant to the success of flexibility. It provided comprehensive overviews of flexibility improvement in manufacturing setting. It also emphasised that flexibility is being concerned in the global automotive industry and the awareness is shifted from technology aspects to organisational and resource aspects. In order to better deal with uncertainty in the supply chain, an understanding of current firm conditions and capabilities is crucial before any actions would be taken. These can provide higher level of confidence for decision-makers, and higher success for such actions or strategies (i.e. increase the level of flexibility to be achieved). This leads to the need for detailed study of flexibility practices and the problems currently faced in order to subsequently form the framework incorporating key issues critical to the flexibility success. As such, managers will be able to justify their alternatives against these key issues. The final decisions can be optimal, as the highest flexibility and profitability can be achieved because of the alignment of such decisions with the firm's current conditions and capabilities. According to these, the exploratory study of flexibility will be conducted in Chapter 4 to investigate the flexibility practices and managerial perspectives on flexibility and develop the flexibility improvement framework. The framework will be empirically tested in Chapter 5. Chapter 6 will develop a decision model and assessment methodology based on the AHP approach. The model and methodology will be tested and verified with practical companies in Chapter 7.

CHAPTER 3: RESEARCH METHODOLOGY

Chapter Two presented the reviews on an agile manufacturing paradigm, and the current flexibility improvement directions and efforts. In addition, it especially provided an overview on manufacturing flexibility in aspects of contents and processes, and the theoretical background of strategic decision-making and resource-based theory to establish a conceptual background to the research. This chapter describes the research perspective and research questions informed by the literature review. It explains and justifies the research approach and methodology adopted and the stages and techniques for data collection, analysis, and validation. The methodology is designed to address the research questions by identifying the current awareness and practices on flexibility improvement; factors considered in planning and implementation; and potential key mechanisms for flexibility success in manufacturing operations. Section 3.1 summarises the research questions of the research and discusses the theoretical foundation and justifies the chosen research philosophy. Section 3.2 to 3.6 describes the research design and explains the research activities. Section 3.7 provides the background of the Thai automotive industry as the primary context of case studies. Finally, the conclusion of the chapter is presented in Section 3.8.

3.1 DEVELOPING RESEARCH QUESTIONS

Prior to developing research methodologies, the primary research question is identified as '*How could companies attain maximum benefits of manufacturing flexibility from approaches they adopted?*' The secondary research questions are '*How are manufacturing flexibility improvements made in various automotive companies?*' and '*How do companies decide and implement the manufacturing flexibility? and what problems they encounter?*' To achieve the goals, the objectives were set as follows.

1. Investigate the approaches or strategies of manufacturing flexibility improvement being employed in different companies, particularly automotive firms.
2. Develop a thorough understanding on current strategic and operational concerns when implementing manufacturing flexibility.

3. Analyse key issues or mechanisms critical for flexibility performance and the other issues relating to flexibility improvement such as obstacles and enhancers.
4. Develop and test a decision-making framework and decision tool providing key factors to be considered in order to facilitate the flexibility improvement activities.

Once research questions were set, the research methodologies could be constructed. The philosophical assumption of this research is formed on the basis of Operations Management research in which the development of scientific knowledge is made. In this research, the means of the knowledge claim are to organise and categorise things or events for establishing better understanding of such events. Hence, the methodology adopted is generally both a qualitative and quantitative method using a case study and survey approach. In a qualitative method, it takes observations from the case studies to identify actual planning and implementation of manufacturing flexibility in order to obtain and develop an improved understanding of the issues relating to flexibility success. The details of research methodology are described in the next section.

3.2 RESEARCH DESIGN

As this research focuses on planning and implementation aspects for manufacturing flexibility, the exploratory study was conducted to obtain pragmatic views on these subjects. The exploratory research was conducted in three main phases. The first phase was to establish a conceptual background on planning and implementation of manufacturing flexibility through a literature review. The taxonomy of manufacturing flexibility, flexibility measurement, flexibility processes, flexibility frameworks, and factors affecting flexibility performance were reviewed. The main outcome of this phase is four possible mechanisms of flexibility improvement based on RBV, which are: ‘production control and management’, ‘process capabilities or resource redundancy’, ‘buyer-supplier relationship’ and ‘supporting structure and infrastructure’.

The second phase was to explore the efforts on improving manufacturing flexibility and strategic and operational concerns on flexibility improvement. It can be accomplished by conducting a series of semi-structured personal interviews with multiple case studies (i.e. five leading automotive firms) to identify patterns of interrelationships between a previously unspecified set of concepts (i.e. manufacturing flexibility improvement and resource-based view). In addition, a survey questionnaire to personnel involved in the production control and management within OEM and supplier companies was conducted to provide validity to the research and to obtain more insights into the different level of analysis. Once they were analysed within and across case studies, the output of this analysis are; a preliminary manufacturing flexibility improvement framework encompassing triggers, obstacles, enhancers, and the refined flexibility mechanisms; and a preliminary strategic decision-making framework illustrating strategic and operational factors.

The final phase was divided into two sub-phases. Firstly, the manufacturing flexibility improvement framework was validated through conducting a survey in the automotive industry. The validation is focused on testing the relationships between the degree of flexibility mechanisms and the outcomes of flexibility performance. The results from the survey are used to refine the improvement framework. Secondly, a decision making framework, model and assessment methodology for evaluating flexibility improvement programme were tested in practical companies to validate the model and to verify the applicability of the methodology. Following these three phases, it can be ensured that the research is conducted in a rigorous manner. The outline of the research design is shown in Figure 3.1.

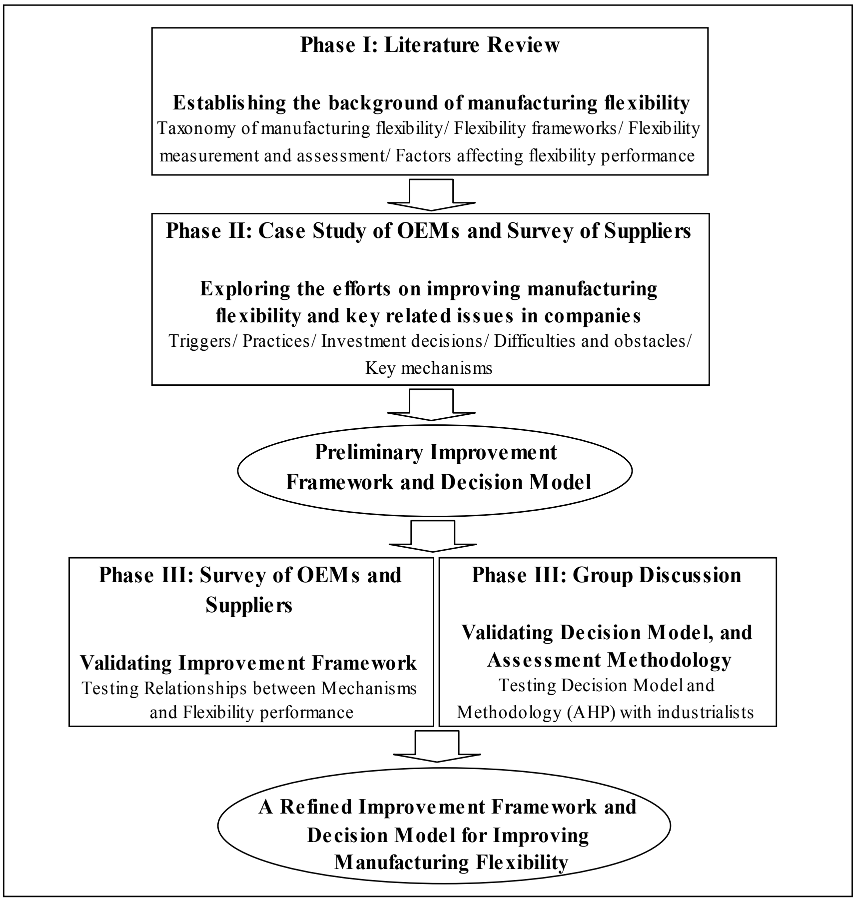

Figure 3.1: Research Stages

3.3 ESTABLISHING A CONCEPTUAL BACKGROUND OF MANUFACTURING FLEXIBILITY IMPROVEMENT

The first phase attempted to provide a general background of manufacturing flexibility improvement and research in relevant areas such as supply chain management and operations management. The elements of manufacturing flexibility, the concepts of manufacturing flexibility improvement, and planning and implementation practices were explored through an extensive literature review. The results from this phase (Chapter 2), enables the author to understand the issues surrounding manufacturing flexibility improvement, and the gaps were identified. The key concepts on manufacturing flexibility and manufacturing flexibility improvement were drawn. Finally, based on the literature review, and in order to assist in organising the interviews and survey in the second phase, an initial set of constructs was developed. As used in social sciences research, a construct is an image or idea specifically developed for a given research and/or theory building purpose. A prior view of general constructs and the relationships between them which satisfies the research aim is important in theory building (Voss et al, 2002). Constructs are developed combining the simpler concepts or indicators that make them up. The conceptual background from the literature review indicated four key areas relevant to manufacturing flexibility improvement. These areas or constructs will be used in the interviews and survey to further identify the practices and key factors of manufacturing flexibility improvement. They were shown in Table 3.1.

Table 3.1: Key Constructs of the Research

Key constructs of Manufacturing Flexibility Improvement	
Environmental conditions • Business context (i.e. market, competitors, environmental uncertainty) • Operations context (i.e. operational performance, production uncertainty) • Business and manufacturing objectives	**Flexibility improvement programme or Implementation of flexibility** • Flexibility strategy • Manufacturing and supply chain management programme
Management practices • Production control and management • Process capabilities or resource redundancy • Buyer-supplier relationship • Supporting structure and infrastructure	**Flexibility outcomes** • Flexibility performance (i.e. volume flexibility and mix flexibility) • Effects on other operational performances

Four key related constructs of manufacturing flexibility improvement were revealed from the literatures. The first two constructs concern the influential factors including the influences of business environments on flexibility needs, both external and internal ones, and the degree and characteristics of management practices within the areas of production control, resources and capabilities, buyer-supplier relationship, and supporting structure and infrastructure. The other two constructs concern the approaches and outcomes of flexibility implementation. The qualitative analysis was employed for categorising the contents of each construct as summarised in Table 3.1. These constructs are used as basic knowledge to develop a research protocol for conducting detailed investigation in the second phase of the research. The next research tasks are to further investigate and clarify the components in each construct and validate their inter-relationships through case study and survey methods.

3.4 CASE STUDY

A contemporary research in operations management (OM) shows an increase in the use of empirical data. The rationale has been to reduce the gap between management theory and practice, to increase the usefulness of OM research to practitioners, and to increase the scientific recognition of the OM field. The case study method is used in the theory development process as it involves investigating a particular contemporary phenomenon and generating rich data from small samples (Yin, 1994). This phase, a field study, provided the awareness and practices of manufacturing flexibility by attempting to investigate the planning and implementation of flexibility within five leading automotive firms in Thailand, which include approaches or strategies being employed, strategic and operational concerns on flexibility implementation, key issues critical for flexibility performances, and other related issues such as obstacles and enhancers. As a result, more understanding on planning and implementation of manufacturing flexibility can be acquired and finally a preliminary flexibility improvement framework can be developed.

The in-depth case study approach was chosen for gaining evidence for the research questions of; ‘How are manufacturing flexibility improvements in various automotive companies made?’ and ‘How do companies decide and implement the manufacturing flexibility? and what problems do they encounter?’ The five automotive companies selected for this research were: Toyota Motor Thailand, Siam Nissan Automobile, Isuzu Motor Company (Thailand), Thai-Swedish Assembly, and Thonburi Automobile Assembly Plant. This range of companies provided a basis to investigate manufacturing flexibility improvement under various strategic and operational contexts but within similar industries.

Within the case study, multiple methods were applied in order to provide adequately rich and detailed information in manufacturing flexibility improvement, which involved many actors and departments. Both primary and secondary data were collected. The interview method provided primary data regarding the current approaches, the decision criteria, current problems, and critical operating issues for flexibility improvement. Secondary data from company annual reports, company document, and articles were used to support the analysis. Finally, the results from case studies allow the author to develop the concepts of enhancing manufacturing flexibility to answer the last research question of ‘How could companies attain the maximum benefits of manufacturing flexibility from approaches they adopted?’

3.4.1 Case Study Selection

The selection of cases is a very important aspect of building the theory from case studies. While the cases may be chosen randomly, random selection is neither necessary nor preferable. Given the limited number of cases that can be studied, it has been suggested that researchers choose cases such as extreme situations and polar types in which the process of interest is transparently observable (Eisenhardt, 1989). The automotive firms in Thailand are considered as the ASEAN's largest automotive market and assembler. These include assembly plants and suppliers. There are 14 automotive plants and over 700 OEM auto part suppliers in the industry. With various flexibility focus and techniques, Toyota Motor Thailand, Siam Nissan Automobile, Isuzu Motor Company (Thailand), Thai-Swedish Assembly, and Thonburi Automobile Assembly Plant were chosen for the study. Two of them strongly focused on flexibility improvement, the other two moderately focused on, and one focused on other competitive priority. In addition, ownership of selected case study companies is varied; three are Japanese-owned, one is European-owned, and another is Thai-owned. The different styles of management can be presented in these companies and they are likely to influence different viewpoints on manufacturing flexibility improvement (see Appendix 6).

3.4.2 Scope and Unit of Analysis

The unit of analysis for this study mainly focuses on the manufacturing level. Interviewees for the study are grouped into three levels, which are top management, middle management, and engineers. The top management was meant to provide current market situations, policies and strategies, decisions about flexibility improvement, and criteria used in the considerations. Top and middle management were asked to provide information about the implementation of flexibility including practices used, and current problems relating to, the implementation. Engineers in the production planning department and the manufacturing planning department were asked to specify the current activities and operations regarding flexibility improvement plans as well as technical and operational problems. The list of total interviewees (n = 29) is shown in Table 3.2.

Table 3.2: Numbers of Interviewees

Interviewees	Case study companies					Total interviews
	Toyota	Nissan	Isuzu	TSA	TAAP	
Top management	2	2	1	1	1	29
Senior managers and Functional managers	5	3	2	2	2	
Chief engineers	2	2	2	1	1	

3.4.3 Research Protocol

Gillham (2000) defined the purpose of the research interview, which is concerned with obtaining information and understanding issues relevant to the general aims and specific questions of the research project. In this research, it is necessary to obtain some in-depth data regarding manufacturing flexibility in the firms that are available via one-on-one discussions. This information would be used to supplement the theoretical basis for the initial constructs (Table 3.1). In-depth, personal interviews were conducted with individuals, who all have a view of manufacturing flexibility being carried out in their respective areas and in which their groups are involved. The main objectives of these interviews were to provide data that helped to refine the research questions and to provide key areas that are distinct to investigate and refine the instrument for the survey. The goal of the interviews was to engage in a discussion of the issues being studied.

The interview protocol was forwarded to the individuals beforehand, to allow them time to reflect on the questions and gather any necessary data or documentation. The interview protocol guided the interviews and it was also offered any unanticipated lines of research that may have opened up during an interview. The sets of semi-structured interview questionnaires are presented in Appendix 9. There were a total of eight areas of interview questions organised around the previously described original constructs. They addressed areas including:

- The overall company business including business context, operations context
- Types of change in production and manufacturing systems
- Current flexibility level (flexibility performances)
- Flexibility improvement programme include flexibility strategies adopted or planned to adopt, methods and tools used to deliver manufacturing flexibility

- The activities and concerns regarding flexibility improvement in terms of planning and implementation
- External and internal influences including resources and capabilities, employees, management, suppliers, and supporting activities
- Problems that are found in flexibility implementation
- Perceived obstacles and keys to success

The interview protocol was pre-tested through reviews by an industrialist and two pilot interviews. These reviewers evaluated the instrument for content validity and question clarity. The interviews were recorded and supplemented by the researcher's notes and materials provided by the interviewees. The voice recorders and notes were transcribed for analysis. From these analyses, a summary of experiences and viewpoints on manufacturing flexibility practices was derived. Several informal follow-up discussions with research participants took place during the course of this research to ensure validity of a preliminary framework.

Not only were manufacturing functions investigated, but an important manufacturing component of manufacturing flexibility, a supplier, was also examined to provide supporting evidence in supply chain aspects. The aims were to examine the current manufacturing flexibility level of suppliers in the Thai automotive industry and to understand the ways suppliers react to the changes of OEMs production and their opinions about flexibility improvement. The supplier survey results can be served as additional and supporting data in terms of supply chain aspects. The research protocol of supplier study was in the form of a questionnaire which contained key open and closed questions. Because there are a number of suppliers in the industry, choosing few of them for a case study is found to be difficult to obtain rich information about the roles of suppliers on manufacturing flexibility improvement of automotive firms. Therefore, the author selected a mail questionnaire method as a means to provide more comprehensive data. The lists of questions are shown in Appendix 10. The details of this survey will be described in Section 3.5.

3.4.4 Stages of Analysis of Case Study

Data analysis consists of examining, categorising, tabulating, or otherwise recombining the evidence to address the initial propositions of a study (Yin, 1994). A number of analysis techniques were employed in the case study. They mainly consist of content analysis, grounded theory, pattern-matching, and explanation building. The qualitative data from the interviews was analysed by using content analysis and grounded theory. Content analysis has been described as a research technique for the objective, systematic, and quantitative description of the manifest content of a communication (Jauch et al, 1980). Content analysis follows a systematic process starting with the selection of an unitisation scheme. The units may be syntactical, referential, propositional, or thematic. Other aspects of the methodology include the selection of a sampling plan, development of recording and coding instructions, data reduction, inferences about the context, and statistical analysis. Content analysis is about organising the substantive content of the interview. The purpose of constructing categories is to be able to assign all the substantive statements to them. Analysing the results must be done in a systematic way. After capturing discussion the researcher must code the data to create a label for each idea or phenomenon. The code should combine like responses and opinions into usable data for the researcher. The coded responses are then sent out to participants for review to ensure that the participants have a chance to respond and clarify any attributed response (Krippendorff, 2004). In this study, the codes confirmed various concerns in planning of manufacturing flexibility improvement. It is noted that, since this study is looking for expert opinions without consensus or interpretation, the descriptive and interpretive reports are not as applicable.

Grounded theory takes a case rather than variable perspective (Borgatti, 2004). This means that the researcher takes different cases to be wholes, in which the variables interact as a unit to produce certain outcomes. The basic idea of the grounded theory approach is to read and re-read a textual database such as field notes, tape scripts and discover label variables (called categories, concepts and properties) and their interrelationships. Conducting such qualitative approaches, the researcher must be aware that the ability to perceive variables and relationships is termed 'theoretical sensitivity' and is affected by a number of factors including literature review, data collection and analysis techniques (Strauss and Corbin, 1990).

Studying multiple cases makes it possible to build a logical chain of evidence (Yin 1994; Miles and Huberman 1994). The cross-case analysis is made to seek a chain of evidence for the relationships studied on the basis of the framework. The cross case analysis was conducted to obtain the different viewpoints on flexibility improvement among five automotive firms and key problems in unsuccessful implementation of flexibility. In cross-case analysis, two techniques of pattern-matching and explanation-building were employed. The pattern-matching is used to identify the replication on key capabilities contributing to successful flexibility implementation from multiple cases, thus increasing the confidence in the robustness of the theory. Trochim (1989) considered pattern-matching as one of the most desirable strategies for analysis. This technique compares an empirically based pattern with a predicted one. If the patterns match, the internal reliability of the study is enhanced. Explanation-building is considered a form of pattern-matching, in which the analysis of the case study is carried out by building an explanation of the case. This implies that it is most useful in explanatory case studies, but it is possible to use it for exploratory cases as well as part of a hypothesis-generating process. Explanation-building is an iterative process that begins with a theoretical statement, refines it, revises the proposition, and repeats this process from the beginning.

It is noted that questionnaire results from suppliers were used as supporting evidence for case study analysis. The descriptive statistical analysis was conducted using Microsoft Excel. This provided better understanding of the roles of suppliers on manufacturing flexibility performance and flexibility improvement of automotive companies, and also made useful suggestions on managing manufacturing processes of OEMs and suppliers to improve manufacturing flexibility performance. The details of supplier survey are described in the next section. Ultimately, incorporating all of data from primary data (i.e. interviews and mailed questionnaires) and secondary data, an initial framework was developed, which encompassed key criteria or factors, to help justify the actions to which flexibility outcomes are effectively obtained.

3.5 SURVEY

In the second phase of the research, the two surveys were also conducted consisting of the supplier survey and the automotive industry survey. As described above, the first survey aimed at investigating the operations of supplier companies in responding to the changes from OEMs production so that the supply chain issue regarding manufacturing flexibility improvement can be acquired. It is supplementary to the case study results. Consequently, the concepts of enhancing manufacturing flexibility both in terms of manufacturing and supply chain aspects were developed. The second survey was conducted to validate the relationship between operating issues and manufacturing flexibility performance, which derived from the case studies and the supplier surveys. It was conducted as a means to further validate and generalise the derived operating issues.

The next tasks consisted of the administration of a sample mail survey instrument to the Thai automotive industry including OEMs and suppliers. When properly undertaken, the survey provides an objective, efficient, and valid method of obtaining the characteristics of an entire population from only a small part of that population (Fowler, 1993). In consequence, the operating factors taken into account to the manufacturing flexibility improvement were derived and validated. Next, by incorporating these factors, the decision-making framework and model for improving manufacturing flexibility were developed and the decision-making tool was developed by choosing among various decision-making techniques in the field of OM.

3.5.1 Selection of Sample

The sample for the survey consisted of both OEMs and suppliers in the Thai automotive industry. The lists of automotive assembly plants and suppliers were obtained from websites of Thailand Automotive Institute and Thai Auto-Parts Manufacturers Association (TAPMA), respectively. To be consistent with case studies, only plants assembling the automobiles (i.e. not including motorcycle plants) were chosen for this study. Suppliers were chosen based on the types of products they manufacture and plant qualification as other criteria, such as the size of the firm and the varieties of products being produced (or manufactured) seem to limit the numbers of sample in the study if taken into account. The sample of suppliers for this study manufacture key vehicle components such as engine parts, bumpers, mirrors, etc. as well as some supporting components such as die and jigs. This is meant to ensure that manufacturing flexibility is having an important impact on their productions and operations.

3.5.2 Survey Instrument

This section described different means of data collection for the mail survey conducted. Both survey instruments were developed based on literatures and the findings from the interviews (see Appendix 11). Before it was considered final, it was also pre-tested with industrialists. Content validation is used to ascertain that the factor/construct provides adequate coverage of the desired topic. The questionnaires were sent to a total of 400 suppliers for the first survey and 300 OEMs and supplier companies for the second survey. They are members of the Thailand Automotive Institute and the Thai Auto-Parts Manufacturers Association (TAPMA). The selection of supplier sample was made within the criteria such as the types of product they produce and standard qualification. In contrast, the OEM sample included all the automotive plants in Thailand (i.e. 14 plants). For the first survey, of 400 postal surveys, 27 questionnaires were returned as the recipient was no longer at that address (i.e. 19 mails) and for other, unidentified reasons (i.e. 8 mails). The response of 43 suppliers was achieved (11.53%).

For the second survey, a total of 45 useable responses were obtained from this survey, two responses were unusable and nine questionnaires were returned as undeliverable. Thus, the usable response rate was 15 percent. The final survey instrument using a 5-point Likert scale consisted of six key constructs including technology and organisational activities, production control and management, resource redundancy, buyer-supplier coordination, manufacturing flexibility performance, and flexibility-related performance. The goal was to determine the relationships of sets of variables or mechanisms to flexibility performance.

3.5.3 Statistical Analysis of Results

The analysis methods of the first and second surveys are different because of different objectives and types of questions being asked. The objective of the first survey is to investigate the characteristics of supplier's production and operations against the changes in OEMs production. Incorporating the results from this survey with ones from case studies, manufacturing and supply chain aspects of manufacturing flexibility improvement were then acquired. This leads to the development of concepts to enhance the level manufacturing flexibility. The second survey was aimed at validating the developed mechanisms, e.g. whether or not these mechanisms are significant to the level of manufacturing flexibility performance or success of manufacturing flexibility.

The first questionnaire mainly contained open-ended questions, while the second questionnaire only contained rating questions. The methods used included descriptive statistical analysis, regression analysis, and analysis of variance. All methods of analysis were made by using SPSS 10.0.

● **Assessing Measurement Quality**

It is traditional for statistical analysis that an assessment of measurement instrument and measurement items must be conducted before commencing the descriptive statistical analysis, regression analysis, and analysis of variance as it affects the validity of the study (Pallant, 2007). The quality of measures is mainly evaluated in terms of validity and reliability. Validity is concerned with whether we are measuring the right concept, while reliability is concerned with stability and consistency in measurement (Bryman and Cramer, 1994).

Reliability indicates dependability, stability, predictability, consistency and accuracy, and refers to the extent to which a measuring procedure yields the same results on repeated trials. Reliability is assessed after data collection by using the internal consistency method (Diamantopoulos and Schlegelmilch, 2000). The internal consistency method uses algorithms to estimate the reliability of a measure from measure administration at one point in time. The most popular test within the internal consistency method is '*the Cronbach coefficient alpha'*. Cronbach's alpha is also the most used reliability indicator in OM survey research.

A measure has construct validity if the set of items constituting a measure faithfully represents the set of aspects of the theoretical construct measured, and does not contain items which represent aspects not included in the theoretical construct. Factor analysis is used to evaluate construct validity. It is a generic term used to describe a number of methods designed to analyse inter-relationship within the set of variables resulting in the construction of a few hypothetical variables, called factors or constructs (Diamantopoulos and Schlegelmilch, 2000). In short, factor analysis helps to explain things by reducing large amounts of information into a manageable form and size.

● Descriptive Statistical Analysis

The questionnaires were analysed by using descriptive statistical analysis where frequency, means, and standard deviation classify various types of sample and various points of the answers from each question. This analysis shows the quantities and frequencies of a particular variable from the sample so that the level of importance of such variable on the constructs being studied can be acknowledged.

● Analysis of Variance (ANOVA)

One-way Analysis of Variance (ANOVA) is used to compare the means of three or more samples while holding the alpha error at a constant level. It uncovers the main and interaction effects of categorical independent variables on an interval dependent variable. This study used ANOVA tests to determine whether there are significant mean differences among the various production efforts in the sample of high, medium, and low flexibility performance companies. The key statistic in ANOVA is the F-test of difference of group, which means to test if the means of the groups formed by values of the independent variable are different enough not to have occurred by chance (Bryman and Cramer, 1996).

● **Regression Analysis**

Regression analysis is used to model the relationship between a response variable and one or more predictor variables. The regression analysis was applied to investigate the relationships between dependent variables (i.e. level of manufacturing flexibility performance) and independent variables (i.e. production practices). The direction of the relationship between dependent and independent variables can be determined by looking at '*the regression coefficient*' (β) associated with independent variables (Bryman and Cramer, 1996). If the regression coefficient is positive, then there is a positive relationship between these variables. In doing so, the critical operating issues important to the manufacturing flexibility performance will be empirically tested. These issues will be taken into account in the improvement framework and decision model as their existences can be used to indicate the success of flexibility strategies being implemented in a manufacturing firm.

To sum up, the first and second phase of the research provided useful insights on manufacturing flexibility improvement. Firstly, the contextual background of manufacturing flexibility improvement including triggers, practices, problems and difficulties in achieving manufacturing flexibility was acknowledged. Secondly, a comprehensive set of flexibility mechanisms emerged from field studies was validated through the questionnaire survey. Lastly, the preliminary framework to enhance successful implementation of manufacturing flexibility was developed. The next phase is aimed at developing a decision-making framework and assessment methodology for practising managers as they enable and promote systematic thinking, which subsequently contributes to successful implementation of manufacturing flexibility and supply chain effectiveness.

3.6 OPERATIONALISING AND REFINING THE DECISION-MAKING FRAMEWORK AND MODEL

The final phase of this research was to conduct a face-to-face validation to validate a framework and model. The author focuses on providing model guidelines and promotes awareness on key issues of flexibility improvement for decision makers. Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty was chosen to achieve these points. This methodology can allow the decision-making process to be more structured and explicit, as decision levels are constructed into a hierarchical fashion (Saaty, 1996; Bhushan and Rai, 2004). Incorporating information from empirical studies, an AHP-based decision model for improving manufacturing flexibility was developed and tested by decision makers in automotive companies. The action research requires close interaction with the researcher as a facilitator within the companies. The process of validation and application of the framework and model is described as follows.

The validation of this research occurred in two stages. During the first stage, the strategic and operational decision criteria were validated through field interviews, survey, and using existing literatures. During the field interviews, the participating firm was asked to discuss, at a high level of detail, many aspects of their overall business strategies, manufacturing strategies and their concerns on flexibility improvement.

The second stage consisted of interviews with a participating company in which decision makers were asked to provide information that eventually became the input data to the model. In this research, Siam Nissan Automobiles Co., Ltd is the company participating in testing a proposed assessment methodology for improving manufacturing flexibility. The testing process was carried out in the form of a discussion session held at Siam Nissan Automobiles Co., Ltd. It involved one top manager and three middle managers in the production planning department. There were four sessions for the testing process, which comprised; introduction of the model and technique; model input from experts; presentation of output and final results; and result discussion and feedback. After presenting the output and final results to managers, they were asked to assess the feasibility, usability, and utility of the model by filling out the questionnaire. The details of assessment questionnaire are shown in Table 3.3 (also Appendix 12). During this second stage, feedback information about the usefulness of the model was also obtained. The discussion included the output from the model (i.e. approach or actions for improving manufacturing flexibility) and the consistency of the results with the firm's adopted approach. The advantages and disadvantages of the model and technique employed were also discussed.

Table 3.3: Assessment Criteria ***(Adapted from Thawesaengskulthai, 2007)***

1. Feasibility
1.1 The input information required for the model is available in the firm. 1.2 The knowledge and experiences of participants can provide effective input information. 1.3 Time consumed for the use of model is appropriate. 1.4 People are willing to use the model in the meeting or discussion.
2. Usability
2.1 The objectives of the model were clear. 2.2 The model and process step were clearly defined. 2.3 Process of the evaluation and selection was easy to follow and use. 2.4 The model was easy to use by all participants. 2.5 The approach and format for evaluating and selecting strategy were appropriate. 2.6 Main problems encountered in evaluation and selection process.
3. Utility
3.1 The decision criteria were relevant to be considered and evaluated among improvement strategies 3.2 Sub-criteria for selecting strategy were relevant to be considered and evaluated among improvement strategies. 3.3 The evaluation and selection process provides useful steps in selecting the best strategy. 3.4 The output of the process were worthwhile for time being consumed. 3.5 What degree of confidence do you have in the suggested strategy from the model?

3.7 THAI AUTOMOTIVE INDUSTRY

This section provides a brief overview of the Thai automotive industry including production volumes, industry objectives and targets, and describes the importance of manufacturing flexibility in the industry level. Thailand's automotive industry is well on the way to solidifying its status as the Detroit of Asia. Thailand is the world's second largest pick-up truck market after the United States and ASEAN's largest automotive market and assembler. Thailand has become the main production base for auto exports in South East Asia. The automotive industry in Thailand has for several decades been a priority sector (i.e. third largest industry) and for many years it has been supported and encouraged by the government. This sector is seen as one of the big driving forces behind the recovery of the economy in the post 1997 crisis era (Limsavarn, 2003).

There are 14 vehicle assemblers in Thailand as illustrated in Table 3.4. Most of them are either foreign owned or joint ventures with Japanese and Western countries. There also are 709 large-scale enterprises and small & medium enterprises, which work as suppliers of original equipment (OEM) including companies with foreign majorities (287 companies), ones with Thai majority (68 companies) and pure Thai companies (354 companies). Vehicle production is expected to reach a target of 1.24 million units in 2006, of which 723,000 units of vehicles are expected to be sold locally, and the remaining 522,000 units are expected to be exported. By considering total market share, the Thai market is dominated by three Japanese companies, which are Toyota Motors Thailand (37.6 %), Isuzu Motor Company (Thailand) (24.1 %) and Honda Automobile (11.6 %); they account for a 73.3 % share of the domestic market. To segment the types of vehicles produced, one-ton pickup trucks accounts for approximately 65 percent of the total vehicle sector in Thailand, passenger cars account for around one third of the total production, and the big truck is only 3 percent. At the current market situation, locally assembled cars account for 95% of the domestic market, which means only five percent of vehicles are imported from other countries (Office of Industrial Economics, 2006; Danish Trade Council, 2006).

Table 3.4: Assembly plants in Thailand and production units

Rank	Assembly plants	Units	Production capacity share
1	Toyota Motor	240,000	22.35%
2	MMC Sittipol	190,200	17.71%
3	Isuzu Motors	180,000	16.76%
4	AutoAlliance	135,000	12.57%
5	Siam Nissan Automobile	124,000	11.55%
6	Honda Automobile	60,000	5.59%
7	General Motors	40,000	3.73%
8	Hino Motors	28,800	2.68%
9	Bangchan General Assembly	20,000	1.86%
10	Thonburi Automotive Assembly	18,100	1.69%
11	Y.M.C Assembly	12,000	1.12%
12	BMW Manufacturing	10,000	0.93%
13	Thai Rung Union Car	9600	0.89%
14	Thai-Swedish Assembly	6000	0.56%
	Total	1,073,700	100%

Source: Office of Industrial Economics, Ministry of Industry (2006)

Global leading automotive companies have promoted Thai manufacturing plants as their strategic regional bases, i.e. South-East Asia, according to the need for economies of scale. It is now very important that automotive companies must serve the domestic market and also seek new foreign markets (see Appendix 7 for the establishment of Thailand as an export base). The exporting vehicles are considered to be approximately more than one-third of the total production. In 2004 Thailand exported 332,053 vehicles, valued at approximately 150 million Baht and it is expected to reach 522,000 units in year 2006. Considered the main target and objective of the industry, the Master Plan for the auto industry expected for 1.8 million units in total production, which are 800,000 export units by 2010. If market trends continue towards the year 2013, it could be said that Thailand would become an export-oriented country in the region of Asia (Danish Trade Council, 2006).

In terms of policies, the development of Thai automotive industry has been based on import-substitution policies over the past 30 years. However, according to the current global trends such as globalisation and outsourcing, the industrial interest has now shifted towards more liberalised policies by loosening tariff barriers, abolishing local content measures, promoting investments and exports, and also cooperating with international communities, such as ASEAN, APEC, and WTO. For instances, trade liberalisation through the agreements of AFTA (ASEAN Free Trade Area) has cut import tariffs to 0-5 percent since 2003. This influences the expansion of the market for the Thailand automotive industry, as such policies offer foreign automobile companies attractive investments. Tariffs on automobile imports among member countries of ASEAN are likely to be reduced to zero percent. In addition, the bilateral free trade area agreements that Thailand has made with some other countries, particularly Australia and New Zealand, can support the exports of Thai cars to the Australian and New Zealand markets as pickup trucks from Thailand occupy 85 percent of all demand for pickup trucks in Australia. Furthermore, Thailand no longer has any specific measures set up to obstruct entry of new companies or imported vehicles and components (Thailand Automotive Institute, 2002). In consequence, in the last couple of years, it can be seen that many car manufacturers have decided to transfer their manufacturing bases to Thailand for export purposes. The distinct example is the announcement of the Innovative International Multi-Purpose Vehicle Project (IMV Project) from the Toyota Motor Corporation in 2002 (Toyota Motor Corporation, 2002).

From reviewing a number of articles relating to the Thai automotive industry (Limsavarn, 2003; Vanichseni, 2007; The Board of Investment of Thailand, 2007), the main challenges which the Thailand automotive industry faces can be identified. Firstly, the degree of product variety and demand variations in the operations of Thai automotive firms is increasing as many North American and Japanese automotive companies invest their plants in Thailand as a production base for their export. Secondly, the competition from regional neighbours, particularly a potential influx of products from China, influences the need for increasing quality of locally-made components and variety of products in the Thai suppliers; upgrading supporting industries, i.e. raw material providers, to become first tier status; and improving research and development (R&D) work including training of more skilled engineers to ensure that components from Thai suppliers meet international standard. According to such challenges, many advantages from improving the level of flexibility can be acknowledged, especially in aspects of maintaining industry competitiveness and improving capabilities of suppliers to satisfy more complex operations required by foreign automotive companies.

3.8 CONCLUSION

The research philosophy of this research is based on the pragmatism paradigm, which considers truth to be 'what works' and provides a solution to the problem. This paradigm shapes and directs the research design and processes. The research processes consisted of three main phases: establishing a conceptual background through extensive literature review; empirically investigating awareness and practices of manufacturing flexibility improvement through case studies and surveys; and developing and refining a decision-making framework and an assessment methodology for improving manufacturing flexibility.

A number of research methods were chosen to address the research questions of (1) how are manufacturing flexibility improvements implemented? in various automotive companies? (2) how do companies decide and implement the manufacturing flexibility? and what problems do they encounter? and (3) how could OEMs and suppliers attain maximum benefits of manufacturing flexibility from the approaches they adopted? In the theory building process, a case study is a key research method, together with a questionnaire survey to explore and gain evidence of current practices and related issues on manufacturing flexibility improvement efforts. Five case companies of Toyota Motor Thailand, Siam Nissan Automobile, Isuzu Motor Company (Thailand), Thai-Swedish Assembly, and Thonburi Automotive Assembly Plant were chosen for case studies. A number of suppliers provided their viewpoints on manufacturing flexibility including flexibility performance, current problems, and expected solutions. Many OEMs and suppliers also provided information on their operational performances (i.e. flexibility) and the degree to which they put the efforts into activities that are likely to enhance flexibility success. The resource-based view is mainly used for case study analysis. In the theory testing process, this research used survey and action research to validate flexibility mechanisms, i.e. resources and capabilities underlie the success of flexibility implementation, emerged from case studies and to test the applicability of decision model and assessment methodology, respectively.

The three main accomplishments of this research are; the understanding of contextual background and current practices of manufacturing flexibility improvement; the development of key strategic and operational decision criteria that are generic to firms within the manufacturing setting; and the decision-making framework and assessment methodology which uses the derived decision criteria for assessing flexibility improvement approach. The development of a generic set of decision criteria and assessment methodology will be providing managers with a good starting point for companies undergoing flexibility improvement endeavours.

CHAPTER 4: MANUFACTURING FLEXIBILITY IMPROVEMENT: EVIDENCE FROM CASE STUDIES AND SURVEY

This chapter explores the efforts of manufacturing flexibility improvement and their related problems in the five case study companies and their suppliers to mainly identify the key mechanisms for enhancing the level of flexibility performance. The insights on manufacturing flexibility improvement including triggers, management practices, investment decisions and their reasons, difficulties and obstacles are derived. A set of key mechanisms critical to the success of flexibility implementation (i.e. highest flexibility outcomes) emerges and the framework and hypothesis are then developed according to these flexibility mechanisms.

The literature review in Chapter Two provided a general background on manufacturing flexibility improvement process (Figure 2.3) developed from the frameworks of Harrison (1998) and Boyle (2006). From the literatures, the factors involved in the process can be characterised into three levels; strategic, tactical, and operational level. Strategic factors involve external and internal business environments influencing the need for flexibility. Tactical factors involve considerations of other competitive priorities such as cost, quality, and delivery against flexibility. Operational factors involve the structure and infrastructure of manufacturing and supply chain system contributing to implementation success of flexibility. Despite this, the roles of resources are recognised to the level of flexibility achieved as they are reflected by a number of literatures. Little is known about which operational factors should be taken into account in the decision-making process in order to ensure the maximum benefits from implementing flexibility strategies (e.g. effective use of resources, risk and chaos reduction, profitability). The literatures confirmed that a thorough study specific to flexibility implementation has not been conducted.

The literatures also showed that the flexibility improvement framework used for evaluating the actions that potentially provide the highest benefits to an organisation, e.g. responding to business requirements, satisfying manufacturing objectives and operational conditions, and delivering the full potential of flexibility was essential. To develop such a framework, a study of flexibility implementation is required as being a key process of the framework. Hence, the proposed conceptual framework that will be developed in this chapter is mainly focused on flexibility implementation on which the operating factors are critical to flexibility performance. As suggested by many literatures, they can be grouped into four areas; *production control and management, process capabilities, buyer-supplier relationship, and supporting structure and infrastructure*.

In this chapter, the manufacturing flexibility improvement framework will be refined by incorporating the results from case studies of automotive companies and supplier survey. Section 4.1 introduces the overview of the study and follows by describing the objective of fieldworks and overviews of flexibility in selected case studies in Section 4.2 and 4.3, respectively. Section 4.4 to 4.8 presents the various aspects of flexibility in five automotive companies. The cross case analysis of the results are conducted in Section 4.9. Section 4.10 provides supporting evidence of flexibility in suppliers. The hypothesis regarding operating factors of flexibility are developed and explained in Section 4.11. The summary of findings and conclusion of the chapter are made in Section 4.12, and 4.13, respectively.

4.1 INTRODUCTION

When operating in an agile environment, a company may fail to change when required and/or be able to change in an ineffective manner; one of the reasons could be that a company has poor flexibility. This can result in a reduced agility of the resources and within the system overall. In this case, there are two possible ways to tackle this circumstance, i.e. by maximising the overall agility result; (1) by identifying potential sources of flexibility, obstacles, enablers and critical success factors in managing the flexibility; and (2) minimising risk by having strategic tools to evaluate and assess the flexibility on potential approaches which a firm tends to adopt. This study attempts to fulfill these two objectives. To achieve the first objective, a number of existing frameworks of manufacturing flexibility is proffered and employed in a case study investigation. The results from the first objective can provide rich information for the second objective on developing strategic tools (i.e. analytical approach) for justifying flexibility improvement initiatives.

This chapter presents the findings from in-depth case studies of 5 automotive plants in Thailand, Toyota Motor Thailand (TMT), Siam Nissan Automobile (SNA), Isuzu Motors Company (Thailand) (IMCT), Thai-Swedish Assembly (TSA), and Thonburi

Automobile Assembly Plant (TAAP). Additionally, the findings from a survey of suppliers are presented. The case studies begin with a brief understanding of management practices relating to agility within the manufacturing functions of each company; e.g. agility policy; overall agility performance; agile manufacturing practices. The overview of flexibility in the five case companies include flexibility performance; tools and practices for flexibility; manufacturing flexibility strategies; and current manufacturing and supply chain flexibility operations are provided. These can offer background and viewpoints regarding agility and flexibility within the firms prior to conducting the detailed investigations.

It is known that flexibility is a wide-enterprise issue, so that it is necessary to focus on a specific level of analysis. In this research, manufacturing operations in the context of '*volume and mix flexibility'* under different company contexts were analysed. Since TMT, SNA, IMCT, TSA, and TAAP have different strategic, operational and management focuses, it is essential to discover various aspects of flexibility issues, thus resulting in a more applicable framework. The author specifically explores flexibility issue surrounding a strategic level to understand how firms in a newly industrialised country, Thailand in particular, need to put emphasis on flexibility and in which aspects. Additionally, the operational level was explored to understand *how they operate* in order to achieve flexibility (e.g. volume and mix flexibility), *what problems* they encounter, and *what causes* of the problems are. As a result, key criteria regarding flexibility improvement concerns both in the strategic and operational level are then derived. Critical sources of flexibility encompassing key manufacturing functions (i.e. production control process, input-supply network, labour force, plant and network structure) and critical factors for flexibility performance are also derived. Ultimately, those findings are used to facilitate the development of a framework for efficient planning and implementing flexibility in manufacturing operations, particularly automotive manufacturing as a primary outcome of this research.

4.2 OBJECTIVES OF FIELDWORKS

The objectives of conducting case studies comprise two main points. Firstly, we focus on flexibility improvement strategy and the reasons to adopt it in order to understand which issues of flexibility firms take into account. Secondly, we focus more specifically on flexibility practices and key problems to understand how and why firms fail to achieve flexibility (i.e. ineffective manner) from their implementation of particular tools, practices or strategies of flexibility they adopt. To achieve these, an interview protocol was developed based on literature reviews, and applied through semi-structured interviews.

4.3 OVERVIEWS OF FLEXIBILITY IN SELECTED CASE STUDIES

This section comprises the interview results of five automotive companies. It mainly focuses on a broad understanding of flexibility in each company; e.g. agility policy; overall agility performance; and flexibility performance according to type (tools and practices on flexibility). Prior to conducting the detailed investigation, a conceptual framework for the analysis is described below. Subsequently, the flexibility improvement strategies, practices, and problems in manufacturing operations of each company were investigated and are discussed in Section 4.4.

4.3.1 Agile Manufacturing in Automotive Firms

This section presents the current viewpoints of five automotive plants on agile manufacturing by looking at their existing focuses. Agility can be measured by the extent to which operations or a system is able to change with speed, responsiveness, and flexibility. This can be reflected by each specific firm's strategy such as marketing-manufacturing coordination, concurrent engineering, etc. Agile manufacturing has been described as 'a manufacturing system with extraordinary capability to meet the rapidly changing needs of the marketplace' (Sohal, 1999). The level of competition within the Thai automotive industry has increased due to the boost of foreign investment by government and international trade participation. In other words, the number of players in the industry has increased, such as new General Motors plant, and suppliers from China. This has driven automotive companies concentrate more on the customers and their requirements. In addition, the number of domestic customers seems to be limited, so the ability to satisfy domestic customers is very important, and it is just as important to satisfy the increased number of customers from various countries. The attempts to increase the agility in manufacturing and supply chain are now under improvement in many automotive plants. Of these five selected case studies, TMT and SNA are very eager to improve the plant according to this perspective, followed by IMCT, TSA, and TAAP, respectively. Obviously, TMT and SNA are now intensively focusing on improving their manufacturing and supply chain operations to improve customer responses and the production process, while the rest of the plants are still focusing on improving cost effectiveness and seeking higher market share through other manufacturing practices.

4.3.2 Flexibility Performance

It is worthwhile to identify flexibility performance in five automotive plants. This can provide a basic understanding and allows the researcher to investigate different aspects affecting flexibility performance within each firm. The measures used are based on a number of literatures (see Appendix 8) and they were applied to informants in the form of an evaluation sheet. A total of 29 questions are included in the evaluation sheet that measures 9 types of manufacturing flexibility. Figure 4.1 shows the result of comparison of manufacturing flexibility performance in five automotive plants.

As evaluated by senior managers, it provides a rough idea about the extent of ability at which plants are currently performing each type of manufacturing flexibility. TMT has a remarkably high level of flexibility compared with the others. In SNA, IMCT and TSA, the flexibility is similar to each other, except for the machine flexibility and sequence flexibility. Regarding the machine and sequence flexibility, TSA can manufacture several models of vehicles within the same production line but the process faces some difficulty in changing from the original sequence to the new required sequence once the production plan has been set. One reason may be that the level of JIT production in the plant is likely to be lower than in the SNA and IMCT plant. In addition, TSA is now using low levels of advanced manufacturing technologies because it required fewer product models, product complexities, and volumes: these results in the lower level of machine flexibility. At last, TAAP which is the assembler for Mercedes-Benz and other customers such as commercial vehicles, ranks as having the lowest manufacturing flexibility in all types.

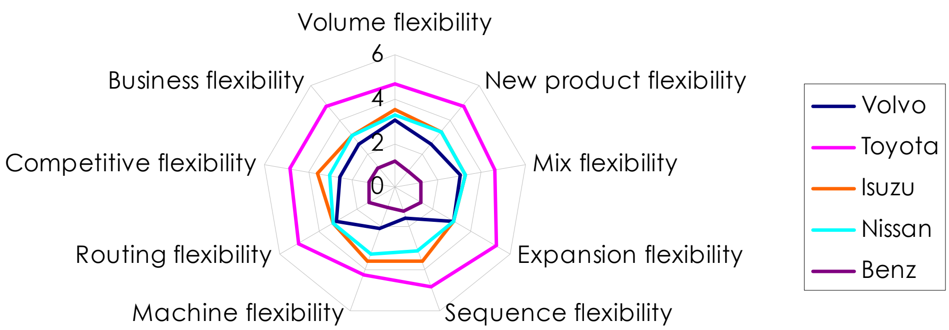

Figure 4.1: Self-assessment of Flexibility performance in automotive plants

4.3.3 Flexibility Capability, Tools and Practices on Manufacturing Flexibility

This section provides the views on what flexibility capabilities were built into the manufacturing system of each plant and how operations management tools and techniques are applied for flexibility purposes. Automotive plants have been found to be aware of flexibility in different perspectives depending on their strategic objective, manufacturing and supply chain conditions, organisational resources, etc. When focusing on specific approaches relevant to flexibility, the following methods from interviewees' responses in Table 4.1 can roughly indicate the current flexibility level within each plant. It can be seen that the use of efficient order processing and forecasting, effective information system, supplier development, and flexible workforce is different among five companies due to different strategic objective, manufacturing and supply chain conditions, organisational resources, etc. It indicates that, for in-depth case studies, it is feasible to acquire similarities and differences on manufacturing flexibility from such five companies, and the exploration is likely to adequately cover key potential issues surrounding flexibility. Current improvement focuses on flexibility of each plant are identified in the next sections.

Table 4.1: General Approaches Used in Automotive Plants

Methods, Tools, Techniques	TMT	SNA	IMCT	TSA	TAAP
Short set-up times	√	√	√	√	
Automatic monitoring devices	√	√	√	√	√
Multi-skilled workforces	√	√	√	√	√
Flexible workforce	√	√	√	√	
Outsourcing	√	√	√	√	√
Lead-time buffers	√	√	√	√	√
Efficient order processing and forecasting	√	√			
Timely and effective information system	√				
Standardisation	√	√	√	√	√
Supplier development	√	√	√		

Improving flexibility seems to be a new and challenging approach for manufacturing firms due to its multi-dimensional nature. Thus, it is necessary to understand the flexibility issues in aspects of planning and implementation in current manufacturing and operations management perspectives so that flexibility can be better employed and critical resources can be prepared in manufacturing firms to respond to an evolving trend of high demand of agile manufacturing. The results of the investigations are derived by using interviews, questionnaires, direct observations, and secondary articles such as company reports and articles. The findings will be presented in two subsections with the general headings of (a) planning stage, (b) implementation stage. Through integrated results from empirical studies, propositions related to flexibility concerns within each stage will be discussed in the cross-case analysis section (Section 4.9).

4.3.4 Conceptual Frameworks for Case Study Analysis

Flexibility issues in strategic planning involve ones contributing to *'the success of flexibility improvement'*. In literatures, within the firms, the configuration and management of strategic planning is mainly composed of assessing environment, setting objectives, implementing and monitoring the performance. Thus, to identify important flexibility issues throughout the planning in each of the case study companies, these key stages are used in the data collection process as the managers in the study indicated that they have no formal or separated assessment of flexibility. It is used to address the question of 'how firms decide to adopt flexibility strategies, i.e. which issues of flexibility that firms take into account'.

The case study also addresses the question of 'how and why firms might fail to achieve flexibility from their implementation'. The questions of how they operate in order to achieve flexibility (e.g. volume and mix flexibility), what problems they encounter, and what causes of problems were explored to identify key operating issues relating to flexibility performance. For this research, the investigations mainly focus on the situations where sudden adjustment or change in production plan has occurred and affect the manufacturing (i.e. in welding process, painting process, and assembly process), and supply network (i.e. between buyer and suppliers). To do so, the framework for this research question is presented and described below.

Firstly, the basic operations in automotive manufacturing operations are illustrated here (see Figure 4.2). Typically, there are three main departments involved in the manufacturing activities; sales, production, and supplier. It starts with the sales department in which customer demands of vehicles in each model and specification are calculated and documented. Production, consequently, allocates its resources to satisfy the requested production volumes provided by the sales department. It also calculates the requirement of part and components from a number of suppliers and distributes the orders to them. Due to the impact of globalisation, the number of customers is higher and demand is more frequently changed from the initial plans. This encourages automotive firms to set the systematic planning procedure to satisfy the demand variations as much as possible. The automotive plants normally allow adjustments to request volumes within a specified period (e.g. a month before actual production starts) even though this sometimes cannot fully satisfy the variation of demand from the sales department. This demand variation not only affects capacity planning but also the manufacturing planning, especially in terms of model mix and part requirements. To successfully operate under model and specification variation, it is necessary that the production line has to reduce the related constraints and to enhance production speed and efficiency; otherwise the plants are not able to support the demand variation and thus result in poor competitiveness.

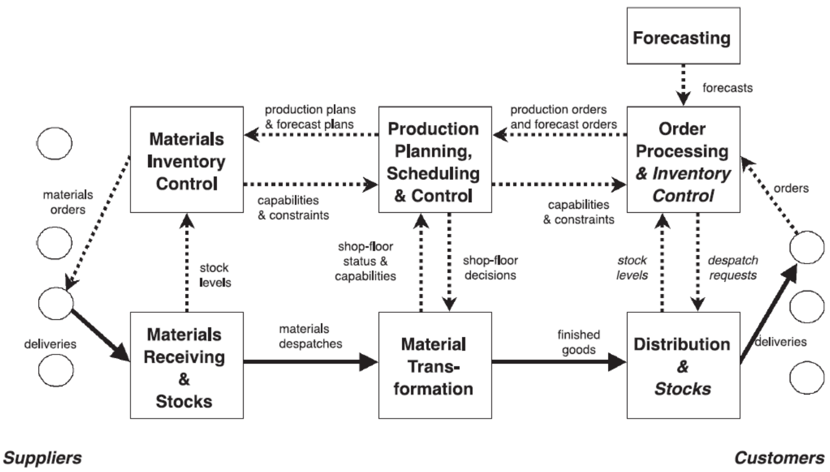

Figure 4.2: Production Processes ***(Matson and McFarlane, 1999)***

The manufacturing operations in automotive firms normally include resource planning (i.e. manpower, machine, and material), quality control and inspection, production and process control in body shop, paint shop and assembly shop. Due to time-based competition, supply chain operations must be squeezed. This also encourages automotive firms to be responsive and flexible by introducing concurrent engineering, modular sourcing, advanced technology, temporary workforce, etc. However, the constraints existing in manufacturing operations can restrict the firm to better perform such methods. Constraints can be found in key manufacturing activities such as capacity planning, manufacturing control, and supply control.

Capacity planning involves three planning stage; production planning, master planning, and material planning (Jonsson and Mattsson, 2003). Capacity serves two functions – to provide the means for producing a long-run, stable level of goods or service, and to provide the means to adapt to fluctuations in demand over the short run and intermediate runs. Without effectively managing capacity, flexibility can obviously be less performed.

A number of literature agreed that flexibility is required for integration and coordination among production activities and organisation resources in order to be successful (Kathuria, 1998; Lau, 1999). Manufacturing control involves several interrelated activities which, if performed in effective ways, have a direct impact on operational performances and overall results. Flexibility is not only obtained through technology and process integration but it also requires the set of principles and management practices for smooth production when faced with uncertainties. The level of manufacturing flexibility also directly relates to supply chain issues, especially in automotive industry where components and activities are sourced to a number of suppliers and subcontractors. Supply control also considered the potential areas significant to the level of flexibility in automotive manufacturing context.

Manufacturing flexibility improvement is an effort by the firm to improve organisational abilities to effectively change its operations and processes (e.g. capacity, sequences) to deal with foreseen and unforeseen uncertainties (e.g. demand, internal failure). The means of flexibility are encompassed by the terms of efficiency, responsiveness, versatility, and robustness (Chuu, 2005). When an adjustment or change occurs in a particular manufacturing process, flexibility success means that the manufacturing system must be able to operate with effective use of resources and provide an efficient output from such change; the system must be able to suddenly respond to such a change within the time limit; the system must be able to cope with foreseen uncertainties; and the system must be able to deal with unforeseen uncertainties by using its existing capabilities. This specified concept is used as frameworks to analyse the current production and problems of manufacturing flexibility. The description of the measures in each production activities are presented in Table 4.2.

In summary, to facilitate a data collection process, key areas influencing flexibility performance which are of interest in conducting such a detailed investigation include (a) capacity planning; (b) manufacturing control; and (c) supply control. Volume flexibility and mix flexibility can be successfully achieved when firms are able to manage, in an efficient way, the capacity planning, manufacturing control, and supply control to satisfy a particular production requirement (e.g. demand fluctuation, change of model mix). The investigation of five OEMs can reveal key operating issues from '*management perspectives'* for better managing flexibility in production system. The results from interviews with senior managers, middle managers, and key engineers in production function are shown in the next sections.

Table 4.2: Characteristics of Flexibility Success in Manufacturing Operations *(Adapted from Chuu, 2005)*

Characteristics of Flexibility Success in Manufacturing Operations	
Flexibility Measures	**Capacity Planning**
Efficiency	Delivering accurate decisions with effective use of information
Responsiveness	Reacting to problems quickly and making decisions quickly
Versatility	Able to produce plans for all foreseen uncertainties (the need for high system understandings and systematic planning system and procedure)
Robustness	Able to produce plans when unforeseen uncertainties happen (the need for high organisational knowledge and competencies, effective forecasting, enthusiasm of decision makers)
	Manufacturing control
Efficiency	Satisfying cost effectiveness; high quality, delivery, and reliability of products
Responsiveness	Responding to production changes with effective use of resources
Versatility	Maintaining competitiveness when dealing with any foreseen uncertainties
Robustness	Maintaining competitiveness when dealing with any unforeseen uncertainties
	Supply control
Efficiency	Supplying required parts to production lines
Responsiveness	Responding to new part requirements and receiving required parts in given time
Versatility	Maintaining competitiveness when dealing with any foreseen uncertainties
Robustness	Maintaining competitiveness when dealing with any unforeseen uncertainties

4.4 CASE 1: TOYOTA MOTOR THAILAND

Toyota Motor Thailand (TMT) is considered as the number one automakers in terms of vehicle sales, production system, quality of products, and brand recognition in Thai market. Operating in a global environment, production management of the plant is advanced and has applied best management practices throughout the whole production processes. Presently, this plant is positioned as production base for one-ton pick up vehicles in Asia. The key objective of this plant is to completely become a regional base for automotive production and to expand export vehicle volumes. However, the company's threats are global competitors as China in terms of cost effectiveness. This plant is a make-to-order plant while serving mass market. Hence, it can be obviously seen that this plant is likely to operate efficiently. The philosophy and principles in production are likely to be the most practical and successful among automotive companies in Thailand, as shown by overall performances of the company. Currently, there are three main plants operating in different locations; one is manufactured passenger vehicles and others are manufactured commercial vehicles. Employees in each plant team have independent authority to manage and adjust their production lines enabling them to enjoy production flexibility (Petison and Johri, 2006).This plant has conducted a business reform since 2003 in order to serve growth strategy. This, now, leads to some remaining problems for production to resolve such as human resource development, cost reduction, flexibility enhancement, etc.

The Vice President of TMT described the current department policy and operational item. The mission is to be World-class production management of vehicle and part export. The sub-objectives consist of; maximising production volume to match with demand by better capacity monitor and control, enhancing production system and preparation to start BanPho plant for smoothing production, strengthening cost management activities by enhancing Kaizen together with benchmarking, and strengthening organisation and continuously developing manpower to become the leader in the region.

4.4.1 Flexible plant expansion and resource exploitation

The company implemented a manufacturing flexibility improvement in organisational scale. The top management recognised the importance of manufacturing flexibility not only at operational level but also at plant level. The practices are mainly focused on managing the resources, improving processes, investing in new structure and infrastructure, and restructuring organisation. The means of manufacturing flexibility were found to be relatively comprehensive in key functions, especially in the production control and manufacturing control departments. The intention of implementing flexibility was to fulfill the current and future markets and customer demands as much as possible. Because of the status of the firm in aspects of corporate, operations, and financial, an investment in plant expansion and an improvement of resource exploitation, improving flexibility in plant level is possible. A new plant with flexible technology, structure, and infrastructure were built.

Processes were reengineered and reorganised in more flexible ways (i.e. more options became available). An exploitation of resources was thus better planned and managed to achieve more flexibility.

4.4.2 Flexibility Improvement Considerations of TMT

Top managers at Toyota have considered flexibility key business requirement as a result of business expansion (e.g. Toyota Motor Corporation's investment for regional production base). TMT plant had already re-engineered the whole processes since 2003 to support the new production environment. As such, top management realised how important flexibility became. The Vice President described that the flexibility alternatives include developing flexibility of processes in the existing plant, or building a new plant to provide flexibility to the whole processes (e.g. buffer plant). From interviews, remarkable flexibility issues taken into account of TMT can be summarised into future market demand and production volumes, abilities of the systems to operate in a flexible environment (e.g. production and supply system), and the ability of resources to operate in a flexible environment, particularly human resources to make and manage changes. They were analysed based on key components of three stages of strategic planning (Section 4.3.4) which are environment, objectives, and performances.

- **Future Market Demand and Production Volumes**

Since 2003, production volumes have shifted approximately two times for TMT. Senior manager in the production planning department said 'it seems to be difficult to build vehicles by depending on existing capacity but investing in new plant is a major project'. He cited that to achieve flexibility in this context it is necessary to have adequate plant capacity otherwise, even if a company has very good internal and external capability, the potential of flexibility can be reduced. Additionally, if market demand seems not to be high or stable in the long run, it is very risky to build a plant since this would not only ruin flexibility but business as a whole.

- **Production and Supply Chain System**

The degree of improvement required is basically considered in aspects of radical change or incremental improvement. As a radical change, i.e. building a new plant, requires plenty of resources and competencies, a firm must ensure that the decision is cost-effective and not overspending, corresponding to the company's current structure, resources, and competencies. Regarding the TMT decisions, infrastructure and process design were commenced as top management was aware of how complex a future organisation (i.e. global scale) would be, and flexibility cannot be achieved without reforming business processes. One of the systems considered in strategic planning is ‘supply chain system’. This involves assessing the relationship of suppliers in portfolios and the availability of potential suppliers in the industry as new plant requires a higher number of suppliers and higher capability of the supplier to produce in higher number of production volumes and more variety of specification. Senior manager cited that TMT has a number of close and reliable suppliers, so that it can ensure that, even operating in a new and flexible environment, suppliers are capable of providing flexibility to TMT’s production as required.

- **Human Resources**

The senior manager at Gateway plant, the second TMT plant manufacturing passenger vehicles, cited that it is also crucial to consider decision consequences on an operational level in order to ensure accuracy of decisions. Building a new buffer plant means that new operations must be formed. Without assessing the impact of key possible operations prior to implementation of flexibility, it is easy to make unworthy investment. For instance, trade-off influenced by the ability of leaders to make and manage change is considered. Where a firm has less efficient leaders in the production line, developing the existing process is preferable as they are not capable of operating in a flexible environment. He believed that the success of the flexibility implementation at TMT has resulted from having experienced managers in terms of capabilities and leadership to implement and manage the projects or circumstances in an effective manner. The senior manager in the Human Resources Department mentioned that labour force issues such as qualification, skills, and turnover rate are also important factors to be considered in building a flexible plant.

4.4.3 Implementation of Flexibility

TMT operates globally especially in terms of a global production base and sourcing. TMT put great emphasis on flexibility as customers are located on different continents and countries. The actors involving capacity planning both in the same and different geographies also increases. The importance of information systems is recognised and it has to be well-managed to allow responsible managers and teams better understanding and responsiveness to customer demand whenever demand is changed. Regarding this, TMC has built the global system to share information among its offshore plants and supply chain networks around the world. It is a fact that the production volumes from each customer located around the world are often adjusted. Capacity planning and resource allocation are crucial tasks of flexibility management at TMT. The company has set the policy to deal with this issue, for example, serving a country whose demand is higher and more stable. The production and operations will be smooth as initially planned if there is no further volume adjustment from any customer within a three month period. However, this hardly occurs in the plant. Only two cases occurred in the plant. Firstly, if there is volume adjustment across the country but the total volume is the same, the manager has to consider other aspects such as part shipping, supplier condition together with plant capacity. Secondly, if the total volume is increased, the manager will also consider the available plant capacity onto which production volumes can be added. According to such practices, it can be implied that the company perceives flexibility performance by considering only in terms of no additional cost or conflicts, line-off volumes as planned, and no late delivery. Also, there is no evaluation of flexibility in other aspects. Thus, it can be said that the flexibility level in manufacturing and the supply chain network cannot be yet assured. It can only be indicated by product quality, on-time delivery and customer satisfaction.

4.4.4 Problems of Flexibility and Key Suggested Solutions

According to the interviews with production control managers, they mentioned that rationale problem solving can establish a supporting environment for manufacturing flexibility. Demand adjustments or production uncertainties tend to be handled with systematic thinking and good coordination among functions and companies. This can minimise the effect of uncertainties. When uncertainties are dealing with supply chain members, managers claimed that TMT is able to effectively exploit the suppliers to achieve manufacturing flexibility. The relationship between the plant and suppliers is much close as the results of effective supplier development programme and long-term agreements. It is interesting that TMT claimed that it is able to postpone or even return parts or components that suppliers have already produced and in transit back to the suppliers if the company is not ready to use them. The operations in the plant and suppliers are likely to be much integrated in terms of process and information flow as many processes had been reengineered.

However, there are a few problems that need to be resolved in order to enhance the flexibility level in TMT production. They include areas of capacity reporting, visibility of plant structure, infrastructure and processes, standardisation of some process, and information system and software development. Capacity reporting is considered as the important issue that can affect the level of manufacturing flexibility due to better capacity planning and resource allocation. Visibility of process, standardisation of operations, and integration of software throughout supply chains (i.e. both local and global systems) are also a concern of the managers in the plant. They can enhance flexibility as the results from production uncertainty reduction, process integration, and high responsiveness. These problems can be reflected by current actions in the Production Control Department, which consist of; enhancing capacity checking; maximising production volume in all models by adjusting model mix; enhancing production system and operations through Kaizen to support production flexibility; and enhancing production systems and operations of new flexible plant. To summarise, improving flexibility in TMT is an ongoing development by focusing on enhancing four main activities central to capacity planning, resource allocation, plant structure development, and information technology modification and development (Toyota Motor Thailand, 2006).

4.5 CASE 2: SIAM NISSAN AUTOMOBILE

Siam Nissan Automobile (SNA) had been recently changed from lot production to unit production four years ago, according to corporate policy. SNA follows the Nissan Production Way (NPW). The basis of this philosophy is best summed up as: build it right the first time and do it with the minimum amount of resources, or better yet quality driven and waste free. Since 1994, Nissan has continued to systemise its NPW concept. The company is committed to realising Douki-Seisan—a build-to-order system schedule synchronised with the customer—which is the ultimate NPW goal (Nissan annual report, 2002). The key current objectives of SNA are to establish a system for worldwide multi-sites; to secure timely product delivery and reduce order to delivery lead-time; to increase the number of new models into the production line, reduce inventory, and become one of the best Quality-Cost-Time (QCT) of worldwide Nissan plants. This plant also includes the development of new environmental-technological based vehicles as a prime focus of its business. In addition, there are a number of key areas which the plant has planned to conduct in the near future such as making trucks in the passenger vehicles' production line, making vehicles for exporting in higher volumes, and developing infrastructure to deal with the future requirements, to ensure the growth and increase higher market share in the industry. Overall, the current action plans of SNA encompassing QCT objectives include; reaching the top three of JD Power's Initial Quality Survey; reducing plant total cost to lower than 2,322 million bahts; targeting CBU stock to 33 days; and stabilising two working shifts (Siam Nissan Automobile, 2007).

The market share of SNA in the Thai market has expanded since 2004. In manufacturing, to achieve a higher market share and profitability, gaining higher speed of production and lowering costs of production are major concerns for the plant as the variety of the current models produced for the market is not high compared with TMT. To achieve these, flexibility improvement is also considered by management teams in SNA. In the SNA production planning and control department, the means of flexibility remarkably are in terms of unit production. This, strategically, can satisfy and respond the customers' needs by offering them good product quality with a short waiting time.

4.5.1 Unit production and ordering system

SNA has now been more concerned by Nissan Motor Company (NMC) by increasing ownership to 60% in recent years. Batch production has restricted manufacturing processes to satisfy the customers and production strategies of delivering more product ranges to the market and increasing export volumes. Process reengineering from batch production to unit production has benefits to the firms in many aspects, one is flexibility. The unit production allows the plant to make a greater variety of models to suit customers' needs with cost effectiveness. Part ordering to suppliers is confirmed weekly, which means customer demand can be adjusted during the week and the amount of inventory in the supply chain can be low compared with that of mass production. Unit production requires supply chain members to be able to match a shortening OEM production process. For SNA, as the number of supplier is not relatively high, unit production operates in an effective manner. However, problems have been found in terms of capability of supplier production itself as SNA put emphasis on supplier selection rather than supplier development. Developing supplier capabilities is the main focus of the company in order to reduce order-to-delivery lead-time from suppliers to the company. Overall, by this practice, SNA claims that it is able to deliver the vehicles to customers within four days.

4.5.2 Flexibility Improvement Considerations of SNA

Flexibility is an important aspect for the plant as it is used to improve competitiveness to the company, especially lead-time. The key flexibility decision is to invest and implement built-to-order strategy. Summarising from the interview results of senior managers, the key flexibility issues taken into account in SNA mainly are the need for higher market share and operational performance, financial aspects, plant structure and capacity (e.g. used and remaining capacity), ability to control the new processes and operations (i.e. the extent to which existing processes/operations such as ordering process, manufacturing technology perform).

- **Market Share and Operational Performance**

The current company performance and market share can drive a company to adopt the built-to-order strategy as it offers a number of benefits. In other words, it is required for strategically evaluating company needs such as market share, operational performances, competitors, etc. The Vice President of SNA had seen that the company is in the position where built-to-order production can provide flexibility and it is advantageous for the company in various ways such as reducing production cost and delivery time. As TMT has problems regarding backorders, reducing lead-time is a competitive weapon which can increase market share from TMT and other competitors.

- **Financial and Knowledge Supports**

Being flexible requires a number of resources, especially financial resource. One of the senior managers said ‘Flexibility is a continual investment and it is necessary to have support from Nissan’s Head office in terms of knowledge, technology, etc’. It can be the case when, for example, a purely Thai-owned manufacturing firm needs to improve its level of flexibility but with limited financial resources the company may end up with unsuccessful implementation. With financial and technical support from NMC, transforming from large batch production to unit production and other process improvement is possible.

- **Plant Structure and Capacity**

The Manager also pointed out that plant structure and capacity were included in decision making. Limitation of plant structure and capacity can affect the extent of performing flexibility as flexibility sometimes requires extra space, facilities, machine capacity, and production capacity. In order to become a built-to-order plant, it requires new installation of processes and facilities. Thus, the firm must ensure that its structure and capacity can be extended in order to deliver the highest level of flexibility corresponding to requirements of a built-to-order plant. Regarding further flexibility improvement, this issue does not restrict the improvement as the plant's production capacity now is using only 50% of its total capacity.

- **Control Abilities**

Built-to-order plant requires new forms of the number of processes. Regarding operational considerations, a built-to-order plant requires a higher degree of control than a mass production plant. Trade-offs should be made upon this issue since it does not only allow decision making being more accurate but also facilitates an implementation stage. For instance, during implementation, SNA encountered problems from an ordering process. As a number of parts have increased due to the unit by unit part ordering process, it is important to monitor and control the accuracy of ordering and receiving parts. In this context, it is better if the company gives more consideration to its capability in controlling production and supply chain.

4.5.3 Implementation of Flexibility

This plant focuses on reducing lead-time in manufacturing vehicles. The production volumes of the plant are not high, and the capacity of the plant is still sufficient to serve the volume fluctuation as it is currently using only about 50%. Thus, mixing the right model in a costly manner or mix flexibility is a big concern. Apart from individual part ordering control, the manufacturing control and the supply control activities play important roles in achieving flexibility and are a point of concentration by SNA managers. Summarising from interview results, the key activities relating to mix flexibility concerns of this plant are; introducing performance indicators into the production process; improving an integrated process management system; and enhancing ability in forecasting demand. The flexibility performance can be indicated by such new measures as Sequence Achievement Ratio (SAR), Direct Run (i.e. measures which indicate actual production time of a specific vehicle from beginning of the production line to off-line compared to planned production time). Nevertheless, it is similar to TMT in that flexibility performance is typically considered in terms of line-off model as planned, no late delivery, quality of final products, and costs. Integrated Process Management System (IPMS) is developed in order to allow mix model production running smoothly, for example, a fool-proof system is used to provide signal for errors or mistakes in the production sequences.

To run flexible production smoothly, managers found that limited capacity of the paint shop, availability of required parts from suppliers, and workforce availability are crucial for improvement. Thus, other key activities relating to flexibility improvement include continually reducing production constraints, developing flexibility capabilities of suppliers, minimising time in product development and implementation, and selecting appropriate technology to serve flexibility. As the plant recently increases the production into two shifts, the workforce issue, especially the subcontracting workforce, is a key issue for the plant on any decisions dealing with the changes and adjustments. The use of overtime is a current workforce practice of SNA production. To summarise, overall flexibility in SNA is likely to be moderate due to the presence of a number of constraints in production. They are mainly embedded in manufacturing and supply control including plant structure, limited capacity in some processes, human resources, and suppliers.

4.5.4 Problems of Flexibility and Key Suggested Solutions

Most managers claimed that built-to-order strategy in SNA has not been effective yet. Make-to-order production was started about two years ago and the flexibility improvement programme is in its early stage. Production managers identified key problems that inhibit flexibility performance in the plant. They are listed as follow:

- Production still requires timing allowance for changing model mix requested by customers due to existence of bottleneck. It consumes response time.
- Part shortage occurs when adjustment is required
- Multiple skills of operators are fairly low, which leads to errors.

They pointed out that the first problem mainly stems from a lack of integration of the production planning system. An effective planning system should include all related functions together, and should be fast and responsive to unexpected problems, especially in unit production. However, their current planning system is not likely to satisfy the manufacturing situation; for example, a spreadsheet is used as a key tool in the planning mode and information is distributed by using email. Good planning requires information from many functions including shop floor, warehouse, sales, suppliers, etc. in order to make appropriate decisions and create the best plan. Planning functions often lack some necessary information as it is not even measured and gathered by those functions or reported to the planning functions.

Regarding the second problem, it is caused by the proximity of suppliers and their internal capabilities. SNA has been struggling with supplier's problems as the buyer and supplier relationship is not very close. One main reason for not yet achieving built-to-order strategy is that lead-time from order to delivery of SNA's supplier of a number of components is approximately two to three months. This inhibits the manufacturing flexibility in the production. Therefore, enhancing the supplier development programme in SNA is considered as a key improvement programme of the plant. The last problem is workforce knowledge and skills. One of the production managers pointed out that knowledge and learning enhancement in terms of technical and engineering is necessary in the flexible operating context as these can provide more speed with accuracy and quality to the products and processes. In summary, flexibility in SNA is explicitly in forms of unit production. The improvement focus involves planning system development, plant structure and infrastructure improvement, enhancing the supplier development programme, and human resources development.

4.6 CASE 3: ISUZU MOTORS COMPANY (THAILAND)

With the reputation of high quality products and technology, durability, reliability and environmental friendliness, Isuzu trucks have been the best sellers in Thailand since 1960. Isuzu Motors Company (IMCT) has ranked number one in the commercial vehicle category for 21 consecutive years (Isuzu Motor Limited, 2007a). The main product of this plant is one-ton pick up vehicles and it is considered to be a top leader in one-ton pick up vehicles in the Thai market. When only considering production volumes, this plant is likely to enjoy the position where market demand is stable to a relative extent. The objective of this plant is to maintain the leading position in the one-ton pick up market and expand production for exporting to foreign customers (Isuzu Motor Company Thailand, 2005). Isuzu Motors (IMC) expects to produce approximately 160,000 units of the next generation pick-up truck a year in Thailand. Some 45,000 units will be produced in the GM Thailand plant and exported by GM Thailand and Isuzu Operations Thailand Co., Ltd., while production at Isuzu's Thailand plant (IMCT) will be primarily for the domestic market (Isuzu Motor Limited, 2007b). The current plan of IMCT mainly focuses on improving quality and introducing more advanced equipment and tooling to the processes due to an increase in demand and the need for increasing production efficiency. With regard to flexibility concerns, this plant does not adopt flexibility strategies in an explicit way.

This may depend on business policy or manufacturing strategy. In addition, creating more manufacturing flexibility in the production processes is considered a major change for the plant.

4.6.1 Methodology-based flexibility

In contrast to TMT and SNA, means of manufacturing flexibility in this company are mainly concentrated on the operational level, which is to improve overall operational performance when faced with variations. This company is currently encountering some poor operational performance, especially due to workforce issues. Due to an emphasis on minimised investment budgets and intention to low cost automation, the firm is likely to put an emphasis on improving multiple skills of workforces and enhancing methodology-based flexibility instead of other flexibility approaches (Isuzu Motor Company Thailand, 2006). By doing this, managers believed that it is adequate for managing model mix and volume fluctuation in production processes in the current company and production contexts. In other words, a methodology-based flexibility approach is chosen as the appropriate mode of flexibility for the firm as it can not only reduce production variations and uncertainties, but also enhance such operational performance as amount of reworks and level of quality in operations with fewer amounts of investments. The distinct examples of methodology-based flexibility approach employed in the plant are; strategic alliances for export model; task management; and continuous improvement practices (i.e. Kaizen).

4.6.2 Considerations of Flexibility Improvement at IMCT

Due to being strategic alliance partners with GM since 2003, the production context of IMCT is slightly different from that in TMT and SNM where export volumes are manufactured in their own plants. The degree of flexibility required in the plant is likely to be lower than in the other two plants. As summarised from interview results, the key flexibility issues taken into account in the planning of IMCT mainly are process uncertainty, government policy, workforce ability, and quality of WIP and final products.

- **Process uncertainty**

An impetus that drives the plant to improve the manufacturing flexibility is process uncertainty, which results from costs and delay in production operations. The senior managers have a clear understanding of the effect of process uncertainty to the plant.

In their viewpoints, there are two alternatives to cope with; installing new advanced manufacturing systems; or leveraging such existing resources as workforce and machines while minimising investment costs. Mostly, the process uncertainty is exhibited in terms of internal uncertainty, which involves internal failure, error or inadequate capability in production activities, rather than such external uncertainty as customer demand variation. Thus, potential flexibility strategies of this plant include improving multi-skilled workers and applying methodology-based flexibility to better managing operational performances with respect to model mix in production lines, especially achieving higher quality of products.

- **Government policy and trading policy**

The role of government was raised by senior managers of IMCT. The instability of policies issued by the government can influence the plant to be well aware of the flexibility due to investment risks. The investment attitude of this plant can be considered as reactive. Top management tends to slow down investment such as new technology, process reengineering, and supplier development until the policies and directions are becoming clearer. For example, the plant expects to increase the production volume of domestic and export vehicles so that installation of advanced manufacturing technology is required as a means to provide more flexibility to a more complex production environment. However, it is necessary to understand policies regarding economic direction, taxation, environmental policy, then the decisions can be made, otherwise flexibility will not be fully utilised within the plant.

- **Workforce ability and relations**

Automotive manufacturing is one manufacturing section that requires a high skill level of workforce in terms of technical, engineering, and management. To achieve the flexibility, the workforce at all levels is required to be multi-skilled, well-trained, and cooperative. In addition, the relationship between management level and operator level does need to be close, and mutual in terms of error reporting, improvement suggestion, objective and goal communication. Without having this in the operations, a number of problems can occur during operations and this can affect the level of manufacturing flexibility in related activities. For example, one of Isuzu managers explained that, in the assembly shop, there are a variety of parts for operators to assemble to the vehicle body due to the number of models currently manufactured. The manager found that the assembly can sometimes be incorrect, especially if the operators are newcomers and they are not confident enough to report the problem they caused. This leads to reducing flexibility performance in the system as the next job has to be stopped or delayed, thus resulting in other operational performances such as quality and delivery. Continuous improvement practices (i.e. Kaizen) has found to be grounded activities helpful in encouraging learning by workforces and improving their capabilities to deal with a stable and uncertain production environment.

- **Quality of WIP and final products**

It is feasible that implementation of flexibility can reduce the level of quality of work-in-process products and final products. Since automotive products require a high standard and quality, it is crucial to balance these issues against volumes and variety of products that the plant will offer to satisfy customer requirement. Despite the fact that new technologies have the potential to deliver a greater variety of products with higher volumes, in aspects of actual operations, there are a number of issues that need to be considered otherwise the quality of products, which is considered imperative for the competitive priorities of IMCT, could be reduced. An example of the issues is that some technology requires retooling from one product to another product; this may reduce the quality of products when it reaches a particular period even though it can increase the variety and volume of products in times. Hence, a senior manager in production is preferred to implement 'low cost automation' rather than technology investment for flexibility purposes as the plant does not ensure the capabilities of internal resources to effectively operate the advanced technology.

4.6.3 Implementation of Flexibility

Process improvement is now a key focus of the management team of IMCT. Despite the fact that managing flexibility within the plant is not formed explicitly, the workforce is considered a key element that plays a significant role for flexibility in IMCT. Production tends to adhere to the original plans due to workforce capabilities to deal with adjustments or changes. In consequence, volume change or model mix change can be adequately handled with the use of methodology-based approaches. Managers mentioned the importance of feedback and the monitoring processes. They mentioned that closely monitoring and reporting the results when dealing with the change is necessary. Lack of effective feedback and monitoring can cause mistakes or errors as team managers or operators may incidentally disregard them. Supplier development is also required for the plant to be more flexible. Suppliers who certified a quality assurance by a company are still in low numbers; the quality issue is a major concern when implementing flexibility.

As IMCT is central to the exported engine operations among ASEAN countries such as Indonesia and Malaysia (Isuzu Motor Limited, 2007a), flexibility in the plant also relates to data and information management aspects. The export of engines to ASEAN countries requires effective order management and most of the investments of the firm are now focusing on the engine export activities. The last issue mentioned by managers is culture and working style. As the Japanese style tends to be less strict than the Western one, employees are much more willing to respond to adjustments with less reluctance. This can to some extent lead to higher efficiency even in situations where adjustment is necessarily often made. The key measures of the flexibility outcome mainly include the quality of WIP and the final products, meeting the due dates, and cost minimisation.

4.6.4 Problems of Flexibility and Key Suggested Solutions

In manufacturing, managing different tasks or scheduling the mix production are crucial activities and they must be done very carefully. Managers agreed that effective planning and an ordering system must be established to deal with increasing flexible production environment. Senior managers described that the ordering process is also a concern as the current process is not adequately sophisticated to support the growing number of product specifications and suppliers. Most managers also highlighted the importance of employee commitment on the aspects of manufacturing flexibility. They described that, in the shop floor, the extents to which operations can perform rely heavily on line managers, team leaders, and group leaders. They experienced the fact that the impact of weak commitment among members in production lines can cause difficulties in being flexible. IMCT has also been struggling with supplier’s problems. The buyer and supplier relationship in this plant is not as good as that in TMT. The capability of suppliers in current portfolios was found to be fairly low. In summary, the main improvements required for the plant to be more flexible included improving activities in production control, developing labour forces capabilities and mindset, and improving supplier portfolio.

4.7 CASE 4: THAI-SWEDISH ASSEMBLY

The Thai-Swedish Assembly (TSA) is owned by the Volvo Car Corporation (VCC) and assembles cars, trucks and bus chassis. This plant manufactures both for domestic and export markets such as Indonesia. The production volumes are not relatively high compared with other brands in the Thai market. This plant is considered a make-to-stock plant, for which parts and components are mainly provided by Swedish suppliers and there also is part exchanging from Malaysia. Production is largely customer order-driven, imposing major demands on flexibility; among other things, several models are built on the same production line. To avoid holding large inventories, systems and components are delivered by suppliers on the just-in-time principle. The entire process of component manufacture, panel pressing, bodybuilding, surface treatment and final assembly is carried out using a combination of high-tech production methods and highly-trained assembly operatives (Volvo Car Corporation, 2004). In order to cut development and production lead times, many suppliers are involved from the initial design and engineering stages. Effective cooperation and interaction with suppliers is an important competitive tool for Volvo Cars. Increasing numbers of suppliers are establishing operations close to the various Volvo Cars plants in order to cut transport times and reduce the need for stocks. A number of suppliers deliver their components in a precise sequence, with a maximum lead time of four hours. Increasing numbers of components are supplied in complete sub-assemblies or systems, further cutting building time in the final-assembly process.

4.7.1 Sourcing and Logistics Development

The main focus of TSA is to minimise the costs. One way to keep the costs down is being capable to exploit the resources efficiently, in both normal and changing conditions. Due to the need to respond to the customisation level, a major issue that production has encountered is additional costs caused by flexibility. There are several problems when it is requested to suddenly adjust the production plan to satisfy demand. For example, such equipment as painting guns, dies and jigs, which have already been prepared, have to be re-set up and this can cause additional costs such as raw material costs and labour costs to the operations. In addition, another key problem is component and part shipping. The Vice President of TSA mentioned that this issue restricts operations to achieve flexibility or respond to the demand and need to be solved. Hence, the development of sourcing and logistics to reduce lead-times is considered a current focus of the plant.

4.7.2 Considerations of Flexibility Improvement at TSA

From the interviews with a number of senior managers at TSA, key flexibility issues taken into account in the planning of TSA can be summarised as demand fluctuation, process infrastructure, commitment, potential direct and indirect benefits.

- **Demand fluctuation**

Demand fluctuation is considered a key driver that requires the plant to be more flexible. One of the senior managers said that 'being a small-scale plant, every customer orders affect the bottom-line so we need to be flexible in order to fulfill their requests'. It is usual for the plant that the demand and production plan are revised on a monthly basis. It is not possible to reduce the workforce dramatically when demand suddenly changes: what is preferable is to establish common production lines that can produce several vehicle models and cut-off the model which the market needs least. Hence, the plant is currently operating with various vehicle models in a single production line, and current operations strategies comprise enhancing flexibility in aspects of the operators, engineering, and logistics as a result of market-driven and demand fluctuation.

- **Corporate and Employee Commitment**

When implementing flexibility (i.e. introducing common production lines), the managers experienced the lack of commitment from stakeholders at an early stage. As the manufacturing flexibility is often hard to measure and shows explicit benefits, this leads to suspension of the projects relating flexibility until their benefits can be clarified. A senior manager said that 'not only commitment from top management is required in an attempt of flexibility improvement, commitment from employees at all levels is also significant'. One of managers provided another example involving the importance of this issue. Job rotation is one of the key activities that are applied to the operators as a result of flexibility improvement. High involvement and commitment from employees who are allocated to do the work on other or additional functions is essential to the overall flexibility performance. He cited that the commitment is not only in terms of individuals but also among employees such as the willingness to help each other in problem solving and training. The manufacturing flexibility cannot be complete once the common production lines had been built, but rather requires all employees to commit to problem solving and further improvement that may be found after implementation.

- **Process infrastructure**

Process infrastructure is meant to offer the plant the ability to effectively leverage operations resources. As the TSA plant has no robots operating in the production lines, most of the operations and assembling is done manually so that process infrastructure in this plant is likely to focus on workforce and process management aspects, rather than technological aspects. Regarding manufacturing flexibility, it is obvious that this plant employs resources such as small-scale facilities and equipment to react or respond to the changes. For instances, the degree to which the particular facilities and equipments can be reconfigured (i.e. capabilities) should be taken into account in the analysis, otherwise existing resources are not well-leveraged and investments could not be considered optimal. Another example is that such factors as plant capacity (e.g. space availability) should also be taken into account. Due to the high expansion flexibility of this plant (see Figure 4.1), establishment of common production lines is feasible to implement, and can provide benefits both in strategic and operational aspects. Thus, it is important that a firm will consider the process infrastructure in the decision-making process as it can influence the degree to which plant can achieve true manufacturing flexibility measured by resource utilisation.

- **Direct and indirect benefits**

Manufacturing flexibility does not only provide benefits for handling uncertainties in the operations but also provides other benefits to the manufacturing and supply chain operations. Senior managers have considered that manufacturing flexibility is one of the means to reduce costs and improve operational performances. The distinct direct and indirect benefits that the managers claimed to obtain include the reduction of inventory level, higher plant utilisation, reduction of risks from introducing new models to the market, supply chain improvement opportunities, and the enhancement of a learning organisation. In the strategic analysis, managers cited that they also put great emphasis on operational level or shop-floor related issues when deciding the adoption of new projects, systems or practices due to the existence of a number of constraints and prime objectives on cost-effectiveness.

4.7.3 Implementation of Flexibility

Manufacturing flexibility is one of the competitive priorities that concern the plant. Transforming the assembly line is aimed at cost savings and reducing lead-times in manufacturing vehicles. Due to the introduction of new models from VCC, top management personnel at TSA implemented the single production line to respond to the model variety. Managers cited that a single production line was not approved by executives in the first place and received lack of commitment from executive teams. This is due to large amounts of investments and somewhat restricted current production and inventory management. As a result, improvement must be gradually made by building the new line while continuing with current production. This required much effort and commitment from employees. Managers stated that 'in spite of this, TSA commenced an adjustment and improvement of assembly lines to become more flexible since 2003 by transforming multiple production lines to a single production line, controlling aspects are what require further improvements'. The key problems can be described in the following section.

4.7.4 Problems of Flexibility and Key Suggested Solutions

The main problems of flexibility achievement in TSA can be summarised in four aspects. Firstly, there is some difficulty in capacity planning and resource allocation. A production manager cited that the production plan tends to be fixed after it is distributed to other functions. He pointed out that the plant operated on a small-scale compared with other Japanese manufacturers so the change in volumes, for example, even in small amounts, can have a relatively major impact on the plant operations and its supply chain. In other words, volume flexibility in this sort of plant is likely to be difficult to obtain when compared with other plants.

The second problem is due to the structure of the assembly line. In contrast to large automakers, small plants like TSA manufacture in lower volumes and the configuration of production line is different from those in large plants, i.e. a shorter production line. To overcome this issue, a greater emphasis on workforce capabilities must be made; otherwise the variety of products cannot be achieved in the plant. For example, in a large plant an operator is normally responsible for not more than ten tasks per one production cycle, but in small plants an operator has to do a number of tasks, e.g. up to one hundred tasks for an operator, in a production cycle.

Thirdly, TSA is not likely to be faced with supplier's problems as most of the parts or components used in the plant are imported from other countries in terms of CKD (Completely Knocked Down), and their number of suppliers is low compared with the big companies. Nevertheless, managers in the TSA plant stated that they experienced the inappropriateness of sourcing in forms of batches when they implemented a common production line. This can reduce the degree to which production can mix various models in a single production line. Although the plant has not changed the way parts or components are supplied, it has modified the loading from batch to unit load so that flexibility in the operations is then improved.

Finally, it can also be seen that visibility of process, standardisation of operations, and integration of software are also a concern of managers in both large and small plants. Unlike other large automakers, the complexities and uncertainties in production of small plants are not likely to be so high but investment regarding these issues is fairly hard to make. Taking a paint shop as an example, it is normally difficult to examine the problems as it operates in a closed containment. The ability of the paint shop to adjust a vehicle colour according to customer demand is needed. As such, close control is needed over the painting process. Thus, the role of plant structure and infrastructure in the processes are considered the key issue for improvements in TSA in the near future, in order to support other organisational competencies, i.e. people and future technology if they are likely to operate in a mass customisation environment.

4.8 CASE 5: THONBURI AUTOMOTIVE ASSEMBLY

Thonburi Automotive Assembly Plant (TAAP) is a Thai-owned automotive assembler, which assembles the passenger vehicles for Mercedes-Benz, Germany, and also commercial vehicles and bus chassis. This plant used to be a joint venture with Mercedes-Benz Company, and gained manufacturing and technical support. However, this plant had been severely affected by the Asian economic crisis in 1997, which dramatically reduced the demand of Mercedes-Benz products in the domestic market, and this resulted in revoking the forms of joint venture. Currently, this plant is considered static as becoming independent and lacking support and funding from foreign investments. Focusing on the manufacturing section, TAAP consists of two main plants. Plant 1 focuses primarily on the assembly of commercial vehicles, while Plant 2 currently assembles the Mercedes-Benz C-Class (C180, C220), E-Class (E230, E280) and S-Class (S280, S320) product range for the domestic market. The maximum capacity of this plant is 1500 passenger vehicles, 180 commercial cars, and 240 bus chassis a month (Thonburi Automotive Assembly Plant, 2006). The production implemented the quality management programme in 2003 and the main focus of the plant in the present is to minimise the costs, improve quality control and product quality, and improve resource planning and utilisation.

4.8.1 Leverage of Resource planning

Depending on the arrival of customer orders, the benefits of built-in capabilities such as technology and assembly lines are not a serious consideration of top management of TAAP. Typically, the required volumes are not very high and existing resource can be handled with the changes. Hence, it is obvious that flexibility in TAAP tends to be focused on resource planning and deployment. The marketing department is more likely to play an important role in overall business than the manufacturing department. The integration of processes between marketing and manufacturing is crucial to overall flexibility performance. Specifically, manufacturing must effectively establish a plan of materials, workforces, and production to minimise the effects from marketing requirements. Leverage of resource planning is a key concern in operations of TAAP.

4.8.2 Considerations of Flexibility Improvement at TAAP

A number of managers had been interviewed, and the results on key flexibility issues taken into account in planning of TAAP are summarised as demand variation, resource competencies, and costs.

- **Demand variation**

Demand variation refers to unplanned change caused by random or seasonal customer demand and bad forecasting (Kara and Kayis, 2004). This plant has been faced with the variability of demand due to the nature of the firm (i.e. assembler-to-order). Senior managers stated that ‘our firm often spends the resources such as raw material and work loads more than was planned as we have to satisfy the sales requests and we are not able to cope with tight delivery times’. It is clear that this plant has to minimise these effects by, as claimed by senior managers, leveraging the resource planning for better handling the variation within the plant. This means manufacturing flexibility is one of the key objectives and it must receive attention. However, the plant has not yet implemented this strategy but it is one of the major concerns of the plant for the next few years.

- **Resource competencies**

As this plant has already been lacking in support from a large foreign company, it tends to have a low level of competencies compared with other automotive plants. Some of its resources such as coating technology have not been used although the plant had invested in it during its growth life cycle (i.e. 1990-1997). The plant seems to be very careful when implementing any strategies or practices. In consequences, manufacturing flexibility improvement is not likely to be preferred during this time in most senior manager perspectives. Flexibility is one of the key competitive priorities in doing business but, with existing competencies, capabilities, production resources, and financial resources, it is certain that the full potential of flexibility cannot be achieved and other operational performances may be affected in negative ways.

- **Costs**

It is a fact that improving manufacturing flexibility certainly increases the investment costs and production costs, especially in the plant that has inadequate resources. Costs of flexibility can be initiated from the flexibility trade-offs, investment costs, implementation costs, development costs, and other unpredicted costs. The example of costs from flexibility trade-offs is that an increase of product variety can reduce the ability to adjust the aggregate output volume so that the opportunity costs can be incurred. This cost of flexibility can be difficult to evaluate. Thus, we can see that TAAP is likely to improve the level of manufacturing flexibility in general areas such as through increasing employee skills, improving ordering and scheduling, and enhancing machine maintenance in which large amounts of risks and money are not much invested.

4.8.3 Implementation of Flexibility

Plant managers of TAAP have close contact with managers in the marketing department. The information sharing between departments is likely to be direct and interactive. To prepare and allocate resources for specific orders, managers must keep close contact with marketing and report the production capacity and capability, especially when marketing needs to change the volumes or product mix. Top managers cited that being able to respond to any order volume and product is very crucial for the plant's current situation. Marketing found it is more difficult to acquire customer orders as demand of products such as coach and chassis is low in some periods. Satisfying customers in all of their requirements is a key strategy for TAAP. As the plant mostly relies on human resources in manufacturing vehicles, the workforce is a key issue for implementing flexibility. Currently, TAAP encourages operators to learn a variety of tasks both through formal company training programmes and individual learning. In addition, to maintain profitability, the management of resources has to be more careful as there is no long-term forecasting plan as in large plants.

4.8.4 Problems of Flexibility and Key Suggested Solutions

This plant has to deal with uncertainty and fluctuation of customer orders. To resolve this issue, production managers tend to buffer the parts and components for unexpected increases of volumes. In addition, it is the responsibility of the marketing department to seek orders to fulfill the production when facing low demand. However, problems still have been found in these two aspects; resource utilisation and organisational knowledge. Resource utilisation in the plant may sometimes be low and high inventory. Allocating some resources to other production unit (i.e. truck production) can help boost the overall resource utilisation rate. Not only is volume flexibility important to the firm, but also 'project flexibility'. As the plant often has to deal with new projects, this kind of flexibility is required. Organisational knowledge, especially technical and engineering know-how is very crucial for TAAP.

In terms of suppliers, TAAP are not likely to be faced with supplier's problems as most of the parts or components used in the plant are imported from other countries in terms of CKD (Complete Knock Down), and their number of suppliers is low compared with the big companies. TAAP seems to have few problems regarding the aspects of supply control: the problems that are found only include the late delivery of parts from suppliers. In summary, the main flexibility improvement focus of this plant includes enhancing interaction between marketing and manufacturing functions, enhancing effective resource planning and utilisation, and improving multi-skills and knowledge.

4.9 CROSS CASE ANALYSIS OF FIVE CASE STUDIES

Regarding the five case studies, the important factors to be considered when improving flexibility both in strategic and operational aspects were acknowledged. The cross case analysis was conducted in order to identify different triggers of flexibility (Section 4.9.1). In addition, similarities and differences of flexibility issues within scope of capacity planning, manufacturing control, and supply control, and their influences on the various degree of flexibility outcome within five case studies are obtained and discussed in Section 4.9.2, 4.9.3, and 4.9.4. The main problems for not achieving flexibility indicated by case study companies are identified in Section 4.9.5 and, subsequently, core areas of flexibility improvement are summarised in Section 4.9.6.

4.9.1 Triggers of Flexibility

Referring to the study of Das and Patel (2002), the possible changes which can occur in manufacturing are identified. Changes can be identified in various forms according to their causes; demand volume, demand variety, supplier constraints, process infrastructure, internal policy, internal failure. Certainly, manufacturing flexibility can be achieved to a lesser extent if those changes are not properly figured out in reactive or proactive ways. It is evident that automotive firms in the case study are faced with the changes and encounter the problems in different ways. Thus, the operations strategy relevant to manufacturing flexibility and supply chain flexibility for each plant can be distinguished as follows.

TSA and TAAP mostly require more flexibility to deal with problems on process infrastructure and from internal failure. Such problems as inadequate ability to retooling from order to order and lack of multi-skilled operators have been found in their operations. Process infrastructure of the IMCT plant is more advanced and well-managed than TSA and TAAP due to investments and supports from the mother company. However, internal failure can often be found in IMCT and it leads to problems regarding quality, cost, delivery, and flexibility. IMCT is currently establishing more intensive programmes and activities to tackle this kind of failure. In addition, it claims to have some difficulty in terms of suppliers, for example, some part suppliers are often unable to meet due dates, so this is one of the main problems that the plant concentrates on.

SNA and TMT plant have similar circumstances in terms of demand volume. The production volume of these plants is often varied and it can be solved by means of increasing manufacturing flexibility. TMT has many customers from various countries to serve; while SNM' major concerns are to match the production to demand as much as possible. It is interesting that the changes regarding demand variety in terms of different needs of customers are not intervening with the manufacturing processes in Thai automotive firms, as in North American firms.

Regarding all the above classifications, the triggers of flexibility in five automotive plants can be outlined. This leads to the differences of manufacturing and supply chain flexibility operations (i.e. new flexible plant investment, unit production, methodology-based flexibility, sourcing and logistic development, and resource planning improvement). The following sections discuss a number of flexibility issues within scope of capacity planning, manufacturing control, and supply control activities derived from case studies. They finally provide key issues critical to be taken into account when flexibility improvement is required.

4.9.2 Capacity Planning

Traditionally, firms plan the capacity according to the customer demand and then allocate their resources. Due to customisation and fierce competition, the forms of capacity planning processes have become more sophisticated. It involves considerations of time-scale in related functions, available lead-time, frequency in adjusting plans, constraints, and variation in order to establish the most suitable plans for the production. In flexibility aspects, capacity planning plays an important role as it affects subsequent manufacturing activities such as part preparation, workforce allocation, and cost evaluation. Therefore, if capacity planning process cannot create adequately effective plan or is unable to adjust the plan as required in an effective way, it is surely that ability of the overall manufacturing system to vary aggregate volume may not be fully performed.

Managers in SNA and IMCT pointed out that the fundamental issue for effective capacity planning in today's business environment is a planning system. A planning system should include all related functions together, and should be fast and responsive to unexpected problems. However, their current planning system is not likely to satisfy the manufacturing situation; for example, a spreadsheet is used as a key tool in the planning mode and information is distributed by using email. Other issues involving the manufacturing flexibility performance is the level of information sharing in capacity planning process and integration of information. TMT put great emphasis on this issue as customers are located in different continents and countries so that information has to be well-managed to allow responsible managers and teams more understanding and be responsive to customer demand whenever it is changed. The actors involved in capacity planning increases operate in different countries, and as a result, TMC has built the global system to share information among its offshore plants and supply chain networks around the world.

Capacity reporting is considered as the important issue that can affect the level of manufacturing flexibility. It is likely that most of the plants are less concerned with this issue. Good planning requires information from many functions including shop floor, warehouse, sales, suppliers, etc. in order to make appropriate decisions and create the best plan. However, it is often apparent that planning functions may lack some necessary information as it is not even measured and gathered by those functions, or reported to planning functions. The last issue derived from case study analysis is manufacturing and other related operating conditions. For example, TSA managers cited that the production plan tends to be fixed after it is distributed to other functions. The plant operates on a small scale compared with other Japanese manufacturers so the change in volumes, for example, even in small amounts, can have a relatively major impact on the plant operations and its supply chain. In other words, manufacturing flexibility in this sort of plant is likely to be difficult to obtain when compared with other plants.

4.9.3 Manufacturing Control

There are different means of flexibility among different processes. Flexibility in the body shop refers to the ability to supply stamping parts as required, to arrange the sequence of body as required, to weld different types of body in the production lines, and to correctly match body parts from different lines. In the paint shop, flexibility means that the ability to paint the vehicles in the colour required, while the ability to assemble the vehicles as required is what flexibility means in the assembly shop. In the case of an increase of volumes and an adjustment of model mix, manufacturing planning generally starts with examining the capacity in the processes including fixed capacity, buffers, and safety stock. Next, calculating the work load for each process together with examining constraints within and between processes, examining arrival of material from external sources, and calculating production costs will be followed, then resource allocation can be made. It is noted that any change or adjustment requested in the appropriate manner (i.e. suitable lead-time provided), these specified processes can be done with little or no penalty. In fact, since it involves many actors and activities both inside and outside the plant to provide the flexibility to such processes, operations are likely to end up with higher risks and losses if the change or adjustment is suddenly required or with very short given time. Therefore, the means of flexibility in the body, paint, and assembly shop may not be achievable.

Manufacturing flexibility is often considered as a hard issue; that means it can be provided by exploitation of technology such as Flexible Manufacturing System (FMS) and group technology. Nevertheless, the soft issues such as management, working culture, commitment, and so on are not likely to be of concern. The findings from interviews confirmed that the latter issues are also significant in aspects of managing flexibility. Focusing on manufacturing activities, there are four main aspects relating to manufacturing flexibility which can be discussed that are; people, technology, process, and control. To successfully achieve manufacturing flexibility, soft issues within these four aspects must be taken into account. The key findings are summarised in the following.

IMCT managers highlighted the importance of employee commitment on the manufacturing flexibility. In the shop floor, the extents to which operations can be performed rely heavily on line managers, team leaders, group leaders. They experienced the impact of weak commitment among members in production lines which can cause difficulties in being flexible. One of SNA' managers pointed out that knowledge and learning enhancement in terms of technical and engineering is necessary in flexible operating context as these can provide more speed with accuracy and quality to the products and processes. TMT managers highlighted that rationale problem solving can establish a supporting environment for manufacturing flexibility. In contrast to large automakers, the small plants like TSA and TAAP plant, manufacture in lower volumes and the configuration of the production line is different from those in large plants, i.e. shorter production line. A greater emphasis on workforce capabilities must be made; otherwise the variety of products cannot be achieved in the plant. For example, in a large plant an operator is normally responsible for not more than ten tasks per one production cycle, but in small plants an operator has to perform a number of tasks, e.g. up to one hundred tasks for an operator, in a production cycle.

It can also be seen that visibility of process, standardisation of operations, and integration of software are also a concern of most managers in both large and small plants. Unlike other large automakers, the complexities and uncertainties in production of small plants are not likely to be so high but investment regarding these issues is fairly hard to make. For example, it is normally difficult to examine problems in a paint shop is as it operates in a closed containment. Ability of the paint shop to adjust vehicle colour according to customer demand is needed. As such, it is necessary for the painting process to be closely controlled. Thus, the role of plant structure and infrastructure in the processes are considered the key issue for future improvements in the TSA plant in order to support other organisational competencies, i.e. people, and future technology if they are likely to operate in customisation environment.

4.9.4 Supply Control

In order to become flexible, it is not possible to focus only manufacturing aspects. The supply chain aspect is increasingly important as automotive manufacturing tends to rely more on suppliers and third-parties in terms of product design, subassembly component production, business planning, etc. In this study, the role of supplier as one of supply chain members is a key focus in providing manufacturing flexibility to OEMs. All of the plants in the study agreed that suppliers play an important role in their operations, however, the extent and issues may vary among the firms.

Of the five plants, TMT is the only plant that is able to exploit the suppliers to achieve manufacturing flexibility. The relationship between the plant and suppliers is very close as the result of effective supplier development programme and long-term agreements. The operations in the plant and suppliers are likely to be well integrated in terms of process and information flow. It is interesting that TMT claimed that it is able to postpone or even return parts or components that suppliers have already produced and in transit back to the suppliers if TMT is not ready to use them. Isuzu and Nissan have been struggling with supplier's problems. The buyer and supplier relationship in these two plants are not as good as that in Toyota. In contrast, TSA and TAAP are not likely to be faced with supplier's problems as most of the parts or components used in the plant are imported from other countries in terms of CKD (Complete Knock Down), and their number of suppliers is low compared with the big companies.

Managers in the TSA plant stated that they experienced the inappropriateness of sourcing in forms of batches when they implemented a common production line. This can reduce the degree to which production can mix various models in a single production line. Although the plant has not changed the way parts or components are supplied, it has modified the loading from batch to unit load so that flexibility in the operations is then improved. TAAP seems not to have many problems regarding the aspects of supply control: the problems that are found only include the late delivery of parts from suppliers. Hence, it can be said that manufacturing flexibility can be harmed by means of buyer-supplier relationship, discrete process flow and information flow between OEMs and suppliers, and supplier selection in TMT, SNA, and IMCT, while TSA considered the network structure and infrastructure as significant factors influencing the level of manufacturing flexibility.

4.9.5 Main Problems for not Achieving Flexibility in Operations

The empirical study of manufacturing and supply operations in five OEMs provided better insights on operating issues surrounding manufacturing flexibility. Firstly, a firm that does not operate effective production control, supply chain management, and competency building is likely to fail in achieving the full potentials of manufacturing flexibility. Secondly, most firms are not keen to integrate tangible and intangible resources in order to be flexible but rather rely on technology and build-in capability. Thirdly, flexibility is considered strategically (i.e. long-term plan) but not used operationally to a serious extent within the firm, for instance, lack of communication from top to bottom level. Finally, flexibility is considered a ‘capacity’ aspect rather than a ‘capability’ aspect when reacting to any adjustment or change in operations. In other words, there is a lack of precise understanding of manufacturing flexibility and how to manage it in most firms. In addition, the issues about top management involvement and main problems for achieving flexibility are also obtained.

These propositions lead to generate the hypothesis on the generic concepts and mechanisms to enhance the level of manufacturing flexibility in the manufacturing operations. These are discussed in this section. Overall, twenty-nine interviewees from five automotive companies mentioned their awareness and problems regarding manufacturing flexibility, as well as possible solutions to improve flexibility in their plants. Their statements were coded and categorised within the three aspects, which are capacity planning, manufacturing control and supply control. Table 4.3 presents a summary of flexibility problems derived from the case companies.

Table 4.3 Summary of Flexibility Problems in Automotive Companies

			TMT	SNA	IMCT	TSA	TAAP
Capacity Planning	1	Planning system is not adequately advanced		X	X	X	
	2	Capacity is not reported with details and accuracy	X	X	X		
	3	Key information is not well distributed and received	X				
	4	Structure is not supportive to changes and avoid the changes in large amount of volume				X	X
Manufacturing Control	1	Lack of employee commitment		X	X	X	
	2	Low technical and engineering knowledge and learning		X	X		X
	3	Workforce skills are relatively low and too specific		X	X		X
	4	Insupportive plant structure and infrastructure			X	X	X
	5	Process is obscure and inadequately standardised	X	X	X	X	X
Supply Control	1	Relationship with suppliers is not close and short-term		X	X		
	2	Mismatch of production lines and sourcing practices		X		X	
	3	Discrete material and information flow between firms and supply chain members	X	X	X	X	X

Through conducting five case studies in OEMs, they revealed a set of factors that can illustrate why one firm outperforms the others in terms of manufacturing flexibility performance. In other words, these factors can be considered the key problems for achieving flexibility in the firms. It can be seen that the causes of problems on manufacturing flexibility are varied among five companies. However, they can be grouped by such characteristics as size of firm, and the degree of proactiveness.

Production planning and control issues were found to be key problems for all Thai automakers but it is likely to affect large companies (i.e. TMT, SNA, and IMCT) to a greater extent than small ones (i.e. TSA and TAAP) due to production complexities and more complicated processes. Also, this complexity and complication cause supplier issues prominent for manufacturing flexibility in large firms. All companies are encountering plant/network structure and infrastructure issues but it is likely that this issue affects small firms to a greater extent than large firms. This is because small firms have limited capabilities, less capital to update and invest new plant and network infrastructure. Regarding this, problems relating to sourcing practice were found in small firms. Small firms, especially TSA, need to implement flexibility to the production but its sourcing practices still do not perfectly align with the production needs. Thus, flexibility strategy cannot be implemented effectively. The final issue affecting the flexibility in Thai automakers is the human resource issue - regardless of the size of the firm. Workforce skill is a problem for all automakers, while consistency and encouragement of management teams upon manufacturing flexibility, and ability in decision making and problem solving are likely to be found in small firms.

Additionally, the problems can be distinguished according to the degree of proactiveness. Proactive plant such as TMT considers the importance of information, qualified suppliers, process structure, and workforce skills as key factors in achieving manufacturing flexibility in its operations. Reactive plant such as SNA, IMCT, and TSA, which have different degrees of reactivity, can experience different levels of problems. When comparing only the large firms, SNA is more reactive than IMCT as the management teams seem to have more commitment and encouragement on flexibility than IMCT does. Despite the fact that TSA and TAAP are considered to be small firms, the degree of seriousness for each key problem in TSA was found to be less than that in TAAP. Thus, this demonstrates that TSA is more reactive than TAAP.

4.9.6 Core Areas for Flexibility Improvement

The case study investigation revealed critical issues important to the degree of flexibility performed in operations. From the analysis of the interview results, the four areas which emerged were the means to improve the flexibility achieved from particular approaches or strategies adopted. The areas for flexibility improvement which all case studies agreed upon could be described as follows:

- **Improving production control and management:** the sub-areas for improvement include responsiveness to uncertainty, standardisation of processes, visibility of plant structure and manufacturing processes, rational-problem solving and decision-making, and allocation of production volumes, resources, and materials to match production constraints.
- **Building and enhancing the internal capabilities ready for flexible environment:** the sub-areas for improvement include workforce skills and knowledge, employee commitment, process control capability, and feedback and monitor capability.
- **Improving buyer and supplier relationships:** the sub-areas for improvement include supplier involvement, effectiveness of the supplier development programme, information sharing, and agreement between buyer and supplier.
- **Leveraging supporting activities:** the need for supporting activities such as levelling production, TQM principles, sourcing practices, and forecasting.

The summary of the evidences from interviews are shown in Table 4.4, Table 4.5, and Table 4.6. They illustrate that specific concerns of flexibility performance and flexibility improvement of respondents can be grouped into four main types of firm capabilities. From Table 4.4, it can be seen that TMT is very aware of production control and management, buyer-supplier relationship, and supporting structure and infrastructure as important aspects of flexibility implementation. SNA is concerned about production control and management and process capability. From Table 4.5 and 4.6, IMCT considers process capability and buyer-supplier relationship as being the means to deliver successful flexibility. TSA and TAAP are likely to have similar concerns on production control and management, and process capability in achieving flexibility. Appendix 13 to 16 shows the critical capabilities and associated dimensions of flexibility.

Table 4.4: Summary of Flexibility Issues Concerned in TMT and SNA

	Evidences of flexibility implementation from interviews	
	TMT	SNA
Production control and management		
Rationality	Systematic thinking and good coordination among functions and companies minimise the effects of demand adjustments and production uncertainties	
Allocation	New plant, i.e. BanPho plant can facilitate capacity allocation of TMC. Production volumes of one-tonned pick up vehicles can be maximised	
Responsiveness		Lack of integration among functions and supply chain members in overall planning system. Current planning tools and procedures do not suit current production
Standardisation	Standardisation of operations has been made as part of Kaizen to support production flexibility	
Visibility	Electrodeposition-paint (EDP) process in paint shop limits the visibility of process. Company now considers new painting method	Painting process has limited capacity and it is hard when higher production volumes from original plan are required
Process capability		
Process control		Introducing new measures such as SAR, Direct Run. Developing fool-proof system to provide signal for preventing errors or mistakes
Feedback and monitoring	Capacity reporting influences better capacity planning and resource allocation	
Skills and knowledge		Recently operating in two shifts, subcontracting workforces are used. Their skills are relatively low and specific so that flexibility can be lessened
Commitment		
Buyer-supplier relationship		
Involvement	Suppliers increasingly have roles in planning process of TMT's production planning department. It is reflected upon more integration of supply chain members	
Supplier development programme		Part shortage occurs when production volumes are increased due to limited capability of suppliers. Close relationship is required to improve
Information sharing/ communication	The operations in companies and suppliers have good degree of integration, i.e. process and information flow, and software integration (NQC)	
Agreement setting	Postponing or returning the use of parts back to suppliers when firm is not ready to use them. Close relationships with suppliers is necessary.	
Technology and organisational support		
Lean practices	The use of levelling production in scheduling can minimise the risks of production uncertainty and standardise the production process	
Agile practices	Perspectives of managers towards flexibility influence the successful flexibility implementation. This can reflect to the leadership of managers	Selection of appropriate technology to improve the operational performances according to unit production strategy being implemented

According to the results, a preliminary framework for flexibility improvement can be formed here. It can be said that to achieve flexibility, these four sets of firm capabilities have found to be important and they can influence the degree of flexibility performed by the company. Nevertheless, an attempt to validate these generic operating issues or mechanisms critical to manufacturing flexibility performance is still required. Thus, these mechanisms for enhancing manufacturing flexibility which emerged from the case study investigation will be further refined by conducting quantitative analysis through an industry survey in the following chapter.

Table 4.5: Summary of Flexibility Issues Concerned in IMCT and TSA

	Evidences of flexibility implementation from interviews	
	IMCT	**TSA**
Production control and management		
Rationality		
Allocation		Configuration of assembly line limits ability to adjust the production volumes. Capacity planning and allocation of infrastructural resources are important.
Responsiveness	Data and information management is required especially for ordering process as growing number of product spec., suppliers, and promoting engine export unit	Production plan tends to be fixed after distributing to related function. Planning requires to be responsive to demand adjustment.
Standardisation		
Visibility		Difficult to examine painting problems as this system operates in a closed environment. It required close control.
Process capability		
Process control		Difficult to examine painting problems as this system operates in a closed environment. It required close control. Technical improvement is required.
Feedback and monitoring	Closely monitoring the production and final results from which adjustments are made to ensure no errors and mistakes as well as along with the plan	
Skills and knowledge		
Commitment	Commitment from top management to operators in shop floor level is important especially for methodology-base flexibility approach	Top management do not ensure the benefits of single line in the first place. Lack of commitment causes delay of the project
Buyer-supplier relationship		
Involvement		
Supplier development programme	Most of suppliers in current portfolio are not certified quality assurance and company has to check quality of product they made and delivered	
Information sharing/ communication		
Agreement setting	Strategic alliance partner with GM, export vehicles are manufactured at GM plant, Rayong province	
Technology and organisational support		
Lean practices		Due to JIT principles, sourcing configuration and strategy must support production strategy. Single line production requires company changing sourcing parts from CKD to unit
Agile practices	Culture and working style allow company dealing with production adjustments with less resistance and reluctance	

Table 4.6: Summary of Flexibility Issues Concerned in TAAP

Production control and management		**Process capability**	
Allocation	Resource planning needs to be careful as there is no long-term forecasting like other plants.	Feedback and monitoring	Capacity report is necessary as to inform about current manufacturing functions to the marketing
Responsiveness	The integration of processes between marketing and manufacturing is crucial as company relies on customer orders and closely deal with marketing	Skills and knowledge	Lack of technical and engineering support. Company encourages operators to learn variety of tasks to support volume and project flexibility
Technology and organisational support		**Buyer-supplier relationship**	
Lean practices	TQM is required to be effectively used in organisation prior to being flexible. Flexibility cannot be achieved without quality control.	Supplier development programme	Late delivery of parts from suppliers is found as one of the problems in operations.

Next, the supply chain aspect was also studied as it is significant to the overall level of manufacturing flexibility. A supply chain member, a particular supplier, was further investigated in order to provide more understanding on the impact they have on the manufacturing flexibility of automotive firms (e.g. buyer and supplier relationships). The data was collected through questionnaire survey and descriptive statistics were used to analyse the important issues of suppliers. Finally the relationship of suppliers and OEMs in the context of flexibility management will be constructed.

4.10 MANUFACTURING FLEXIBILITY PRACTICES OF AUTOMOTIVE SUPPLIERS: SURVEY RESULTS

This section aims to explore the level of flexibility in Thai suppliers and to examine how suppliers affect flexibility issues and manage their production to respond to the requirements of OEMs. The results of the survey can reveal the problems in achieving flexibility in supply chain aspects. In consequence, the attempt to seek generic operating issues and mechanisms critical to flexibility performance in supply chain aspects can be made. Main questions in the questionnaires include two key themes, which are performances and practices, as presented in the Appendix 10.

Of 400 postal surveys, 27 mails were returned as no longer at that address (i.e. 19 mails) and unidentified reasons (i.e. 8 mails). The response of 43 suppliers was achieved (11.53%). Figure 4.3 shows the supplier profiles categorised according to tier (i.e. first-tier, second-tier, and third-tier supplier).

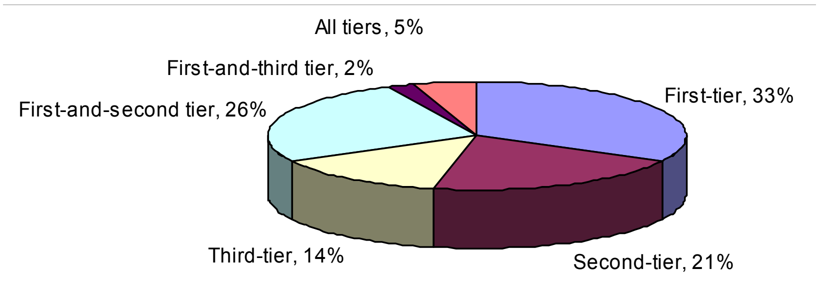

Figure 4.3: Supplier Profiles (n=43)

The aim of this survey is to understand the supplier perspectives on manufacturing flexibility, which is governed by OEMs. Supply chain aspects influencing manufacturing flexibility performance of OEMs can be understood. Therefore, it is necessary to ensure that the sample of suppliers is those supplying the parts and components to five OEMs (i.e. TMT, SNA, IMCT, TSA, and TAAP). The following figure (Figure 4.4) shows the frequency of suppliers which provide components to each automotive firm. All of the suppliers from the sample have more than one buyer. Thus, the frequency is used as a measurement for this chart.

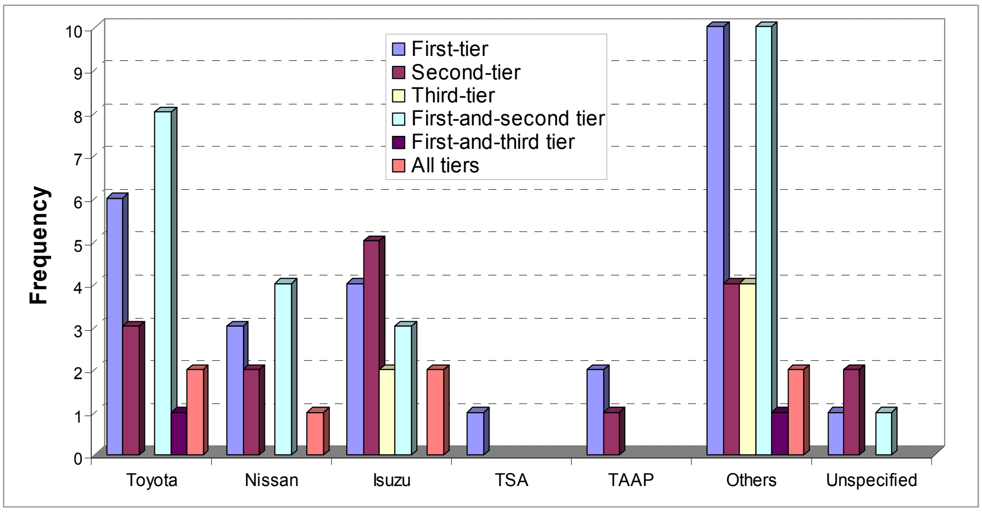

Figure 4.4: Classification of suppliers on each OEM

It is confirmed that the sample of suppliers here can be used in an analysis on the impact of five OEMs on suppliers' responses and it can represent the overall supply chain as most of the samples have supplied the parts to them (i.e. 62% of samples provide parts and components to five OEMs). Next, the results from the questionnaire survey are presented.

4.10.1 Flexibility performances

It is noted that there is some missing data from the fourth-three samples; it is possible that analysis may not be able to include all samples. The importance of flexibility and current flexibility performance were evaluated from ranking and rating by respondents. From the sample (n = 33), mean and standard deviation of importance and performance of each flexibility types were calculated and presented in Table 4.7. The importance and performance ratio (P/I) is calculated by dividing the rank of performance to one of importance to indicate the need of each flexibility type. The results showed that new product, machine, and mix flexibility can be performed at high performance compared with other flexibility types while their requirements are not very high. It can be said that these types of flexibility are not primary flexibility that firms should focus on or they are considered over-flexibility. On the other hand, volume, expansion, sequence, and routing flexibility are considered under-flexibility as their performances are low but they are important for the operations. Thai suppliers tend to require improving these types of flexibility if flexibility improvement programme is a concern.

Table 4.7: Importance and Performance of Flexibility Types in Thai Suppliers

Flexibility types	Importance ranking (max = 1, min = 7)			Performance rating (min =1, max =7)			Ratio (P/I)
	Mean	SD	Rank (I)	Mean	SD	Rank (P)	
Volume	3.188	2.494	1	4.600	0.950	5	5.00
New product	4.281	2.399	3	4.859	1.026	1	0.33
Mix	5.781	2.433	7	4.680	1.358	4	0.57
Expansion	4.156	2.357	2	4.708	1.269	3	1.50
Sequence	4.531	1.778	4	4.523	1.362	6	1.50
Routing	5.594	2.408	5	4.438	1.424	7	1.40
Machine	5.688	1.908	6	4.781	1.485	2	0.33

Sample n = 33, Ratio>1 = Under flexibility; <1 = Over flexibility

In terms of performance, it can be classified into three group; company with low flexibility, medium flexibility and high flexibility. From the results, the performance can be explained by these factors; the degree of complexity of products; and the degree of relationship with OEMs. The profiles of suppliers on product complexity and relationship with OEM in Table 4.8 can indicate such relationship.

Table 4.8: Profiles of Suppliers on Product Complexity and Relationship with OEM

			Product complexity					
Degree of flexibility	n	%	Low	%	Medium	%	High	%
Low performance	7	20.6	3	**42.8**	2	28.6	2	28.6
Medium performance	10	29.4	4	40	5	**50**	1	10
High performance	17	50	5	29.5	8	**47**	4	23.5

Low = Bolts, nuts, springs; Medium = Component parts;
High = Die, jig, and engine parts

			Degree of relationship with OEM					
Degree of flexibility	n	%	Low	%	Medium	%	High	%
Low performance	7	20.6	1	14.3	4	**74**	2	11.7
Medium performance	10	29.4	1	10	7	**70**	2	20
High performance	17	50	2	11.7	7	41.2	8	**47.1**

Low = Tier 3; Medium = Tier 2, Tier 1 and 2; High = Tier 1

To sum up, most of the suppliers in the Thai automotive industry have average level of flexibility. The ratio of importance and current performance in the samples shows that machine flexibility is over-utilised and volume flexibility is under-utilised and requires an improvement. It can also be implied that, in general, volume flexibility requires an improvement as it is important to shift the level of overall flexibility in the Thai automotive industry.

4.10.2 Production management

Focusing on supplier's production, one of the main tasks of the supplier is to serve OEMs and respond to OEMs changes. The need for flexibility in suppliers is mainly caused by OEMs, as their productions are increasingly more interdependent and require more cooperation. Firstly, respondents were asked about which key changes from OEMs they are currently faced with and the results are shown in Figure 4.5. OEMs might encounter such problems as their limited capability in demand forecasting and order processing; these might lead to delayed procurement but still require fast delivery from their suppliers, which accounts for 41.86%. Some activities regarding production adjustments in OEMs might take longer and can have an impact on suppliers' production. This results in changing production plans in terms of volume, sequences, and part requirements (34.88%).

The model change in OEMs occurs regularly ranging from 2 years to 7 years. This is considered by suppliers, which accounts for 11.63%. Suppliers have to prepare organisational resources to respond to the new design and configuration of parts OEMs need for their new model with specific quality and time. The last issue is that OEMs may reduce order quantities to a relative extent due to unpredictable circumstances (6.98%). This causes the suppliers a waste of resources, time, and profitability.

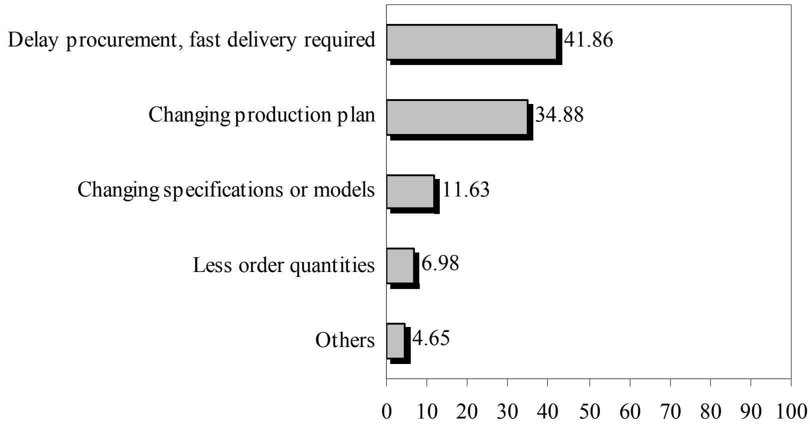

Figure 4.5: Flexibility drivers from OEMs in supplier production

The next question concerns which actions suppliers need to pursue to handle the above drivers from OEMs. It can be considered that most suppliers are concerned with such daily changes as procurement and production plan to be a key point in managing their operations and it is what the role of flexibility focuses on. The activities (see Figure 4.6) which are adopted regarding this can be; making sequence adjustment, work arrangement, and resource allocation (32.56%); conducting problem follow-up and improvement (23.26%); evaluating the impact of changes and creating new plans (16.28%); updating process according to customer requirements (9.3%). These can be considered primary activities regarding flexibility in the suppliers. It can be seen that suppliers have to respond to OEMs requirements as fast as possible. Conducting capacity planning (4.65%); adjusting safety stock and inventory (4.65%); outsourcing (2.33%); test run (2.33%); and reducing cycle times and enhancing productivity (2.33%) are considered secondary activities.

The results showed that most suppliers feel that the need for '*fast response*' is critical in terms of flexibility management. The means of planning, resource utilisation, and performance improvement are not likely to be a concern. This, to some extent, can lead to lower actual flexibility performance as they perceive that they meet flexibility but actually they are not. As flexibility is the ability of the system to change, it is claimed that a firm cannot deal with any change itself but the way in which a firm manages and organises is more important. Thus, to deliver the highest flexibility to manufacturing firms, an identification of flexibility drivers and implementation of tactical and strategic strategies are critical.

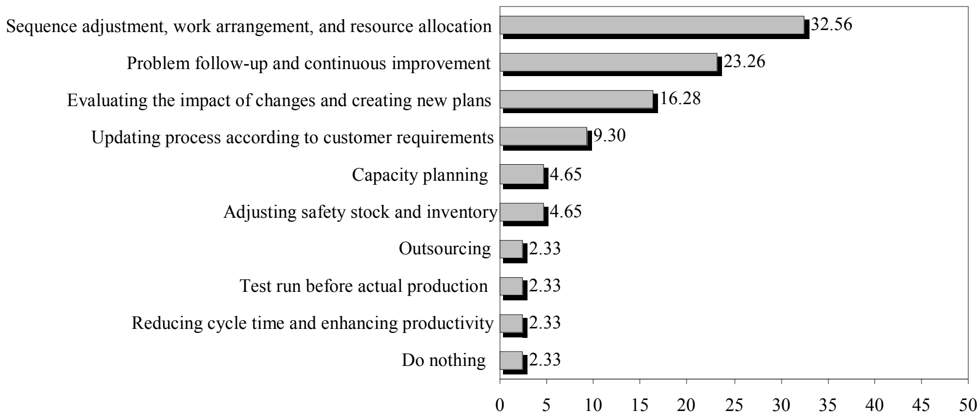

Figure 4.6: Activities for Managing Flexibility in Supplier Companies

4.10.3 Problems encountered

Next, the set of problems which suppliers encounter were revealed. They are considered to be the causes of unsuccessful flexibility achievement. Flexibility cannot be easily managed as it is multidimensional and it is hard to measure. However, the problems which suppliers encounter are identified based on the activities mentioned above. The results were shown here in Figure 4.7. Workforce capabilities in terms of part handling, production, responsiveness, and decision-making; and training tends to be key problems in achieving highest flexibility (34.88%), followed by having too much costs and wastes from overproduction and waiting time (20.93%), tooling set-up and reprogramming (11.63), delay of raw material from second or third tier suppliers (9.30%), the number of specific-purpose machine and process (6.98%), and the inability to identify appropriate safety stock (4.65%).

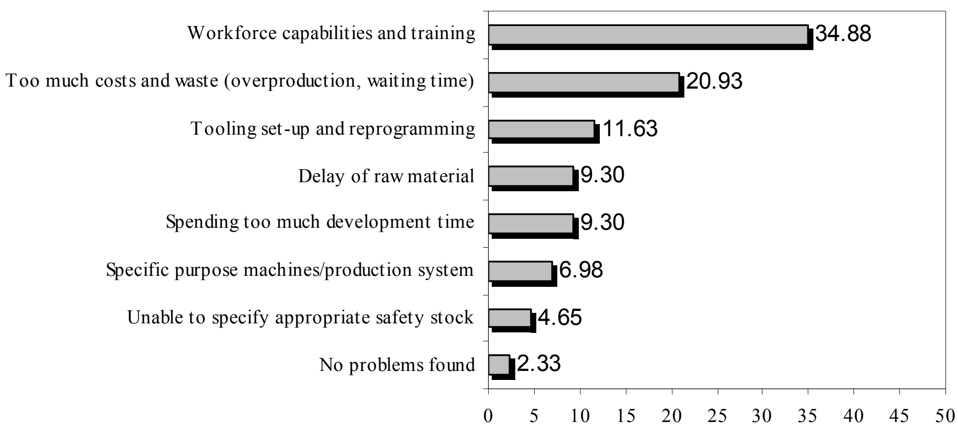

Figure 4.7: Problems in Flexibility Achievement of Suppliers

It is clear that better management in workforce, material, machine, and process is required. The results illustrated that workforces are a critical source of problems as they are incapable of fulfilling the flexibility requirements. The understanding of processes and implementation of production practices is likely to be inadequate so that means of flexibility are turned into additional costs and wastes instead.

Then, possible solutions were suggested to understand suppliers' perception on the ways to resolve the problems (Figure 4.8). The results showed that training and evaluating workforce capabilities are the most preferred (23.26%) followed by establishing new order forecasting and safety stock (18.6%) and solving other workforce related issue (16.28%). These account in total as 58.14% so it can be implied that they consider workforce and safety stock as primary sources of flexibility. It can be seen that they do not have much attention to devote other organisational resources to the manufacturing flexibility issue. One of the reasons can be that they do not have adequate knowledge and understanding of manufacturing flexibility; how imperative and beneficial flexibility is and its effects on profitability, as they only consider the reliability they can offer to OEMs.

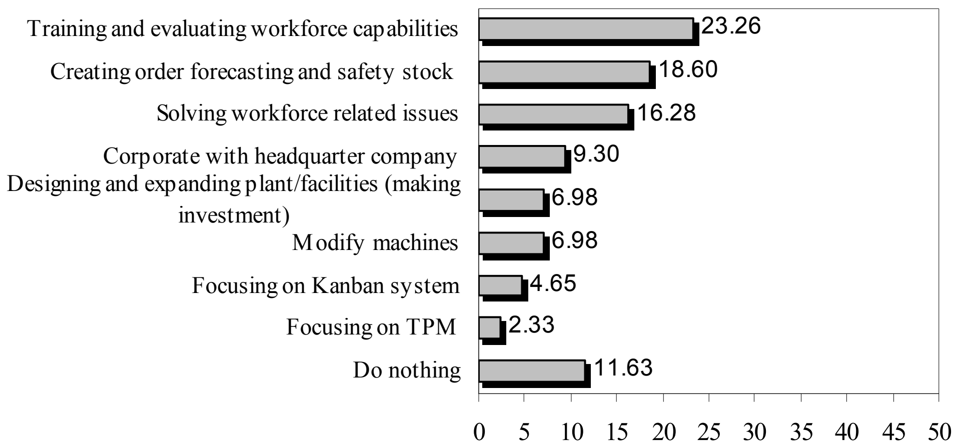

Figure 4.8: Possible Solutions regarding Flexibility in Suppliers

4.10.4 Barriers and Success factors

Flexibility issues in supplier companies have been found to be unsuccessfully solved and this can result in lower operating results. Those solutions mentioned above are what suppliers adopt in order to allow their existing system performing at highest flexibility. However, there have been barriers to constrain the companies from effective managing flexibility. To address perspectives of suppliers on the importance of manufacturing flexibility, the next objective is to question which are considered barriers and success factors in implementing or encouraging flexibility issues in their plants. The results are presented in Figure 4.9. They revealed that operational factors are considered primary barriers. Workforce skills and capabilities are major barriers which restrain suppliers from flexibility success, accounting for 32.56%. Cooperation between functions and departments follows, accounting for 16.28%. This is probably due to inadequate communication of goals and objectives when requirements in production are changed. The inability of managers in planning effectively within a short period of time counts for 11.63% due to lack of information, good planning system, and process understanding. Such strategic factors as capital, organisational know-how, and plant or network structure are 9.3%, 9.3% and 6.98%, respectively. As a result, most suppliers currently operate in a way in which existing production processes and procedures have not yet supported the manufacturing flexibility.

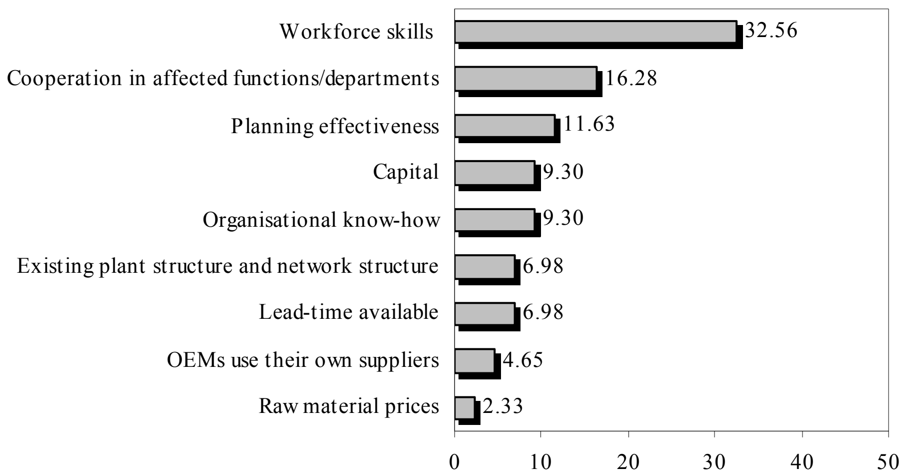

Figure 4.9: Barriers of Manufacturing Flexibility in Suppliers

To effectively operate within flexible environment, suppliers need to be aware of the following issues and establish plans according to these in order to successfully implement flexibility. These are the outcomes from the last question on what suppliers perceive to be success factors in achieving manufacturing flexibility (see Figure 4.10).

From the perspective of Thai suppliers, the efficient planning and forecasting (25.58%), high engagement and cooperation among employees (20.93%) are considered primary success factors. The results are consistent with the problems, solutions and barriers mentioned above. These factors can reduce the problems and obstacles in achieving manufacturing flexibility. For example, enhancing planning and forecasting can reduce the possibility that resources are exploited in an ineffective way that can result in additional production costs and time. High level of engagement and cooperation among employees can reduce the workforce problems in both direct and indirect ways.

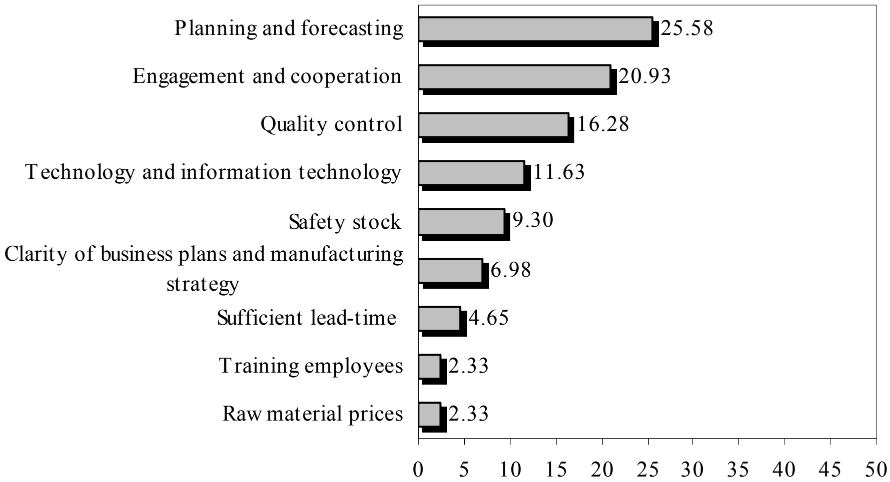

Figure 4.10: Success Factors of Manufacturing Flexibility in Suppliers

It can be implied, therefore, that one of the important approaches by which OEMs can enhance their manufacturing flexibility is to select the suppliers who have efficient planning, or to develop the supplier capability in planning due to a more complicated process flow and material flow existing in current production environment, otherwise their flexibility can be reduced. The ability in planning is regarded as an individual issue that each supplier has to be responsible on its own with less support from OEMs. The helping hands of OEMs or more OEM involvement in buyer-supplier activities can possibly enhance the level of overall manufacturing flexibility. The results from the survey extend the buyer-supplier relationship literature, manufacturing flexibility literature, and agile manufacturing literature. The support of OEMs for production planning activities of their suppliers can enhance the level manufacturing flexibility of OEM to some extent.

4.10.5 The Roles of Suppliers on Manufacturing Flexibility

From an empirical study, the interaction of OEMs and suppliers in managing flexibility can be described here. In aspects of OEMs, flexibility in supplier is required in order to supply parts and components to match OEM production conditions. This leads OEMs to force their suppliers, and thus additional costs can be given to these suppliers. The driving forces from OEMs such as power of OEMs, agreement and penalty policy, degree of relationship that OEMs provide with their suppliers impel suppliers to deliver the parts and components within given quantities and time. It can be seen that manufacturing flexibility can be reduced because suppliers have inadequate internal capabilities (i.e. planning, forecasting, workforce abilities) or there are some limitations and problems from second and third tier suppliers like delivery of raw materials and prices of raw materials.

According to the results from the case studies of automakers and the supplier survey, the gaps in managing flexibility were derived. They are summarised into three main points. Firstly, suppliers have to take responsibilities for any adjustment or change and are forced by OEMs so that they cannot achieve full potential of flexibility. This leads to lower level of flexibility in the overall supply chain. Secondly, information and communication between OEMs and suppliers during adjustment plans is possibly not well clear or not even made as it is considered independently in each function or department. Reporting the production capacity and capability from suppliers is also not properly done, which causes difficulty in the OEM's capacity planning and lower overall flexibility. Finally, internal capabilities for manufacturing flexibility are not sufficient in supplier production.

Therefore, the suggestions for suppliers to enhance overall manufacturing flexibility are made here; minimising the losses from unplanned changes; enhancing the capability of existing resources; communicating the problems and coordinating with OEMs; participating in the supplier development programme and providing support to OEMs. According to these, it can be seen that the central issue that encompasses all of these activities is 'buyer and supplier coordination'.

4.11 RESOURCE-BASED VIEW ON FLEXIBILITY IMPROVEMENT: HYPOTHESIS DEVELOPMENT

Referring to the flexibility performance examined in Figure 4.2, it can be confirmed that, from the survey and analysis of case study companies, the success of high flexibility performance within the manufacturing plants comes from great efforts on many activities such as capacity planning, manufacturing control, and supply control. These activities play important roles in flexibility performance. According to the self-assessment of flexibility performance in Figure 4.2, TMT ranks the highest overall manufacturing flexibility followed by SNA, IMCT, TSA, and TAAP. This shows consistence with the degree of efforts in flexibility improvement within the manufacturing and supply chain. The degree of flexibility improvement is ranked from TMT, SNA, IMCT, TSA, and TAAP. It is obvious that TMT is concerned about flexibility in manufacturing and supply chain views, while SNA, IMCT, and TSA are concerned about flexibility only in manufacturing view. TAAP put the efforts on flexibility improvement only within operational or internal process view.

Since each firm is typically capable of performing activities in different ways, the level of flexibility achieved by each firm is varied. One plant may not be able to achieve flexibility as much as another plant due to many constraints and limitations. However, in order to succeed with the highest flexibility for each of them, all of them must attempt to exert its efforts on all of these activities as much as they can. In addition, in terms of decision-making, it is claimed that they must consider all elements in flexible production activities (i.e. rationality, allocation, commitment, etc.) and may use them as criteria in order to come up with the most appropriate actions or approaches that assure the result of highest flexibility performance.

From the case studies, the operating factors critical to flexibility improvement which emerged from the five case study companies are revealed. These reflect how the firms in five automotive plants are aware of these operating factors, but also how these factors have an impact on manufacturing flexibility. The efforts on improving production control and management, process capability, buyer-supplier coordination, and technology and organisational support were found to be different amongst them.

In the context of production and operations management, the use of resources is considered very important to operational success. Two common types of resources consist of tangible and intangible resources. As the results from fieldworks demonstrate, failure of flexibility can be caused by three cases; no resources (i.e. firm has no required resources at all); unavailability of resources (i.e. firm has required resources but being not able to use now); and misuse of resources (i.e. firm has all required resources but cannot provide good final outcomes from using them). Most of the firms do not adequately or effectively use their resources. Manufacturing flexibility can be enhanced by minimising or removing these problems from current operations. Thus, based on a resource-based view, it can be concluded that the flexibility improvement efforts should focus on the efforts on leveraging production control and management, process capabilities, buyer-supplier coordination, and improving technology and organisational support.

Next, the characteristics of operating factors which emerged from the case study analysis are described in detail. The observations from five automotive companies are summarised to illustrate the influences of such operating issues on flexibility performance and, subsequently, hypotheses are developed.

4.11.1 Production Control and Management

As previously identified, the production control and management issue critical to flexibility performance consists of; standardisation of processes, visibility of plant structure and manufacturing processes, rational-problem solving and decision-making, responsiveness of the overall system, and allocation of production volumes, resources, and materials to match production constraints. According to the evidence from case studies, how each plant put an emphasis on such activity is described as follows:

Improving Planning Activity refers to the activities relating to improving the rationality of workforce in making decision and improving the resource management such as material, resource, and capacity allocation. TMT, TSA, and TAAP are aware of the importance of resource and workforce on manufacturing flexibility success. Management teams enhance employee skills through training programme, and on-the-job training. In doing this, employees have a higher level of understanding of process and operations in various functions. As they have more knowledge on various operations, this can build up the understanding of the whole system to them, especially staff members involved in planning. As a result, the use of resources becomes more effective.

Improving Responsiveness: This refers to improvement efforts on the evaluation of situations and clarification of problems within a short period of time. This must be a matter of concern as it can increase the opportunities to deal with uncertainties, especially unforeseen ones. The integration of the planning system (i.e. roles of information technology) was found to be helpful in responsiveness as suggested by SNA, TSA, and TAAP.

Improving Plant Structure and Infrastructure: This refers to the activities which focus on improving the current plant structure and infrastructure for better operational performance, particularly flexibility such as process improvement efforts. This effort can deliver higher standardisation of procedures and visibility of processes so that the implementation of flexibility can be facilitated and additional costs can be reduced or can disappear. TMT, SNA, and TSA pointed out that the improvement on the painting process can enhance the overall flexibility of the plant by means of reducing capacity limitation and enhancing the ability to control the process. Standardisation of procedures and processes can be included in Kaizen activity as suggested by TMT.

Summarising from the case studies, the following constructs are developed, which include rationality; allocation; responsiveness; standardisation; and visibility.

- **Rationality**

In the field of operations management, knowledge management technology has been considered critical for the firms to effectively plan and forecast for future operations. For example, customer relationship management (CRM) systems provide an integrated view of the entire operation so that forecasting and planning can be more effective (Desouza et al, 2003). In this regard, it can be seen that the use of information with rationality is a necessary concern. In order to achieve flexibility, it requires information from various sources. If the firms are not able to collect, interpret, and use them systematically, the degree of flexibility they would gain could be easily reduced. TMT managers emphasise the roles of rational problem-solving and claimed that it can enhance the flexibility. The rationality in decision-making is also likely to affect the degree of flexibility success. In some cases, managers can be forced to make decisions within short period of time so that the decision may only be made on general information or intuition.

- **Allocation**

In production aspects, the allocation of resource plays a significant role in the operational performance of the system, as well as profitability. Shirley (1987) studied the design of flexible systems by considering the choice of portfolios, allocation to manufacturing cells, and the choice of specific products within different portfolios to be manufactured in a given period. Companies have been striving for increased production and supply chain efficiency through higher resource utilisation. The resource utilisation can be made through gathering information, evaluating, planning, optimising, implementing, and monitoring the resources at different levels (e.g. capacity planning, task allocation, inventory control, production volumes). When resources are effectively allocated, the flow of process can be optimised and the uncertainty can be better handled. For instance, as TAAP has no long-term forecasting plan, this can lead to a high inventory when volumes are reduced. Allocation of this inventory can be made to other production units or business units. In consequence, not only can the plant attain some level of flexibility but also other benefits. The degree of flexibility obtained is likely to relate to the extent to which firms can allocate and manage their resources such as raw material, subassembly parts, machines, and workforce in both stable and unstable circumstances within functions and across organisation. This element requires that many departments work together such as marketing, distributors, manufacturing, and purchasing.

- **Responsiveness**

The construct of responsiveness is described as the ability to react purposefully and within an appropriate timescale to significant events, opportunities or threats (especially from the external environment) to bring about or maintain competitive advantage (Holweg, 2005). Since any change may occur in the production at any time, the effects would be minimised if the manufacturing system pertains to a number of sources of responsiveness as much as possible. The examples of these sources are such as long-term forecasting and planning, manufacturing involvement, and commitment to a long-term programme. Most of the case studies, i.e. SNA, IMCT, TSA, and TAAP, recognise this construct in terms of data and information management and interaction among functions. This means the firm would gain more manufacturing capabilities and allow them to deal better with the uncertainties or reducing the effects of sudden or unplanned changes in the production by means of better evaluation of situations and clarification of problems within a short period of time.

- **Standardisation**

Standardisation is defined as ‘the use of standard procedures, materials, parts, and/or processes in designing and manufacturing a product’ (Jayaram and Vickery, 1998). According to Imai (1992), standard procedures have the following features; they represent the best, easiest, and safest way to do an activity; they provide a method for managing knowledge through the preservation of ‘know how’ and expertise; they can be used as a reference to evaluate performance; they provide a basis for both maintenance and improvement activities; and they provide a basis for training, auditing, and diagnosis. The use of standard operating procedures should ease the tasks involved in identifying the root causes of a problem in the production process and reduce the possibility of errors and misalignment. Once a problem has been fully identified, corrective action can be ensured and quickly implemented and the procedures may be rewritten to eliminate the problem. TMT has included the standardisation as one of Kaizen activity in its continuous improvement programme. Hence, standardising the processes or plant structure and infrastructure is an important activity as errors can be minimised and options for dealing with uncertainties can be increased.

- **Visibility**

Visibility can influence the degree of production and inventory control efficiency both in manufacturing and supply chain aspects. Lack of demand visibility has been identified as an important challenge for supply chain management (Smaros et al, 2003). One of the most common types of these automatic replenishment programmes is vendor-managed inventory. It allows the vendor access to its customer’s inventory and demand information so that the ability to response to demand becomes more effective. Arranging the structure and infrastructure in the new forms can reveal the problems and make the causes more obvious and easy to identify. As a result, this can enhance the degree of flexibility, for example, mixing a variety of models in the same production line can lead the way for mistakes to occur due to complexities within the production processes. Hence, by reducing complexity through building process visibility, the model mix can be better managed and monitored as managers are able to identify and clarify the problems in exact ways. The painting process is given as a good example of this construct as pointed out by TMT, SNA, and TSA.

4.11.2 Resource Redundancy

Redundancy or 'reserve' of the capability of resources helps the system respond better to a changing circumstance (Correa, 1994). The study of Correa (1994) identified three kinds of resource redundancy including resource capability, resource capacity, and resource utilisation. Manufacturing flexibility success requires a specific set of redundancies, especially in aspects of workforce, process, and technology. In this context, it means that the organisation's workforce, process, and technology must be available for planned or unplanned change as much as possible in order to achieve manufacturing flexibility. The author found that the term 'process capability' should be more specific to represent the context of flexibility. Thus, it is replaced by the term of resource redundancy for the further study.

To achieve true manufacturing flexibility in the system, it is significant to build the extra capabilities throughout the processes in order to provide the degree of integration to the processes when dealing with uncertainties. It can be said that lack of capabilities in some processes or activities can affect the others as the level of integration in the system is spoiled. They should be built in order to accommodate or respond to the uncertainties. One of the examples of the importance of readiness in manufacturing aspects can be that of readiness in conducting concurrent engineering (Khalfan et al, 2001). This aims at enabling the managers to evaluate and benchmark its project delivery processes; and providing better and more effective CE implementation. In the same manner, the readiness in workforce, process, and technology is required in order to effectively manage and implement the operations strategy with the highest results of manufacturing flexibility.

The sub-areas for improvement (i.e. redundancy) include workforce skills and knowledge, employee commitment, process control capability, and feedback and monitor capability. From the case studies, the extent to which process and technology redundancy are built for prompt response is different among the firms. TMT, SNA, and IMCT put their efforts on this issue through, for example, installing new technology for better handling variations, improving information system, and encouraging staff to work under uncertainties. TSA and TAAP were found to put less effort into this issue, probably due to such factors as corporate strategy, financial aspects, and resource capabilities. On the contrary, workforce redundancy is strongly focused on by all companies. To enhance the level of manufacturing flexibility, the following constructs comprising workforce readiness; process readiness; and technology and information technology readiness are proposed.

- **Workforce Readiness**

Workforce is considered as one of the key elements to provide manufacturing flexibility to the system. The more competent the existing workforce is, the more unexpected problems and risks are minimised, and manufacturing flexibility can be enhanced. Key concerns on workforce readiness consist of an improvement or development of multiple skills and commitment. From observations, it is found that top management only is responsible for this role in all plants. Flexibility is not adequately communicated to the lower level such as functional and operational level. This results in the lack of focus and enthusiasm for manufacturing flexibility in the functional and shop-floor level. Despite the fact that managers in some plants (e.g. IMCT) understand the importance of operators in shop floor level upon the level of manufacturing flexibility, the actions regarding this are not taken seriously. For this reason, it is likely that flexibility is then considered in terms of capacity rather than capability when reacting to any adjustment or change in operations. In other words, most managers use the measures such as production volumes, inventory level, capacity, and manpower hours when the production plan needs adjustment and the actions that are taken are often based on this kind of measure. However, the capability terms such as skill level, employee satisfaction, and supplier capability are not likely to be evaluated and communicated within managers for flexibility purpose.

- **Process and Technology Readiness**

Process readiness refers to the extent to which processes can operate effectively under any production conditions due to high level of organisational experience, organisational understanding of processes and business conditions, and organisational management capabilities. This can result in better management of organisational resources, interaction between functions, process design, implementation process, and problem solving. Manufacturing flexibility in an overall organisation is likely to be enhanced as it is proactively managed and this can enable a firm to react more effectively with prompt resources and capabilities. Technology readiness refers to an organisation's propensity to embrace and use existing or new technologies for accomplishing goals with high resulting performance. It is necessary that a firm must leverage or build new capabilities in order to obtain more options for operations strategy. When faced with variations and uncertainties, the greater degree of technology readiness in existence, the wider the range of problems that can be encountered. As reflected in the case study companies, improving capacity reporting, enhancing use of measures in controlling operations, and improving technical aspects such as equipments are considered as means of providing a higher degree of flexibility.

Hypotheses are developed as follows according to the above operating issues. The hypothesis will be tested by statistical analysis of a questionnaire survey in the automotive industry. The detailed construction and testing of the questionnaire will be presented in Chapter 5.

> **Hypothesis 1:** ***The level of manufacturing flexibility is heavily dependent on the extent of production and control, and resource redundancy that firms adopt in manufacturing operations.***

4.11.3 Buyer-Supplier Coordination

As the supplier survey results showed, the support of OEMs for production planning activities of their suppliers can enhance the level of manufacturing flexibility of OEM. The term of 'coordination' was emerged. Based on Fredriksson (2006), three basic mechanisms for coordination in organisations are identified; coordination by plans; coordination by standardisation; and coordination by mutual adjustment. Coordination by plans means that pre-defined rules prescribe the characteristics of the output from an activity or unit and the terms for the delivery of this output. The use of a delivery schedule determining when parts for certain products should be delivered to the OEM is an example of this mechanism. Coordination by standardisation concerns the use of rules directing how activities are undertaken and what resources are used. Rules are established *a priori* for the execution of the activities and also presume that the activities are relatively similar, stable and repetitive. A company policy determining the use of certain quality control procedures is an example of standardisation. Coordination by mutual adjustment means a continuous exchange of information between actors when they undertake activities and use resources that are interdependent. How and when activities are performed and resources used, as well as the expected output, are then determined in detail along the way. Mutual adjustment, corresponding to what Brusoni and Prencipe (2001) refer to as interaction, is an appropriate coordination mechanism when the situation is variable and unpredictable. The coordination by mutual adjustment is mostly related to manufacturing flexibility.

OEM and supplier should be keen for this type of coordination in order to achieve the highest potentials of manufacturing flexibility for this study. This is likely to potentially resolve the problems and minimise the gaps in managing flexibility of OEM and supplier, which are mentioned above.

In examining the level of efforts on buyer and supplier coordination, it is possible to derive it from looking at how information is given and provided among them in the form of formal meetings and reviews. From the viewpoint that information can ease the operations of and between buyer and suppliers and also, if required, allow the conducting of the process improvement in their production more effectively, coordination is one of the primary activities to be concerned with. From the case studies and survey, the coordination can be divided into four key dimensions, which are; enhancing involvement of both buyer and supplier in decision-making and improvement process; improving buyer and supplier development programme for more integrated production; increasing the level of information sharing and communication; and setting agreement for mutual benefits. Once firms achieve such activities, it is probable that flexibility will succeed. In TMT, SNA, and IMCT, the meetings are used as key tools to report the problems and communicate with mother company and suppliers. The firms can achieve flexibility as the involvement offers the staff opportunities to share ideas for solutions and reduces the time spent in making decisions. An effective supplier development programme also allows manufacturing flexibility to be more successful. This can enhance the ability of suppliers to fulfill requirements of the company in stable and instable production environments so the production between them is more integrated. Finally, the efforts to improve information sharing and communication between company and suppliers is also important as this can facilitate those activities (i.e. enhancing involvement, improving supplier development programme) to achieve their objectives. It can be in the form of technological or behavioral aspects. The agreement and mutual benefits dimension are not mentioned in this examination due to accessibility of data. However, this construct is pointed out by managers in TMT.

Thus, in supply chain aspects, the hypothesis on manufacturing flexibility level is proposed as follows. This hypothesis will be tested by statistical analysis of a questionnaire survey in automotive industry. The detailed construction and testing of the questionnaire will be presented in Chapter 5.

> **Hypothesis 2:** ***The level of manufacturing flexibility is heavily dependent on the extent of buyer and supplier coordination that firms adopt in manufacturing operations.***

4.11.4 Technology and Organisational Support

Developing proper technology portfolio and organisational activities can enhance the flexibility performance of the plants. Regarding planning, it involves developing the technology and organisational mechanisms that support the production in terms of decision-making, information gathering, information sharing, and communication. Technology and organisational activities in implementation are meant to facilitate and enhance the success of implementation in terms of financial, organisational, and social aspects. They must support the planning and implementation in both aspects of lean and agile production (Jiang and Chen, 2007).

There has been a notion between the concept of lean thinking and agile thinking. The lean production model relates manufacturing performance advantage to adherence to a number of key principles such as improving flow of material and information across business functions; lean manufacturing operations which force problems to be surfaced and corrected; low inventories; the management of quality by prevention rather than detection and subsequent correction; small numbers of direct workers, and small-batch, just-in-time production; and close, shared destiny relations with suppliers, typically in the context of much smaller supply bases (Womack and Jones, 1996).

Agility means being able to reconfigure operations, processes, and business relationships efficiently while at the same time flourishing in an environment of continuous change (Hormozi, 2001). From the fieldworks, it seems like agility thinking does not receive much attention in most OEMs. Only TMT and SNA plants consider this concept to any great extent. By looking at their flexibility performance, they seem to outperform the others. However, critics claim that agile manufacturing may be better suited to less complicated commodity products rather than to an automobile. It is interesting to investigate more on how present automotive industry concerns with agile manufacturing.

Lean and agile productions contain various kinds of technology and organisational practices. Lean production contains a number of supporting elements that facilitate the manufacturing flexibility such as levelling production, TQM practices, JIT principles, and close relationship with suppliers. Agile manufacturing mainly comprises real-time demand management.

Among five automotive plants, the different existing use of technology and production practices can be found. From the case studies, it can be seen that TMT has strong technology and organisational supports in both lean and agile aspects (e.g. e-kanban, real-time demand management system, Heijunka-levelling production) and these lead to high level of flexibility of the plant, while TAAP is still struggling with quality management. The more a plant possesses strong support to perform lean and agile practices, the more success of such practices is obtained so that the planning and implementation of manufacturing flexibility can be easier. As a result, the ability of the plant to deliver the manufacturing flexibility becomes higher. To sum up, the author found that lean thinking and agile thinking should be integrated together in order to deliver the highest level of manufacturing flexibility. The hypothesis can be developed as follows.

> **Hypothesis 3:** ***The level of manufacturing flexibility is depended on the extent of technology and organisational support on lean and agile practices that firms adopt in manufacturing operations.***

4.11.5 Flexibility-Related Performances

As this study shows, the success of manufacturing flexibility can be achieved and can also minimise cost and time, as well as maximising quality: other benefits can also be realised. It is possible that obtaining flexibility can negatively affect the other operational performances such as quality and cost, especially when inadequate consideration was made. Therefore, it is crucial to ensure that all efforts on flexibility that firms make do not affect the other operational performances and profitability so that the full potentials of manufacturing flexibility can be obtained. The production costs, supply chain costs, final product quality, delivery time, wastes, and risks are considered to be other key operational performances that must be concerned when actions relating to flexibility are taken. Therefore, the above proposed mechanisms will be considered effective for enhancing manufacturing flexibility when they offer high manufacturing flexibility performance as well as low costs, less wastes, low risks, short time, and high quality. The hypothesis is then presented as follows.

Hypothesis 4: ***The efforts on improving production and control, resource redundancy, buyer-supplier coordination, and technology and organisational support positively influence the level of manufacturing flexibility and flexibility-related performance.***

4.12 SUMMARY OF FINDINGS FROM FIELDWORKS

This empirical study of case studies and survey identified the linkages between competitive environment, institutional environment and the choice of operations and supply chain flexibility strategies as well as the decision criteria; identifies the problems on flexibility achievement in manufacturing operations; and proposes critical operating factors for flexibility achievement with respect to supply chain and operation management perspectives. The evidence from fieldworks showed a number of flexibility issues in manufacturing operations as follows;

- No formal procedure for specifically assessing and evaluating flexibility in case study firms
- Flexibility is considered strategically (e.g. long-term plan) but not operationally in all companies, as can be seen from lack of understanding, lack of strong and continuous commitment, no strict control of operations so that approaches adopted can be less successful in terms of performance
- Flexibility strategies are different among the firms mainly depending on demand structures, existing resources (i.e. organisational and technological capabilities), and the extent to which manufacturing deals with global business environment.
- Most of the firms (4 out of 5) can be considered reactive and inert as flexibility is not a primary strategy of the firm. Additionally, these firms are not keen on leveraging their tangible and intangible resources in order to be more flexible.
- Most of the firms consider ‘capacity’ rather than ‘capability’ when deciding how to react to any adjustment or change. As a result, they do not ensure that an approach they had taken regarding flexibility could deliver the highest flexibility, as they focus on the performances specifically based only on quantitative factors.
- The reasons for unsuccessful manufacturing flexibility are lack of resources and capabilities in areas of capacity planning, manufacturing control, and supply control. The supplier aspects that influence the

unsuccessful manufacturing flexibility in OEMs are that suppliers lack adequate knowledge and commitment to enhance the performance with respect to manufacturing flexibility. The support of OEMs in production planning activities of their suppliers can enhance the level of manufacturing flexibility of OEM to some extent.

- The critical operating factors or mechanisms for enhancing manufacturing flexibility consist of production control and management, resource redundancy, coordination between OEM and supplier, and technology and organisational support.

4.13 CONCLUSION

This chapter reveals the current awareness and practices of manufacturing flexibility in the context of the Thai automotive industry in order to provide more understanding of manufacturing flexibility from pragmatic management perspectives. The investigation of flexibility strategies, a number of key flexibility issues taken into account in planning and operations, and key potential problems within different five automotive firms were conducted. The differences and similarities among the manufacturing flexibility practices implemented by the five automotive companies were examined. The findings showed that manufacturing flexibility requires a systematic analysis since an approach for one firm may not be suitable for other firms. Additionally, it requires great efforts and integration of manufacturing and supply chain functions if it needs to be successfully achieved.

In this chapter, the framework used to analyse the problems of manufacturing flexibility in present operations was suggested; by considering such key production activities as capacity planning, manufacturing control, and supply control. Also, the mechanisms for enhancing manufacturing flexibility were proposed including production control and management, resource redundancy, coordination between OEM and supplier, and technology and organisational support. The statistical analysis will be conducted to verify the relationships between these mechanisms and flexibility performance within the context of the Thai automotive industry (Chapter 5).

Arising from literatures, the tools needed to support the design of policy schemes that would ensure the implementation of flexibility in an efficient way are still lacking.

Therefore, it is important to also develop models to facilitate flexibility improvement efforts on a smaller scale, such as in production chains and/or operations. The findings from the fieldworks in this chapter such as flexibility issues taken into account in planning and operations, and mechanisms for enhancing manufacturing flexibility emerged will be used as basic knowledge to develop models for flexibility evaluation in the next chapter (Chapter 6).

CHAPTER 5: AN EMPIRICAL STUDY OF PRODUCTION PRACTICES AND MANUFACTURING FLEXIBILITY PERFORMANCE: SURVEY RESULTS

5.1 INTRODUCTION

The number of literatures provides the understanding of decision-making on manufacturing flexibility in terms of strategic factors. For example, investing flexible manufacturing systems can include such factors as financial position, technology position, human resource management, and government policies in the decision-making process (Rao and Deshmukh, 1993). There is also some indication that faulty or inadequate justification practices can result in firms not recognising or considering some factors which indeed affect the eventual flexibility performance. The study of the operating factors critical to manufacturing flexibility performance is still lacking. It is possible that the comprehension of the operating factors that have a direct impact on manufacturing flexibility level can offer managers more accurate justification on manufacturing flexibility improvement. This chapter presents the statistical analysis of the key operating factors which emerged from case study investigation (Chapter 5), which consisted of production control and management, resource redundancy, buyer and supplier coordination, and supporting structure and infrastructure, on the manufacturing flexibility performance and establish the link between them.

Responding to this need, this chapter undertakes an empirical examination of current production practices from a cross-section of the automotive industry in Thailand. It examines the interrelationships between flexible production activities, plant activities, and various performance aspects. *Flexible production activities* are concerned with manufacturing flexibility activities in aspects of production control and management, resource redundancy, and buyer and supplier coordination. *Plant activities* refer to the degree of efforts on improving the plant structure and infrastructure supporting the flexible operations (see Chapter 4). Section 5.2 provides a brief background of the empirical study and research questions. The research framework, propositions, data collection, and development of measurement scales for research constructs are described in Section 5.3. The descriptive analysis and the testing relationships of survey results are presented in Section 5.4 and 5.5, respectively. The summary of findings and discussion are described in Section 5.6. Finally, the conclusion of this chapter is made in Section 5.7.

5.2 RESEARCH FRAMEWORK

Recalling the cross-case analysis in the Chapter 4, the roles of resource availability and production capabilities are significant in performing successful actions. For the context of flexibility implementation, an important set of resources and capabilities can be grouped into four key areas including production control and management, resource redundancy, buyer-supplier coordination, and supporting structure and infrastructure. It is evident that different production strategies and structures of the plants lead to various degrees of these resources and capabilities and finally result in various degree of flexibility performance. To obtain the highest benefits of flexibility implementation, it is essential that manufacturing personnel must consider their resource availability and production capabilities prior to the implementation. In other words, firms which are likely to successfully implement flexibility and achieve high level of flexibility are ones focusing on building such resources and capabilities into their operations. Hence, to test this proposition, a research framework is developed to empirically investigate the relationship between the current production activities adopted by a cross-section of the Thai automotive firms including OEMs and suppliers, and manufacturing flexibility performance as shown in Figure 5.1.

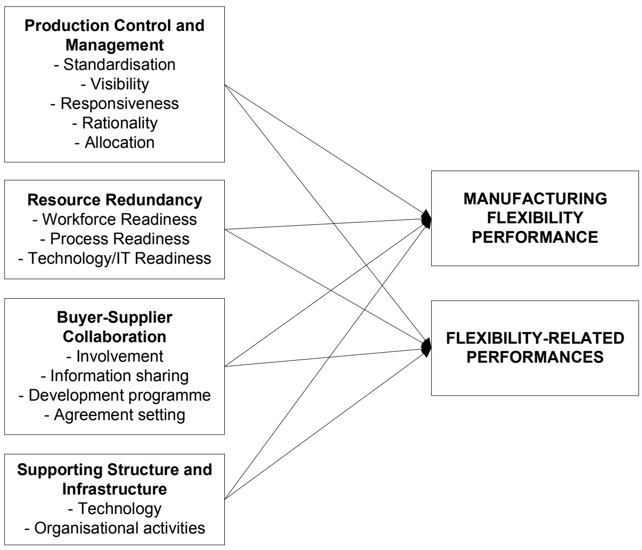

Figure 5.1: Relationship between production activities and manufacturing flexibility performance: Research framework

The production activities in this study mainly encompass ones associated with building or improving key resources and capabilities for flexibility, i.e. flexibility mechanisms. In consequence, the flexibility mechanisms which emerged from the case study in Chapter 4 will be tested and verified. Finally, a manufacturing flexibility improvement framework can be refined.

5.2.1 Research Questions and Propositions

Arising out of the information gleaned from the literature review and case study results, the key research questions that guide the study are:

> RQ1: Do differences in the level of effort on the various flexible production activities help to explain differences in manufacturing flexibility performance?
>
> RQ2: Can plant activities adopted be represented into lean and agile practices?
>
> RQ3: Do differences in the level of effort on plant activities help to explain differences in manufacturing flexibility performance?

To facilitate the analysis, three propositions are advanced as a basis for testing this research framework. Statements of each of these propositions are presented below:

> P1: Plants that exert a higher level of effort on flexible production activities will achieve a higher level of manufacturing flexibility performance.
>
> P2: Plants that exert a higher level of effort on flexible production activities will achieve a higher level of other manufacturing flexibility-related performance.
>
> P3: Use of both high lean and agile practices contributes to a higher level of manufacturing flexibility performance and other manufacturing flexibility-related performance.

5.2.2 Methodology

The mailed questionnaire survey is chosen for the study. The questionnaires were sent to a total of 300 OEMs and supplier companies which are members of the Thailand Automotive Institute and the Thai Auto-Parts Manufacturers Association (TAPMA). The selection of supplier sample was made within the main criteria of types of product they produce and standard qualification. In contrast, the sample of vehicle manufacturer includes all the automotive plants in Thailand (i.e. 14 plants). A total of

45 useable responses were obtained from this survey, two responses were unusable and nine questionnaires were returned as undeliverable. Thus, the usable response rate was 15 percent.

Regarding the measurement instrument, the questionnaire used in this study solicited information on the extent of effort applied to the flexible production activities and plant activities by the responding plants. The questionnaire was reviewed by two plant managers and a board member of the Federation of Thai Industries (FTI). The reviewers were asked to critique the content, structure and relevance of the survey instrument. The three reviewers who responded reacted favorably to the questionnaire, indicating that there was a need for the type of data to be collected. The final survey instrument incorporated some minor changes that were suggested by the reviewers such as revised definitions of flexible production activities and performance measures.

5.2.3 Development of Measurement Scales

The main objective of the survey is to understand the relationships between the current efforts of Thai automotive firms (i.e. OEMs and suppliers) on specified production improvement activities and their level of flexibility performance. As discussed in Chapter 4, four key mechanisms were identified from the case study investigation and are considered as critical to flexibility outcomes in manufacturing operations. In order to verify such relationships, the key measurement items for the constructs including flexible production activities, plant activities, and manufacturing flexibility performance are developed by the author and empirically tested through the mailed survey. They can be briefly described as follows:

- **Flexible Production Activities**

The identification of production activities that are relevant to the manufacturing flexibility performance are made here. Based on the case study, focusing more on production resources and capabilities when improving manufacturing flexibility is crucial, however, fewer firms investigate this construct in details. The key flexible production activities were determined through an extensive review of manufacturing flexibility literature and case study investigation. Summarising from the fieldworks, the author uses three main groups of key activities associated with flexibility improvement including production control and management, resource redundancy, and buyer-supplier relationship. They also existed in the number of literatures (Salvador et al, 2007; Gindy and Saad, 1998; Lau, 1999).

- **Plant Activities: Lean and Agile Practices**

In this study, plant activities consist of technological and organisational activities. This construct emerged from the literatures (Coronado, 2003; Zhang et al, 2006; Kathuria, 1998; Chang et al, 2005) and case study investigation in which supporting structure and infrastructure is crucial in improving flexibility. One possible way to classify these technological and organisational activities is to lend support from the concept of lean and agile practices. Since a manufacturing paradigm has been typically focused on these two fundamental concepts, it is typical that most plant activities in present manufacturing firms are then based on these conundrums. The interesting point is that it is still a question of how firms should employ these two practices to achieve a high level of manufacturing flexibility; individual or combination. Therefore, not only the linkages between plant activities and manufacturing flexibility are revealed through this survey, but the effects of such practices on the degree of manufacturing flexibility are also exposed.

- **Manufacturing Flexibility Performance and Related Performance**

This study focuses on fifteen essential measures of flexibility performance that reflect the overall ability of a manufacturing system based on the taxonomy of flexibility by Narasimhan and Das (1999). Firms were asked to provide a self-assessment of outcomes in manufacturing flexibility performance attributable to the adoption of specified production activities. The author selected to assess performance from an internal rather than external perspective because of the difficulty of previous research in this area to obtain data on external performance measures such as return-on-assets, profits, and wide supply chain performance. According to previous literatures, manufacturing flexibility is only measured by the flexibility dimension itself regardless of the performance trade-off on the operations. Thus, eleven measures of flexibility-related performance, i.e. indirect flexibility performance, are developed by the author for the survey; they are based upon cost, time, quality, and risk measures.

In this study, six groups of measures were developed including; technology portfolio and organisational activities; production control and management; resource redundancy; buyer-supplier coordination; direct flexibility performance; and indirect flexibility performance. It is noted that the measures of technology portfolio and organisational activities represent the degree of plant activities. The factor analysis with varimax rotation was performed to extract multivariate measures of those six groups of measures. In doing this, a simple structure and better explanation of the measurement scales can be achieved as the number of variables that have high loadings on the scale are minimised. Each scale was then labeled according to the content of those variables included. The reliability of scales must be tested. The internal consistency method was used to assess the scale reliability. The internal consistency of a set of measure items refers to the degree to which the items in the set are homogeneous (Flynn et al., 1994).). Internal consistency was estimated using Cronbach's Alpha value. Normally, the Cronbach's Alpha value should be more than 0.8 for measure items to be considered high degree of internal consistency. The following section presents the results from development of reliable and valid measurement scales characterising production improvement efforts and flexibility performances within the company by using SPSS 10.0.

(a) Technology Portfolio and Organisational Activities

For each plant activity, respondents were requested to choose a response on a five-point interval scale; anchored at one end with "no effort at all" meriting a score of 1, and at the other by "an extremely high level of effort" meriting a score of 5. The factor analysis is used to figure out the underlying concept explaining the adopted plant activities. With loadings of 0.30 or higher being considered significant for each factor, several of the variables loaded on more than one factor, suggesting that there is indeed some interrelationship among the elements of some of the factors. The reliability of the implementation scale containing all elements was tested using Cronbach's Alpha. The Cronbach's Alpha of technology portfolio and organisational activities are 0.879 and 0.884, respectively. The results from factor analysis are shown in Table 5.1.

The factors loading of technology portfolio measures are labelled to lean-supported technology and agile-supported technology. Measures of organisational activities are labelled to three groups; lean thinking; management focused agile thinking; and production focused agile thinking. Lean thinking refers to the extent to which a plant focuses on improving utilisation of equipment and facilities; improving workforce abilities and productivity; training workforces to succeed TQM and JIT; and controlling and minimising costs of production. Management focused agile thinking refers to the extent to which plants concentrate on such activities as planning reinforcement, restructuring or reengineering, decision-making improvement, and customer and demand forecasting enhancement to better deal with uncertainties.

Production focused agile thinking refers to activities on improving reliability, flexibility, and responsiveness.

Table 5.1: Confirmatory Factor Analysis of Technology Portfolio and Organisational Activities

Technology portfolio variables	Component	
	F1	F2
Automatic control		0.56
Robotic		0.677
Numerical control		0.667
Material handling		0.759
CAD/CAM		0.697
FMS		0.573
Computerised	0.835	
MRP	0.721	
ERP	0.786	
EDI	0.887	
MRPII	0.785	

F1= Lean-supported technology,
F2= Agile-supported technology

Organisational activities	Component		
	F1	F2	F3
Use of equipment	0.807		
Workforce ability	0.834		
Training and retain workforce	0.828		
Cost control	0.722		
Reinforce planning		0.695	
Restructuring		0.658	
Management decision-making		0.716	
Customer forecasting		0.796	
Sale volume forecasting		0.832	
Reliable delivery			0.704
Increase flexibility			0.637
Increase responsiveness			0.684

F1= Lean thinking, F2= Agile thinking-management focused,
F3= Agile thinking-production focused

(b) Effort on Flexible Production Activities

Respondents were asked to indicate the level of effort applied to each of the flexible production activities. For each activity, respondents were requested to choose a response on a five-point interval scale; anchored at one end with "no effort at all" meriting a score of 1, and at the other by "an extremely high level of effort" meriting a score of 5. The variables in three constructs of production control and management, resource redundancy, and buyer-supplier coordination were developed and tested. The results are shown as follows:

Production Control and Management

The Cronbach's a value for this activity scale containing 20 variables was 0.956. The three-factor orthogonal (Varimax) rotation explained 71.83 percent of the common variance among all variables. The factor loadings for the three-factor solution are presented in Table 5.2. The factor analysis results indicate that the production control and management activities can be grouped into a three-factor structure representing the following separate but interdependent production dimensions which have been given the following labels:

F1: Workforce development and resource management;

F2: Evaluation of situations and clarification of problems; and

F3: Production and process improvement

Workforce development and resource management refers to the planning activities including dimensions of rationality and allocation. Evaluation of situations and clarification of problems refers to dimensions of responsiveness and visibility. Production and process improvement refers to dimensions of standardisation and visibility where they are meant to improve plant structure and infrastructure rather than to workforce ability like measures of evaluation of situations and clarification of problems.

Table 5.2: Confirmatory Factor Analysis of Flexible Production Activities: Production Control and Management

No.	Production control and management variables	Component		
		F1	F2	F3
PC1	Reduce complexity and establishing standardisation			0.814
PC2	Employ part commonality			0.563
PC3	Document key procedures for common understanding			0.752
PC4	Use standard evaluation tools to improve production			0.682
PC5	Improve processes for better identifying problems		0.639	0.588
PC6	Allow people in production lines quickly detecting the problems		0.733	
PC7	Rearranging position and layout of facilities		0.844	
PC8	Effectively collecting and evaluating the production information		0.701	
PC9	Effectively evaluating system capability		0.673	
PC10	Improve ability in making decision of all level of employees	0.486	0.561	
PC11	Encourage and promote capability of planning teams	0.643	0.437	
PC12	Solve problems by using cross-functional	0.766		
PC13	Employ rationale-problem solving	0.809		
PC14	Employ decision-making support and tool for planning	0.781		
PC15	Leveling the production to minimise production variation	0.785		
PC16	Effectively plan, allocate and use buffers or inventory		0.768	
PC17	Establish responsiveness in production and supply chain		0.712	
PC18	Effectively manage lead-time in production and supply chain	0.568		0.561
PC19	Effectively allocate the volumes within and across the plants	0.756		
PC20	Effectively allocate and transfer raw material or components within and across the plants	0.768		

F1: Workforce development and resource management; F2: Evaluation of situations and clarification of problems; and F3: Production and process improvement

Resource Redundancy

The Cronbach's a value for this activity scale containing ten variables was 0.922. Exploratory factor analysis was used to determine the minimum number of underlying factors that could be used to explain the inter-correlations among the variables in resource redundancy. The factor loadings for the two-factor solution are presented in Table 5.3. The factor analysis results indicate that the competency building activities can be grouped into a two-factor structure representing the following separate but interdependent production dimensions which have been given the following labels:

F1: Process and technology readiness; and

F2: Workforce readiness

Process and technology readiness refers to the extent that a plant builds and prepares the structural and infrastructural resources and capabilities to deal with foreseen and unforeseen uncertainties. In the same manner, workforce readiness focuses on human resources in terms of skills, knowledge and commitment.

Table 5.3: Confirmatory Factor Analysis of Flexible Production Activities: Resource Redundancy

No.	Resource redundancy variables	Component	
		F1	F2
R1	Promote training programme for whole organisation		0.885
R2	Encourage employee commitment and involvement in solving problems and improving processes		0.81
R3	Encourage continuous improvement programme		0.818
R4	Enhance Just-In-Time principles for production	0.733	
R5	Improve scheduling to match production requirements and conditions	0.736	
R6	Improve ability in managing change	0.8	
R7	Improve process capability to respond to the changes	0.839	
R8	Improve resource planning system and procedures	0.61	
R9	Improve ordering system and procedures	0.648	
R10	Improve forecasting ability	0.795	

F1: Process and technology readiness; and
F2: Workforce readiness

Buyer-Supplier Coordination

The Cronbach's value for this activity scale containing 19 variables was 0.959. Exploratory factor analysis was used to determine the minimum number of underlying factors that could be used to explain the inter-correlations among the variables in buyer-supplier coordination. The four-factor orthogonal (Varimax) rotation explained 77.40 percent of the common variance among all variables. The factor loadings for the four-factor solution are presented in Table 5.4. The factor analysis results indicate that the buyer-supplier coordination activities can be grouped into a four-factor structure representing the following separate but interdependent production dimensions which have been given the following labels:

F1: involvement in decision-making and improvement process;

F2: buyer and supplier development programme;

F3: information sharing and communication; and

F4: agreement setting

Table 5.4: Confirmatory Factor Analysis of Flexible Production Activities: Buyer-Supplier Coordination

No.	Buyer-supplier coordination variables	Component			
		F1	F2	F3	F4
BS1	Participate in decision-making with suppliers			0.82	
BS2	Emphasise on sharing general information with suppliers for making decision			0.713	
BS3	Emphasise on sharing business information with suppliers for making decision			0.637	
BS4	Improve communication in strategic planning with suppliers			0.582	
BS5	Use information and communication technology			0.487	0.673
BS6	Share costs, risks and benefits with suppliers				0.818
BS7	Emphasise on benefits for all stakeholders	0.645			0.55
BS8	Share and exchange information with suppliers	0.619			
BS9	Synchronise the production with suppliers	0.427			
BS10	Unite the goals, policies, and measures with suppliers	0.726			
BS11	Suppliers and companies improve production in the same direction	0.707			
BS12	Promote the integration in planning and implementation	0.849			
BS13	Promote the integration of production and management	0.752			
BS14	Suppliers involve in long-term planning		0.676		
BS15	Improve product development process of suppliers		0.721		
BS16	Improve technical knowledge of suppliers		0.655		
BS17	Exchange engineering knowledge among companies		0.653		
BS18	Transfer knowledge to suppliers		0.768		
BS19	Supplier involve in making production policies, i.e. safety stock, lead-time		0.644		

F1: involvement in decision-making and improvement process;
F2: buyer and supplier development program;
F3: information sharing and communication; and
F4: agreement setting

(c) Manufacturing Flexibility Performance

Respondents were asked to provide a self-assessment of outcomes in manufacturing flexibility performance, both direct and indirect performance, attributable to the adoption of production activities. The variables used in this study reflect the attributes of flexibility performance. For each variable, respondents were asked to indicate the level of performance using a five-point scale; which was anchored at one end with “very low” meriting a score of 1, and at the other by “very high” meriting a score of 5. The Varimax (orthogonal) three-factor solution loadings are presented in Table 5.5. This solution results in clear clusters which are adequately separated from each other, with three variables loading on each factor. The factors are labelled:

F1: operational flexibility measure;
F2: production flexibility measure; and
F3: customer order measure

Table 5.5: Confirmatory Factor Analysis of Performance: Manufacturing Flexibility Performance

No.	Manufacturing flexibility performance variables	Component		
		F1	F2	F3
FLEX1	Machines can perform variety of tasks effectively	0.792		
FLEX2	Equipments and tools can be used for different products effectively	0.84		
FLEX3	Production sequences can be adjusted	0.61		0.543
FLEX4	Material handling and feeding system can manage different tasks effectively			0.748
FLEX5	Equipments and machines can be operated in unexpected situations	0.586		0.572
FLEX6	Different products can be produced effectively	0.879		
FLEX7	Different production volumes can be produced effectively	0.521	0.563	
FLEX8	Different product specification can be produced effectively		0.796	
FLEX9	New parts and products can be effectively produced by company and suppliers		0.799	
FLEX10	Manufacturing can effectively respond to market changes		0.797	
FLEX11	Production is operated smoothly when suppliers have problems or difficulties		0.683	
FLEX12	Suppliers can produce parts in different volumes and lead-times			0.49
FLEX13	Plant can reduce backorders			0.782
FLEX14	Plant can increase sale volumes			0.66
FLEX15	Plant can reduce late delivery of products			0.78

F1: operational flexibility measure; F2: production flexibility measure; and F3: customer order measure

The Cronbach's reliability value for 15 measures of flexibility performance was 0.934. The operational flexibility measures refer to the measures which focus on the shop floor level. Unlike operational flexibility measures, production flexibility measures and customer order measures involve manufacturing and supply chain members such as suppliers and customers. Customer order measures are meant to measure the aspects of meeting customer demand and on-time delivery. It can also be seen as system flexibility.

In addition, respondents were asked to provide a self-assessment of outcomes in other flexibility–related performance attributable to the adoption of production activities. The variables used in this study reflect the attributes of other performance relating to flexibility such as cost, quality, time-based performance, waste, and risk. For each variable, respondents were asked to indicate the level of performance using a five-point scale; which was anchored at one end with "very low" meriting a score of 1, and at the other by "very high" meriting a score of 5. The Varimax (orthogonal) three-factor solution loadings are presented in Table 5.6. This solution results in clear clusters which are adequately separated from each other, with three variables loading on each factor. The factors are labelled:

F1: Indirect performance measure;

F2: Operational performance measure; and

F3: Cost effectiveness measure

Table 5.6: Confirmatory Factor Analysis of Performance: Manufacturing Flexibility-Related Performance

No.	Flexibility-related performance variables	Component		
		1	2	3
OF1	Production costs			0.626
OF2	Supply chain costs			0.911
OF3	Inventory costs			0.865
OF4	Delivery performance		0.693	
OF5	Quality of work-in-process products		0.876	
OF6	Quality of final products		0.898	
OF7	Amounts of wastes from production	0.908		
OF8	Amounts of rework	0.935		
OF9	Degree of risks	0.909		

F1: Indirect performance; F2: Operational performance; and
F3: Cost effectiveness

*Question no. 7 and 8 were deleted

The Cronbach's reliability value for 9 measures of flexibility-related performance was 0.845. Indirect performance measure refers to the wastes, reworks, and risks that occur during implementing flexibility. The operational performance measure indicates the ability of a manufacturing system to maintain the product quality and delivery performance when implementing flexibility. In the same manner, cost effectiveness measure focuses on estimated production costs, supply chain costs, and inventory costs as the results from implementing flexibility.

5.2.4 Summary of Factors Used in the Analysis

The generic operating issues incorporating manufacturing and supplier aspects from Chapter 4 were modified according to the results of data reduction process. The summaries of factors that will be used in the analysis to figure out the relationships are presented in Table 5.7.

Table 5.7: Summary of Variables

Construct	Operating Issues	Factors
Plant activities	Technology Portfolio	Lean-supported technology, Agile-supported technology
	Organisational Activities	Lean thinking, Agile thinking-management focused, Agile thinking-production focused
Flexible production activities	Production Control and Management	Workforce development and resource management Evaluation of situations and clarification of problems Production and process improvement
	Resource Redundancy	Workforce readiness, Process and technology readiness
	Buyer-Supplier Coordination	Involvement in decision-making and improvement process, Buyer and supplier development program, Information sharing and communication, Agreement setting
Manufacturing flexibility performance	Direct Manufacturing Flexibility Performance	Production flexibility measure, Operational flexibility measure Customer order measure
	Indirect Manufacturing Flexibility Performance	Indirect performance measure, Operational performance measure, Cost effectiveness measure

Next, the analysis of the relationship between three constructs will be presented in Section 5.3 and 5.4. The results of the data analyses are divided into two main parts, namely the background of flexibility practices in the Thai automotive industry, and the relationships among independent variables (i.e. plant activities, flexible production activities) and dependent variable (i.e. manufacturing flexibility performance).

5.3 CURRENT FLEXIBILITY PRACTICES OF THAI AUTOMOTIVE INDUSTRY: DESCRIPTIVE ANALYSIS

This section provides the background of flexibility practices and the attributes towards the flexibility practices in the Thai automotive industry. The samples are classified into OEM (n = 8), supplier tier 1 (n = 22), tier 2 (n = 9), and tier 3 (n = 3). It is noted that the following descriptive analysis does not take into account the types of firm due to the limited number of samples. The aim is to provide an overview of manufacturing practices and awareness of flexibility issues in the Thai automotive industry. The results begin with understanding the use of technology and organisational practices, perception on flexibility problems, various efforts on flexibility improvement, and the overall flexibility performances.

5.3.1 Technology and Organisational Practices

From Table 5.8, Flexible Manufacturing System is not widely used compared with conventional technology such as MRP and EDI in Thai automotive companies. In terms of manufacturing practices, when focusing on agile practice in particular, management aspects are not likely to receive emphasis. It can be seen that manufacturing has given much concern to the agile practices by focusing on the aspects of responsiveness, flexibility, and forecasting but less attention has been paid to managerial aspects of agile practices.

Table 5.8: Technology and Organisational Practices

Technology and Organisational Practices	Agile-Supported Technology	Lean-Suppported Technology	Lean Practices	Agile Practices-Management	Agile Practices-Production
N	40	41	41	41	42
Mean	2.6333	3.1951	4.2805	3.5951	4.4127
Std. Deviation	0.85917	1.12738	0.70311	0.65953	0.50905
Variance	0.738	1.271	0.494	0.435	0.259

5.3.2 Perception on Flexibility Problems

Table 5.9 shows the means and standard deviation of flexibility problems perceived by managers. According to perception on flexibility problems from 42 companies, the most concerning problems include lack of workforce capability, lack of planning capability, no commitment to problem-solving, no commitment to technology improvement, and unclear communication.

Table 5.9: Flexibility Problems

Problems for not achieving flexibility	N	Minimum	Maximum	Mean	Std. Deviation
Lack of workforce capability	42	2	5	**3.88**	0.889
Lack of planning capability	42	2	5	**3.81**	1.018
Poor organisation structure	42	1	5	3.45	1.109
Inadequate capacity	42	1	5	3.36	1.165
Ineffective machine, equipment	42	1	5	3.26	1.061
Technology obsolescence	42	1	5	3.14	0.977
Vertical integration	42	1	5	3.26	1.037
Ineffective forecasting	42	1	5	3.31	1.259
Poor suppliers	42	1	5	3.38	1.209
Poor sourcing practices	42	1	5	3.14	1.002
No commitment in technology improvement	41	1	5	**3.54**	1.002
No commitment in workforce improvement	41	1	5	3.37	1.019
No commitment in problem solving	41	2	5	**3.68**	1.035
Unclear communication	41	2	5	**3.59**	1.048
Poor information sharing	41	1	5	3.44	1.05
Top level and operator communication	41	1	5	3.05	1.094

The results suggest that firms should particularly put more emphasis on leveraging workforce and planning capability, enhancing commitment to employees at all levels, and improving communication among functions and plants. This conforms to the findings from case studies that improving production control and management, building resource redundancy, improving buyer-supplier relationship, and improving supporting structure and infrastructure are considered as key areas for flexibility improvement.

5.3.4 Various Efforts on Flexibility Improvement

As identified in the case companies, consideration of the resources and capabilities is important. The success of flexibility implementation and the degree of flexibility performance rely heavily on the amounts of a firm's resources and capabilities. This section provides the results of the degree of efforts on activities relevant to manufacturing flexibility performance in automotive firms. In consequence, this can reflect the broad picture of manufacturing flexibility improvement efforts in Thai firms.

From the results shown in Table 5.10, the activities that most Thai firms are focusing on are building workforce readiness as a means to deliver flexibility. Other activities are receiving only moderate concern. The efforts on improving planning activities, enhancing responsiveness, and leveraging plant structure and infrastructure are not heavily made. There are fairly low concerns on improving an exchange of information for planning, supplier involvement, and agreement setting between buyers and suppliers. In addition, improving process and technology readiness is moderately focused on. This might imply that most companies' viewpoints on flexibility is relatively broad because they primarily concern and put their efforts on the workforce readiness (Mean = 4.111). According to this viewpoint, current flexibility practices in the Thai automotive industry mainly rely on workforce aspects such as skills and knowledge. It confirms the importance of this research on the attempts to provide more understanding on managing flexibility and extend the scope of flexibility to wider production and organisation management.

Table 5.10: Efforts on Flexibility Improvement

Production control and management	F1	F2	F3
N	42	42	42
Mean	3.7275	3.7698	3.869
Std. Deviation	0.83372	0.76682	0.73486

F1: Workforce development and resource management;
F2: Evaluation of situations and clarification of problems; and
F3: Production and process improvement

Resource redundancy	F1	F2
N	42	42
Mean	3.8299	4.1111
Std. Deviation	0.72791	0.81539

F1: Process and technology readiness; and
F2: Workforce readiness

Buyer-supplier coordination	F1	F2	F3	F4
N	41	41	41	41
Mean	3.5643	3.3699	3.4098	3.4959
Std. Deviation	0.83296	0.93505	0.78861	0.79275

F1: involvement in decision-making and improvement process;
F2: buyer and supplier development program;
F3: information sharing and communication; and
F4: agreement setting

5.4.5 Overall Flexibility Performance

According to the above results, the characteristics of companies on flexibility improvement efforts can be described here. Most companies understand the importance of flexibility improvement on today's business. However, their practices do not cover all aspects of flexibility improvement; they seem to focus on the workforce issue but show less concern for technology and the supplier aspects. These are reflected by a low degree of efforts on production control, buyer-supplier coordination, and technology portfolio. Next, it is necessary to examine the degree of flexibility performance that companies achieve, and distinguish the characteristics of low, medium, and high flexibility companies based on the flexible production activities and plant activities. By doing this, it can be illustrated that flexibility performance is varied according to different efforts on production control, resource redundancy, buyer-supplier coordination, and supporting structure and infrastructure.

From the results of descriptive analysis (Table 5.11), it can be seen that the overall flexibility performance of Thai automotive firms is moderately good ($Mean_{Flex\_1}$ = 3.6341, $Mean_{Flex\_2}$ = 3.6095, $Mean_{Flex\_3}$ = 3.5128). Moreover, indirect performances related to flexibility implementation seem to be relatively low. It might be said that such efforts on flexible production activities are not sufficient. These results support the hypothesis on which efforts on production control, resource redundancy, buyer-supplier coordination, and supporting structure and infrastructure can influence the flexibility performance. The further analysis, i.e. cluster analysis, was conducted to understand the effects of such issues on different types of companies (low, medium, and high flexibility companies).

Table 5.11: Manufacturing Flexibility Performance

Direct Flexibility Performance	Flex_1	Flex_2	Flex_3
N	41	42	39
Mean	3.6341	3.6095	3.5128
Std. Deviation	0.74183	0.69697	0.69502

Indirect Flexibility Performance	OF_1	OF_2	OF_3
N	42	42	42
Mean	3.1984	3.7619	2.5952
Std. Deviation	1.07461	0.68782	0.79475

Conducting cluster analysis can provide a rough classification of companies with respect to flexibility performance (see Table 5.12). Three main groups are classified, which can be labelled; low flexible company (n = 8); high flexible company (n = 13); and medium flexible company (n = 14).

Low flexible companies (Group 1) heavily put less effort on flexible production activities even though a high degree of agile practices is employed in the plants. They are unable to gain a higher level of flexibility performance compared with other groups. High flexible companies (Group 2) can be claimed as the most successful firms to handle uncertainties and achieve high operational performances and competitive advantages. They have focused on improving many aspects of flexibility capabilities together with using conventional technology. However, this type of plant seems not to achieve cost effectiveness from the flexibility implementation. Finally, medium flexible companies (Group 3) are likely to improve or leverage their capabilities associated with flexibility. This contributes to a moderately high degree of overall flexibility performances. However, such performances as cost effectiveness, and amounts of wastes and errors produced seem to be relatively low.

Table 5.12: Results of Cluster Analysis

Variables	Cluster		
	Low (n=8)	High (n=13)	Medium (n=14)
LTECH	2.13	4.25	2.99
AGTECH	2.1	3.18	2.63
LORG	3.59	4.75	4.18
AGORG_mgt	3.08	4.09	3.4
AGORG_prod	4.13	4.72	4.1
PC_1	2.61	4.5	3.64
PC_2	2.82	4.14	3.84
PC_3	2.92	4.38	3.83
R_1	2.86	4.36	3.86
R_2	3.25	4.77	4.07
BS_1	2.71	4.14	3.46
BS_2	2.23	4.19	3.2
BS_3	2.65	4.02	3.23
BS_4	2.67	4.13	3.29
FLEX_1	2.77	3.9	3.8
FLEX_2	3.03	3.97	3.57
FLEX_3	2.84	4.1	3.51
OF_1	3.13	3.41	2.98
OF_2	3.38	3.97	3.86
OF_3	2.79	2.56	2.43

Using ANOVA, the means of efforts on plant activities of low flexible company, high flexible company, and medium flexible company were compared to further analyse the effects of technology and organisational practices. From Table 5.13, the result from the ANOVA analysis confirms that agile practices both technology and organisational aspects in low and medium flexibility performance companies are not different.

It can be concluded that the more companies focus on flexible production activities, the more they achieve flexibility. Despite the fact that low flexibility performance companies focus on agile practices to a similar extent, their flexibility performance is still low due to less concern on flexible production activities. In addition, it can be confirmed that firms should develop both lean and agile practices in order to gain higher flexibility performance. The results also revealed that, in order to improve flexibility, indirect flexibility performances should be treated separately as they are not always proportional to direct flexibility performances (i.e. means of indirect flexibility performances do not significantly differ among three groups of company). In other words, controlling wastes, errors, quality from flexibility implementation is difficult to achieve in a flexible environment so that careful management is required.

Table 5.13: Results of ANOVA

Dependent Variable	(I) PerfGroup	(J) PerfGroup	Mean Difference (I-J)	Std. Error	Sig.
LTECH	High Performance	Low Performance	**2.121**	0.370	0.000
		Medium Performance	**1.260**	0.317	0.000
	Medium Performance	Low Performance	**0.861**	0.365	0.024
FTECH	High Performance	Low Performance	**1.075**	0.333	0.003
		Medium Performance	**0.549**	0.285	0.063
	Medium Performance	Low Performance	0.527	0.328	0.118
LORG	High Performance	Low Performance	**1.156**	0.267	0.000
		Medium Performance	**0.571**	0.229	0.018
	Medium Performance	Low Performance	**0.585**	0.263	0.034
AGORG_mgt	High Performance	Low Performance	**1.017**	0.226	0.000
		Medium Performance	**0.692**	0.194	0.001
	Medium Performance	Low Performance	0.325	0.223	0.155
AGORG_prod	High Performance	Low Performance	**0.593**	0.195	0.005
		Medium Performance	**0.623**	0.167	0.001
	Medium Performance	Low Performance	-0.030	0.193	0.878

Upton (1995) estimated that 40 percent of flexibility improvement efforts are unsuccessful and claimed that one of the major causes of poor performance was the inability to identify which factors most affected it. The findings from this study demonstrate the importance of a number of factors that companies need to be concerned with when they wish to achieve flexibility. The managerial implications of the findings are that the managers must be:

(1) willing to commit their resources to improve planning activities, visibility and standardisation of process, enhance process control capability and coordination between buyer and suppliers;
(2) encouraging employees on skill development and enhancing the commitment level of employees in all levels;
(3) improving and sustaining lean and agile practices throughout the organisations; and
(4) carefully monitoring and controlling the costs and wastes when implementing flexibility.

Due to being a wide enterprise issue, improving flexibility needs to be more specific. One may question, for example, how to reduce the waste occurring from flexibility implementation. It is certain that managers are not able to improve all aspects of flexible production activities but decide which ones they should improve. The next question, then, is how each flexible production activity and plant activity affects flexibility performance. These effects will be further investigated by using regression analysis in the next section to examine how different flexible production activities and plant activities link with specific dimensions of manufacturing flexibility performances. The relationships between each improvement efforts and flexibility outcomes will be empirically tested. In consequence, the determinants of manufacturing flexibility improvement can be understood and a manufacturing flexibility improvement framework can be developed.

5.4 DETERMINANTS OF MANUFACTURING FLEXIBILITY IMPROVEMENT: SURVEY RESULTS

Recalling, the propositions presented in the following will be examined through the use of multiple linear regression analysis.

> *Proposition 1*: Plants that exert a higher level of effort on flexible production activities will achieve higher level of manufacturing flexibility performance.
>
> *Proposition 2*: Plants that exert a higher level of effort on flexible production activities will have positive impact on other flexibility-related performance.
>
> *Proposition 3*: Plants that use both intensive lean and agile thinking are likely to achieve higher level of direct and indirect manufacturing flexibility performance.

The multiple regression analysis was run by treating nine variables of flexible production activities (PC_1, PC_2, PC_3, R_1, R_2, BS_1, BS_2, BS_3, BS_4) as independent variables and six variables of manufacturing flexibility performance (FLEX_1, FLEX_2, FLEX_3, OF_1, OF_2, OF_3) as dependent variables. Section 5.4.1 presents the results and discussion from testing of the first and second proposition. For the third proposition, the results and discussion are presented in Section 5.4.2.

5.4.1 Flexible Production Activities and Manufacturing Flexibility Performance

Proposition 1: Plants that exert a higher level of effort on flexible production activities will achieve higher level of manufacturing flexibility performance.

In Table 5.14, the relationships between flexible production activities and manufacturing flexibility performance are presented. All flexible production activities, except production and process improvement, buyer and supplier development programme and agreement setting, are significantly related to one or more dimensions of manufacturing flexibility. They enable enhancing the degree of efficiency, responsiveness, versatility, and robustness of the manufacturing system and supply chain as well as enhancing customer satisfaction. It can be discussed that, for operational flexibility performance, encouraging the ability to evaluate situations and clarify the problems based on the rational problem solving can strongly provide managers to acknowledge foreseen and unforeseen production uncertainties and appropriate actions can be taken effectively so that flexibility can be obtained. Focusing on activities associated with supplier involvement is likely to facilitate the operations and contribute to customer satisfaction. These activities allow managers both in OEMs and on the supplier side designating the upper or lower production limits for specific circumstances and constraints. As such, some standard or procedure can be established for them to follow, and this can result in better flexibility performance.

Regarding production flexibility dimension, only activities on responsiveness, workforce readiness, and information sharing had found significant relationships. Workforce is considered the most important aspect in managing and improving flexibility as it significantly relates to all flexibility dimensions. If the workforce has no adequate skills, commitment, involvement, and capabilities, it is not possible that a manufacturing system can operate efficiently and responsively. Encouraging the degree of readiness in both OEMs and supplier workforces (i.e. workforce can have more skills, capabilities) can be beneficial to the overall supply chain such as reduced lead-time and more responsiveness.

Table 5.14: Summary of Relationships between Flexible Production Activities and Direct Manufacturing Flexibility Performance

Independent variables	Direct Manufacturing Flexibility Performances					
	Operational		Production		Customer order	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Production Control and Management						
Workforce development and resource management (Planning activities)	0.179	0.367	0.107	0.617	**0.507**	0.021
Evaluation of situation and clarification of problems (Responsiveness)	**0.594**	0.004	**0.504**	0.022	0.174	0.413
Production implementation and process improvement (Plant structure and infrastructure)	-0.056	0.768	0.056	0.784	-0.017	0.935
Resource Redundancy						
Process and technology readiness	**0.299**	0.086	0.174	0.332	**0.361**	0.044
Workforce readiness	**0.376**	0.033	**0.437**	0.018	**0.29**	0.102
Buyer-Supplier Coordination						
Involving in decision-manking and improvement process	**0.464**	0.063	0.048	0.851	**0.457**	0.048
Supplier development programme	0.067	0.749	0.083	0.707	0.147	0.453
Information sharing and communication	-0.081	0.716	**0.399**	0.092	0.017	0.936
Agreement and mutual benefits setting	0.228	0.29	0.122	0.587	0.145	0.465

Regarding customer order dimension, it also had found significant relationships with flexible production activities. The results showed that the higher efforts on planning activities, process and technology readiness, workforce readiness, and supplier involvement are key activities enhancing the ability of a manufacturing system to fulfill customer orders. For instance, activities on supplier involvement can facilitate the production planning so that appropriate customer orders and sequences can receive a better response and management. Overall, the results suggested that the proposed flexible production activities are potentially served as mechanisms to enhance the manufacturing flexibility performance (i.e. operational, production and customer order). Six out of nine activities contribute to flexibility performance dimensions. However, to confirm that these activities are able to enhance the highest potential of manufacturing flexibility, the other flexibility-related performance must also be tested. This was conducted in proposition 2.

Proposition 2: Plants that exert a higher level of effort on flexible production activities will have positive impact on other flexibility-related performance.

During the preparations for production adjustment or change, ideally, it is necessary that such performances as cost effectiveness, operational performance, and indirect performance must also be achieved. The measures of such performances are crucial as they reflect the true value of flexibility on the actions which a firm is taking. From Table 5.15, the efforts exerted on the flexible production activities do not always positively affect such indirect flexibility performances as cost, operational performance, and amounts of wastes as expected.

Table 5.15: Summary of Relationships between Flexible Production Activities and Flexibility-Related Performance

Independent variables	Indirect Manufacturing Flexibility Performances					
	Indirect performance		Operational performance		Cost effectiveness	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Production Control and Management						
Workforce development and resource management (Planning activities)	-0.062	0.798	-0.053	0.843	0.111	0.682
Evaluation of situation and clarification of problems (Responsiveness)	-0.213	0.38	0.209	0.443	-0.306	0.26
Production implementation and process improvement (Plant structure and infrastructure)	**0.652**	0.008	0.101	0.695	0.074	0.776
Resource Redundancy						
Process and technology readiness	**0.385**	0.07	0.25	0.236	-0.086	0.688
Workforce readiness	-0.258	0.218	0.026	0.9	-0.114	0.593
Buyer-Supplier Coordination						
Involving in decision-manking and improvement process	0.102	0.729	**-0.612**	0.035	0.163	0.581
Supplier development programme	**-0.472**	0.07	0.388	0.116	-0.408	0.116
Information sharing and communication	0.048	0.857	0.375	0.149	-0.28	0.302
Agreement and mutual benefits setting	0.401	0.127	0.185	0.455	0.398	0.13

The results indicate that there are significant relationships between production and process improvement, process and technology readiness and indirect performance. It is likely that the more firms put great effort on these activities, the lower the degree of risks and wastes seems to be. In addition, among the efforts to improve flexibility, the activities on supplier involvement and supplier development programme show negative impacts on operational performance (β = -0.612) and indirect performance (β = -0.472), respectively, as errors and mistakes tend to be high. Supplier involvement may be sometimes considered time-consuming activities. This creates an awareness that buyer-supplier coordination may contribute to low operational performances and overall flexibility performance. It is necessary to control the degree of involvement of suppliers and to manage processes in which suppliers are embraced. In the same manner, implementing a supplier development programme can increase errors and mistakes in the production. This is perhaps due to the focus of the supplier development programme. The programme usually focuses on delivery and quality of parts from suppliers to buyer, but less attention was paid on the level of wastes and risks in suppliers' production as well. In consequence, ineffectiveness in suppliers' production generates some effects on buyer production. Thus, it is an issue requiring more attention and further investigation on how to effectively manage the supplier involvement and supplier development programme.

In summary, controlling quality, cost, risk and mistakes during flexible production are difficult to achieve as flexible production activities cannot offer better performances on all of such aspects and some activity has negative impacts on performance. According to this, it may be implied that adopting flexible production activities cannot improve flexibility-related performance such as quality, costs, degree of wastes and reworks; rather it requires other additional activities. This raises an issue for further study that an investigation of other activities that can particularly improve flexibility-relate performance is useful to conduct.

It is clearly seen from the results on the first and second hypotheses that most flexible production activities significantly relate to manufacturing flexibility performance. This supports all the hypotheses developed from case study investigation and confirms the importance of having a clear understanding of flexible production activities in managing flexibility. Next, the impacts of technology and organisational activities on flexibility performance are investigated (Hypothesis 3). Various technology portfolio and efforts on organisational activities in terms of 'lean' and 'agile' are empirically tested as to how they relate to manufacturing flexibility performances.

5.4.2 Lean Practices, Agile Practices and Manufacturing Flexibility Performance

Proposition 3: Plants that use both intensive lean and agile practices are likely to achieve higher level of direct and indirect manufacturing flexibility performance.

The regression analysis was employed to analyse the relationship between technology and organisational activities in aspects of lean practices and agile practices, and manufacturing flexibility performance. Table 5.16 shows the results from regression analysis. The independent variables include technology and organisational practices based on lean and agile thinking.

Table 5.16: Summary of Relationships between Plant Activities and Manufacturing Flexibility Performances

	Direct Manufacturing Flexibility Performances					
	Operational		Production		Customer order	
	Coefficient	*p* -value	Coefficient	*p* -value	Coefficient	*p* -value
Technology						
Lean	0.1	0.561	0.045	0.783	**0.364**	0.015
Agile	**0.332**	0.059	**0.478**	0.005	**0.37**	0.014
Organisational Activities						
Lean	0.106	0.573	0.047	0.806	0.259	0.117
Agile_Management	0.211	0.302	0.152	0.466	**0.455**	0.013
Agile_Production	0.167	0.376	0.223	0.248	-0.288	0.775
	Indirect Manufacturing Flexibility Performances					
	Indirect performance		Operational performance		Cost effectiveness	
	Coefficient	*p* -value	Coefficient	*p* -value	Coefficient	*p* -value
Technology						
Lean	-0.166	0.361	0.217	0.238	-0.039	0.834
Agile	0.292	0.113	0.019	0.919	0.144	0.44
Organisational Activities						
Lean	0.144	0.464	0.303	0.131	0.077	0.704
Agile_Management	-0.116	0.586	0.027	0.899	0.059	0.789
Agile_Production	-0.271	0.173	-0.183	0.358	-0.235	0.249

The results showed that lean and agile technologies have an impact on manufacturing flexibility performance in different dimensions. Lean technologies are likely to affect customer order dimension (β_{Flex_3} = 0.364), while agile technologies affect all flexibility dimensions (β_{Flex_1} = 0.332, β_{Flex_2} = 0.478, and β_{Flex_3} = 0.37). Given much effort on improving and investing in this set of technology can influence manufacturing flexibility initiatives into becoming more successful. Paradoxically, lean technology should directly increase manufacturing flexibility. However, the result showed that lean technology influences flexibility indirectly; the effect of lean practices only appears in terms of backorders reduction and on-time delivery rather than operational and production flexibility dimensions. In contrast, firms with a high degree of technology portfolio supporting agile production are likely to be more successful in manufacturing flexibility improvement.

The results also showed that the influences of management-based agile organisational activities on the flexibility performance were only found in customer order dimension. Firms with high effort in agile practices are more likely to be able to reduce backorders and make on-time delivery than those with less effort (i.e. AGORG_mgt; $\beta = 0.455$). There appears to be no significant relationship between production based-agile organisational activities and flexibility performances. It may be explained that even though companies claimed that they focus on production based-agile organisational practices like improving forecasting and responsiveness in operations, the implementation may not be successfully achieved and the outcomes may be varied in each company. In the same manner, lean organisational activities do not show significant relationship to flexibility performance; this is perhaps because the implementation may focus on other competitive priorities and may not inadequately be focused on flexibility aspects.

Overall, the results showed that both lean and agile practices influence manufacturing flexibility performances in different dimensions, even though there is no significant relationship found between them and indirect flexibility performances. In a broad sense, it can be concluded that supporting structure and infrastructure are moderately important in achieving flexibility. The manufacturing strategy should be focused on the efforts to improving the technology, manufacturing process, organisational resources both in terms of lean and agile practices if improvement of flexibility is required. Moreover, the firms must put more emphasis on improving understanding of agile practices and how to successfully implement them as this seems to be the new manufacturing paradigm for the Thai automotive industry.

5.5 SUMMARY OF SURVEY FINDINGS

This section summarises the findings derived from the survey analysis. The key findings from statistical analysis conclude that:

- The linkages between production practices and flexibility performances are evident. All proposed flexible production activities can be potentially served as key mechanisms as they have impacts on the manufacturing flexibility performance.
- Buyer-supplier coordination such as supplier development programme and supplier involvement needs more consideration in terms of management. It is not necessarily true that a higher extent of involvement and development programme always lead to higher performances.
- Controlling related operational performances from flexibility implementation is difficult; yet, it is considered a major issue in flexibility management. The need for additional activities to manipulate other operational aspects in order to achieve true manufacturing flexibility is called for in further research.
- Enrichment of understanding of the true meaning of manufacturing flexibility and promoting the efficient manufacturing flexibility programme throughout the organisations are desired. The firms must put emphasis on improving understanding on both lean and agile practices in managing flexibility.

5.6 INSIGHTS AND PRINCIPLES IN FLEXIBILITY IMPROVEMENT

This section presents the insights derived from case study and survey analysis and how the existing literature on flexibility improvement is extended. A number of insights or characteristics of manufacturing flexibility implementation were derived and principles in flexibility improvement were developed as follows:

- Establishing the scope of flexibility improvement as different firms' contexts influence various degrees of importance on flexibility sources (i.e. large firms should especially focus on production control and supplier issues, small firms should especially focus on workforce and structure/infrastructure issue);
- Critical flexibility capabilities should be carefully identified and developed depending upon required flexibility targets;
- Setting flexibility improvement into operational policy in order to improve communication among employees, functions, and supply chain members (i.e. TMT case);
- Reducing obstacles of flexibility prior to implementation; and

- Monitoring implementation and regularly providing information (i.e. capacity, capability) and performances among relevant functions and supply chain members.

According to empirical findings from managerial perspectives in five companies and supplier companies, the author can capture the common ideas on manufacturing flexibility improvement which they employ. It has been found that key sources of flexibility are surrounding manufacturing and supply chain functions such as production and control, workforce, sourcing, suppliers, and plant and network structure. Thus, when designing flexibility in manufacturing or a supply chain it is necessary to encompass all of these areas. The sources of flexibility are summarised in Table 5.17.

The factors in Table 5.17 provide broad perspectives for the first stage of flexibility improvement in which scope of flexibility within manufacturing operations can be identified. Managers can examine which areas of flexibility sources they need to focus on to improve flexibility of a particular process. As reflected in the case study, according to their flexibility objectives (i.e. building new flexible plant, launching unit production system), large firms like TMT and SNA focus on production control issues, while small firms like TSA and TAAP focus on workforce and plant structure/infrastructure issues.

Table 5.17: Sources of Flexibility from Case Study Investigation

Areas	Factors
Workforce	Skills of workforce Effective decision making and problem evaluation Consistency and encouragement in management teams
Plant and network structure and infrastructure	Technological advancement Visibility and standardisation of processes Efficient domestic logistics system and supporting infrastructure such as Just-In-Time, Continuous Improvement programme Alignment of sourcing and production Efficient local sourcing system and control
Production control and management	Effective planning activities Efficient supporting activities (i.e. capacity planning, resource planning, process control, training, workforce planning for optimally allocating resources) Speed and accuracy of information
Supplier	Qualified suppliers (in terms of capability, relationship) Compatibility of process and control among suppliers and OEMs

Once focal areas are examined, managers have more understanding about which flexibility sources they need to concentrate on. The next task for managers is to carefully identify flexibility capabilities as they strongly influence the outcomes of flexibility implementation. However, from the survey results, it suggests that each flexibility capability has a direct impact on flexibility performances in different ways. The relationships are presented in the forms of the following table (Table 5.18).

Table 5.18: Key Factors for Various Flexibility Targets

Important Factors (suggesting actions)	Flexibility Targets		
	Operational Flexibility	Production Flexibility	Customer order
Generic factors			
- Workforce readiness	x	x	x
- Technology (Agile)	x	x	x
Specific factors			
- Process and technology readiness	x		x
- Responsiveness	x	x	
- Supplier involvement	x		x
- Information sharing and communication		x	
- Rationality and allocation			x
- Technology (Lean)			x
- Organisational activities (Agile-management focused)			x

Such relationship as in Table 5.18 provides the manager with comprehensive guidance on the effects of flexibility capabilities on the performance targets. This could, to some extent, help managers justify the relative importance of flexibility capabilities within the manufacturing flexibility improvement process. Hence, the decision-making process becomes more systematic and rigorous. Enhancing human resource redundancy and improving technological aspects associated with agile practices are fundamental requirements for all flexible companies. They can be considered generic factors as all flexibility performances are related. Specific factors such as responsiveness, supplier involvement, communication, etc. have impacts on particular flexibility performance. For examples, if managers need to improve production flexibility, information sharing and communication among company and suppliers is crucial. In contrast, this is not particularly required for operational flexibility.

Once managers identify which set of capabilities they need to improve, the plan should be established in order to clearly communicate goals and objectives to employees and supply chain members. Flexibility is difficult to understand, so it becomes helpful if it is formulated into simple and comprehensive goals and objectives. According to many problems from managerial viewpoints identified in previous chapter, these problems provide the suggestions on obstacles of manufacturing flexibility implementation. The list of main obstacles of flexibility success is described as follows:

- Lack of effective control
- Failure to realise other aspects of flexibility
- Inadequate capabilities of supply chain members
- Inadequate planning and decision-making
- Difficulty in obtaining technology and organisational support
- Poor infrastructure prohibits the flexibility improvement initiatives
- Fear of complication

It is obvious that obstacles exist within individuals, between OEMs and suppliers, and between first tier suppliers and second/third tier suppliers that can lead to a lower level of flexibility in the overall system. In general, these obstacles are mainly caused by ineffective planning (planning stage), ineffective operating and control of processes, and communicating within or between functions, inefficient performance measurement (implementation and monitoring stage), and employee characteristics. It is necessary to minimise the effects from such obstacles so that flexibility outcomes can be maximised. In the planning, the resources and capabilities for implementing particular flexibility should be examined and prepared. The framework mentioned above can provide useful guidelines for capability-based analysis. In implementation, the main obstacles derived from five case studies, monitoring implementation and regularly providing information (i.e. capacity, capability) and performances among relevant functions and supply chain members contributes to flexibility achievement. Also, top management commitment and communication of flexibility objectives are key factors to drive the flexibility across the organisation.

The results from the interviews together with the confirmation from the survey revealed a set of resources and capabilities underpinning effective flexibility improvement. This shows that flexibility improvement decisions can be assessed by resource-based view. To sum up, these following capabilities that have an effect on the success of manufacturing flexibility are summarised as follows.

- **Resource Redundancy:** Readiness of the physical, human, and information resources in terms of the amounts of redundancy, i.e. *resource level*, that are expected to be able to cope with planned and unplanned changes. The resources and capabilities in this category include:
    - Process Control, Feedback and monitoring
    - Workforce skills, Communication
- **Production Control and Management:** Ability in planning, controlling, and managing the production processes, i.e. *control level*, and the effectiveness of production system to effectively handle the planned and unplanned changes. The resources and capabilities in this category include:
    - Rationality
    - Allocation
    - Responsiveness
    - Visibility
    - Standardisation
- **Buyer-Supplier Coordination:** The ability of supply chain processes to facilitate the overall production processes according to the planned and unplanned changes, i.e. *supply chain level*. The resources and capabilities in this category include:
    - Involvement in decision-making and improvement process
    - Buyer and supplier development programme
    - Information sharing and communication
    - Agreement and mutual benefits
- **Technology and Organisational Support:** The effectiveness of practices, programmes, and portfolios employed in the production processes to support core production processes dealing with planned and unplanned changes, i.e. *structural level.* The resources and capabilities in this category include:
    - Technology based on lean and agile practices
    - Organisational activities based on lean and agile practices

Thus, when one needs to select the approaches that can successfully deliver the manufacturing flexibility, it is critical to consider these capabilities in the selection process by evaluating the degree to which these capabilities are performed in the current processes against the degree to which each alternative requires. The alignment should be met otherwise the selected alternative cannot successfully achieve the highest flexibility. These can be used to guide managers on the process to improve manufacturing flexibility performance. Also, they serve as useful guidelines for managers to prepare their resources and processes before implementing the flexibility strategies in order to ensure the success of investments and benefits to the firm.

By incorporating results from case studies and surveys, the manufacturing flexibility framework is developed (Figure 5.2). The need to improve manufacturing flexibility is triggered by external and internal environment including globalisation, customer needs, competition, economy of scale, trading policies, and the firm's position. The key tasks of manufacturing are to; respond to the uncertainties associated with those triggers while improving organisational and operational capabilities; and maximise competitiveness of the organisation by considering flexibility, cost, time, quality, and indirect benefits.

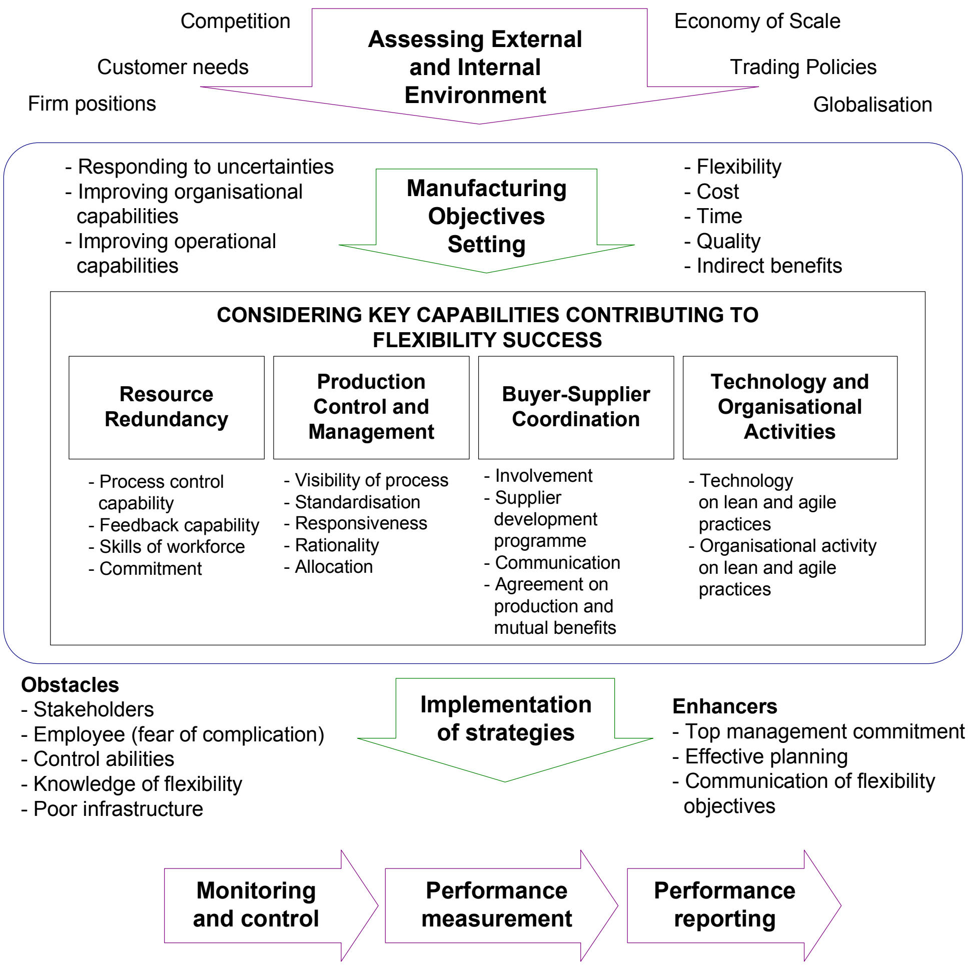

Figure 5.2: Manufacturing Flexibility Improvement Framework: Resource-Based View

There are choices of manufacturing strategy for a firm to select in order to satisfy the triggers and the company's needs. One practical approach which can be used to evaluate the choices is to consider key capabilities contributing to flexibility success, which exist in the current manufacturing system. These capabilities include resource redundancy, production control and management, buyer-supplier coordination, and technology and organisational activities (i.e. supporting structure and infrastructure). They could help in identifying the readiness of a company to pursue particular manufacturing flexibility improvement, thus resulting in the highest benefits from flexibility implementation. Moreover, to successfully achieve flexibility implementation, firms must improve the quality of strategic analysis, gaining more commitment from top management and employees at all levels, and improve controlling activities.

Table 5.19 identifies key issues of manufacturing flexibility studied in previous literatures and presents the extended issues deriving from conducting the research. This study applied the viewpoints on manufacturing flexibility from these four previous works and aimed to empirically investigate the multiple issues surrounding manufacturing flexibility in the real firms. In consequence, the findings were verified through such methods as face-to-face validation and statistical validation.

Table 5.19: Extension of Existing Frameworks

Authors	Key issues of Framework	Points to be extended
Vokurka and O'Leary-Kelly (2000)	This framework identified four variables; organisational strategy; environmental factors; organisational attributes; and technology that are believed to influence the firm's choice of manufacturing flexibility types.	The case study findings provided more insights on these four variables in different firms. This also confirmed that firm's choice of manufacturing flexibility in each firm was different.
Correa (1994)	Outlines relationship between planned and unplanned changes and manufacturing flexibility	The framework was applied in capacity planning, manufacturing control, and supply control activities to analyse flexibility performance. Thus, key problems of flexibility failure were obtained.
Gerwin (1993)	Framework proposed flexibility improvement process including identification uncertainties, development of a manufacturing strategy, determination of required flexibility, and development of performance measurement.	Awareness and practices of manufacturing flexibility improvement were investigated. The suggestion on flexibility improvement process was then made.
Suarez et al (1991)	Fit between the required and observed types and levels of flexibility when implementing and managing manufacturing flexibility improves organisation's performance	Strategic and operating issues were examined to be used in identifying the fit when implementing manufacturing flexibility.

Next, this study aims at integrating the results from an empirical investigation to develop a decision model and decision tools which can provide managers with more explicit understanding of manufacturing flexibility and can improve the accuracy of decisions for improving manufacturing flexibility as a means of process improvement.

5.7 CONCLUSION

This chapter presents the results from the automotive industry survey on the empirical investigation of critical capabilities and the flexibility performance. According to the findings from case studies in Chapter 4, it showed that the understanding of manufacturing flexibility at the operational level has not been very clear. The framework encompassing the operating factors (i.e. capabilities) critical to flexibility performance was developed to address the importance of such capabilities on manufacturing flexibility outcomes. The results of the quantitative study illustrated that the improvement efforts on flexibility capabilities are varied and these lead to different result on manufacturing flexibility performance. In addition, the extent to which firms emphasise lean practices and agile practices also influences the level of flexibility performance. The results from the quantitative study support the viewpoints derived from five automotive plants (i.e. TMT, SNA, IMCT, TSA, and TAAP). Thus, it is confirmed that the firms that expect good results from flexibility implementation are required to put forth more intense improvement efforts on flexibility capabilities – from a greater emphasis on workforce development and resource management, to greater levels of coordination between company and suppliers.

The critical flexibility capabilities were also derived as the main outcome of the chapter. The study took a first step towards providing key capabilities contributing to flexibility success (i.e. focusing on operational level) for the assessment of success on individual flexibility decisions. The next stage of this research (Chapter 6) will be the operationalisation of the manufacturing flexibility improvement framework to provide a model and tool to assist managers to make decisions in a more structured and consistent manner.

CHAPTER 6: DEVELOPMENT OF STRATEGIC DECISION-MAKING FRAMEWORK FOR MANUFACTURING FLEXIBILITY IMPROVEMENT

The findings in previous chapters provided deeper insights on how OEMs and suppliers should manage processes, i.e. planning, implementing and monitoring, and clarify what strategic and operating issues including supplier issues should be taken into account in order to achieve higher flexibility in manufacturing and the supply chain context. These can be used as decision-making criteria when flexibility improvement is needed. The purpose of this chapter is to construct a strategic decision-making framework for manufacturing flexibility improvement and an analytical framework for the evaluation of selected strategy that would provide the highest degree of flexibility fit and flexibility success, by employing the findings derived from the case study investigation (Chapter 4) and survey (Chapter 5). This chapter begins with viewpoints on justification of manufacturing flexibility improvement from the case studies described in Section 6.1. Next, Section 6.2 describes an importance of analytical framework and criteria in the strategic decision-making process. The set of decision criteria in strategic and operational levels are established in Section 6.3. The preliminary decision-making framework for manufacturing flexibility improvement was developed and described in Section 6.4. The background of decision-making techniques of Analytic Hierarchy Process (AHP) is provided in Section 6.5 and detailed steps in justifying manufacturing flexibility improvement based on such techniques are described in Section 6.6. Finally, the conclusion of this chapter is presented in Section 6.7.

6.1 JUSTIFICATION OF MANUFACTURING FLEXIBILITY IMPROVEMENT

Manufacturing flexibility can be more efficiently performed when it is prepared and planned prior to the variations or fluctuation which would have occurred. Despite the fact that this is implicit in current strategic planning process of Thai automotive firms, the managers found it to be of interest as it can support the final decision by including flexibility considerations into strategic planning tools. The observations resulting from the qualitative analysis of the strategic planning are that; manufacturing flexibility improvement can be effectively obtained when there is an alignment between business strategy and organisational capabilities. In other words, such improvement can be achieved when considering all related manufacturing functions when designing for flexibility, and flexibility dimension should be directly evaluated by its own term together with such other measures as cost, time, quality, and deficiencies.

The five case studies revealed the characteristics that five automotive firms employ in making decision regarding manufacturing flexibility improvement and the relationship between many variables and selected strategies. Figure 6.1 shows the mapping of the flexibility improvement programme and the degree of flexibility in five automotive plants. The flexibility deployment can be characterised by three levels of implementation.

- ***Proactive:*** Decision makers of this type seek to develop flexibility through integrated supply chain management techniques across the entire supply chain in a planned and staged manner. A long-term project is expected to deliver higher manufacturing flexibility and other business benefits.

- ***Reactive:*** Decision makers seek to improve manufacturing flexibility in specific processes within the business to improve efficiencies in production or supply chain functions. At this level adequate planning, costing and definition of the project are recommended, and real cost savings are a primary objective.

- ***Inert:*** This is viewed as the lowest level of improvement. Flexibility improvement can be considered as just adding cost to the business.

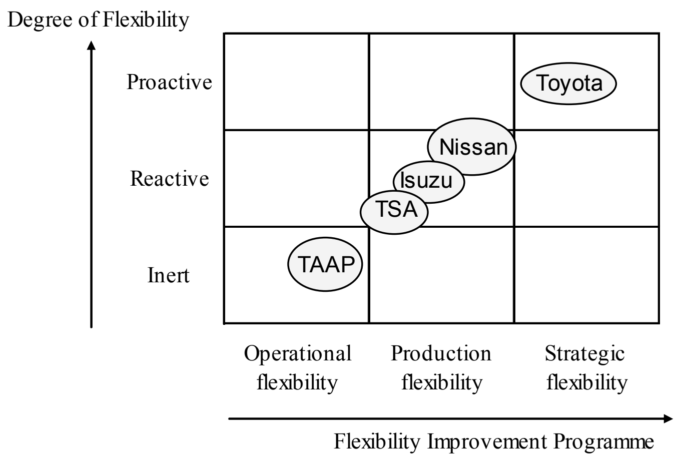

Figure 6.1: Classification of Flexibility in Automotive Plants

From the case study evidence regarding considerations of flexibility improvement, three main types of flexibility; operational flexibility, production flexibility, and strategic flexibility are exposed. Also, the decision variables related to those three types of implementation consist of;

(1) Business Requirements. This refers to uncertainty (i.e. business circumstances) and current firm requirements. From case studies, due to different contextual factors, TMT is most likely to concentrate on the importance of flexibility improvement, followed by SNA, IMCT, TSA, and TAAP, respectively. Despite the fact that IMCT has gained a big market share and has performed better manufacturing performances than SNA, flexibility performance in the former plant seems to be lower than the latter plant (see Figure 6.1). One reason can be that IMCT mainly operates in the domestic market where manufacturing conditions, complexity, and variety are not significantly high, whereas SNA operates on a higher level of global scale by exporting vehicles in a higher ratio than IMCT does. Unlike the other four plants, TMT is progressing globally and expanding their plant capacity and capability to deal on an extreme global scale. Flexibility is the key management weapon to smooth the operations for TMT production. Thus, it is evident that any firms that are going to operate on a global scale and with an extended network need to build flexibility properly and manage it effectively beforehand if they want to be successful. Also, flexibility is manufacturing capability that is independent and it is not guaranteed by looking at other capabilities such as cost, quality, time, and overall performance.

Tools, techniques, and approaches regarding flexibility can be classified at three main levels; operational, production, and strategic flexibility. It had been found that firms with global operations like TMT are likely to pursue tools, techniques, and approaches of all levels. In contrast to TAAP that operates only for the local market, it concerns only operational flexibility or day-to-day basis approaches for reacting to changes. It can thus be concluded that the importance of tactical and strategic views of flexibility increases when firms deal with global issues. It can be reflected from such aspects as part commonality, supplier parks, manufacturing-marketing coordination, is introduced in the firms when operating globally. In summary, the influential factors characterising various flexibility implementation include:

- ***Types of Uncertainty.*** Based on industry level, five automotive firms are aware of the importance and benefit of manufacturing flexibility in the same perspectives (i.e. pursuing economies of scale). However, the awareness and practices of manufacturing flexibility are very different when considered at the firm level. Firms are dealing with different types of uncertainty to various extents. TMT has encountered the uncertainties mainly caused by global demand and regional growth. Methods focusing on operational flexibility, production flexibility, and strategic flexibility are all employed in this plant.

- ***Firm Requirements.*** Different strategic objectives have directly influenced the firms to implement different flexibility strategies. SNA is concerned with the increased customer satisfaction and market share as the main strategic focuses. These result in transforming production from batch to unit production and introducing a wider range of new products to customers. Thus, key flexibility strategies in the plant involves enhancing flexibility level in new production, implementing new information technology to support the flexibility within the production and supply chain. In contrast, TAAP focuses on increases of order quantities and cost savings so that flexibility strategies are likely to involve utilising the resources in more flexible and effective ways.

(2) Benefits and Costs of Flexibility. Cost and benefit of flexibility can be seen as explicit factors to classify the implementation. Due to different resources and conditions, it is likely that flexibility seems to add costs to the business in TAAP perspectives but it can generate many benefits to the production of TMT. To implement a flexibility programme, the author suggests that costs and benefits must be considered in each flexibility type. In other words, focusing on volume flexibility, mix flexibility, machine flexibility, sequence flexibility, etc. costs and benefits for achieving these all flexibility types must be examined in the analysis both at the plant level and shop-floor level.

(3) Implementation and Operations. Flexibility requires a number of actors and agents, who have to manage and control during and after implementation. Based upon the resource-based theory, firms find it necessary to understand how capable their existing resources are prior to deciding to implement any strategies. IMCT considers workforce skills and knowledge as critical factors for flexibility improvement, while TMT is aware of supplier capabilities when making such flexibility decisions. Introducing a new ordering process or enhancing supplier development programme is likely to use less efforts and resources for SNA than in TSA due to different firm configurations; make-to-order vs. make-to-stock, large vs. small supplier network. Overall, from the case studies, it is likely that, among key issues influencing flexibility, capabilities or performances in relation to plant/network structure and infrastructure and workforce issues are critical to decision-making in IMCT, TSA, and TAAP, while performance regarding supply chain and production control issues influence flexibility improvement decisions in TMT and SNA. The evidence reflects that effective strategic planning process must consider a number of factors at the operational level, apart from the strategic level, to ensure appropriateness and applicability of the decisions. It is necessary to consider the extent to which flexibility decisions would be successfully implemented and operated.

The issues obtained from the empirical investigation (i.e. case study and survey) are grouped to four major areas including; production and control management; resource redundancy; buyer-supplier coordination; and technology and organisational support. They are considered '*the flexibility success factors*' that managers have to be aware of when making their selection of actions. In doing this, the possibility of flexibility failure is likely to be reduced as key factors affecting flexibility performance are thoroughly examined by decision maker teams prior to making the final decision.

To sum up, from the case study evidence, systematic justification on manufacturing flexibility is feasible to create and it is likely to provide many advantages to the decision makers. The decision model will be further constructed and applied to the decision makers in automotive manufacturing setting. The results from the model testing will be presented in forms of comprehensiveness, utility, and applicability of the model. The detailed construction and testing of the decision model will be presented in Chapter 7.

6.2 MANUFACTURING FLEXIBILITY DECISION MAKING PROCESS

This section presents a normative model of manufacturing flexibility decision making by exploring various models of decision-making with identification of contributions and limitations for applicability to the current research. Currently, the literatures on decision-making process in relation to manufacturing flexibility only intend to measure flexibility level and evaluate the flexibility types (Cox, 1989; Son & Park, 1990; Sethi and Sethi , 1990). Nevertheless, processes of successful flexibility implementation were suggested in the literatures (Correa, 1994; Gerwin, 2003; Boyle 2006). However, the analytical frameworks inadequately provided understanding of components of a decision making system for flexibility improvement and the set of criteria in those frameworks was not empirical. Also, the frameworks do not show how integration of the criteria and the whole decision making process is to be accomplished. Thus, to fill the gaps from the existing frameworks, the following sections will present the decision making model that better represents the purposes and goals of flexibility improvement (i.e. to align with business strategy, manufacturing strategy, operations conditions, and to succeed in flexibility implementation).

6.2.1 Strategic Decision-Making Process

As previously mentioned, manufacturing flexibility often lacks comprehensive framework and is not properly managed in most manufacturing firms. The study of the current problems in managing manufacturing flexibility and establishing underlying concepts for improving the level of flexibility achieved become beneficial. Also, the justification framework for assessing the actions which provide the highest level of manufacturing flexibility is challenging to be developed.

Typically, the decision model has to include three main processes; reviewing process, planning assessment process, and implementation assessment process (Brugha, 2004). Firstly, the review process is used to confirm if an improvement initiative or activity conforms to established goals, objectives, and targets of the firm. Secondly, the planning assessment process refers to an investigation, by appropriate decision makers, of the impacts of the initiatives in order to determine who and what will be influenced by the initiatives and how. This process involves data sets, ratings, and impacts. Thirdly, the implementation assessment process involves determining the success level of actual commencement and actions and also includes auditing to determine if actions are achieved and the impacts are expected and acceptable.

To simplify the decision model, it is useful to develop the criteria and components of a decision making system for flexibility improvement with respect to these processes. The success of flexibility improvement can be justified against criteria representing desirable attributes and the success level can be quantified. In this study, only critical variables that represent the issues surrounding flexibility from empirical investigations are used in the decision-making process in order to simplify the strategic decision-making.

6.2.2 Analytical Framework for Manufacturing Flexibility Decisions

A truly flexible plant, a plant which is flexible on all dimensions, may be impossible to achieve: different flexibility types tend to be achieved through different configurations of, and emphases on, production technology, production management techniques, relationships with suppliers, human resource management, and product development processes. As little is known about the interrelationships among the various flexibility types and the trade-offs (Koste and Malhotra, 2000), the best way to make such flexibility decisions is that they must be aligned with the environmental conditions in which it operates such as external environment, firm's business strategy, operations, technology, resources.

The purpose of developing an analytical framework is to have a means to structure the critical analysis of flexibility improvement. This new analytical framework can be used in the evaluation of various actions to come up with the one that provides the highest flexibility to an organisation. It was designed to model strategic and operational perspectives of manufacturing flexibility. For the purpose of this study, a '*criterion*' is defined as a rule or a standard for making judgment about whether the selected actions can deliver the highest flexibility, i.e. flexibility improvement success (Keeney and Gregory, 2005) .

6.3 ESTABLISHING DECISION HIERARCHY FOR FLEXIBILITY IMPROVEMENT

Based on the framework described above, this section attempts to establish decision criteria and hierarchy for facilitating the decision making process of manufacturing flexibility improvement. Section 6.3.1 describes key factors in strategic level as reflected in the five case studies. The factors in operational level are then presented in Section 6.3.2.

6.3.1 Strategic Level: Aligning with Business Conditions and Manufacturing Objectives

For evaluating the flexibility strategies in the manufacturing firms, parameters in both strategic, tactical, and operational level need to be looked into. In the strategic level, the strategic objectives are mapped to four perspectives, which are improving competitiveness, improving customer satisfaction, improving operational performances, and reducing uncertainties. Based on case studies, two critical parameters in the strategic level, which are uncertainty and firm requirements, influence different strategic objectives that the firm might pursue. They are described as follows:

a) Uncertainties: External Triggers

In the automotive industry, the uncertainty which may affect the firm's performance can be classified from these five main sources that are customer, market demand, competitors, government, and production. The firm must respond to the customer in terms of product, price, delivery and quality. Nowadays, the automotive firms in Thailand do not only serve domestic customers but also international customers so that manufacturing must put more emphasis on the number of product variety, production cost for offering a good price to customers, lead-time and delivery time, and quality of finished vehicles to match fast-changing trends and each demographic customer. All of the five automotive plants agreed that product variety is a key factor that plays an important role in automotive industry in customer perspective.

Uncertainty in demand volume in the markets also influences the automotive firms to be enthusiastic in adapting their manufacturing. The inability to adjust volume can lead to many aspects of losses such as customer satisfaction, sales opportunities, manufacturing losses, competitiveness and so on. The demand on products can be divided into two types; demand on current or available models, and demand on new models. In terms of the demand on current models, it had been found that export vehicle demand has an influence on the need to be flexible in TMT, SNA, IMCT, and TSA. The variation in export volume occurs more frequently since they now rely on the export, not only the domestic market. Local demand is a typical factor for any manufacturing firms to be focused on. Demand for new models such as changing specification, minor model changes, and major model changes need more frequent responses as product life cycles are shortened.

Competitors are one of the sources that provide uncertainties to the company. Competitiveness in aspects of advanced technology, short delivery time, low price offers, and so on may be a result of a superior manufacturing capability of competitors. The firms have to be flexible in the way they react and change their process and capabilities in the competition. Global competitors and local competitors are taken into account when considering a flexibility improvement plan.

Automotive firms in Thailand are mostly from direct foreign investment so that government has a measure of control over the industry in many aspects. All firms claimed that government policies can often apparently constrain their original business plans and companies have to adjust and create new plans in a short period of time. Taxation policy and environmental policy can be changed within the period of three to five years. Instability of government-related actions is one of the issues that firms must deal with.

b) Firm requirements: Internal Triggers

Gerwin (1993) stated that flexibility can be represented by the four generic strategies: *adaptive*, e.g. the defensive or reactive use of flexibility to accommodate unknown uncertainty; redefinition, e.g. the *proactive* use of flexibility to raise customer expectations, increase uncertainty for its rivals and gain competitive edge; *banking*, e.g. the defensive use of flexibility to accommodate known types of uncertainty such as surges in demand or alternatively the proactive use of surplus flexibility to redefine competitive conditions; and *reduction*, e.g. the use of long term contracts with customers and suppliers, preventive maintenance and total quality control programmes and designing for manufacture to limit the need for manufacturing flexibility. Making appropriate selection on such strategy is important as it is believed that choices of flexibility are inherently distinguished and have their own specific purpose.

The evidence from the case studies suggests that different companies require flexibility for different purposes. Therefore, it is necessary to assess internal environment such as organisational capabilities and operational capabilities to identify the needs of the firm. From the case studies, internal triggers can be grouped here. The identification of organisational capabilities includes configuration and knowledge. The configuration refers to the characteristics of existing structure and infrastructure of the firm such as process complexity and supply chain structure. This was found to be important to decision-making on flexibility. When the operations within the plant or its supply chain are more complex, the firm needs to improve its operations and processes by such methods as restructuring, reengineering, etc. In other words, the firm needs to determine whether its operations and processes are consistent with current business context, and which aspects an improvement is required so that the decision on the improvements can be effectively made. In the same manner, the firm also needs to determine the extent to which its organisational knowledge is capable to compete with competitors and create profitability to the firm.

Operational capabilities including production control, inventory control, process reconfiguration, and supply chain management are determined as key areas for improvement in a manufacturing setting. It is certain that the improvements must be made within the capability of these manufacturing functions.

c) Manufacturing Objectives: Benefits and Costs of Flexibility

In practical situations, decisions on flexibility improvement are not always clear cut and factors often need to be a trade-off in order to reach a decision. Thus, the best procedure is to identify benefits and pitfalls of flexibility. They are considered at a tactical level. However, this research does not study this factor in detail, but rather provides only general background in the decision-making process. Thus, the author combines and presents this factor into the strategic level to simplifying the decision stages. They can provide guideline on which decisions should be adopted to satisfy manufacturing objectives in terms of costs and benefits. Based on literatures and case studies, the examples of key impacts on manufacturing flexibility in each activity can be described as follows, and this can outline a set of benefits and pitfalls of flexibility for the decision-making process:

- Flexibility is '*the degree to which a firm is able to adjust the time in which it can ship or receive goods*' (Prater et al, 2001). One can establish subcontracting networks to facilitate a form of flexible production designed to meet the diverse needs of customers. Regarding this, the number of subcontractors as being a means to provide flexibility can have impacts on sourcing performance and firm performance. For example, loss of control of subcontractors, and low final product quality can result.
- Close suppliers can be used as flexibility strategy. Using close and few suppliers for specific subassembly parts to improve flexibility in production can lead to some pitfalls. Suppliers may find themselves being in difficulty but they cannot do anything much because of the power of OEMs, as mentioned in Chapter 4. Thus, to some extent, even though suppliers can deliver parts that meet the standard and quality in a given time their production can be unbalanced. That means the supply chain system is not optimised when considering the broader view.
- The impacts of flexibility on production mainly involve efficiency and responsiveness. It is obvious that implementing flexibility can sometimes reduce the quality of final products, reinforce the opportunities to respond

to another market requirement or uncertainty, and lower the level of control ability.

- The workforce is a critical issue for flexibility implementation. It is a sensitive issue and impacts must be evaluated for all involved aspects. As flexibility deals with uncertainties, clear understanding and direction in terms of operational procedures, problems currently faced with, and directions of the solution need to be made and they must be communicated to the workforce at all levels.
- Implementation of flexibility sometimes requires changing or adjusting the plant and network structure and infrastructure. The perceived benefits to supply chain structure must be evaluated against perceived costs from implementing such actions. For instances, implementation of Build-to-Order plant (BTO) may include an increased risk for capacity utilisation and the benefits from reduced reaction time from market to production.

Since manufacturing flexibility requires actions from all the above functions in an organisation, any impact involving flexibility performance on each manufacturing activity has to be taken into account in the decision analysis to ensure the highest benefits and least negative impacts to an organisation. A proposed set of benefits of flexibility and related pitfalls relating to those key functions were developed from the literatures and case study results (Chandrashekar, 1994; Newman and Hanna, 1994; Mohamed et al, 2001; Biesebroeck, 2007; Hutchison and Das, 2007). For instance, Chandrashekar (1994) concluded that utilisation level is a key determinant of the effectiveness of the process improvement for flexibility. Trade-offs between cost advantage and flexibility advantages were considered in the study of Newman and Hanna (1994) on equipment flexibility problems. Mohamed et al (2001) studied the relationship between the degree of machine flexibility and the level of system performance. Biesebroeck (2007) studied the productivity penalties in the use of mass and flexible technology in producing greater product variety. The results showed that, for a decrease of the degree of machine flexibility, it reduced the degree of routing flexibility and capacity flexibility, and also decreased the inventory level. Hutchison and Das (2007) included cost, quality, and delivery performance measures in their contingency framework for manufacturing flexibility. The set of benefits and pitfalls of flexibility are shown in Figure 6.2.

Flexibility	**Cost**
Machine can adjust production volume	Machine and equipment costs
Availability of parts in any situations	Capital investment costs
Suppliers can produce required parts	Unplanned costs
Accuracy in demand and market forecast	Labour and employee costs
Commonality of parts	Costs from spare machines or equipments
Suppliers can produce new required parts	Costs in developing suppliers
Ability of workers to learn about new parts	Training costs
Distribution of new part information to functions	Costs from designing new parts and products
Suppliers can produce a variety of parts	Switching costs
Managing part from various sources to production line	Costs in managing supply chain
Multi-skills of workers	Costs from errors in forecasting
A number of model mixes	Production costs
Plant and capacity expansion	
Capacity expansion of suppliers	**Time**
Ability of workers to work in new production unit	Idle time
A number of production sequences	Production lead-time
A variety of production sequences	Development time
Suppliers can produce parts along with company sequences	Switching time
Arrangement of workforces for each required sequence	Set-up time
Set-up time reduction	Learning time
Ability of workers to program and control machines	
Scheduling in accordance with operations of machines	**Indirect benefits**
Fast recovery and emergency system of machines	Supply chain efficiency
Maintenance teams performance	Inventory reduction
Ability of workforce and process for overtime production	Investment postponement
	Plant and resource utilisation
Quality	Knowledge transfer and enhancement
Work-in-process quality	Risk reduction
Final product quality	Business opportunity

Figure 6.2: Benefits and Costs of Flexibility from Literature and Case Studies

6.3.2 Operational Level: Satisfying Operations Conditions

The success of decision-making for flexibility improvement depends on a variety of factors, the foremost being the ability to meet critical business and manufacturing requirements. However, success also depends on the alignment between current operational capabilities and the selected action. Therefore, referring to the case studies and survey, the list of capabilities shown in Figure 6.3 was developed in order to enable identification of the current operational capabilities in such areas as production control, resource redundancy, buyer-supplier coordination, and supporting structure and infrastructure. They are the key set of capabilities that ensure the efficiency of the process of change.

Resource redundancy	
● *Process control*	The degree of readiness of process and technology to effectively analyse, interpret data, and implement actions for coping with the changes
● *Feedback control*	The degree of readiness of process and technology to effectively evaluate the performance of implemented actions
● *Skills*	The extent of skill level and variety of workforces in technical, communication, and management both of the firm and suppliers
● *Commitment*	The extent to which employees are committed for pursuing the missions and various key strategies are objective to the same goal
Production control and management	
● *Visibility*	The degree of ease that problems in production can be recognised, and the degree of availability and accessibility of data in problem-solving
● *Standardisation*	The use of standard procedures, materials, and processes within manufacturing and design functions
● *Responsiveness*	The extent to which system can react to foreseen and unforeseen problems and solve them in quick manner
● *Rationality*	The extent to which firm collects, interprets, and uses information systematically to planning and solving problems
● *Allocation*	The extent to which firm can effectively manage and use resources to achieve high profitability and order requirements
Buyer-supplier coordination	
● *Involvement*	The extent to which buyer and supplier involves in problems-solving and goal setting
● *Supplier development program*	The degree of effectiveness of supplier development program in terms of supplier improvement level in planning and technical knowledge
● *Information sharing and communication*	The degree of effectiveness of information sharing among buyer and suppliers, and the information technology for communication among them
● *Agreement setting*	The degree of clarification and effectiveness of agreement and mutual benefits being made between buyer and suppliers for handling variations and changes
Supporting structure and infrastructure	
● *Technology*	The degree of lean and agile technology and structure within the firm to successfully implement the actions
● *Organisational activities*	The degree of lean and agile organisational activities within the firm to successfully implement the actions

Figure 6.3: Operational attributes for flexibility improvement considerations

To sum up, the three main groups and eleven sub-groups of criteria which emerged from the empirical investigations are summarised in Table 6.1. They attempt to provide a scope of flexibility improvement decisions and structure the complex process into a simpler framework. The next section will describe the decision-making framework and incorporate such criteria developed into the framework.

Table 6.1: Criteria to evaluate successful flexibility improvement initiatives

Level of decision criteria	Objectives	Criteria	Sub-criteria
Strategic factors	Aligning with business conditions	Uncertainties	Customer, Competitors, Government, Market, Production
		Organisational capabilities	Configuration, Knowledge
		Operational capabilities	Production control, Inventory control, Supply chain management, Process reconfiguration
	Aligning with manufacturing objectives	Benefits of flexibility	Workforce, Production control, Supplier, Sourcing, Plant/network structure and infrastructure
		Pitfalls of flexibility	Cost, Time, Quality
		Indirect benefits	Business opportunities, Risk and mistake reduction, Future investments
Operating factors	Satisfying operations conditions	Resource redundancy	Skills of workforce, Commitment, Process control, Feedback and monitoring
		Production control and management	Rationality, Allocation, Responsiveness, Visibility, Standardisation
		Buyer-supplier coordination	Involvement, Supplier development programme, Information sharing and communication, Agreement settings
		Supporting structure and infrastructure	Technology and Organisational activities

6.4 A PROPOSED FLEXIBILITY IMPROVEMENT PROCESS

Developed from the study of Gerwin (1993), Boyle (2006) and an empirical study of this research, a flexibility improvement framework for evaluating the actions that provide the highest level of flexibility were constructed as shown in Figure 6.4. The framework consists of six key stages. The details in each stage are described as follows:

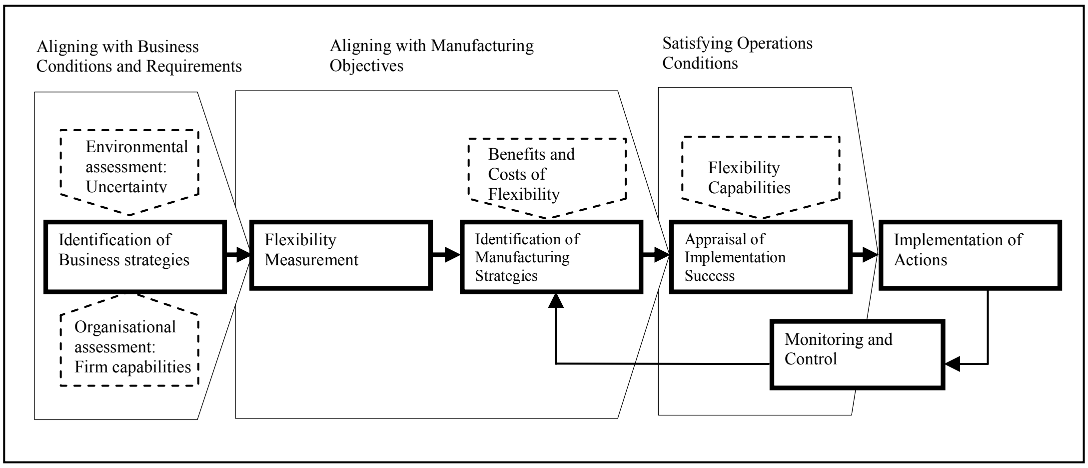

Figure 6.4: A Proposed Decision-Making Process of Manufacturing Flexibility Improvement with Evaluation Criteria

6.4.1 Identification of Business Strategies

The empirical study in Chapter 4 showed that the business strategy which a firm adopts is different. These subsequently reflect the actions that each firm adopts. One of the ways to identify which strategic objective should be focused on is to firstly understand the external (current and future market situations, competition etc.) and internal business environment (current strength and weakness). Once the business requirements are clearly defined, the strategic objective is examined and business strategy can be identified according to such parameters as uncertainties, organisational capabilities, and operational capabilities. The outlines of uncertainties and organisational capabilities that should be included in the analysis are presented as follows:

● Uncertainties: the firms should develop a specific type of flexibility corresponding to the unique features of the external environments. The uncertainties that are taken into account include:

a) Market and demand trends
b) Customer trends
c) Competitors
d) Government
e) Production

● Organisational capabilities: Organisational capability consists of various types of knowledge that are created and accumulated within the firm and it cannot be understood as a single entity, but rather as having a multilayered structure (Kusunoki et al 1998). The organisational capabilities that are taken into account include:

a) Configuration: Process and supply chain complexity
b) Organisational knowledge

● Operational capacities: This indicates the performance of operations in the following areas that include:

a) Inventory control
b) Production control
c) Process reconfiguration
d) Supply chain management

6.4.2 Flexibility Measurement

Gupta and Somers (1992) developed an instrument for measuring and analysing manufacturing flexibility. The instrument consists of 21 items representing nine components of manufacturing flexibility. Tsourveloudis and Phillis (1998) suggested a knowledge-based methodology for the measurement of manufacturing flexibility. Flexibility is an inherently vague notion, and an essential requirement in its measurement is the involvement of human perception and belief. Nine different flexibility types are measured, while the overall flexibility is given as the combined effect of these types. It can be seen that flexibility measurement is conducted in order to identify required flexibility. The required flexibility must be consistent with current flexibility capabilities of a manufacturing system and market requirements to avoid over or under flexibility investment. This point is described in the study of Olhager and West (2002). They proposed a framework employed methodology from quality function deployment (QFD) for modelling the deployment of the need for flexibility from the customers' viewpoints into manufacturing flexibility at various hierarchical levels.

The use of fuzzy logic methodology of Tsourveloudis and Phillis (1998) seems not to be appropriate in practice. As flexibility measurement is considered a new aspect for some manufacturing firms, it would be better to introduce the methodology that is easier to comprehend but effective such as a rating method. The author recognises the need to develop the '*spreadsheet*' for flexibility measurement including a list of flexibility types and their measures (see Appendix 8). The measures are the same as those used in the survey in Chapter 5. This can be distributed to relevant functions as a survey tool to achieve more accurate flexibility evaluation.

6.4.3 Identification of Manufacturing Strategy

Once the business strategy and required flexibility are derived, the manufacturing strategy can be established. In a strategic approach, it is necessary to build a bridge between manufacturing strategy and individual flexibility options to ensure the degree of strategic alignment. A multi-level decision hierarchy and intermediate decision levels are required to link flexibility benefits and pitfalls with the company's manufacturing strategy. Thus, the next step is to identify trade-offs relating to such manufacturing strategy to obtain the most appropriate action for flexibility that links to manufacturing strategy and provides the highest benefits to its organisation. In doing this, it affirms that selected action for flexibility is taken corresponding to business strategy and manufacturing objective. Trade-offs that should be taken into account include flexibility, cost, time, quality, and indirect benefits. For this research, the manufacturing objective is to improve and achieve the highest manufacturing flexibility. Thus, the most preferred actions must fulfill all required flexibility types at that time, while minimising cost and time, and maximising quality and indirect benefits. The outlines of flexibility, cost, time, quality, and indirect benefits that are taken into account in the analysis are shown in Figure 6.2.

6.4.4 Appraisal of Implementation Success

Boyle (2006) suggested the failures in implementing flexibility. They may cause from, firstly, problems implementing, operating and utilising the required technological tools (e.g. a FMS was required, but a lack of training on the FMS is slowing or preventing the flexibility benefits that the technology may offer). Secondly, change management obstacles such as behavioural resistance, lack of communication, lack of management support, information bottlenecks and loss of commitment for flexibility (e.g. people resist using the FMS technology; flexibility no longer a priority for senior management, making it difficult to obtain the monetary and human resources required to achieve desired levels of flexibility). Therefore, once action for flexibility has been evaluated and selected in the strategic level, the next critical step is to ensure that the selected action is aligned with current operations conditions and can deliver the highest flexibility performance when implemented. The outlines of operating factors that are taken into account in the analysis are shown in Figure 6.3.

It is noted that, with support from the survey results, *production control and management, resource redundancy, and buyer-supplier coordination* are capabilities which are significant to the success of manufacturing flexibility. In addition, the "*supporting structure and infrastructure on lean and agile practices"* also need to be taken into account as being means to deal with technological and organisational aspects of lean and agile practices. These can include technology-related capabilities (e.g. capability of the workforce to re-program the machines), and production and organisation-related activities (e.g. levelling production, Kanban, TQM practice).

6.4.5 Implementation of Actions

According to the case study investigation (Chapter 4), the issues of flexibility implementation have been pointed out, which consist of three main aspects including manufacturing aspects; workforce aspects; and supply chain aspects. In manufacturing aspects, two main issues that firms need to be more focused on consist of; improving process understandings and improving control infrastructure and activities. Process understandings refer to the understanding of what flexibility is accounted for and which resources are involved in each type of flexibility. An importance of control infrastructure and activities should be recognised by managers as they facilitate the implementation process and enhance the level of implementation success.

In workforce aspects, communication was found to be critical in flexibility implementation. In the context of the Thai automotive industry, it was found that functional personnel are likely to do their work according to standard procedures or specific directions without fully understanding them. The communication from managers to staff can, to some extent, provide clear background of the implementation and specific roles and responsibilities for staff in particular functions. As a result, this allows staff to provide more support to the related activities apart from their own tasks. In addition, this communication can be served as mechanisms to gain employee involvement and commitment.

In supply chain aspects, supply chain partners must consider sharing the responsibility for implementing and managing the required flexibility. Vickery et al. (1999) found that manufacturing is generally responsible for volume flexibility, marketing is generally responsible for distribution flexibility and research and design is responsible for new product introduction flexibility. By focusing on these flexibilities from an internal perspective, much of the contribution of a supply chain perspective is lost (Duclos et al., 2003). This showed that the responsibility in achieving each type of required flexibility should be shared by various stakeholders. Close cooperation between manufacturers and suppliers is essential for manufacturing flexibility achievement. For example, the ability of the suppliers can sometimes limit the ability of a manufacturer to respond rapidly to customer requirements. Thus, in achieving flexibility, both suppliers and manufacturers must share the responsibility so that overall processes can be effectively managed and implemented. In the context of the Thai automotive industry, many problems regarding suppliers have been found. For instance, supplier capability seems to be limited and extensive training is required. This leads to the tendency of higher global sourcing of Thai automakers. In consequence, the flexibility implementation with suppliers becomes more difficult to control. It can be said that this issue is found to be important for the Thai automotive industry with respect to flexibility management.

6.4.6 Monitoring and Control

The final stage of flexibility improvement framework is monitoring and control. It emphasises the importance of a control mechanism in monitoring and controlling the implemented flexibility types and levels. As discussed earlier, many frameworks suffer from not including a feedback loop in their frameworks to ensure continuous assessment of the implemented flexibility. The essence here is to continuously monitor and evaluate the strategic and operational fit between observed flexibility types and implemented flexibility types. As a result, suggested by Suarez et al. (1991), the observed and required flexibility must be compared to ensure that there is adequate fit. If there is a good fit between implemented and required flexibility types (i.e. they are equal), then it is expected that an organisation would obtain improvements in the business performance. If not, the control mechanism would trigger an alarm indicating that some adjustments are needed in the required flexibility types or at the implementation stage to improve manufacturing, supply chain and firm performance. Boyle (2006) suggested that the managing required flexibility stage focuses on three activities:

(1) Periodically measuring the actual flexibility to ensue that the required flexibility is still being achieved over time;

(2) Changing the required flexibility, when needed, to correspond to changing uncertainty and competitive, manufacturing and marketing strategies; therefore, ensuring that; and

(3) The required flexibility continues to help achieve the competitive, manufacturing and marketing strategies and positively influence business performance.

The managing required flexibility stage also addresses any problems regarding why the actual and required flexibility are not helping to improve business performance or helping to achieve the competitive, marketing, or manufacturing strategy. Possible reasons for a lack of business improvement include:

- inaccurately analysing the uncertainty faced by the manufacturing unit;
- developing an ineffective competitive strategy;
- developing a manufacturing strategy that does not match the competitive or marketing strategy;
- implementing the incorrect flexibility types and levels; and
- the uncertainty facing the organisation has changed since the required flexibility types and levels were first identified; as a result, the required flexibility types or levels are not those needed to address this new uncertainty.

According to the empirical study in Chapter 4, there is an important issue on monitoring and control that is an enhancement of both capacity and capability view of flexibility. Flexibility should be considered in terms of capacity (quantitative terms) and capability (qualitative terms) when assessment or evaluation are made. In doing this, it can offer a more accurate measurement of flexibility. Hence, the evidence suggests that flexibility measures should involve the quantitative and qualitative aspects of flexibility. This confirms that development of analytical framework incorporating qualitative dimensions of flexibility is necessary and useful in flexibility decision-making and implementation process.

The manufacturing flexibility improvement process developed in this research are summarised in the Table 6.2 by comparing to the work of Gerwin (1993) and Boyle (2006). It can be seen that important elements of the developed manufacturing flexibility improvement process are prioritisation of the decision criteria, especially in the appraisal of actions and implementation success.

Table 6.2: Summary of Key Elements of Manufacturing Flexibility Improvement Process

Processes of flexibility improvement	Key elements of processes by the authors		
	Gerwin (1993)	**Boyle (2006)**	**In this research**
Identification of business strategies	Identifying environmental uncertainties and strategic objectives.	Determining organisational competitive strategy and performing uncertainty analysis.	Determining environmental uncertainties, organisational competitive strategy and strategic objectives. Prioritising the business strategy based on suggested criteria.
Flexibility measurement	Measuring specific flexibility types affected by environmental and strategic objectives, and analysing the need for flexibility by evaluating required, potential, and actual flexibility.	Identifying and prioritising required aggregate, component, system flexibility.	Use of document for flexibility measurement by means of survey to obtain flexibility at all levels, i.e. aggregate, component, system and required, potential, and actual flexibility can be evaluated. Further works are required.
Identificaton of manufacturing strategies	Establishing manufacturing strategies under four modes of flexibility; adaptation, redefinition, banking, reduction, based on flexibility gaps analysed above.	Establishing manufacturing strategies under four modes of flexibility based on required flexibility.	Establishing manufacturing strategies under four modes of flexibility based on flexibility gaps analysed above. Prioritising the strategies based on suggested criteria.
Appraisal of actions and implementation success	Need for mathematical models to reduce the heuristic nature of the procedure.	Determining flexibility fit by considering required, potential and actual flexibility. It suggests that technological capabilities and organisational attributes should also be considered as they can be affected by changing potential and actual flexibility, i.e. flexibility level is changed over time.	Prioritising actions based on suggested criteria, i.e. set of manufacturing resources and capabilities.
Implementation of actions		A number of issues are addressed in order to effectively manage required flexibility.	The suggestions are made upon; manufacturing aspects (improving process understandings, and control structure and activities); workforce aspects (communication); and supply chain aspects (sharing of responsibilities btween OEMs and suppliers).
Monitoring and control	Continuous assessment of the gap to see if it is moving in the desired direction.	Periodically measure the actual flexibility.	Enhancement of capacity and capability views of flexibility is suggested.

6.5 BACKGROUND OF AN ANALYTIC HIERARCHY PROCESS

This section will be mainly devoted to a discussion of the overall framework model for the manufacturing flexibility improvement and evaluation methodology. Since most of the competence characteristics are qualitative, the comprehensive approaches regarding the subjective assessment procedure to conduct the evaluation process must be established. Also, the necessity of conducting a multi-dimensional performance analysis implies solving a multi-criteria decision-making problem.

MCDM is a wide research area comprising various methods and techniques (French 1986), including Utility Theory, outranking and mathematical multi-objective programming methods. Multi-Attribute Value Function (MAVF) and Analytic Hierarchy Process (AHP) are popular scoring methods and have been successful in a variety of applications. The application of the AHP is based on the following four principles:

1. Decomposition: a complex decision problem is decomposed into a hierarchy with each level consisting of a few manageable elements. Each element is also further decomposed into a manageable one;
2. Prioritisation: this involves pair-wise comparisons of various elements situated at the same level with respect to an element from the upper level of the hierarchy;
3. Synthesis: the priorities are pulled together through the principle of hierarchic composition to provide the overall assessment of the available alternatives; and
4. Sensitivity analysis: the stability of the outcome is determined by testing the best choice against 'what-if' type of change in the priorities of the criteria.

AHP aims at evaluating of a set of criteria elements and sub-criteria elements. The former method uses a value function, while the latter uses pair-wise comparisons. Despite its popularity, there are some criticisms imposed upon AHP for practical decision-making such as ambiguity in ratio scales (Dyer 1990), pair-wise comparisons (Watson and Freeling 1982), criteria weight, and problems in the rank reversal (Belton and Gear 1983). However, AHP overcomes other decision-making methods in many ways. It is a method with large penetration both in academic and professional environment and is implemented by business tools widely tested and validated. It is also possible to visually accomplish the sensitivity analysis in a practical way and allows decision makers to monitor the consistency while making their judgments (Roper-Lowe and Sharp, 1990). Most importantly, it has been used in many applications related to manufacturing decisions and found to be easily understood and applied by managers rather than sophisticated decision-making techniques. An important advantage of the AHP approach is its suitability to be used in both individual and group decision settings. In a group setting, it can be used to accommodate the views and judgments of the participants in the priority process (Byun, 2001).

The AHP also employs a consistency ratio (CR) measure to check the consistency of judgment. Inconsistency is likely to occur when decision-makers make careless errors or exaggerated judgment during the process of pair-wise comparisons. A CR of 0.1 is considered as an acceptable upper limit. If the CR is found to be greater than 0.1, the decision makers need to re-evaluate their judgments in the pair-wise comparison matrix, until an acceptable ratio (<0.1) is finally achieved. The details of structure and calculation of AHP are presented in Appendix 5. In summary, the characteristics of the AHP approach are totally compatible with the flexibility decision that is qualitative in nature. The AHP-based model developed is served as an aid and not as a closed box able to find a non-existent 'final answer' by offering the considerations of business environment, manufacturing objectives, and resources and capabilities in the operations in the context of manufacturing flexibility.

6.6 A PROPOSED STEPS FOR EVALUATING FLEXIBILITY IMPROVEMENT PROGRAMMES: AHP-BASED APPROACH

The Dynamic Equilibrium Model developed by Newman et al (1993) provided an importance on establishing balance between uncertainty and manufacturing options to minimise such pitfalls as technological overkill, obsolete infrastructure, and capability imbalances when manufacturing flexibility is required. According to this, the application of MCDM technique, especially AHP, was found to be applicable to the flexibility improvement by means of balancing the relevant factors in this complex problem. According to the empirical results and literatures on decision-making process, an examination of flexibility improvement can be decomposed into two main important phases, which are strategic and operational assessment. AHP principles can be applied to facilitate the assessment. Figure 6.5 presents schematic process of flexibility improvement by using AHP.

The explanation of the process is presented in Section 6.6.1 and Section 6.6.2 for strategic and operational assessment, respectively. The detailed steps for assessment are also described. In Section 6.6.3, the process is operationalised by providing a set of criteria and their descriptions for assessing actions for flexibility in a holistic view.

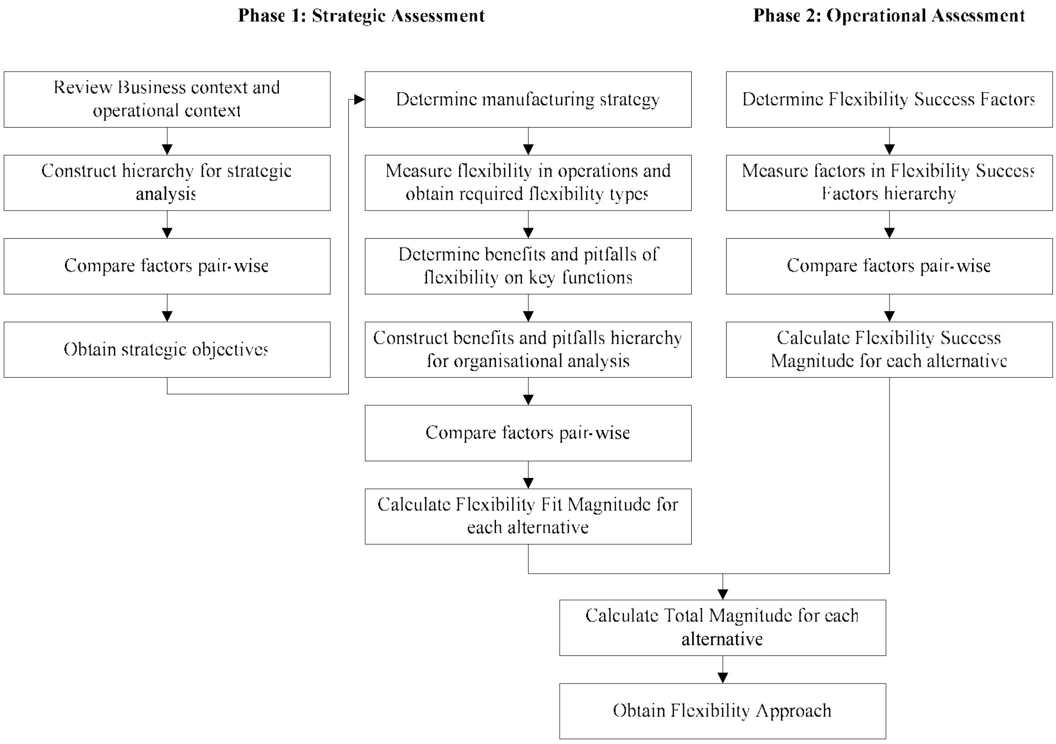

Figure 6.5: Process for Flexibility Improvement: AHP-Based Approach

6.6.1 Strategic Assessment

The preferences of companies for their external and internal environment influence the whole process of decision-making. External and internal environments are defined by three variables based on the literature review and survey and case study research. They consist of environmental uncertainty; organisational capabilities; and operational capabilities. The fact of being a manufacturing firm faced with high environmental uncertainties and having low organisational and operational capabilities can lead the company toward a different path from company, facing with high environmental uncertainties and having high organisational and operational capabilities. Therefore, companies have to be aware of their external and internal environments' needs in order to be able to have a systematic decision making process according to these needs. As such, the strategic assessment step is very important for companies to construct the right basis and understanding among the decision makers. Companies will be aware of their self-interests at the end of this step. The detailed activities in this step can be decomposed as follows:

- Identifying business strategy
- Measuring required flexibility
- Prioritising types of flexibility to be improved

- Formulating manufacturing strategy according to required flexibility type
- Evaluating benefits and costs of flexibility
- Selecting possible strategies

To operationalise these activities, two main steps to select the best manufacturing flexibility improvement strategy regarding strategic assessment are developed as follows:

Step 1: Identifying business conditions and firm requirements, and prioritising strategic objectives

In this stage, managers have to, firstly, assess business environment and identify key forces. Next, the prioritisation of triggers such as types of uncertainties, areas of organisational capabilities and operational capabilities are made with respect to current business conditions. Next, the weighting of relative importance on sub-factors of the triggers will be made. Finally, the influence of sub-factors on each strategic objective will be assessed and relative importance weighting will be made. The weighting data in Step 1 will be input to 'Expert Choice Software' to calculate the ranking results of strategic objectives. The ranking can be good information for managers to formulate manufacturing strategy and possible lists of manufacturing flexibility improvement initiatives. The outputs from this step are then used to formulate manufacturing strategy. This can be done by firstly measuring required flexibility and prioritising the flexibility types. Subsequently, manufacturing strategy is subsequently formed, which identifies targets and goals of flexibility for related functions to follow.

Step 2: Achieving Flexibility Fit

Once manufacturing strategy is formulated, the possible lists of manufacturing flexibility improvement initiatives can be identified. In order to select the best initiative, the degree of flexibility fit must be examined. In this study, the definition of flexibility fit is as follows:

> Flexibility fit is defined as the alignment between manufacturing objectives and selected flexibility initiative. Manufacturing objectives with respect to manufacturing flexibility are to maximise benefits of flexibility and minimise the effects of pitfalls of flexibility in manufacturing and supply chain functions.

The selection process begins with weighting the relative importance of manufacturing views in relation to flexibility. The manufacturing views on flexibility will be assessed; to which extent that the managers are concerned about the benefits of flexibility or pitfalls of flexibility by considering the effects of flexibility implementation on manufacturing and supply chain performances. Next, the weighting of relative importance on sub-factors of the benefits and pitfalls of flexibility will be made. Finally, the influence of sub-factors on flexibility initiatives will be assessed and relative importance weighting will be made.

In the same manner, the weighting data in Step 2 will be input to Expert Choice Software to calculate the ranking results of flexibility initiatives. This weighting process ensures the highest degree of flexibility fit. Therefore, the one with the highest ranking score can be considered the best strategy as it can provide maximum benefits throughout manufacturing and supply chain functions.

6.6.2 Operational Assessment

This section describes the assessment of the degree of flexibility implementation success. A list of actions in Step 2 is taken into account for the operational assessment; companies have to evaluate their current operations to ensure that flexibility can be implemented successfully. The detailed activities in this step can be decomposed as follows:

- Evaluating degree of flexibility success in current operations by considering possible flexibility strategies against operating factors critical to flexibility performance
- Reconciling the action for flexibility from strategic and operational viewpoints
- Making final decisions
- Final decisions or strategies obtained

It is noted that the right data sources for the analysis are critical since the selection is going to be totally dependent on these data. If the data are incorrect, the decision will be inaccurate. The steps involve selecting the best manufacturing flexibility improvement strategy regarding operational assessment are developed as follows:

Step 3: Evaluating Flexibility Success

This step concerns the degree of the implementation success of the flexibility initiatives. The operating factors critical to the flexibility success were examined through the empirical studies. In this study, these factors are served as indicators to measure the degree of implementation success of flexibility initiatives.

> Flexibility success refers to the outcomes of which manufacturing system can be effectively respond and adjust to demand and uncertainties effectively with no penalties such as additional costs, quality reduction, and late delivery

The evaluation process starts with weighting relative importance of operational areas significant to the plant. The description of these operational areas is provided and it will be used as the evaluation standard (see Chapter 5). Next, the evaluation of current performance in each operational sub-area will be made. Finally, the degree of implementation success will be assessed on each flexibility initiative with respect to operational sub-area and relative importance weighting will be made.

In the same manner, the weighting data in Step 3 will be input to Expert Choice Software to calculate the ranking results of flexibility initiatives. This weighting process ensures the highest degree of flexibility success when implemented. Therefore, the one with highest ranking score can be considered the best strategy as it can provide the highest degree of success when the initiative is implemented.

Step 4: Combining Score on Flexibility Improvement Initiatives

The results from Steps 2 and 3 will be combined to obtain the final score on each flexibility improvement initiative. The one with the highest score implies the highest degree of flexibility fit and flexibility success so that the highest potential of flexibility and the highest benefits to an organisation can be acquired.

6.6.3 Operationalisation of the Proposed Framework

Manufacturing flexibility is becoming a competitive priority and many firms seek to improve their flexibility by adopting initiatives. Since flexibility is multi-dimensional, selecting such initiatives which can provide full potentials of flexibility is challenging. It is necessary to evaluate a number of factors surrounding flexibility in order to optimise the selection of initiatives. A decision-making framework was developed based on the literature review and the findings from the survey and the case study results of Chapter 5 and 6 in the previous section. The decision-making framework is operationalised in this section to structure the framework into simple and comprehensive steps, including critical variables that have proven effects on the flexibility improvement decisions in the model. It includes both strategic issues including uncertainty, organisational capabilities, operational capabilities, manufacturing objectives, and operational issues including the important flexibility success factors.

The Multi-Criteria Decision-Making technique acts as the heart of the decision support system. MCDM adopts the factors involving flexibility success derived from empirical study and interacts with the user inputs. It can evaluate the most effective initiative on flexibility improvement based on the user input. In a brief summary, the framework consists of five main processes. Firstly, the strategic position of the firm must be articulated to all stakeholders and policy makers. Secondly, the external and internal environment factors such as customer, market, production, etc. are assessed in terms of uncertainties and current capabilities of the firm to identify the strategic requirements. Thirdly, manufacturing strategy can be formed on the basis of specified strategic objectives and manufacturing objectives are then derived. Thirdly, based on manufacturing objectives, benefits and pitfalls of flexibility can be prioritised and the most appropriate approach is then obtained. Fourthly, the examination on flexibility implementation is made by assessing current operation conditions against a set of flexibility success factors. Finally, the flexibility approach is derived with having the highest alignment to market, business strategy, manufacturing strategy, and highest degree of success when implemented. The basic steps of how this framework works are explained as follows.

Step 1: Assessing Uncertainties and Firm Capabilities

Prior to deciding which actions to improve specified required flexibility, firms must assess the external and internal business environment. Such strategic management tools as SWOT analysis and Balanced Scorecard (BSC) can be employed.

Step 2: Alternatives on Business Strategy

The results from Steps 1 and 2 are reconciled to derive possible alternatives on business strategy. This can be made through brainstorming among policy makers and management teams.

Step 3: Judgment on Business Strategy

Analytic Hierarchy Process (AHP) is used to justify the appropriate business strategy for specific firm requirements and business environment. Figure 6.6 shows the decision hierarchy for analytical evaluation of the strategic objective. The details of factors are explained in Section 6.3.1.

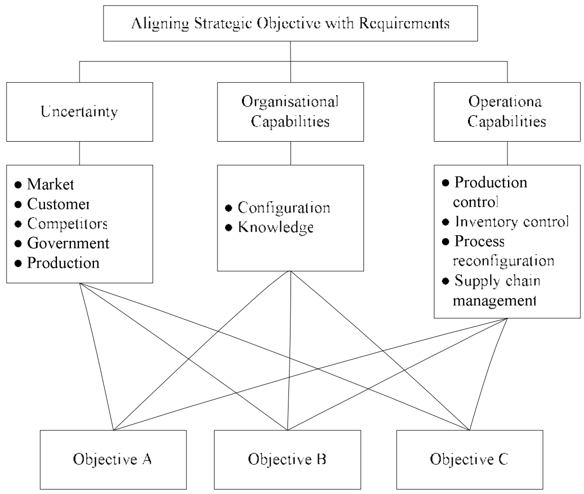

Figure 6.6: Hierarchy for analytical evaluation of strategic objectives

Step 4: Flexibility Measurement

Using the developed spreadsheet containing key flexibility types and their measures, the rating method is applied to examine the current level of flexibility in the manufacturing system. In consequence, the required flexibility is identified.

Step 5: Alternatives on Actions

Regarding weightings of each business strategy, the manufacturing strategy can be then examined. Through brainstorming among managers in related functions, the alternatives of actions for improving required flexibility are acquired. The alternatives on business strategy can be presented in four modes of flexibility, which are adaptive, banking, reduction, and proactive mode.

Step 6: Trading-Off Manufacturing Objectives

The candidate actions are required to justify against manufacturing objectives such as flexibility, cost, time, quality, and indirect benefits. In doing this, an optimisation of manufacturing objective is achieved. In other words, flexibility benefits are optimised. Using constructed AHP model in Figure 6.7, trading-off among those manufacturing objectives is made.

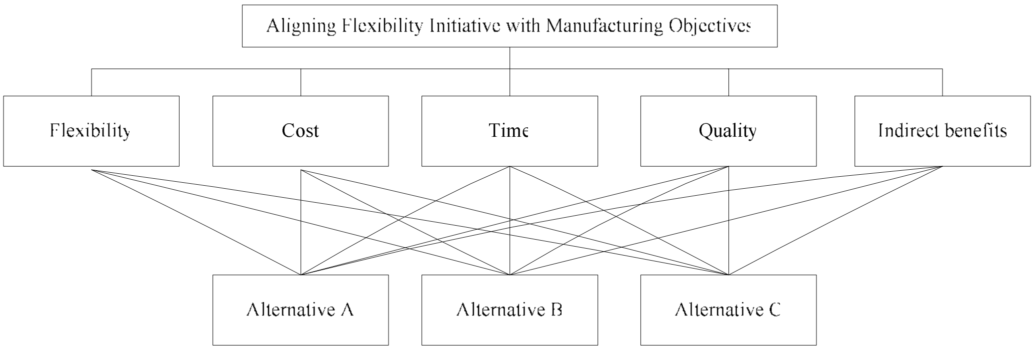

Figure 6.7: Hierarchy for analytical evaluation of flexibility strategies: aligning with manufacturing objectives

Step 7: Weighting Results on Aligning with Market, Business Objectives and Manufacturing Objectives

Based on the input in the previous step, the MCDM will generate the potential action ratings and the recommended decisions.

Step 8: Evaluating Flexibility Success

It is significant to ensure the success of actions in terms of flexibility performance. Hence, this step concerns the degree of flexibility success for each candidate action (from Step 5). Based on key mechanisms of manufacturing flexibility (i.e. production management and control, competency building, coordination), the evaluation methodology of manufacturing flexibility can be constructed. The '*Flexibility Success Factors'* as developed in Chapter 5 are used as criteria for the evaluation. Figure 6.8 shows the decision hierarchy for analytical evaluation of flexibility approach.

Step 9: Weighting Results on Aligning with Operations Conditions

Based on the input in the previous step, the MCDM will generate the potential action ratings and the recommended decisions.

Step 10: Global Weighting Results (Integration of Results from Steps 7 and 9)

The selection of the actions for flexibility improvement is made based on the one which has the highest rating. It implies being the most fit to market, business objectives, and manufacturing objectives, as well as the highest flexibility success when implemented.

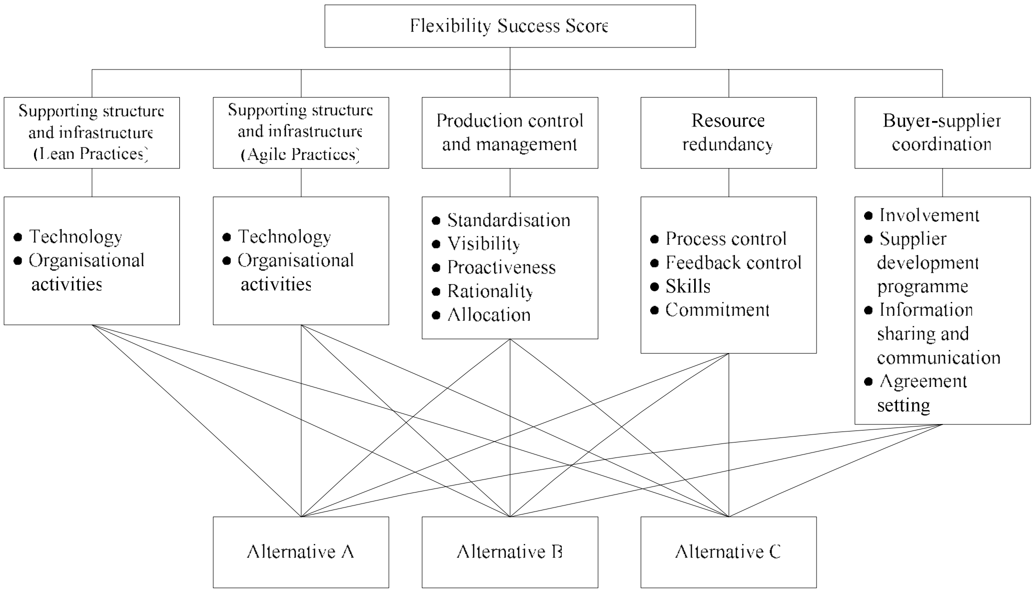

Figure 6.8: Hierarchy for analytical evaluation of flexibility approach

6.6.4 Quantifying the Qualitative Data

As explained previously, this type of decision is a multi-criteria decision and a multi-level decision. Because of these characteristics, an analytical approach is needed to better evaluate vast amounts of data. Especially, the use of qualitative data causes difficulties in the decision-making process since this type of data is not inherently metric in nature. Nevertheless, it is hard to consider both the qualitative and the quantitative data in the same calculation and make a decision at the end; the decision-maker should consider both types of data simultaneously.

Most of the attributes of flexibility capability are qualitative by nature. This means that the pairwise comparisons of the evaluations need to rely upon the subjective judgment of the decision-makers. If there is more than one decision-maker involved, the pairwise scores assigned to the criteria would be based on the geometric mean of the individual scores. Regarding these viewpoints, the represented variables are necessary for flexibility improvement decisions due to the complexity of the process. They are illustrated in Figure 6.9, 6.10, and 6.11.

Strategic level - Aligning with business requirements and conditions

Uncertainties	
• *Customer*	The changing of behaviour and orders in terms of product type, model, and volumes from customers
• *Market demand*	The changing of demand in each product segment such as domestic and export
• *Competitors*	The changing of competition as a result of new move and strategy of competitors within the local and global market
• *Government*	The changing of policies from government such as taxation, local content agreement, trading policy
• *Production*	The changing of operational performances due to inefficient production, operations, management, and external triggers
Firm capability	
• *Organisational capability*	The abilities of the firm in an organisational level including configuration (i.e. structure) and knowledge
• *Operational capability*	The abilities of the firm in an operational level consisting of production control, inventory control, process reconfiguration, and supply chain management

Figure 6.9: Summaries of Descriptions of Factors: Business Requirements

Strategic level -Aligning with manufacturing objectives

Benefits	
• *Flexibility*	The benefits of flexibility to manufacturing functions in areas of workforces, production and control, plant structure/infrastructure, sourcing, and supplier that firm is expected to attain.
Pitfalls	
• *Cost*	The costs that relate to implementation of flexibility such as investment costs, overhead costs, labour costs, etc.
• *Time*	The effects of flexibility on lead-time and production time
• *Quality*	The effects of flexibility on quality of work-in-process and final product
• *Indirect impacts*	The benefits of flexibility in other aspects such as risk, investment and to other functions such as supply chain, business

Figure 6.10: Summaries of Descriptions of Factors: Benefits and Pitfalls of Flexibility

Operational level - **Satisfying operations conditions i.e. existence of resources and capabilities**

Resource redundancy

● *Process control*	The degree of readiness of process and technology to effectively analyse, interpret data, and implement actions for coping with the changes
● *Feedback control*	The degree of readiness of process and technology to effectively evaluate the performance of implemented actions
● *Skills*	The extent of skill level and variety of workforces in technical, communication, and management both of the firm and suppliers
● *Commitment*	The extent to which employees are committed for pursuing the missions and various key strategies are objective to the same goal

Production control and management

● *Visibility*	The degree of ease that problems in production can be recognised, and the degree of availability and accessibility of data in problem-solving
● *Standardisation*	The use of standard procedures, materials, and processes within manufacturing and design functions
● *Responsiveness*	The extent to which system can react to foreseen and unforeseen problems and solve them quickly
● *Rationality*	The extent to which firm collects, interprets, and uses information systematically to planning and solving problems
● *Allocation*	The extent to which firm can effectively manage and use resources to achieve high profitability and order requirements

Buyer-supplier coordination

● *Involvement*	The extent to which buyer and supplier involved in problems-solving and goal setting
● *Supplier development program*	The degree of effectiveness of supplier development program in terms of supplier improvement level in planning and technical knowledge
● *Information sharing and communication*	The degree of effectiveness of information sharing among buyer and suppliers, and the information technology for communication among them
● *Agreement setting*	The degree of clarification and effectiveness of agreement and mutual benefits being made between buyer and suppliers for handling variations and changes

Supporting capabilities

● *Technology*	The degree of lean and agile technology and structure within the firm to successfully implement the actions
● *Organisational activities*	The degree of lean and agile organisational activities within the firm to successfully implement the actions

Figure 6.11: Summaries of Descriptions of Factors: Resources and Capabilities

6.7 CONCLUSION

This chapter presented the development of the decision making framework and model of flexibility improvement for a manufacturing setting. The flexibility improvement framework was developed over six stages; identification of business strategies; flexibility measurement; manufacturing strategy formation; appraisal of implementation success; implementation of actions; and monitoring and control.

The key possible factors involved in the decision-making process were structured into a hierarchy. There are two group of factors; strategic factors and operational factors. Strategic factors involve the planning assessment stage in which the objective is to select actions aligning with market, business strategy, and manufacturing strategy. Operational factors involve the implementation assessment stage in which the objective is to select actions providing the highest level of success when implemented. By incorporating the framework and decision hierarchy, a decision model for improving flexibility was constructed. The selection process is dominated by AHP technique. The role of a computer-aid model system (AHP model) in the decision-making process is to provide a framework and guide for flexibility improvement. The AHP model assists decision-makers in achieving an objective assessment in manufacturing flexibility improvement. It enables the decision-making process to consider strategic and operational factors systematically. It allows decision-makers to make objective assessment of the flexibility improvement alternatives based on benefits and pitfalls. In addition, the objective assessment of the factors involving the level of success implementation can be made.

This developed model is intended to fill the gap by recognising the importance of flexibility improvement, by providing critical data on the criteria considered, and by outlining a recommended process for improving flexibility. This research overcomes the disadvantage of the AHP model on possible influence or bias from stakeholders in developing criteria by using the empirical results from interviews and survey to develop the key criteria for flexibility improvement for manufacturing firms. Finally, the model will be tested in companies to capture more details about the contents and the final strategies of the testing firm, and to confirm that the framework is applicable for general use (Chapter 7).

CHAPTER 7: APPLICATION AND VALIDATION OF FLEXIBILITY IMPROVEMENT FRAMEWORK

This chapter illustrates the use of the Analytic Hierarchy Process (AHP) as a decision support model to help managers understand the trade-offs between strategic and operational dimensions relating to flexibility improvement. It also demonstrates how AHP can be used to evaluate the relative importance of various strategic and operational traits and to assess the relative success performance of several options along these traits.

These following sections present case examples to demonstrate the proposed methodology. Compared with those traditional methods, the advantages of the proposed method can be summarised as; it can handle with the expert knowledge, engineering judgment and the historical data for selecting an approach for improving flexibility in a consistent manner; the approach can be evaluated directly using representing quantifying factors; and the introduction of flexibility capability index enables decision makers to perform a selection more systematically so that a more reliable result can be obtained. Section 7.1 summarises the key features of manufacturing flexibility improvement framework as developed from fieldworks. The validation process is then described in Section 7.2 which comprises two main stages; testing on strategic assessment and operational assessment. The testing results on strategic assessment and operational assessment are presented in Section 7.3 and Section 7.4, respectively. Section 7.5 summarises the implications of the model and Section 7.6 presents the conclusion of the chapter.

7.1 FLEXIBILITY IMPROVEMENT FRAMEWORK

Referring to Chapter 6, the author had conducted the interviews with senior managers and engineers in leading Thai automotive companies to investigate the current practices of manufacturing flexibility, and to seek problems and key issues for achieving manufacturing flexibility. In addition, the survey had been conducted to validate the factors critical to manufacturing flexibility performance within the Thai automotive industry. As a result of the fieldworks, ‘the framework and decision tool for manufacturing flexibility improvement’ were developed. The framework is presented in Figure 7.1.

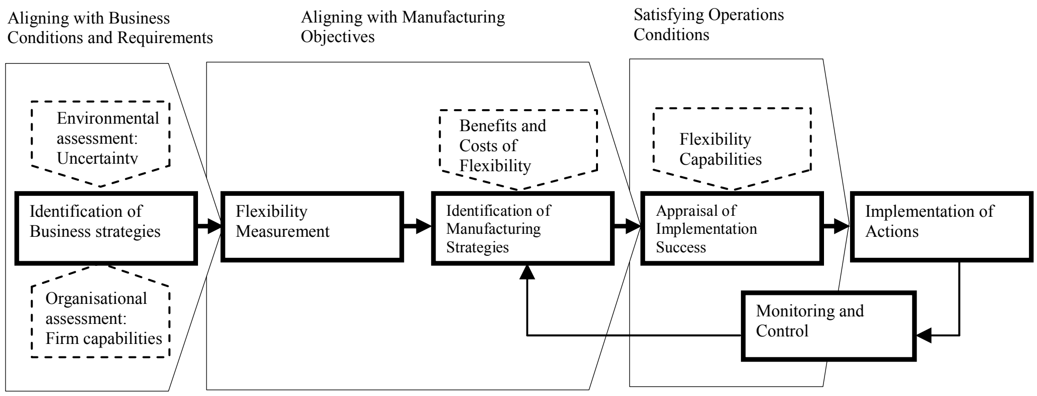

Figure 7.1: Decision-Making Framework of Manufacturing Flexibility

In terms of decision-making, the framework of manufacturing flexibility improvement was designed for facilitating managers in assessing strategy for manufacturing flexibility improvement in the plant. Due to multi-dimensions of manufacturing flexibility, a number of factors from manufacturing and supply chain aspects taken into account can cause complexity for making final decisions; on which strategy can maximise the potentials of flexibility and align with the firm's business objectives, manufacturing objectives, and current operations conditions. The evaluation framework comprises the following three main steps.

1. Aligning with business requirements means the requirements of the firm to deal with current business circumstances, including the need to respond to various types of uncertainties, the need to improve organisational and operational capabilities.
2. Aligning with manufacturing objectives means the achievement of the highest manufacturing priorities including flexibility, cost, time, quality, and organisational benefits.
3. Satisfying operational conditions means the consideration of operational factors critical to the success of flexibility implementation, for example degree of skilled workforces, degree of technology and organisational support on agile manufacturing, degree of production control and management, etc.

7.2 FRAMEWORK AND MODEL VALIDATION PROCESS

This section provides a brief introduction to the decision-making tool and validation process. Firstly, the main objective of this tool, i.e. AHP, is to facilitate the decision-making process and allow decision-makers to put their emphasis on the consideration of important factors relating to manufacturing flexibility improvement in order to select the best improvement initiative for their current business conditions, manufacturing objectives, and operations conditions. The software of Expert Choice employed for weighting on decision criteria was developed to facilitate data input of the evaluation and selection process.

The case study method is chosen for the validation stage (Zebda, 2003*)*. The framework and model were directly applied to decision-makers. Due to various contexts of flexibility improvement in each case company, the case studies can increase the validity of the framework and model. The objective of validation is to test the feasibility of the model including two key steps of assessment; strategic and operational assessment. Three case studies of automotive companies were conducted. Two case studies were conducted to test the strategic assessment of the model, while one case study was made for testing operational assessment. The detailed stages of validation process will be further explained in Section 7.3 and 7.4, for strategic and operational assessment, respectively.

Once the framework and model were applied to the decision-makers, it is necessary to assess whether the model is practical to use in the actual decision-making process. The following questionnaire (Figure 7.2) is used to assess the applicability of the developed model. The questionnaire contains fifteen questions indicating three criteria of applicability; feasibility; usability; and utility (Platts, 1993). The five point-Likert scales are used to assess the degree to which the user is satisfied with the model and framework. The open-end questions of user's suggestions on the model and framework are also included in the questionnaire. However, it is noted that questionnaire assessments are made only in testing of operational assessment as it is a focus of the research emphasising on flexibility implementation rather than business and manufacturing formation.

Assessment Criteria	1	2	3	4	5
1. Feasibility					
1.1 The input information required for the model is available in the firm.					
1.2 The knowledge and experiences of participants can provide effective input information.					
1.3 Time consumed for the use of model is appropriate.					
1.4 People are willing to use the model in the meeting or discussion.					
2. Usability					
2.1 The objectives of the model were clear.					
2.2 The model and process step were clearly defined.					
2.3 Process of the evaluation and selection was easy to follow and use.					
2.4 The model was easy to use by all participants.					
2.5 The approach and format for evaluating and selecting strategy were appropriate.					
2.6 Main problems encountered in evaluation and selection process.					
3. Utility					
3.1 The decision criteria were relevant to be considered and evaluated among improvement strategies					
3.2 Sub-criteria for selecting strategy were relevant to be considered and evaluated among improvement strategies.					
3.3 The evaluation and selection process provides useful steps in selecting the best strategy.					
3.4 The output of the process was worthwhile for time being consumed.					
3.5 What degree of confidence do you have in the suggested strategy from the model?					
4. Suggestion					
4.1 Strengths of the model					
4.2 Weakness of the model					
4.3 Suggestions for improvement					

5 = Strongly agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly disagree

Figure 7.2: Assessment Questionnaire

7.3 TESTING OF AHP MODEL: STRATEGIC CONSIDERATIONS

As mentioned in the previous chapter (Chapter 5), there are different focuses or directions on manufacturing flexibility improvement. This testing of AHP-based model was conducted and it is necessary that, to confirm the application of the proposed model, the resulted improvement option has to be consistent with one that the firm currently adopts or intends to adopt. The users for this testing are top managers who are in charge of the strategic planning process and investment decisions of the plant. The detailed description of testing are illustrated in Section 7.3.1 and the results are shown in Section 7.3.2.

7.3.1 Description of Testing

During the interview stage, a focus of flexibility improvement in the companies was obtained. The objective of this test is to select the alternatives that align to market, business strategy and manufacturing strategy and to test whether criteria derived from the previous research stage are valid. The AHP model guides the decision makers through a systematic evaluation of the flexibility strategies and uses the decision makers' judgments to construct an overall composite score called '*the flexibility fit score*'. The testing began with identification of business strategy and flexibility measurement. After a review of the current flexibility performance in key processes, decision makers decided what criteria they should consider in evaluating the strategies.

There are two major sub-models that were used to identify the flexibility fit score. Each of them consists of four components (referring to Chapter 6). For the first model, the first component is the goal, which is aligning strategic objectives with business conditions. The next is criteria, which illustrates external and internal environment considerations associated with flexibility. The third is sub-criteria, which detail the measurements for each criterion above. The fourth component consists of the strategic objectives on flexibility improvement. The goal of the second model is to align flexibility strategy with the manufacturing objectives. The components include criteria and sub-criteria which illustrates the manufacturing objective considerations, i.e. flexibility, cost, time, quality, and indirect benefits. The final component of the model is alternatives, which portray potential flexibility improvement initiatives or techniques. The next section illustrates the results from testing of the model. They are shown as follows:

7.3.2 Model Results of Toyota Motors Thailand

To obtain the criteria and the weight of each sub-criterion, the researcher held discussions with decision-makers in relation to senior manager's experiences in improving flexibility. The quantitative results from the manager are shown as follows:

7.3.2.1 Business Environmental Assessment

The key questions for a senior manager are that of when a firm should strive for flexibility and by which methods. The decision-making process presented in Chapter

6 was followed. Based on sub-criteria of the first model, each sub-criterion was evaluated within its own group and between groups with respects to current external and internal environment of the firm. According to the literature, strategic objectives can be mainly grouped into four key objectives; increasing competitiveness, improving customer satisfaction, improving operational performances, reducing uncertainties. From the senior manager's evaluation, TMT is meant to improve operational performances and reduce uncertainties as the result of market expansion and higher competition of a local market. The results of rating are shown in Table 7.1.

Table 7.1: Ranking of Strategic Objectives

Requirements	*Strategic Objectives*	*Local rating*	*Global rating*
R1: Environmental uncertainties; wt: 0.413	S1: Increasing competitiveness	0.181	0.075
	S2: Improving customer satisfaction	0.261	0.108
	S3: Improving operational performances	0.307	0.127
	S4: Reducing uncertainties	0.251	0.104
R2: Organisational capabilities; wt: 0.260	S1: Increasing competitiveness	0.153	0.040
	S2: Improving customer satisfaction	0.140	0.036
	S3: Improving operational performances	0.286	0.074
	S4: Reducing uncertainties	0.421	0.109
R3: Operational capabilities; wt: 0.327	S1: Increasing competitiveness	0.115	0.038
	S2: Improving customer satisfaction	0.182	0.060
	S3: Improving operational performances	0.386	0.126
	S4: Reducing uncertainties	0.316	0.103

Inconsistency ratio = 0.05

The firm was able to decide which flexibility strategy can fulfill the firm's needs as strategic objectives were identified. According to the business environmental assessment results, all flexibility modes were considered and can be included in alternatives. However, the proactive mode is the most preferred for TMT. The alternative of the plant is whether or not to build the new plant containing flexible technology, infrastructure and structure as well as process improvement based on flexible thinking. However, the most important is that not only the selected strategy has to meet the requirements, but also it has to deliver the highest level of flexibility outcomes as much as possible. In relation to flexibility, it is then necessary to consider the benefits and costs for being flexible to obtain optimal decisions. Thus, the evaluation of the second model was made by considering the benefits and pitfalls of flexibility on key functions in the organisation (i.e. production, sourcing, supplier, workforce, plant structure and infrastructure) if specific action was adopted and implemented. The impacts include perceived outcomes in terms of flexibility, cost, time, and quality on the key functions. For example, in aspects of supplier, building the new flexible plant has little impact on cost of the plant due to existence of quantified suppliers. Table 7.2 summarises key factors that senior manager of TMT consider for flexibility improvement.

Table 7.2: Summaries of Key Strategic Factors or Criteria Considered in TMT

Business context	Benefits	Pitfalls
External environment - Global demand - Shorter lead-time *Internal environment* - Product variety - Plant capacity - Operational performance	- Increases of demand forecasting ability - Ability to manage information flow - Ability to manage part flow from various sources - A numbers of model and sequence can be produced - Higher skills and multi-skills of workforces - Supplier capability to produce as required - Inventory reduction - Plant utilisation - Reduction of investment in the future	- Increases of idle time - Increase of set-up time - Increase of total production time - Reduction of quality of WIP and final products - Costs from mistakes or errors - Costs from sparing resources - Investment costs

Once the importance of flexibility improvement in current business context, and the benefits and pitfalls of flexibility for each alternative were discussed with key managers, the next task is to construct decision modelling of AHP and input the weighting of those factors based on senior manager's perspectives. The relative importance of factors and the potential actions that align with the firm's business context and objectives are shown in Section 7.3.2.2.

7.3.2.2 Weights of Alternatives on Flexibility Improvement

The key strategic factors in Table 7.2 were input and the decision model was formed. The summary of manager rating was shown in Table 7.3 and 7.4. Table 7.3 illustrated the importance of each factor with regards to current perspectives of the firm such as manufacturing objectives, organisational, operational resources. The importance of each factor on each alternative was shown in Table 7.4.

Table 7.3: Final ratings of flexibility strategies in TMT

Criterion	*Sub-criterion*	*Weight*	*F1*	*F2*
Benefits	**Relative weight of benefits 0.750**			
	Demand forecasting	0.068	0.750	0.250
	Information flow	0.054	0.333	0.667
	Part/material flow	0.070	0.333	0.667
	Number of model and sequence	0.176	0.750	0.250
	High and multiple skills	0.181	0.250	0.750
	Supplier capability	0.087	0.333	0.667
	Inventory reduction	0.108	0.750	0.250
	Plant utilisation	0.207	0.750	0.250
	Future investment reduction	0.049	0.667	0.333
	Sub-rating with respect to benefits		**0.567**	**0.433**
Pitfalls	**Relative weight of pitfalls 0.250**			
	Idle time	0.114	0.667	0.333
	Set-up time	0.164	0.667	0.333
	Total production time	0.196	0.667	0.333
	Quality	0.235	0.500	0.500
	Costs from mistakes or errors	0.108	0.500	0.500
	Costs from sparing resources	0.108	0.333	0.667
	Investment costs	0.075	0.333	0.667
	Sub-rating with respect to pitfalls		**0.548**	**0.451**
Final rating			**0.562**	**0.438**

Table 7.4: Relative importance of strategic factors in TMT

Variables	Weight	Investing plant expansion (F1)	Leveraging existing resources (F2)
Demand forecasting	0.0510	0.0383	0.0128
Information flow	0.0405	0.0135	0.0270
Part/material flow	0.0525	0.0175	0.0350
Number of model and sequence	**0.1320**	**0.0990**	0.0330
High and multiple skills	**0.1358**	0.0339	**0.1018**
Supplier capability	**0.0653**	0.0217	**0.0435**
Inventory reduction	**0.0810**	**0.0608**	0.0203
Plant utilisation	**0.1553**	**0.1164**	**0.0388**
Future investment reduction	0.0368	0.0245	0.0122
Idle time	0.0285	0.0190	0.0095
Set-up time	0.0410	0.0273	0.0137
Total production time	0.0490	0.0327	0.0163
Quality	**0.0588**	0.0294	0.0294
Costs from mistakes or errors	0.0270	0.0135	0.0135
Costs from sparing resources	0.0270	0.0090	0.0180
Investment costs	0.0188	0.0062	0.0125

7.3.2.3 Discussion of AHP results

This section discusses the results from AHP modelling. The senior manager in TMT was confident that, with its excellent manufacturing and operations, the plant can manage the operations to prevent the costs of flexibility. This also associates with the business strategy of the firm which focuses on differentiation, focus, or cost strategy. The firm tends to rely on differentiation strategy, therefore, the benefits of flexibility were considered more important. When considering the benefits of flexibility, building new plant with flexible technology and operations tends to provide higher flexibility outcomes than only leveraging existing resources. Managers realised the extent to which a number of constraints such as process complexity and plant capacity are presented in the current operations so that it may be hard to achieve highest flexibility outcomes if relying on existing resources. When considering pitfalls of flexibility, building the new plant is likely to reduce the effects of such pitfalls to a greater extent than another alternative. For instance, idle time can sometimes occur when there is a switch between models. Idle time may not be reduced with existing technology and operations but rather with investing new ones. Another pitfall is that of investment costs. Flexibility is not free, so the company must ensure that it can accept the amounts of investment costs for its selected alternative before making final decisions. It is obvious that leveraging existing resources yield lower investment costs than building the new plant. However, the decisions rest on many factors and they must trade-off against each other in order to derive the optimal decisions. Finally, by considering all factors, the results from weighting showed that building the new plant is preferable as it met the firm's manufacturing objectives and firm resources.

Among the benefits and pitfalls taken into account, number of model and sequence, high and multiple skills, supplier capability, inventory reduction, plant utilisation, and quality are most concerned in this plant with respect to flexibility improvement decisions (Table 7.4). An explanation can be made as follows:

- **Increases of number of model and sequence to the system**

Flexibility can be made through reducing the number of batch sizes, ordering parts unit by unit, and installing more flexible technology. As a result, these allow more models and model mixes being produced to meet customer demand in terms of product variety thus resulting in higher customer satisfaction. Existing manufacturing operations can only produce some limited models and sequences due to fixed process and limited capacity expansion of such operations. These restrict the ability to increase a number of models and sequences. Thus, to increase a number of models and sequences and to manage them effectively, investing new plant and improving resource exploitation throughout the organisation were selected as key manufacturing strategy rather than only leveraging existing firm resources.

- **High and multiple skills of workforce**

It is clear that producing more product varieties and process complexity requires high and multiple skills of workforces. TMT expected higher and more multiple skills of workforces from an improvement initiative, as its product portfolio has been increased due to the company's global export. When compared investing new plant to leveraging existing resources, the latter is likely to increase skills of workforces more than the former does. However, it is noted that the skills of workforces mostly depend on soft aspects such as effectiveness of training programme that a firm adopts, employee empowerment and involvement, rather than hard aspects like the influences of plant structure and infrastructure.

- **Enhancement of supplier capability**

One of the indirect benefits of flexibility is that supplier capability can be enhanced. A company needs to search for suppliers who can produce and provide required parts to the company when it operates in a more flexible environment. Since suppliers are competitive among each other, it can be said that they have to improve their capabilities to satisfy the needs of the OEMs, receive a number of orders, and be able to effectively manage the orders by the required delivery date. TMT perceived this kind of benefit that flexibility offers. Supplier capability is likely to be enhanced mainly through supplier development programme of the firm. Thus, leveraging existing resources such as improving communication technology, enhancing level of information sharing, etc. seem to provide more direct impacts on supplier capability than the influences of plant structure and infrastructure.

- **Inventory reduction**

One of the distinct advantages of flexibility is the reduction of inventory level. This is simply because production closely responds to market demand, so the inventory level is then reduced. For TMT, inventory control requires investing in new technology and control system. Leveraging existing resources seems to be difficult to obtain effective inventory control compared with investing in new technology and systems. According to the business plan of the company, TMT had expanded the warehouse area and installed a control system to cope with a flexible environment.

- **Plant utilisation**

As production can manufacture the vehicle model for which demand is high, and reduce the model with declining demand, plant utilisation can be in higher level. This seems to be a very distinct benefit of flexibility for this firm. Prior to implementing the concept of flexibility, this plant encountered the plant utilisation problem in 2003 due to demand uncertainty. To improve the plant utilisation rate under manufacturing conditions such as high production volume and product variety, establishing a new plant (i.e. sister plant) is preferable. Not only can a model under low demand reduce volumes within the main plant, but the plant can also choose to move to manufacture within the sister plant.

- **Quality**

The most noticeable pitfall of flexibility is quality of work-in-process and final product. It is clear that flexibility can lead to quality problems if there is a lack of good planning, employee involvement, communication, and implementation. The standard procedure should be set and clearly stated so that uncertainties and variations can be better coped with. It is not remarkable to say that which alternatives can better result in higher quality performance. It rather depends on the operational aspects in which the further detailed justification is required. Therefore, in this stage, the relative importance is applied equally as the weighting for this variable is hardly made.

7.3.3 Model Results from Isuzu Motor Company (Thailand)

The discussion with decision-makers in relation to their experiences in improving flexibility was made. The results from using AHP can reveal key points relating to flexibility improvement of the firm.

7.3.3.1 Business Environmental Assessment

The key question is that of when a firm should strive for flexibility and by which methods. Based on sub-criteria, each sub-criterion was evaluated within its own group and between groups with respects to current external and internal environment of the firm, from strategic objectives of increasing competitiveness, improving customer satisfaction, improving operational performances, reducing uncertainties. IMCT tends to improve operational performances and improve customer satisfaction in order to maintain competitiveness and improve profitability. The results from AHP are shown in Table 7.5. From this point, flexibility strategy can be identified according to specified strategic objectives. The alternatives are whether or not to implement methodology-based flexibility. This method could contribute not to the flexibility of the specific machine but to the flexibility of the manufacturing system such as modularity and transportability (Schonberger, 2000). The methodology-base flexibility approach that the manager proposed was the use of low cost automation. The question is whether the manager can ensure that this approach can offer the highest benefits to the manufacturing system.

Table 7.5: Ranking of Strategic Objectives

Requirements	*Strategic Objectives*	*Local rating*	*Global rating*
R1: Environmental uncertainties; wt: 0.571	S1: Increasing competitiveness	0.154	0.064
	S2: Improving customer satisfaction	0.256	0.106
	S3: Improving operational performances	0.353	0.146
	S4: Reducing uncertainties	0.236	0.097
R2: Organisational capabilities; wt: 0.143	S1: Increasing competitiveness	0.195	0.051
	S2: Improving customer satisfaction	0.199	0.052
	S3: Improving operational performances	0.408	0.106
	S4: Reducing uncertainties	0.199	0.052
R3: Operational capabilities; wt: 0.286	S1: Increasing competitiveness	0.169	0.055
	S2: Improving customer satisfaction	0.229	0.075
	S3: Improving operational performances	0.369	0.121
	S4: Reducing uncertainties	0.232	0.076

Inconsistency ratio = 0.00

The importance of flexibility improvement in current business context, and the benefits and pitfalls of flexibility for each alternative, were discussed with key managers. By considering the current needs of the plant and conditions, key aspects that manager considered regarding the flexibility improvement, are shown in Table 7.6.

In the next section, the evaluation was made by considering the benefits and pitfalls of flexibility on key functions in the organisation if specific action (i.e. low cost automation) is adopted and implemented. The impacts include perceived outcomes in terms of flexibility, cost, time, and quality on the key functions. For example, in aspects of production and control, low cost automation has little impact on cost of the plant but the benefits may not be compared with advanced technology.

Table 7.6: Summaries of Key Strategic Factors or Criteria Considered in IMCT

Business context	Benefits	Pitfalls
External environment - Fierce competition in local market (e.g. time-based competition) *Internal environment* - Operational performance - Product variety	- Ability to adjust and expand capacity - Increases of part commonality - Ability to manage information flow - Supplier capability to produce as required - Set-up time reduction - Higher skills and multi-skills of workforces - Plant utilisation - Reduction of investment in the future - Reduction of risks	- Increases of idle time - Increase of set-up time - Increase of Total production time - Reduction of quality of WIP and final products - Costs from sparing resources - Investment costs - Switching costs - Overhead costs

7.3.3.2 Weights of Alternatives on Flexibility Improvement

Based on the sub-criteria in level 6, all flexibility modes were considered and can be included in alternatives. However, the adaptive mode is the one preferred by Isuzu. The alternative of the plant is to implement either low cost automation or advanced technology in order to achieve a higher level of manufacturing flexibility. As the key strategic factors in Table 7.6 were input and the decision model was formed, the summary of manager rating was shown in Table 7.7 and 7.8. Table 7.7 resulted from the data input from managers of the plant illustrating the importance of each factor with regards to current perspectives of the firm such as manufacturing objectives, organisational, operational resources. The importance of each factor on each alternative for IMCT was shown in Table 7.8.

Table 7.7: Final ratings of flexibility strategies in IMCT

Criterion	*Sub-criterion*	*Weight*	*F1*	*F2*
Benefits	**Relative weight of benefits 0.333**			
	Capacity adjustment/expansion	0.118	0.667	0.333
	Part commonality	0.070	0.333	0.667
	Information flow	0.091	0.333	0.667
	Supplier capability	0.077	0.500	0.500
	Set-up time reduction	0.127	0.250	0.750
	High and multiple skills of workforce	0.199	0.333	0.667
	Plant utilisation	0.176	0.250	0.750
	Future investment reduction	0.049	0.750	0.250
	Risk reduction	0.094	0.250	0.750
	Sub-rating with respect to benefits		**0.380**	**0.620**
Pitfalls	**Relative weight of pitfalls 0.667**			
	Idle time	0.077	0.333	0.667
	Set-up time	0.070	0.333	0.667
	Total production time	0.145	0.250	0.750
	Quality	0.217	0.333	0.667
	Costs from sparing resources	0.048	0.750	0.250
	Investment costs	0.242	0.800	0.200
	Switching costs	0.060	0.333	0.667
	Overhead costs	0.141	0.750	0.250
	Sub-rating with respect to pitfalls		**0.500**	**0.500**
Final rating			**0.458**	**0.542**

Table 7.8: Relative importance of strategic factors in IMCT

Variables	Weight	Methodology-based (F1)	Advanced technology (F2)
Capacity adjustment/expansion	0.0393	0.0262	0.0131
Part commonality	0.0233	0.0078	0.0155
Information flow	0.0303	0.0101	0.0202
Supplier capability	0.0256	0.0128	0.0128
Set-up time reduction	0.0423	0.0106	0.0317
High and multiple skills of workforce	**0.0663**	0.0221	**0.0442**
Plant utilisation	0.0586	0.0147	0.0440
Future investment reduction	0.0163	0.0122	0.0041
Risk reduction	0.0313	0.0078	0.0235
Idle time	0.0514	0.0171	0.0343
Set-up time	0.0467	0.0155	0.0311
Total production time	**0.0967**	0.0242	**0.0725**
Quality	**0.1447**	0.0482	**0.0965**
Costs from sparing resources	0.0320	0.0240	0.0080
Investment costs	**0.1614**	**0.1291**	0.0323
Switching costs	0.0400	0.0133	0.0267
Overhead costs	**0.0940**	**0.0705**	0.0235

7.3.3.3 Discussion of AHP results

Among the benefits and pitfalls taken into account, investment costs, quality of WIP and final products, total production time, overhead costs, and skills of workforce receive the most concern in this plant with respect to flexibility improvement decisions (Table 7.8). An explanation can be made as follows:

- **Investment costs**

Despite the fact that flexibility is one of key competitive priorities; it can be of less concern than others. Flexibility can offer competitiveness to the firms both in direct and indirect ways, so it cannot be often taken seriously by most managers. For this plant, investment costs are very aware of when improving flexibility and methodology-based flexibility (i.e. low cost automation) is preferred. In production, employees are encouraged to adapt the existing and available resources (i.e. Kaizen) to improve the operational performances including flexibility.

- **Quality**

It is clear that flexibility can lead to quality problems if there is lack of good planning, employee involvement, communication, and implementation. Employee capability is considered the main issue that affects the quality when implementing flexibility in this plant. A methodology-base approach can be unsuccessful with the current level of workforce capability. Therefore, investing in advanced technology seems to have a greater potential for achieving higher flexibility outcome than methodology-based approach.

- **Total production time**

With growing fierce competition in one-ton pick up vehicle and limited local market demand, IMCT recognises the importance of the customer in terms of reducing waiting time for vehicles and minimising backorders. This drives manufacturing to reduce production time as much as possible. Flexibility can be disadvantageous to the production time. For instance, modularity which provides product flexibility, requires module assembly unit and final assembly unit (Fredriksson, 2006). It is the case that if operations within the module assembly unit or between module and final assembly unit are not effectively managed, the production time can be then increased. In contrast, installation of advanced technology is likely to cause fewer problems on the production time as it does not involve as much additional activity or functions as the methodology-based approach.

- **Overhead costs**

It is clear that flexibility comes with overhead costs. For instance, the decisions on whether or not to implement flexible manufacturing system (FMS), overhead costs should be taken into account. The advanced technology requires the firm to dedicate the amounts of resources such as financial, technical, human resources, etc after it implemented. Since methodology-based approach tends to adapt what a firm already has and it is likely to be continuous improvement rather radical change, the costs after its implementation seems not too high.

- **High and multiple skills of workforce**

Workforce is a major element in production activities. IMCT also expected higher and more multiple skills of workforces from an improvement initiative. Investing more advanced technology is likely to increase skills of workforces more than using methodology-based approach. The skills and knowledge that employees of IMCT are still lacking include technical and engineering aspects. They are considered to be important knowledge in a flexible environment. Therefore, due to the consequences of new technology adoption, this can indirectly influence the improvement of knowledge in technical and engineering areas.

7.3.4 Key Findings from Initial Testing of Decision Model

The developed framework and decision hierarchy were initially tested in two automotive companies (i.e. TMT and IMCT). However, only strategic factors were tested due to the limited availability of top managers. The results from expert input revealed interesting issues of flexibility improvement within two companies. They also confirmed that the developed decision hierarchy was able to use in practice as the final results derived from model calculation were consistent with current approach of the firms. Key summarised findings consisted of;

- In the TMT case, the results from the model found to be consistent with approach that was pre-determined by the firm. In contrast, in the IMCT case, the results from the model were not consistent with what the firm adopted. The reason may be that the model is only concerned with strategic aspects of flexibility. To improve the effectiveness of the model, the consideration of operational aspects is very useful and should be included in the selection analysis.
- The company management saw the proposed AHP approach as a systematic decision-making tool to determine the strategic implications

of flexibility improvement and an improvement over individually-developed ways that are currently used in the company. The management also found this strategic justification tool more suitable as a group decision-making tool and the input from various departments especially necessary to perform pair-wise comparisons correctly.

- The degree of pitfalls of flexibility depend on the extent to which capability of resources such as machine, people and process are able to attain requirements of specific flexibility approach.
- The strategic issues that can be considered being common in flexibility improvement include plant utilisation, skills of workforce, and effects on quality regardless of selected flexibility approach.

From the findings, to ensure that benefits of flexibility can be met and pitfalls of flexibility are minimised, the operating issues need to be considered. The operating issues that relate to those benefits and pitfalls were investigated in Chapter 4 and were statistically tested in Chapter 5. They can enhance the benefits and prevent or reduce the effects of pitfalls to occur. In this study, the techniques to assess a successful implementation of flexibility can be made in a similar way to those for risk assessment. Flexibility capabilities, i.e. flexibility success factors had been developed and used for justification process. They are focused on operational aspects on making decisions. The success scores are calculated by using AHP to quantify the success level of flexibility implementation for each candidate alternative. The second stage of the validation process was conducted in the case of SNM with groups of senior and middle managers. The details of this stage are described in Section 7.4.

7.4 OPERATIONAL CONSIDERATIONS OF FLEXIBILITY IMPROVEMENT: SIAM NISSAN AUTOMOBILES

Siam Nissan Automobile Co., Ltd., as described in Chapter 4, has recently implemented flexibility practices and has regarded the flexibility as a key business strategy to better cope with customer demand. The author had received permission from the Vice President, Mr. Viroon Paiboonthanasombat, to test the decision model. The participants included one senior manager and three middle managers in the production planning and control department. All of them agreed upon the importance of flexibility improvement in the manufacturing processes. The discussion session was formed in order to briefly introduce the purpose, provide an instruction of the decision model and assessment methodology, and allow managers to experience the use of AHP in evaluating flexibility strategies they currently have concerns with. Due to time limitation, it is not possible to test the model in all sections. Therefore, the author attempted to test the final part of the model, which is '*evaluation of flexibility success'* as it is considered new and especially is developed by the author. The results from testing and from assessment of the model are illustrated in Section 7.4.1 and 7.4.2, respectively.

7.4.1 Results and Analysis: Operational Considerations

Firstly, the degree of importance of capabilities associated with flexibility improvement was examined. All the managers consider the capabilities of resource redundancy and production control as key issues on flexibility improvement in their plants (see Figure 7.3). From Figure 7.4, among sources of redundancy, the most important capability is process control capability. Managers believed that lack of wider ranges of process control capability (e.g ability to effectively manage subcontract workforces, inventory, buffer capacity, etc.) can reduce flexibility performance. They also stated that this capability relates to the current manager's expertise and experience of the plant. The ranking score on each criterion is presented in Appendix 17 and 18.

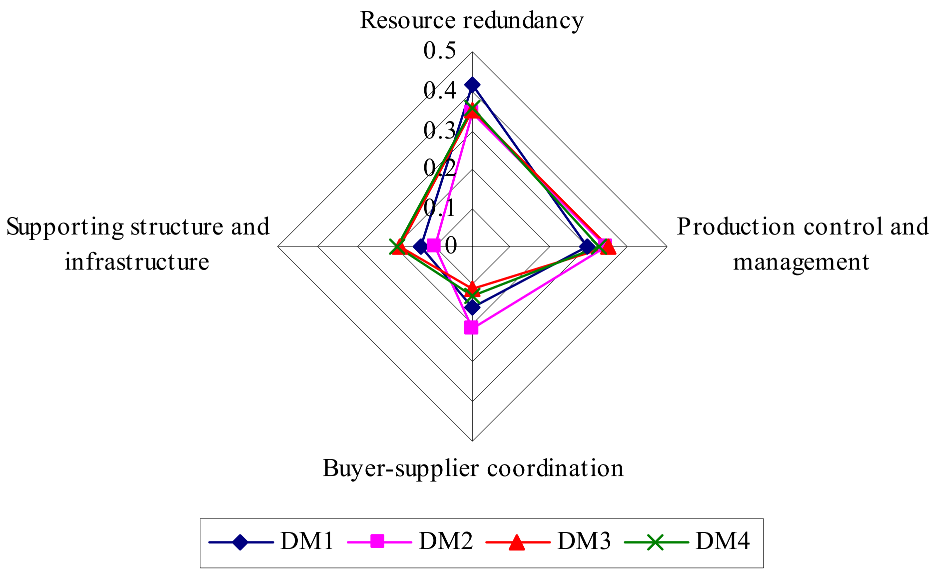

Figure 7.3: Relative Weightings on Flexibility Capabilities

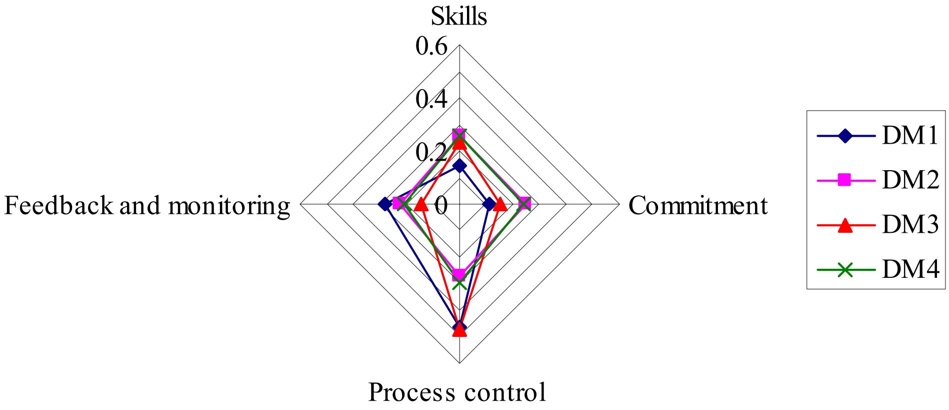

Figure 7.4: Relative Weightings on Resource Redundancy

As seen in Figure 7.5, production control and management issue are ranked as important as resource redundancy. Standardisation, visibility, and allocation are key elements that managers concentrate on for achieving flexibility. This implies that plant structure and infrastructure is a major issue of flexibility at SNM. Managers mentioned that current plant improvement projects include reengineering the plant structure and infrastructure such as layout, machines, and processes to support flexible production.

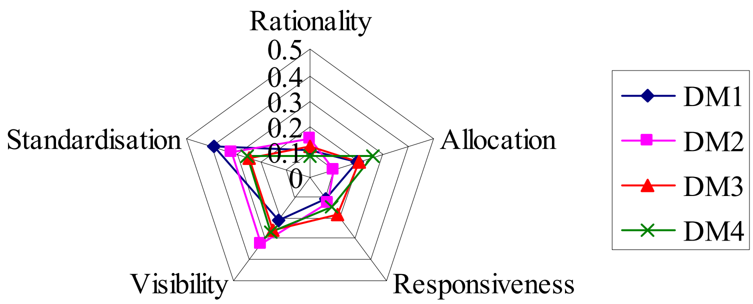

Figure 7.5: Relative Weightings on Production Control and Management

Buyer-supplier coordination and supporting structure and infrastructure are considered secondary issues, as shown in Figure 7.3. The effectiveness of supplier development programme and information sharing are important issues for SNM (see Figure 7.6). Managers stated that most suppliers in Thailand heavily rely on OEMs both in technical and managerial aspects. Thus, it is necessary to develop a number of programmes to enhance flexibility capabilities of suppliers. The distinct example is to introduce an unit ordering system and provide technical support to close-relationship suppliers. The efforts on information sharing and communication can be found in terms of frequent supplier meetings and discussions.

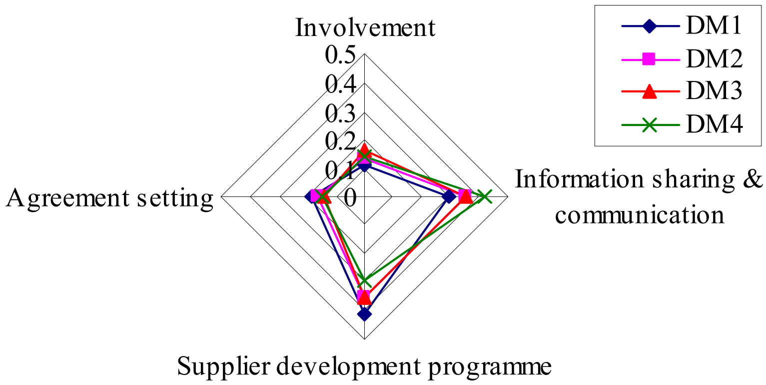

Figure 7.6: Relative Weightings on Buyer-Supplier Coordination

According to Figure 7.7, technological capabilities were found to be more important than organisational capabilities. Managers cited that capabilities of most employees in technical and engineering aspects are fairly low. The effectiveness of the training programme was found to be unsatisfactory. In addition, the advancement of technology in the plant is moderate. Thus, managers believed that flexibility can be obtained only when technology and technological capabilities are leveraged in the first place.

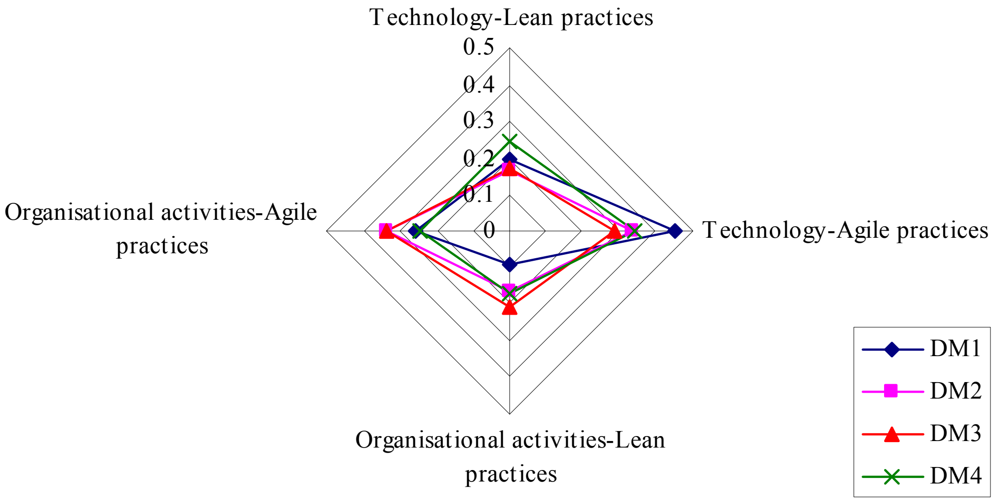

Figure 7.7: Relative Weightings on Supporting Structure and Infrastructure

As the author discussed the alternatives on flexibility improvement that the plant tends to adopt in the near future as part of manufacturing strategy, two possible alternatives are '*introduction of line expansion*' and '*modular sourcing*'. According to the current flexibility capabilities within the firm, managers were asked to rate them against each of alternative was made. In doing so, the flexibility approach most suitable to the current operational context will be obtained. The results from manager evaluation showed that line expansion strategy is agreed to be the most preferable strategy and it aligns with current flexibility capabilities of the plant. The rating from four decision makers and average scores are shown in Table 7.9 (see Appendix 19 for assessment scores from decision makers). As shown in Figure 7.8, all managers agreed that line expansion strategy is dominant to modular sourcing strategy in aspects of resource redundancy, production control and management, and supporting structure and infrastructure. However, there is a contradiction in aspects of buyer-supplier coordination among managers, as illustrated in Figure 7.9. Some reckoned that with the current degree of buyer-supplier coordination, modular sourcing strategies are able to perform as effectively as the line expansion one.

Table 7.9: Overall Score of Flexibility Improvement

Flexibility Improvement	DM1	DM2	DM3	DM4	Average
Line Expansion Strategy	0.686	0.584	0.540	0.709	0.630
Modular Sourcing Strategy	0.314	0.416	0.460	0.291	0.370

Modular sourcing strategy involves many changes in terms of process, procedures, and behaviour. Modular sourcing requires an arrangement of material and part handling process so that all dimensions of production control and management capabilities must be relatively high. Additionally, this strategy is a more radical change than line expansion strategy and involves many actors. The process and workforce readiness needed to be high for successful implementation. Nevertheless, the overall results demonstrated that line expansion strategy is preferred. It can be said that the results from AHP model can generate the issues and provide managers opportunities for further discussion on what specific capabilities required further improvement.

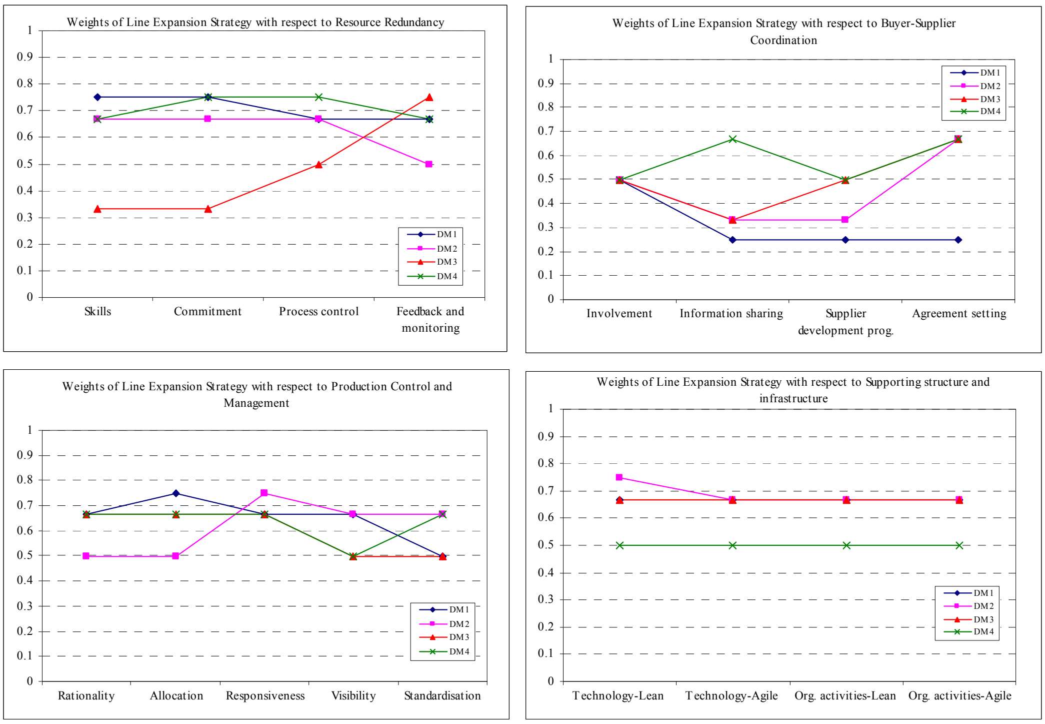

Figure 7.8: Relative Weightings for Alternative 1: Line Expansion

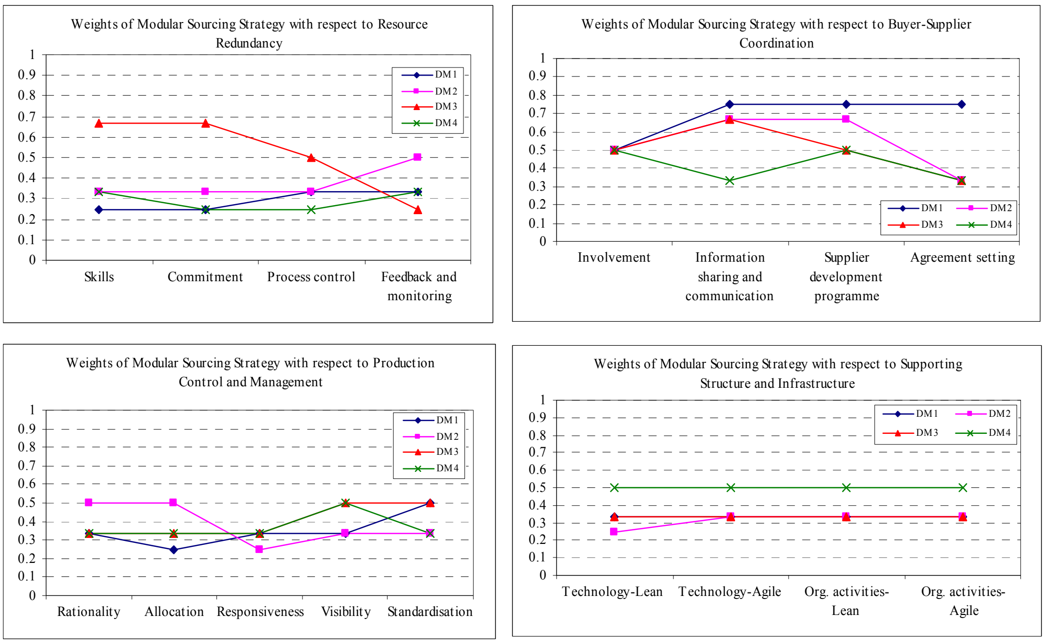

Figure 7.9: Relative Weightings for Alternative 2: Modular Sourcing

In summary, the set of capabilities that is crucial to flexibiliy improvement in the SNM plant includes process control capability, feedback and monitoring capability, workforce skills and commitment, standardisation and visibility of production (see Figure 7.10). These capabilities mainly contribute to the manufacturing flexibility of the plant. In other words, they must be leveraged so that more opportunities for implementing wider choices of flexibility approaches are enabled. In consequence, the firm can increase competitive advantages over competitors under today's customisation pressure.

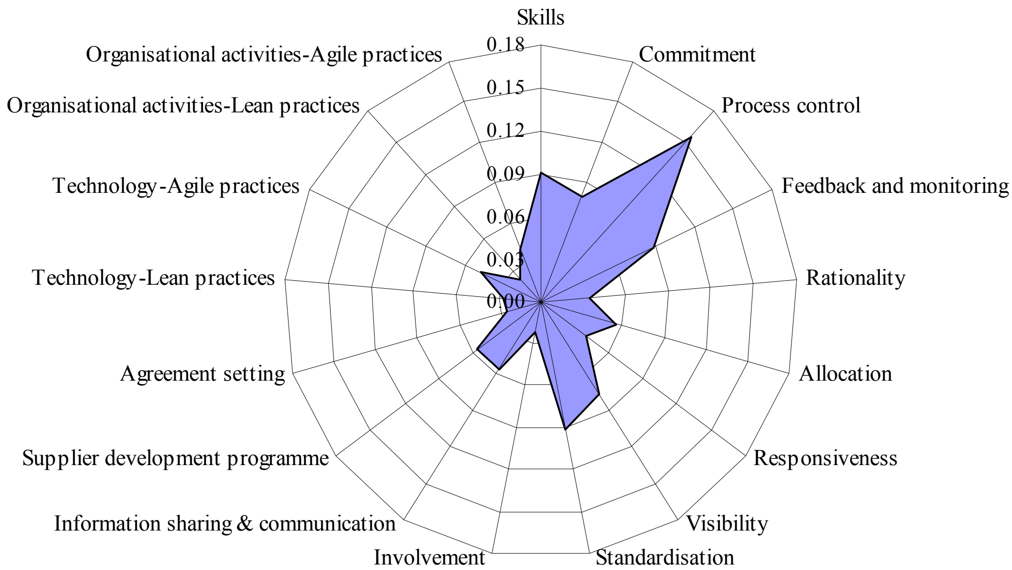

Figure 7.10: Importance of Flexibility Capabilities at SNM

7.4.2 Applicability of the Model

The framework and model were tested by industrialists. The feedback of the framework and model was provided in forms of an assessment questionnaire. Once managers were provided with the graphical results of their judgement and assessment questionnaire was evaluated, the author discussed the feasibility, utility, and usability of the framework and model. The results of feasibility, usability, and utility are shown in Figure 7.11. Managers agreed upon the list of criteria in the framework. All managers found the model to be useful to facilitate the decision-making process regarding process improvement for better flexibility. From the assessment results, it illustrates that the model is only suitable for senior managers for strategic analysis and time used for the evaluation seems to be fairly long. They also mentioned that flexibility is a difficult issue to communicate among managers and engineers. The set of flexibility capabilities in the framework can be used as useful indicators representing critical sources of flexibility to guide whether or not to implement a particular strategy in more explicit ways.

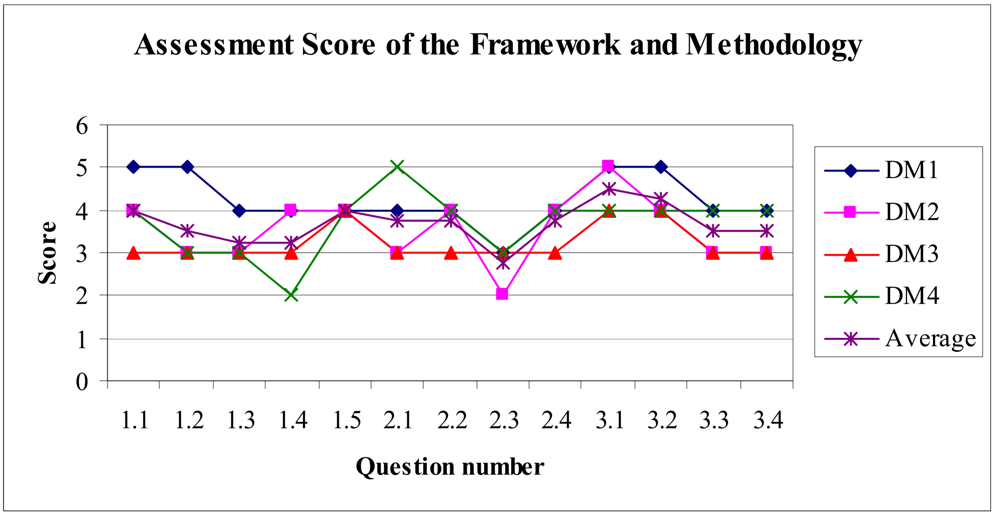

Figure 7.11: The Results of Framework and Methodology Assessment

They also mentioned that AHP enables them to thoroughly evaluate the criteria, while other methods cannot. In the Thai context, the systematic approach in making strategic decisions is considered new. Most managers tend to employ generic measures such as financial aspects, total time production, lead-time, capacity, etc. in making the decisions. They can only provide managers with the views on what end results they desire and are not able to justify the appropriateness of the programme being adopted. Most of the improvement programmes in Thai automotive plants are established at the corporate level (i.e. foreign headquarter). However, it is likely that local managers seems to have more roles in making decisions. Therefore, promoting decision making tools and techniques which allow individual or group judgement can be useful for Thai companies.

7.5 IMPLICATIONS OF THE DECISION MODEL

The findings from testing indicate that the decision-making framework and model are applicable to practical use in the manufacturing settings. They provide more understandings on flexibility, especially through the lens of resource-based theory. Managing manufacturing flexibility can be more comprehensive by following the strategic decision-making process. Moreover, it becomes more manageable by considering four sets of flexibility capabilities; which are resource redundancy; production control and management; buyer-supplier coordination; and supporting structure and infrastructure. The following sections summarise the points from conducting the testing in case companies.

7.5.1 Obtaining Manufacturing Flexibility Strategy

To reduce complexity of flexibility decisions, an assessment of key criteria critical to the overall flexibility performance can facilitate production managers. The criteria within the model are key variables for successful implementation of flexibility. Overall, the results from the initial testing (i.e. TMT and IMCT) and formal testing (i.e. SNM) confirmed that the model can provide useful insights on manufacturing flexibility improvement to managers and allow flexibility decisions to be more obvious and comprehensive.

7.5.2 Manufacturing Flexibility Implementation

From the results, it is clear that the reasons why managers choose one approach rather than others are that capabilities of production control and management are major constraints. This limits the firms to perform some strategy, even it is more favourable. The results from the model can also guide managers on which production or supply chain aspects require an improvement in order to maintain competitive advantage in the future.

7.5.3 Model Refinement and Further Suggestions

The second decision maker suggested that the evaluation process will be easier if detailed definitions of factors are provided. In addition, he mentioned that there should be a short training session or the introduction of AHP methodology in the training programme for the managerial level of the company, if the methodology would be actually implemented. The fourth decision maker suggested that it would be more beneficial to strategic level if the framework integrated to the quantitative analysis such as financial analysis, rate of return. Thus, the confidence level of the decision model can be increased.

7.6 CONCLUSION

Flexibility is considered multi-dimensional and involves a number of implicit issues in terms of management and decision-making. The decision support tool was found to be useful to facilitate managers simplifying the means of flexibility improvement and selecting the suitable flexibility strategies for their company's context. Analytic Hierarchy Process incorporates the quantitative and qualitative factors in the decision-making process and provides a structured way to thoroughly assess the importance of each influential factor against the potential alternatives. Based on a resource-based view, the AHP model allows managers to evaluate the degree of their current capabilities of manufacturing system and linking them to the choices of flexibility improvement strategies. The methodology strongly intends to promote an objective judgment on flexibility issue, enhance the effectiveness on resource deployment of the plant, and reinforce the strategic decision-making process among managers. The results of the validation process confirmed that the framework and AHP-base model can be used as a potential tool for flexibility improvement and can be applied in a company's investment decision analysis.

CHAPTER 8: DISCUSSION AND CONCLUSION

This research examines the manufacturing flexibility improvement and investigates how flexibility could be enhanced. Managers are likely to implement flexibility strategies based on information of capacity, general measures, and financial aspects in particular. The research aims to fill the gap by exploring the efforts on manufacturing flexibility improvement, the required further improvement, and key criteria contributing to flexibility performance in automotive companies. Focusing on the resource-based view, a structured manufacturing flexibility improvement framework was developed to help evaluating the flexibility improvement programmes that firms tend to adopt. In addition, an assessment methodology of AHP was developed and tested in order to operationalise the framework for practical use. Section 8.1 discusses and summarises the findings from research. Section 8.2 presents the contribution to knowledge in the field of flexibility management. Finally, the recommendation on future research is then made in Section 8.3.

8.1 SUMMARY OF RESEARCH FINDINGS

The main outcome of this research is to provide more understanding of manufacturing flexibility in aspects of triggers, practices, decision criteria, and key flexibility mechanisms or capabilities and to develop a manufacturing flexibility improvement framework and assessment methodology. The research started with the five case studies of automotive companies which were chosen to provide knowledge and experiences in improving manufacturing flexibility. Subsequently, key flexibility mechanisms were emerged from case study analysis including; resource redundancy, production control and management, buyer-supplier coordination, and supporting structure and infrastructure. They were tested and verified through the questionnaire survey of Thai automotive firms. Incorporating the literature and empirical findings from case studies and surveys, manufacturing flexibility improvement framework and assessment methodology based on AHP were developed. The framework and methodology were then tested in practical companies with participation of a number of senior managers. The responses from managers were positive and the results demonstrated high feasibility, usability, and utility of the methodology. Next, the summary of research findings is illustrated as follows:

8.1.1 Manufacturing Flexibility Practices in Thai Automotive Companies

In firm (On a company) level, the flexibility improvement programmes are varied among companies from operational flexibility to strategic flexibility depending on the firm's context. At the industry level, most automakers in Thailand apart from TMT are considered reactive (i.e. adapting to uncertainty or changes rather than accommodating them). One main reason is that they are currently operating in a domestic-based market where demand patterns, customer preferences, and competition are predictable.

Triggers of flexibility improvement mainly are; the need to respond to internal and external uncertainties of market needs, competition, production, and trading policies; and the need to improve internal capabilities and performances including economies of scale, capacity utilisation, and operational performances.

In planning aspects of manufacturing flexibility improvement, the factors taken into account are grouped into three levels including strategic, tactical, and operational level. Strategic factors involve business requirements (i.e. types of uncertainties that firms are faced with and firm capabilities that firms need to improve). Tactical factors involve manufacturing objectives (i.e. benefits and pitfalls of flexibility). Operational factors involve operational conditions (i.e. the extent of resources and capabilities that firms currently possess to pursuing manufacturing flexibility).

In implementation aspects of manufacturing flexibility improvement, the main reasons for not achieving flexibility are lack of resource redundancy, ineffective production control and management, poor cooperation between buyer and suppliers when changes occur, and inadequate supporting structure and infrastructure. These are supported by the survey findings that the most concerning problems include lack of workforce capability, lack of planning capability, no commitment to problem-solving, no commitment to technology improvement, and unclear communication in manufacturing and supply chain functions.

A key supply chain flexibility problem is poor cooperation between buyer and suppliers. Currently, suppliers have to mainly be responsible for any changes and adjustments requested by OEMs, which are mostly made at very short notice and are sometimes not very clear. The survey findings revealed that most suppliers need more effective forecasting and actual plans from OEMs as their current capacities and capabilities are limited.

According to the survey findings, the activities that most Thai firms are focusing on are building workforce readiness as a means to deliver flexibility. The efforts on improving process and technology readiness, improving planning activities, enhancing responsiveness, and leveraging plant structure and infrastructure are moderately concerned. There are only minimal efforts on supply chain issues such as exchange of information for planning, supplier involvement, and agreement setting between buyers and suppliers. This suggests that Thai automotive companies should focus on other aspects in manufacturing flexibility improvement as they are important in achieving overall manufacturing flexibility.

8.1.2 Mechanisms Enhancing Manufacturing Flexibility Performance

The core areas for improving flexibility are building the capabilities ready for flexible environment, improving planning activities and structure for better production control and management, improving buyer and supplier cooperation, and leveraging supporting activities on technological and organisational aspects. Based upon flexibility problems and the necessary activities to improve manufacturing flexibility, there are four mechanisms or capabilities contributing to high flexibility performance. They can be grouped into resource redundancy, production control and management, buyer-supplier coordination, and supporting structure and infrastructure.

8.1.3 Relationship between Mechanisms and Manufacturing Flexibility performance

Six out of nine activities contribute to direct flexibility performances. Four out of nine activities show relationships with indirect flexibility performances. There are relationships between plant structure and infrastructure improvement, process and technology readiness and indirect performance. However, with effort to improve flexibility, the results showed that activities on supplier involvement and supplier development programme have negative impacts on operational performance and indirect performance. Agreement setting tends to have positive impacts, while not significant, on indirect manufacturing flexibility performance.

Key factors significant to improve three different flexibility dimensions are suggested. This can be served as a useful guideline for establishing appropriate actions to improve flexibility. Operational, production flexibility, and customer order effectiveness can be improved by focusing on different specific factors. For instance, responsiveness and information sharing and communication are regarded as distinct factors to improve production flexibility. Generic factors such as workforce readiness and technology in relation to agile practices are commonly required for any flexibility improvement.

Buyer-supplier coordination such as supplier development programme and supplier involvement need more concerns in terms of management. It is not necessarily true that a higher extent of involvement and development programme always leads to higher performances. Controlling related operational performances from flexibility implementation is difficult; yet, it is considered a major issue in flexibility management.

Agile practices influences direct manufacturing flexibility performances more than lean practices do. However, there is no significant relationship found in indirect flexibility performances. The effect of lean practices only appears in terms of backorders reduction and on-time delivery rather than manufacturing dimension. Overall, the quantitative analysis confirmed that a set of resources and capabilities developed in the research can be employed in the decision-making process.

8.1.4 A Decision-Making Framework for Flexibility Improvement.

The process of flexibility improvement can be drawn into three main steps; aligning with business conditions; aligning with manufacturing objectives; and satisfying operational conditions. The criteria for justifying flexibility improvement programmes are identified with respect to these three steps. Firstly, the criteria for assessing the alignment on business conditions include uncertainties and firm capabilities. Secondly, flexibility, cost, time, quality, and indirect benefits are criteria for assessing alignment on manufacturing objectives. Finally, four criteria of resource redundancy, production control and management, buyer-supplier coordination, and supporting structure and infrastructure are introduced and used to assess the degree of fit to current operational conditions in which the success of flexibility implementation is evaluated.

8.1.5 Analytic Hierarchy Process-based model for Assessing Flexibility Strategies.

The decision hierarchy is formed based on the framework derived from case study and survey analysis. The techniques of AHP are applied to the process of manufacturing flexibility improvement to allow the manager's judgment to become more constructed and systematic. Two main stages of assessments are set, which are strategic and operational assessment. The theory of manufacturing strategy and resource-based view are used to establish the assessment processes.

It is shown that operational assessment is critical to provide more accuracy of the decisions. The decision-makers in automotive companies found that the framework and AHP methodology are helpful in clarifying the complexities of manufacturing flexibility aspects and also in communicating among functional managers to make the discussion about process improvement and finally reach the consensus.

8.2 CONTRIBUTION TO KNOWLEDGE

This research provides contributions to the field of flexibility management in which most existing literatures have only focused on taxonomy and measurement. The main areas of flexibility management are extended both in terms of contents and processes. Most literature provides flexibility management in relatively broad aspects. Firstly, this research attempts to provide more specific and comprehensive means of flexibility management by looking it in aspects of resources and capabilities. The resources and capabilities underlying the success of flexibility outcomes are developed through rigorous qualitative and quantitative research methods. They are classified as resource redundancy, production control and management, buyer-supplier coordination, and supporting structure and infrastructure. Also, the obstacles and enhancers for manufacturing flexibility improvement are identified. Secondly, this research provides the managerial implications in managing the flexibility performances both in direct and indirect flexibility dimensions. Each various flexibility dimension requires different resources and capabilities in order to be successful. The quantitative analysis shows significant relationships between required capabilities and flexibility performances. Key factors for various flexibility targets are suggested and this provides deeper insights in the selection of specific actions to improve flexibility. Finally, by incorporating the criteria, the strategic decision-making process is constructed and operationalised based on the principles of MCDM to provide managers with more objective judgments when flexibility improvement is required.

8.3 LIMITATION OF RESEARCH AND RECOMMENDATION

The research presents some limitation in three main aspects. Firstly, the case studies used in the research are only within the Thai automotive industry. Other industrial sectors and demography of case studies can improve the generalisation of the framework by which other influential factors may be added. Secondly, a number of samples in the survey limit the generalisation of the results. In addition, the measures of flexibility are subjective indicators. Objective measures such as number of changeovers, number of part types, average changeover times, may improve precision of measurement and thus result in a higher degree of generalisation. Finally, the testing of the framework is conducted on a small-scale in which both strategic and operational assessments are not tested within a singular case study due to time constraints and time availability of the decision-makers. Instead, the strategic assessment is tested in TMT and IMCT while an operational assessment is made in SNM. In addition, the number of decision-makers participating in validation process is relatively small. To improve the validity of the decision making model and tool, full-scale testing with a higher number of decision-makers is required.

According to the limitation presented above, the recommendation for further research is made here in three areas. Firstly, specific focus on each aspect of flexibility capabilities should be further investigated in order to provide more detailed criteria for the flexibility improvement framework. For instance, the study on production control and management may be further investigated to discover other relevant factors of flexibility improvement. Secondly, other dimensions of manufacturing flexibility such as new product flexibility should be also studied so that the improvement framework can be extended and adequately represent key flexibility types for organisation, i.e. volume, mix, and new product flexibility. Thirdly, the further development of a decision-making model can be made by integrating quantitative analysis such as financial analysis and simulation-based operational performance with an AHP model from the research.

8.4 CONCLUSION

The effectiveness of a manufacturing strategy could be measured through the degree of internal and external consistency of its content. It includes the internal coherence of manufacturing choices, and their coherence with the external environment, the competitive strategy and the choices in other functional areas (Hayes and Wheelwright, 1984). A number of studies provided the links between many improvement programmes and business or manufacturing goals, and performance dimensions for facilitating the manufacturing strategy formation process. According to the emerged Agile Manufacturing paradigm, one of the competitive priorities has been of interest both for the academic and the practitioner is Manufacturing Flexibility. The main purpose of this research is to investigate the planning and implementation aspects of flexibility and to establish a framework and methodology for effectively selecting the programmes or approaches particularly focused on flexibility performance dimension as a prime objective.

A case study method was conducted in five automotive firms in Thailand to investigate their efforts and relevant issues on flexibility improvement such as current practices, triggers, motivations, difficulties and obstacles and to identify the critical resources and capabilities underpinning the successful flexibility implementation. In addition, a survey of 43 Thai suppliers was conducted to examine their flexibility practices as a means to respond to the changes from their OEMs. The findings from the case study and survey analysis revealed a four set of manufacturing capabilities contributing to the success of flexibility implementation. They can be classified as resource redundancy, production control and management, buyer-supplier coordination, and supporting structure and infrastructure.

To validate the findings, another survey was conducted to test the relationships between those set of capabilities and flexibility performance. The results showed that the relationships were confirmed and different flexibility performance dimensions require different set of capabilities. By incorporating the findings from the case study and survey, the framework of manufacturing flexibility improvement was developed based on the theory of manufacturing strategy and the resource-based view. The assessment methodology was constructed by using one popular decision-making technique of Multiple-Criteria Decision Making; Analytic Hierarchy Process (AHP). They were tested by key decision makers in three automotive companies. The results showed that the framework and methodology were applicable and could yield benefits to the organisation in improving manufacturing flexibility.

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APPENDICES

Appendix 1: Taxonomy of Manufacturing Flexibility by Key Authors

	Key elements	References
Dimensions	**The general characteristics and behaviours of flexibility, i.e. how to define flexibility** - Range, Uniformity, Mobility - Range, Response	 Upton (1994) Slack (2005)
Types	**The classification of flexibility in various viewpoints based on operations and functions in manufacturing** - Machine, Sequence, Routing, Expansion, Volume, Product mix, New product, Production flexibility	 Sethi and Sethi (1990); Browne et al (1984)
Level	**The hierarchy of flexibility based on system viewpoints (e.g. strategic importance, customer, and resource)** - Operational, Tactical, Strategic - System, structural and infrastructural resources - Lower-order flexibility, first order flexibility - Hard, Soft, Intangible	 Carlsson (1989); Cannon & St. John (2004) Slack (2005) Suarez et al (1996) Aggarwal (1997)
Techniques	**Characteristics of the flexibility strategy linking manufacturing and environmental uncertainties** Banking, Adaptive, Redefinition, Reduction	 Gerwin (1993)
Measures	**Developed measures for assessing or evaluating the level of manufacturing flexibility** System measures (e.g. efficiency, responsiveness, versatility, robustness) Process measures (e.g. lead-times on orders, set up times, cycle times, lot size, WIP inventory, costs) Resource measures (e.g. multi-skilled workforce, cross-training workforce, programmable equipments)	 Chuu (2005) Cox (1989); Son & Park (1987); Narasimhan & Des (1999); Chenhall (1996) Chen & Chung (1996); Kochikar & Narendran (1992); Cox (1989)

Appendix 2: Theoretical perspectives on manufacturing flexibility improvement process

Concepts/Approaches	Key characteristics and Techniques	References
Descriptive	Based on conceptual frameworks or empirical works illustrating the relationships between influential variables and manufacturing flexibility. Decisions can be made by mapping the variables according to the guidelines from conceptual frameworks or empirical works.	Swamidass & Newell, (1987); Chang et al, (2002); D'Souza (2006)
Strategic decision-making	Following strategic decision-making process and implementation frameworks. The relevant techniques include Environmental assessment, Gap analysis, SWOT analysis, and Strategic fit.	Narain et al (2000); Gerwin (1993)
Operations strategy	Matching the market requirements and company context for firm performances. The tool developed is House of Flexibility (adapted from Quality Function Deployment).	Olhager & West (2002)
Resource-based view	Considering the firms' resources contributing to competitive advantages (i.e. flexibility)	Not yet studied

Appendix 3: Resource-based theory in OM research

Areas	Description	References
Principles	Providing theoretical perspectives and explanation of resource-based view in itself and in OM disciplines.	Barney (2001); Rungtusanatham et al (2003); Gagnon (1999); Lowson (2003)
Methodology	Suggesting the methodology to analyse the key resources for competitive advantages, i.e. strategic analysis.	Mills et al (2003); Wilk & Fensterseifer (2003); Lewis (2003); Pandza et al (2003)
Application	Employing resource-based view in the empirical studies to guide the decision-making in particular areas	Caldeira & Ward (2003); Chmielewski & Paladino (2007); Miller & Ross (2003); Chen & Liaw (2001)

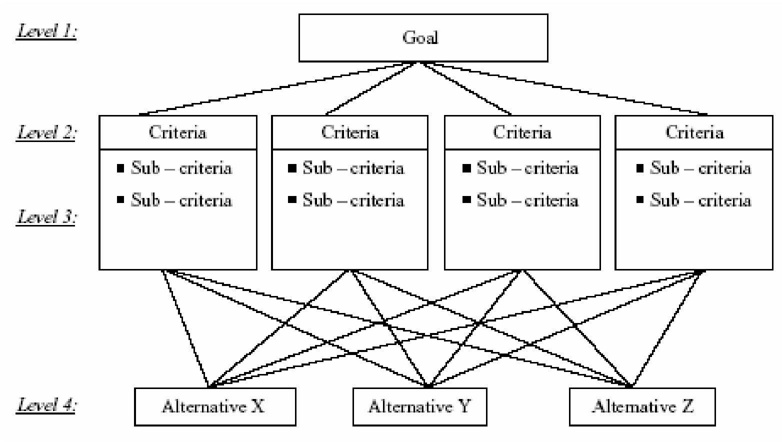
Appendix 4: Examples of works on the application of AHP in OM research

Areas of study and application	References
- Use of AHP in decision-making for flexible manufacturing systems	Bayazit (2005)
- Using analytic hierarchy process (AHP) to improve human performance	Albayrak & Erensal (2004)
- Evaluating Machine Tool Alternatives	Ayag & Özdemir (2006)
- Selecting automated manufacturing systems	Mohanty & Venkataraman (1993)
- An effective maintenance system	Labib et al (1998)
- Supplier selection	Perçin (2006)
- Outsourcing non-core assets and competences of a firm	Hafeez et al (2007)
- Justification of new manufacturing technology	Albayrakoglu (1996)
- Prioritising customer requirements in QFD	Armacost et al (1994)
- Selection for flexible manufacturing systems	Myint & Tabucanon (1994)

Appendix 5: Structure and calculation of AHP

The AHP was developed by Saaty (1990), who demonstrated the feasibility of expressing, either verbally or numerically, the importance of one element (or alternative) relative to another with respect to a given criterion. AHP has been proposed in recent literature as an emerging solution approach to large, dynamic, and complex real world multi-criteria decision-making problems. It has been used in a wide variety of complex decision-making problems, such as the strategic planning of organisational resources (Saaty, 1990), the evaluation of strategic alternatives (Tavana and Banerjee, 1995), or the justification of new manufacturing technology (Albayrakoglu, 1996). As a convenient methodology, it has been used in combination with other methodology such as Linear programming to determine goal priorities and objective function weights (Gass, 1986).

The characteristic of AHP is allowing both qualitative and quantitative attributes to be included to carry out evaluation. For each sub-criterion, ratings are necessary to provide a basis and ease for the comparison of the performance of a large number of companies to be evaluated. The priorities of criteria and sub-criteria are synthesised to establish the overall priorities for decision alternatives. Conceptually, AHP methodology can be used whenever a problem can be reduced to a hierarchical representation consisting of at least two levels: (1) evaluation criteria – those elements that allow taking a decision; (2) alternatives – those elements that influence the evaluation criteria.



Expert judgement concerning alternatives is elicited using a pair-wise comparison method. Each pair of alternatives is considered in turn using the numerical scale or linguistic responses given by Saaty. Experience has confirmed that a scale of nine units is reasonable and reflects the degree to which humans can quantify relationships among elements (Saaty, 1990).

Numerical Scale	Verbal scale	Explanation
1.0	Equal importance of both elements.	Two elements contribute equally.
3.0	Moderate importance of one element over another.	Experience and judgement favour one element over another.
5.0	Strong importance of one element over another.	An element is strongly favoured.
7.0	Very strong importance of one element over another.	An element is very strongly dominant.
9.0	Extreme importance of one element over another.	An element is favoured by about an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Intermediate value between two adjacent judgements.	Used for compromise between two judgements.

In terms of the commonly used semantics, the AHP is described as the pairwise comparison of a number of alternatives in order to grade the alternatives. However, in this application it is not strictly alternatives that are considered but rather components, all of which contribute to the performance of the parent. It is the relative level of contribution that must be determined. Saaty (1990) establishes four axioms that must be true of any system under consideration:

(1) Reciprocal comparison. The decision-maker must be able to make comparisons and state the strength of preferences. A reciprocal comparison must be the direct inverse of the initial comparison.
(2) Homogeneity. The preferences are represented by means of a bounded scale.
(3) Independence. Criteria are assumed to be independent of the properties of the alternatives, i.e. a comparison between one pair of elements is not affected by the properties of any other element.
(4) Expectations. For the purpose of making a decision, the system structure is assumed to be complete, i.e. all possible alternatives are represented.

In the computation of the weights, the numerical scale is applied directly as a ratio of importance. The judgements are recorded in a matrix, which describes a set of equations that can be solved for the principal right eigenvector. This vector gives the normalised weights for all of the alternatives, which are used as factors to indicate the degree of correlation between individual component effects and their parent. The calculation procedure of AHP is presented here. Let C_1, C_2,…, C_n be the set of elements, while a_{ij} represents a quantified judgement value of C_i and C_j. The above numerical values are assigned to rate the relative importance of C_i and C_j, which values W_i/W_j.

$$A = \left[a_{ij}\right] = \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} \begin{vmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{vmatrix}$$

The pair-wise comparisons generate a matrix of relative rankings for each level of the hierarchy. The number of matrices depends on the number elements at each level. The order of the matrix at each level depends on the number of elements at the lower level that it links to. After all matrices are developed and all pair-wise comparisons are obtained, eigenvectors or the relative weights (the degree of relative importance amongst the elements), global weights, and the maximum eigenvalue (λ_{max}) for each matrix are then calculated. The λ_{max} value is an important validating parameter in AHP. It is used as a reference index to screen information by calculating the consistency ratio CR (Saaty, 1994) of the estimated vector in order to validate whether the pair-wise comparison matrix provides a completely consistent evaluation. The consistency ratio is calculated by firstly calculating the eigenvector or the relative weights and λ_{max} for each matrix of order *n*

$$\lambda_{\max} = \sum_{j=1}^{n} a_{ij} \frac{W_j}{W_i}$$

Then, computing the consistency index for each matrix of order *n* by the formulae

$$CI = (\lambda_{max} - n)/(n-1)$$

Finally, the consistency ratio is then calculated using the formulae:

$$CR = CI/RI$$

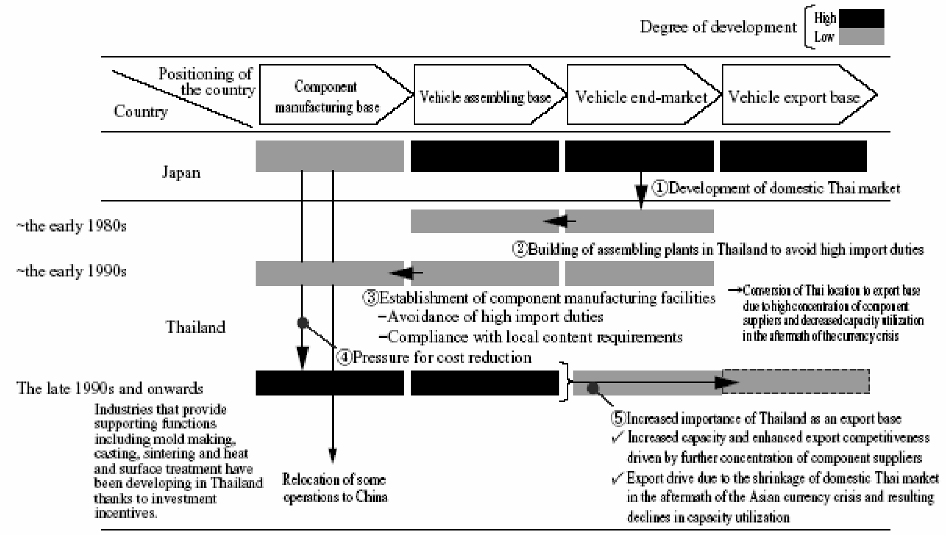
where RI is a known random consistency index obtained from a large number of simulation runs and varies depending upon the order of matrix. The following table shows the value of the random consistency index (RI) for matrices of order 1 to 10 obtained by approximating random indices using a sample size of 500 (Saaty, 1994). It is noted that the Expert Choice software is used to calculate and provide visual representations of overall ranking on a computer screen.

Size of matrix (n)	Random consistency index (RI)
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

Appendix 6: Background of Case companies

Company	Established year	Number of Employees	Vehicle models	Key Business strategy	Key Features of Flexible Production practices
TMT	1964	6,172	Camry, Corolla, Vios, Wish, Hilux VIGO, Yaris	Employ continuous improvement by means of challenge and change, Respect people and their needs, Pursue customer satisfaction, Dedicate to the highest standards, Adopt a spirit of social responsibility to our communities and the environment	Sister plant, Close relationship with suppliers
SNM	1962	1,515	Frontier, Teana, Tiida	Providing unique and innovative automotive products and services that deliver superior measurable values to all stakeholders in alliance with Renault, Enriching people's lives	Unit production, Directing customer orders to production
IMCT	1957 (1963 started production)	3,200	D-Max, Truck	High quality products, Utmost customer satisfaction, All Model and Types, Country Wide Network, Customer Relationship Programme	Buffering capacity and inventory, Avoidance of major capital investment
TSA	1974	416	S60, S80, V70, C70, XC90, Truck and Bus	Customer order-driven, Production efficiency improvement	Single production line with unit loading principles
TAAP	1960	1,060 (Factory only)	Mercedes-Benz, Daewoo, Truck and bus chassis	Increasing the customer orders and plant utilisation, cost savings	Arrangement of task, human resource, and machine

Appendix 7: Establishment of Thailand as an Export Base (*Kasuga et al, 2002*)



Appendix 8: Spreadsheet for Manufacturing Flexibility Self-Assessment

1 = Very low …………………→ 7 = Very high

1 2 3 4 5 6 7

2.1 Volume flexibility
- 2.1.1 Machines can adjust volumes being produced
- 2.1.2 Parts are available at any time as required
- 2.1.3 Workforces are ready and available when required
- 2.1.4 Suppliers can produce parts or raw materials in any amounts required
- 2.1.5 Able to forecast customer demand effectively

2.2 New product flexibility
- 2.2.1 The extent of part commonality
- 2.2.2 Suppliers can produce new required parts or raw materials
- 2.2.3 Ability of workers in learning new parts and products
- 2.2.4 Ability to manage information of new products to related functions

2.3 Mix flexibility
- 2.3.1 Suppliers can produce varieties of parts
- 2.3.2 Able to manage parts from multiple sources effectively
- 2.3.3 The extent of multi-skilled in workforces
- 2.3.4 Able to produce and manage mixed products

2.4 Expansion flexibility
- 2.4.1 Able to expand plant layout and capacity
- 2.4.2 Suppliers can expand capacity
- 2.4.3 Workforces can work in new production unit and environment

2.5 Sequence flexibility
- 2.5.1 Able to feed parts or raw materials in various sequences
- 2.5.2 Suppliers can produce in accordance with your production conditions
- 2.5.3 Able to arrange workforces for required sequences

2.5.4 Able to arrange sequences of production as required

2.6 Machine flexibility

2.6.1 Set-up time of machines

2.6.2 Workers can program and control machines effectively

2.6.3 Able to create any production schedule when machines are adjusted

2.6.4 Able to manage overall production effectively when machines Are adjusted

2.7 Routing flexibility

2.7.1 Machines can operate under unexpected or emergency situation

2.7.2 Ability of operators in repairing machines

2.7.3 Able to effectively manage production process and workforces for overtime production

2.8 Competitive priorities flexibility

2.9 Business flexibility

Appendix 9: Semi-Structured Interview Protocol

1. How is current business in overall business context and operations context?
2. What are main types of changes or uncertainties in current production and manufacturing systems?
3. How is current flexibility level (flexibility performances) in the manufacturing systems? Please indicate by using spreadsheet provided.
   1 = Very low …………………→ 7 = Very high 1 2 3 4 5 6 7

   3.1 Volume flexibility

   3.1.1 Machines can adjust volumes being produced

   3.1.2 Parts are available as and when required

   3.1.3 Workforces are ready and available when required

   3.1.4 Suppliers can produce parts or raw materials in any amounts required

   3.1.5 Able to forecast customer demand effectively

   3.2 New product flexibility

   3.2.1 The extent of part commonality

   3.2.2 Suppliers can produce new required parts or raw materials

   3.2.3 Ability of workers to learn new parts and products

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   3.3 Mix flexibility

   3.3.1 Suppliers can produce varieties of parts

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   3.3.4 Able to produce and manage mixed products

   3.4 Expansion flexibility

   3.4.1 Able to expand plant layout and capacity

   3.4.2 Suppliers can expand capacity

   3.4.3 workforces can work in new production unit and environment

   3.5 Sequence flexibility

   3.5.1 Able to feed parts or raw materials in various sequences

   3.5.2 Suppliers can produce in accordance with your production conditions

   3.5.3 Able to arrange workforces for required sequences

   3.5.4 Able to arrange sequences of production as required

3.6 Machine flexibility

3.6.1 Set-up time of machines

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3.6.3 Able to create any production schedule when machines are adjusted

3.6.4 Able to manage overall production effectively when machines Are adjusted

3.7 Routing flexibility

3.7.1 Machines can operate under unexpected or emergency situation

3.7.2 Ability of operators in repairing machines

3.7.3 Able to effectively manage production process and workforces for overtime production

3.8 Competitive priorities flexibility

3.9 Business flexibility

4. What are the current flexibility improvement programmes in the manufacturing? Please describe the flexibility strategies adopted or planned to adopt, methods and tools used to deliver manufacturing flexibility in your production processes.
5. What are the activities or functions involved in the flexibility improvement programmes the firm adopted? And what are key concerns for the firm to adopt such flexibility improvement programmes?
6. External and internal influences include resources and capabilities, employees, management, suppliers, and supporting activities
7. What are problems that are found in implementing flexibility?
8. What are the perceived obstacles of effective flexibility implementation and keys to success?

Appendix 10: Supplier Survey Questionnaire

Introduction

Dealing with uncertainties has been considered an important aspect for manufacturing, especially in the automotive industry. The ability of manufacturing systems to adapt or change, manufacturing flexibility, is becoming crucial. This research aims at; (1) investigating how Thai suppliers are coping with such adjustments or changes caused by OEM production; (2) investigating current manufacturing flexibility performance of Thai suppliers; (3) examining key problems in providing manufacturing flexibility to the system; and (4) acquiring the suggestions on success factors of manufacturing flexibility.

Part 1: Manufacturing Flexibility of Company

1. Which types of manufacturing flexibility are important to your business? Please put the rank in the space provided (1 = most important,…, 9 = least important)

____ Volume flexibility
____ New product flexibility
____ Mix flexibility
____ Expansion flexibility
____ Sequence flexibility
____ Routing flexibility
____ Machine flexibility
____ Competitive priorities flexibility
____ Business flexibility

2. Please evaluate the level of manufacturing flexibility performance in your manufacturing system by ticking √ in the box.

1 = Very low …………………→ 7 = Very high

1 2 3 4 5 6 7

2.1 Volume flexibility
- 2.1.1 Machines can adjust volumes being produced
- 2.1.2 Parts are available whenever they are required
- 2.1.3 Workforces are ready and available when required
- 2.1.4 Suppliers can produce parts or raw materials in any amounts required
- 2.1.5 Able to forecast customer demand effectively

2.2 New product flexibility
- 2.2.1 The extent of part commonality
- 2.2.2 Suppliers can produce new required parts or raw materials
- 2.2.3 Ability of workers in learning new parts and products
- 2.2.4 Ability to manage information of new products to related functions

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- 2.3.1 Suppliers can produce varieties of parts
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- 2.4.1 Able to expand plant layout and capacity
- 2.4.2 Suppliers can expand capacity
- 2.4.3 Workforces can work in new production unit and environment

2.5 Sequence flexibility
  2.5.1 Able to feed parts or raw materials in various sequences
  2.5.2 Suppliers can produce in accordance with your production conditions
  2.5.3 Able to arrange workforces for required sequences
  2.5.4 Able to arrange sequences of production as required

2.6 Machine flexibility
  2.6.1 Set-up time of machines
  2.6.2 Workers can program and control machines effectively
  2.6.3 Able to create any production schedule when machines are adjusted
  2.6.4 Able to manage overall production effectively when machines Are adjusted

2.7 Routing flexibility
  2.7.1 Machines can operate under unexpected or emergency situation
  2.7.2 Ability of operators in repairing machines
  2.7.3 Able to effectively manage production process and workforces for overtime production

2.8 Competitive priorities flexibility

2.9 Business flexibility

Part 2: Responding to OEM production, problems, and solutions

3. What are the impacts that your production is faced with as a result of the changes of OEM production and order requirements? And what changes are considered the vulnerable problems for your production?

4. How does your company, as a supplier, manage the production processes to cope with the circumstances in Question 3?

5. What are the problems you have faced when managing the production processes to cope with the circumstances in Question 3?

6. How do you resolve such problems?

7. What are the barriers for resolving such problems?

8. In overall, is your customer, i.e. OEM, satisfied with your company in aspects of flexibility? If not, please describe why.

9. In your perspectives, what are the proactive solutions to cope with the changes of OEM production in order to improve your overall performances and satisfy the OEM requirements?

Part 3: General information

10. Your company is ❒ Tier 1 ❒ Tier 2 ❒ Tier 3

11. What are the automotive assemblers that your company supply the parts to?

12. What are the key parts/ components your company manufacturer?

13. How many employees are there in your company?

Thank you very much for your help in completing the questionnaire

Appendix 11: Automotive Industry Survey Questionnaire

Introduction

Dealing with uncertainties has been considered an important aspect for manufacturing, especially in the automotive industry. The ability of manufacturing system to adapt or change, manufacturing flexibility, is becoming crucial. One way to achieve this is to consider the firm's existing resources and capabilities and assess the possible degree of success that a firm might achieve. The understandings on the set of critical resources and capabilities underpinning the success of flexibility implementation can facilitate the flexibility improvement process and, in turn, finally enhance the level of manufacturing flexibility. This research aims at investigating the linkages between the set of critical resources and capabilities, and manufacturing flexibility performance by asking respondents to evaluate their current emphasis on such resources and capabilities in their operations and production processes and their manufacturing flexibility level in current manufacturing systems.

Part 1: General information

1. Your plant is ❐ OEM ❐ Supplier tier 1 ❐ Tier 2 ❐ Tier 3

2. Please indicate the degree of manufacturing technology and information technology in your plant.

(1) None (2) Less extent (3) Moderate
(4) A great extent (5) A very great extent

1 2 3 4 5

2.1 Automotive control
2.2 Robotics
2.3 Numerical control machines
2.4 Material handling system
2.5 Computer-aided design and manufacturing (CAD/CAM)
2.6 Flexible Manufacturing System (FMS)
2.7 Computerised system for inventory, maintenance, scheduling
2.8 Material Requirement Planning System (MRP)
2.9 Enterprise Resource Planning System (ERP)
2.10 Electronic Data Interchange (EDI)
2.11 Manufacturing Resource Planning System (MRPII)

3. Please indicate the efforts of the following activities in your plant.

(1) Not important at all (2) Less important
(3) Moderately important (4) Very important but it depends
(5) Very important and continuously focused on

1 2 3 4 5

3.1 Effective use of equipments
3.2 Improve the workforce abilities
3.3 Training and retaining workforces
3.4 Controlling costs of production
3.5 Reinforcing planning capabilities
3.6 Restructuring the organisation
3.7 Improving management decision-making
3.8 Improve customer forecasting capabilities
3.9 Improve accuracy on sale volume forecasting
3.10 Improving delivery reliability
3.11 Increasing flexibility of the manufacturing system
3.12 Increasing the responsiveness of the manufacturing system

Part 2: Flexibility problems

4. Please indicate, in your opinion, the problems that lead to ineffectively managed and implement flexibility level in your overall manufacturing system.

(1) Strongly disagree (2) Disagree (3) Neutral (4) Agree (5) Totally agree

1 2 3 4 5

4.1 Lack of workforce capability
4.2 Lack of planning capability
4.3 Poor organisation structure
4.4 Inadequate capacity
4.5 Ineffective machine, equipment
4.6 Technology obsolescence
4.7 Vertical integration
4.8 Ineffective forecasting
4.9 Poor suppliers
4.10 Poor sourcing practices
4.11 No commitment in technology improvement
4.12 No commitment in workforce improvement
4.13 No commitment in problem solving
4.14 Unclear communication
4.15 Poor information sharing
4.16 Top level and operator communication
4.17 Others (Please specify)

Part 3: Production control and management in the plant

Please indicate the extent to which your plant focuses on the following activities in aspects of production control and management.

(1) Not important at all (2) Slightly important
(3) Moderately important (4) Very important but it depends
(5) Very important and continuously focused on

1 2 3 4 5

5.1 Reduce complexity and establish standardisation
5.2 Employ part commonality
5.3 Document key procedures for common understanding
5.4 Use standard evaluation tools to improve production
5.5 Improve processes for better identification of problems
5.6 Enable people in production lines to detect problems quickly
5.7 Rearrange position and layout of facilities
5.8 Effectively collect and evaluate the production information
5.9 Effectively evaluate system capability
5.10 Improve ability in making decision of all level of employees
5.11 Encourage and promote capability of planning teams
5.12 Solve problems by using cross-functional
5.13 Employ rationale-problem solving
5.14 Employ decision-making support and tool for planning
5.15 Level the production to minimise production variation
5.16 Effectively plan, allocate and use buffers or inventory
5.17 Establish responsiveness in production and supply chain
5.18 Effectively manage lead-time in production and supply chain
5.19 Effectively allocate the volumes within and across the plants
5.20 Effectively allocate and transfer raw material or components within and across the plants

Part 4: Resource Redundancy in the plant

Please indicate the extent to which your plant focuses on the following activities in aspects of production control and management.

(1) Not important at all (2) Slightly important
(3) Moderately important (4) Very important but it depends
(5) Very important and continuously focused on

1 2 3 4 5

6.1 Promote training programme for whole organisation
6.2 Encourage employee commitment and involvement in solving problems and improving processes
6.3 Encourage continuous improvement programme
6.4 Enhance Just-In-Time principles for production
6.5 Improve scheduling to match production requirements and conditions
6.6 Improve ability in managing change
6.7 Improve process capability to respond to the changes
6.8 Improve resource planning system and procedures
6.9 Improve ordering system and procedures
6.10 Improve forecasting ability

Part 5: Buyer-supplier coordination

Please indicate the extent to which your plant focuses on the following activities in aspects of production control and management.

(1) Not important at all (2) Slightly important
(3) Moderately important (4) Very important but it depends
(5) Very important and continuously focused on

1 2 3 4 5

7.1 Participate in decision-making with suppliers
7.2 Emphasis on sharing general information with suppliers for making decision
7.3 Emphasis on sharing business information with suppliers for making decision
7.4 Improve communication in strategic planning with suppliers
7.5 Use information and communication technology
7.6 Share costs, risks and benefits with suppliers
7.7 Emphasis on benefits for all stakeholders
7.8 Share and exchange information with suppliers
7.9 Synchronise the production with suppliers
7.10 Unite the goals, policies, and measures with suppliers
7.11 Suppliers and companies improve production in the same direction
7.12 Promote the integration in planning and implementation
7.13 Promote the integration of production and management
7.14 Involve suppliers in long-term planning
7.15 Improve product development process of suppliers
7.16 Improve technical knowledge of suppliers
7.17 Exchange engineering knowledge among companies
7.18 Transfer knowledge to suppliers
7.19 Involve supplier in making production policies, i.e. safety stock, lead-time

Part 6: Flexibility Performance of the manufacturing system

Please indicate the degree of manufacturing flexibility in your plant.

(1) Very low (2) Low (3) Moderate
(4) High (5) Very high

1 2 3 4 5

8.1 Machines can perform variety of tasks effectively
8.2 Equipments and tools can be used for different products effectively
8.3 Production sequences can be adjusted
8.4 Material handling and feeding system can manage different tasks effectively
8.5 Equipments and machines can be operated in unexpected situations
8.6 Different products can be produced effectively
8.7 Different production volumes can be produced effectively
8.8 Different product specification can be produced effectively
8.9 New parts and products can be effectively produced by company and suppliers
8.10 Manufacturing can effectively respond to market changes
8.11 Production is operated smoothly when suppliers have problems or difficulties
8.12 Suppliers can produce parts in different volumes and lead-times
8.13 Plant can reduce backorders
8.14 Plant can increase sale volumes
8.15 Plant can reduce late delivery of products

Please indicate the degree of operational performances in your plant during responding to the changes, i.e. when flexibility is implemented.

(1) Very low (2) Low (3) Moderate
(4) High (5) Very high

1 2 3 4 5

9.1 Production costs
9.2 Supply chain costs
9.3 Inventory costs
9.4 Delivery performance
9.5 Quality of work-in-process products
9.6 Quality of final products
9.7 Development time
9.8 Production time
9.9 Amounts of wastes from production
9.10 Amounts of rework
9.11 Degree of risks

Thank you very much for your help in completing the questionnaire

Appendix 12: Assessment questionnaire for model validation

Assessment Criteria	1	2	3	4	5
1. Feasibility					
1.1 The input information required for the model is available in the firm.					
1.2 The knowledge and experiences of participants can provide effective					
input information.					
1.3 Time consumed for the use of model is appropriate.					
1.4 People are willing to use the model in the meeting or discussion.					
2. Usability					
2.1 The objectives of the model were clear.					
2.2 The model and process step were clearly defined.					
2.3 Process of the evaluation and selection was easy to follow and use.					
2.4 The model was easy to use by all participants.					
2.5 The approach and format for evaluating and selecting strategy were					
appropriate.					
2.6 Main problems encountered in evaluation and selection process.					
3. Utility					
3.1 The decision criteria were relevant to be considered and evaluated among					
improvement strategies					
3.2 Sub-criteria for selecting strategy were relevant to be considered and					
evaluated among improvement strategies.					
3.3 The evaluation and selection process provides useful steps in selecting					
the best strategy.					
3.4 The output of the process were worthwhile for time being consumed.					
3.5 What degree of confidence do you have in the suggested strategy from					
the model?					
4. Suggestion					
4.1 Strengths of the model					
4.2 Weakness of the model					
4.3 Suggestions for improvement					

5 = Strongly agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly disagree

Appendix 13: Critical resources and capabilities of flexibility implementation and associated flexibility dimensions in TMT, SNM, IMCT

	Flexibility dimensions				Evidences of flexibility implementation from interviews		
	Eff.	Res.	Ver.	Rob.	TMT (1)	SNA (2)	IMCT (3)
Production control and management							
Rationality	1				Systematic thinking and good coordination among functions and companies minimise the effects of demand adjustments and production uncertainties		
Allocation			1	1	New plant, i.e. BanPho plant can facilitate capacity allocation of TMC. Production volumes of one-tonned pick up vehicles can be maximised		
Responsiveness	3	2 3				Lack of integration among functions and supply chain members in overall planning system. Current planning tools and procedures do not suit current production	Data and information management is required especially for ordering process as growing number of product spec., suppliers, and promoting engine export unit
Standardisation	1	1			Standardisation of operations has been made as part of Kaizen to support production flexibility		
Visibility			1 2	1 2	Electrodeposition-paint (EDP) process in paint shop limits the visibility of process. Company now considers new painting method	Painting process has limited capacity and it is hard when higher production volumes from original plan are required	
Process capability							
Process control	2					Introducing new measures such as SAR, Direct Run. Developing fool-proof system to provide signal for preventing errors or mistakes	
Feedback and monitoring	1 3		1		Capacity reporting influences better capacity planning and resource allocation		Closely monitoring the production and final results from which adjustments are made to ensure no errors and mistakes as well as along with the plan
Skills and knowledge	2	2	2	2		Recently operating in two shifts, subcontracting workforces are used. Their skills are relatively low and specific so that flexibility can be lessened	
Commitment	3						Commitment from top management to operators in shop floor level is important especially for methodology-base flexibility approach

Appendix 14: Critical resources and capabilities of flexibility implementation and associated flexibility dimensions in TMT, SNM, IMCT (cont.)

	Flexibility dimensions				Evidences of flexibility implementation from interviews		
	Eff.	Res.	Ver.	Rob.	TMT (1)	SNA (2)	IMCT (3)
Buyer-supplier relationship							
Involvement		1			Suppliers increasingly have roles in planning process of TMT's production planning department. It is reflected upon more integration of supply chain members		
Supplier development programme	2 3		2	2		Part shortage occurs when production volumes are increased due to limited capability of suppliers. Close relationship is required to improve	Most of suppliers in current portfolio are not certified quality assurance and company has to check quality of product they made and delivered
Information sharing/communication	1	1	1		The operations in companies and suppliers have good degree of integration, i.e. process and information flow, and software integration (NQC)		
Agreement setting	1 3	1		1	Postponing or returning the use of parts back to suppliers when firm is not ready to use them. Close relationships with suppliers is necessary.		Strategic alliance partner with GM, export vehicles are manufactured at GM plant, Rayong province
Technology and organisational support							
Lean practices	1				The use of levelling production in scheduling can minimise the risks of production uncertainty and standardise the production process		
Agile practices	1 2 3				Perspectives of managers towards flexibility influence the successful flexibility implementation. This can reflect to the leadership of managers	Selection of appropriate technology to improve the operational performances according to unit production strategy being implemented	Culture and working style allow company dealing with production adjustments with less resistance and reluctance

Eff. = Efficiency, Res. = Responsiveness, Ver. = Versatility, Rob. = Robustness

Appendix 15: Critical resources and capabilities of flexibility implementation and associated flexibility dimensions in TSA and TAAP

	Flexibility dimensions				Evidences of flexibility implementation from interviews	
	Eff.	Res.	Ver.	Rob.	TSA (4)	TAAP (5)
Production control and management						
Rationality						
Allocation	5		4		Configuration of assembly line limits ability to adjust the production volumes. Capacity planning and allocation of infrastructural resources are important.	Resource planning needs to be careful as there is no long-term forecasting like other plants.
Responsiveness		4 5			Production plan tends to be fixed after distributing to related function. Planning requires to be responsive to demand adjustment.	The integration of processes between marketing and manufacturing is crucial as company relies on customer orders and closely deal with marketing
Standardisation						
Visibility	4		4		Difficult to examine painting problems as this system operates in a closed environment. It requires close control.	
Process capability						
Process control	4		4		Difficult to examine painting problems as this system operates in a closed environment. It requires close control. Technical improvement is required.	
Feedback and monitoring	5		5			Capacity report is necessary as to inform about current manufacturing functions to the marketing
Skills and knowledge			5	5		Lack of technical and engineering support from developed-country companies. Company encourages operators to learn variety of tasks to support volume and project flexibility
Commitment			4		Top management do not ensure the benefits of single line in the first place. Lack of commitment causes delay of the project	

Appendix 16: Critical resources and capabilities of flexibility implementation and associated flexibility dimensions in TSA and TAAP (cont.)

	Flexibility dimensions				Evidences of flexibility implementation from interviews	
	Eff.	Res.	Ver.	Rob.	TSA (4)	TAAP (5)
Buyer-supplier relationship						
Involvement						
Supplier development programme	5					Late delivery of parts from suppliers is found as one of the problems in operations.
Information sharing/communication						
Agreement setting						
Technology and organisational support						
Lean practices	4 5				Due to JIT principles, sourcing configuration and strategy must support production strategy. Single line production requires company changing sourcing parts from CKD to unit	TQM is required to be effectively used in organisation prior to being flexible. Flexibility cannot be achieved without quality control.
Agile practices						

Eff. = Efficiency, Res. = Responsiveness, Ver. = Versatility, Rob. = Robustness

Appendix 17: Ranking score from decision makers at SNM

	DM1	DM2	DM3	DM4	Average	Global weight
Level 1						
Resource redundancy	0.414	0.346	0.351	0.356	0.367	-
Production control and management	0.295	0.346	0.351	0.326	0.330	-
Buyer-supplier coordination	0.157	0.209	0.109	0.124	0.150	-
Supporting structure and infrastructure	0.134	0.098	0.189	0.194	0.154	-
Level 2						
Skills	0.14	0.255	0.23	0.253	0.220	0.091
Commitment	0.116	0.246	0.155	0.239	0.189	0.078
Process control	0.464	0.275	0.475	0.299	0.378	0.157
Feedback and monitoring	0.28	0.224	0.14	0.209	0.213	0.088
Rationality	0.107	0.154	0.124	0.082	0.117	0.034
Allocation	0.188	0.098	0.198	0.26	0.186	0.055
Responsiveness	0.107	0.118	0.172	0.138	0.134	0.039
Visibility	0.201	0.315	0.253	0.26	0.257	0.076
Standardisation	0.397	0.315	0.253	0.26	0.306	0.090
Involvement	0.107	0.131	0.161	0.139	0.135	0.021
Information sharing & communication	0.293	0.354	0.351	0.419	0.354	0.056
Supplier development programme	0.415	0.354	0.351	0.297	0.354	0.056
Agreement setting	0.185	0.161	0.137	0.144	0.157	0.025
Technology-Lean practices	0.198	0.167	0.169	0.243	0.194	0.026
Technology-Agile practices	0.451	0.333	0.288	0.343	0.354	0.047
Organisational activities-Lean practices	0.094	0.167	0.205	0.172	0.160	0.021
Organisational activities-Agile practices	0.257	0.333	0.338	0.243	0.293	0.039
Level 3						
Line Expansion Strategy	0.686	0.584	0.54	0.709	0.630	-
Modular Sourcing Strategy	0.314	0.416	0.46	0.291	0.370	-

Appendix 18: Ranking score of two alternatives with respect to manufacturing resources and capabilities from decision makers at SNM

		Resource redundancy			
		Skills	Commitment	Process control	Feedback and monitoring
Line expansion strategy	DM1	0.75	0.75	0.667	0.667
	DM2	0.667	0.667	0.667	0.5
	DM3	0.333	0.333	0.5	0.75
	DM4	0.667	0.75	0.75	0.667
Modular sourcing strategy	DM1	0.25	0.25	0.333	0.333
	DM2	0.333	0.333	0.333	0.5
	DM3	0.667	0.667	0.5	0.25
	DM4	0.333	0.25	0.25	0.333

		Production control and management				
		Rationality	Allocation	Responsiveness	Visibility	Standardisation
Line expansion strategy	DM1	0.667	0.75	0.667	0.667	0.5
	DM2	0.5	0.5	0.75	0.667	0.667
	DM3	0.667	0.667	0.667	0.5	0.5
	DM4	0.667	0.667	0.667	0.5	0.667
Modular sourcing strategy	DM1	0.333	0.25	0.333	0.333	0.5
	DM2	0.5	0.5	0.25	0.333	0.333
	DM3	0.333	0.333	0.333	0.5	0.5
	DM4	0.333	0.333	0.333	0.5	0.333

		Buyer-supplier coordination			
		Involvement	Information sharing	Supplier development prog.	Agreement setting
Line expansion strategy	DM1	0.5	0.25	0.25	0.25
	DM2	0.5	0.333	0.333	0.667
	DM3	0.5	0.333	0.5	0.667
	DM4	0.5	0.667	0.5	0.667
Modular sourcing strategy	DM1	0.5	0.75	0.75	0.75
	DM2	0.5	0.667	0.667	0.333
	DM3	0.5	0.667	0.5	0.333
	DM4	0.5	0.333	0.5	0.333

		Supporting structure and infrastructure			
		Technology-Lean	Technology-Agile	Org. activities-Lean	Org. activities-Agile
Line expansion strategy	DM1	0.667	0.667	0.667	0.667
	DM2	0.75	0.667	0.667	0.667
	DM3	0.667	0.667	0.667	0.667
	DM4	0.5	0.5	0.5	0.5
Modular sourcing strategy	DM1	0.333	0.333	0.333	0.333
	DM2	0.25	0.333	0.333	0.333
	DM3	0.333	0.333	0.333	0.333
	DM4	0.5	0.5	0.5	0.5

Appendix 19: Assessment score from decision makers at SNM

Criteria	Question no.	DM1	DM2	DM3	DM4	Average score
Usability	1.1	5	4	3	4	4
	1.2	5	3	3	3	3.5
	1.3	4	3	3	3	3.25
	1.4	4	4	3	2	3.25
	1.5	4	4	4	4	4
Feasibility	2.1	4	3	3	5	3.75
	2.2	4	4	3	4	3.75
	2.3	3	2	3	3	2.75
	2.4	4	4	3	4	3.75
Utility	3.1	5	5	4	4	4.5
	3.2	5	4	4	4	4.25
	3.3	4	3	3	4	3.5
	3.4	4	3	3	4	3.5