UNIVERSITY OF LIVERPOOL

Aligning Purchasing Strategy with Business Strategy for Manufacturers

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor of Philosophy by

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Abstract

The importance of aligning purchasing strategy with business strategy is argued through a literature review. Different business strategies will lead to different competitive priorities, some purchases will have a greater impact on the competitive priorities of the business and suppliers cannot be expected to achieve optimal performance in everything they do, especially at day one. To analyse these differences in priorities in the context of strategic purchasing, current portfolio models have been introduced. However, weaknesses are seen in the exiting models.

This thesis develops a purchasing portfolio model to support competitive advantage through purchasing strategy. The research considers five case studies in South Korea; four elevator manufacturers and one electric water boiler manufacturer. The thesis presents the application of the Analytic Hierarchy Process (AHP) to prioritise the components of an electric traction elevator in the context of their importance to the business strategy of the manufacturer. This is the first step in the formulation of the manufacturers' purchasing strategies. The relative importance of the competitive elements in the form of quality, cost, availability and time are first established for the manufacturers' business strategies, along with the relative importance of the sub-criteria used to measure these elements. The components of the elevator are then assessed to see which have the greatest impact on these sub-criterion measures to establish component priorities and groupings to guide those forming the purchasing strategy. Secondly, a purchasing portfolio model is developed for purchasing strategy. Two dimensions are used, one related to the importance of a purchase, 'component value' and one related to the nature of the supply, 'supply risk'. It is argued that 'component value' is a relative measure based on qualitative measurement whereas 'supply risk' is an absolute measure. For 'component value' the AHP is suited. However, the AHP is not appropriate for assessing the supply risk associated with an individual component, which should be measured independently or directly, so the 'supply risk model' is introduced. Two case studies in the elevator manufacturing industry are used to demonstrate the application of the portfolio model. This reveals how two companies that appear on the surface to be facing the same situation actually face different situations that require different purchasing strategies. Finally, the 'lean & agile component model' is developed using two dimensions, 'leanness' and 'agility'. The model is applied to one of the elevator manufacturers and the electric boiler manufacturer to demonstrate how functional and innovative products require different component purchasing strategies. This reveals some notable differences in the component characteristics in the 'lean & agile component models' of the two different manufacturers, and therefore differences in the purchasing strategies derived for the companies. The case studies support the argument that when purchasing strategies are developed, a manufacturer must consider its components' characteristics to support its business strategy, and therefore its manufacturing strategy, for competitive advantage.

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Chapter 1

Introduction to the Study

1.1 The reason for this thesis

"We are dependent on suppliers. We cannot succeed without them. Our success is their success." declared Shoemaker, vice president of procurement in Hewlett-Packard Company (Carbone, 2004). A firm cannot provide its customers with better quality goods than it receives from its suppliers without rework. The final product is directly dependent on the quality, cost, availability, and delivery time of its components. Traditionally, however, purchasing was separated from a firm's final customers (Grant et al., 2006). It was considered just as a relatively unimportant clerical function in business. More recently purchasing has become recognised as an important function by many researchers (e.g. Burt, 1989; Carter and Narasimhan, 1996; Kraljic, 1983; Pearson and Gritzmacher, 1990, Spekman et al., 1994), and the role of purchasing has changed dramatically from an administrative function into a strategic one (Gadde and Hakansson, 2001).

The first step in developing purchasing strategy is linking strategy to the firm's objectives (Duffy, 1999). It is important that purchasers understand their business strategies that contribute to achieving competitive advantage. This understanding will allow the purchasing function to make the right decisions to support the firm's business strategy. A portfolio model is an effective tool for strategic management of purchased components (Wagner and Johnson, 2004). However, according to Gelderman (2003), most publications on the purchasing models are conceptual or anecdotal in nature (Gelderman, 2003). Moreover, existing models are not directly linked to a firm's business strategy (Gelderman and van Weele, 2005). This thesis addresses this gap in the research.

1.2 Definition of purchasing

Any manufacturer, whatever it produces, whether it be an automobile, furniture, elevator or boiler, buys materials, parts and components from external firms to support its operations. Manufacturing firms purchase raw materials and components from suppliers and transform them into final products, which are then distributed to customers. Many different terms and definitions are used to describe purchasing both in practice and in the literature. There is no agreement on definitions for terms such as *purchasing*, *procurement*, *logistics*, *sourcing* and *supply management*; in practice, these terms are often used interchangeably (Bowersox et al., 2002). What these terms have in common is that they involve the purchase and supply of materials, parts and components from current and potential suppliers to manufacturing or assembly plants, or warehouses in a firm.

Van Weele (2005) defined purchasing as the management of the company's external resources in such a way that the supply of all goods, services, capabilities and knowledge, which are necessary for running, maintaining and managing the company's primary and support activities, is secured in the most favourable conditions. This definition includes the flow of materials and service in both the manufacturing and service sectors. Although purchasing is not confined to manufacturing operations alone, for the purpose of this thesis, the term *purchasing* will be used only in the context of the manufacturing field.

1.3 Importance of purchasing

It has been widely accepted for many years that the fundamental purpose of the purchasing function is to obtain the right quality in the right items at the right price and at the right time for the right customer (Monczka et al., 2002; Watts et al., 1995). Traditionally, best practice purchasing was to buy components at the lowest possible purchase price from a supplier. However, the purchasing function is no longer viewed as a clerical function with decisions based only on price (Pearson and Gritzmacher, 1990). Since the 1980s, purchasing has shifted its focus from an administrative task to a more strategic role in order to increase the competitive advantage of the organisation (Ahonen and Salmi, 2003; Carter and Narasimhan, 1996; Ellram and Carr, 1994; Gadde and Hakansson, 2001). Spekman et al. (1994) argued that purchasing provides new opportunities for a company to become strategic positioned in a competitive environment that is changing rapidly. Moreover, many firms recognise that purchasing is not restricted to buying material but is a value-adding resource that can be used to increase competitiveness when managed strategically (Carr and Pearson, 1999; Dyer, 1994; Narasimhan and Das, 1999).

The purchasing function has become one of the most critical activities of a manufacturing business (Parikh and Joshi, 2005; Sarkis and Talluri, 2002). The increasing importance of purchasing can be traced to several factors. The most basic of these factors is that the cost of purchased goods and services is one of the largest parts of the total cost of a product in many firms. Between 50-70% of a manufacturing company's expenditure consists of purchased goods and services (van Weele, 2005). It is clear that the potential cost savings from the strategic management of purchasing are considerable. For most companies a 1% cut in the cost of purchasing can increase profits by the same amount as a 10% increase in sales value (DTI, 1993).

The significance of purchasing has greater impact than just the cost of components purchased. Other impact factors include the quality, availability and delivery time of components, which can affect the firm's operations greatly (Joyce, 2006). Manufacturers' products are also affected significantly by the performance of external suppliers in terms of cost, quality, availability and delivery time (Krause and Scannell, 2002). For example, if poor-quality components are used, then the finished product will not meet the customer quality required (Bowersox et al., 2002). A firm can increase its product variety using its suppliers' capabilities (Narasimhan and Das, 1999). The flexibility and delivery time of purchased components can be critical factors in the commercial success of the final product (Hou and Su, 2007).

Since purchasing is recognised as an important factor in increasingly competitive markets, a growing number of firms are developing and implementing proper purchasing strategies. Purchasing plays a key role in corporate strategic success, supporting a firm's long-term strategy and competitive positioning (Katsikeas et al., 2004). All purchasing activities have the potential to be critical in supporting and enabling a particular business strategy. Moreover, the role of purchasing strategy is crucially important to the success of a manufacturing firm. The findings of previous research indicate that firms that adopt effective purchasing strategies tend to perform better than others that do not have purchasing strategies (Carr and Pearson, 2002; Carr and Smeltzer, 2000; Chen et al., 2004; Freeman and Cavinato, 1990; Narasimhan and Das, 2001; Kekre et al., 1995; Sanchez-Rodriguez et al., 2006;

Thompson, 1996; Vereecke and Muylle, 2006). Purchasing strategy is especially critical in cases where purchased components determine the quality of the final products (Carr and Pearson, 1999).

1.4 Research problem

The most widely used classification of purchased items in many books are production materials and components, maintenance materials and supplies, capital equipment, and services on the basis of product use (Laios and Moschuris, 2001). Xideas and Moschuris (1998) have already argued that firms have different structures for the purchasing functions and processes for different types of purchased items. For example, decisions about the purchase of raw materials differ from those for the purchase of maintenance, repair and operating (MRO) items. However, this classification is not enough to develop and implement differentiated purchasing strategies to support a firm's business strategy. In general, production parts account for more than half of all purchased item costs (van Weele, 2005) and they have a very direct impact on the quality and success of the final product. Therefore, when a firm considers its purchasing strategy, production-related items (raw materials and components) should be analysed in detail. Consequently, this thesis focuses on the analysis of production-related components for the purpose of developing purchasing strategy in support of business strategy. The term *components* is used here to include all the types of production-related items seen in a bill of materials (BOM).

In managing components, a very well known tool that is used for grouping is "ABC analysis", which ranks components into three categories, A, B and C by the value of their usage (Slack et al., 2007). This classification differentiates components with significant spend from the mass of components with only small purchase volume for the purposes of inventory management. For a long time, ABC analysis has been a very helpful inventory management tool. However, to develop a purchasing strategy, the financial value of consumption alone can sometimes be misleading. For example, it over-emphasizes items that have a high value of consumption but do not have critical effects on the production operation or the quality of the product. At the same time, it may under-emphasize items that have a low value of consumption but are critical to quality; just because something is cheap and low volume it does not necessarily mean that it is not critical to quality. Burt (1989) also argued that the cheapest component is not always the least expensive when the cost of poor quality is considered; the cheapest component may be the most expensive. Moreover, decisions on purchasing strategies cannot be based only on internal factors (i.e. purchase financial value or volume) but should also consider external factors such as perceived risk in supply (Gemunden, 1985).

In 1983, Kraljic introduced his seminal purchasing portfolio model. By measuring the 'importance of purchasing' and the 'complexity of the supply market', purchased items are classified into four quadrants with different purchasing strategies corresponding to each quadrant. From this, a firm can consider how to develop its relationships with its suppliers. There is a considerable amount of literature that considers the portfolio model as a useful starting point for strategic analysis in the purchasing field (Gelderman, 2003). After Kraljic's model, Olsen and Ellram (1997) developed a similar portfolio model to assist in managing different kinds of supplier relationships based on two dimensions, 'strategic importance of the purchase' and 'difficulty of the purchasing situation'. For classifying supplier relationships

Bensaou (1999) also developed a portfolio model using two dimensions but different measures or factors to Kraljic (1983) and Olsen and Ellram (1997). Based on case studies within the automotive industry, Bensaou (1999) emphasised 'buyers' specific investments' and 'suppliers' specific investments' as the two dimensions.

Although portfolio models are a useful tool to give practical guidelines on how to manage different components, suppliers and supplier relationships (Dubois and Pedersen, 2002), there are still some critics of the actual use of portfolio models in purchasing. Decisions based on portfolio models have proven to be sensitive to the choice of dimensions, factors and weights (Gelderman and van Weele, 2005). In addition, the existing portfolio models are not connected directly with business strategy.

The fundamental questions of this thesis are, "What is the purchasing strategy to improve the business strategy?" and "How can a firm develop and use this purchasing strategy?" With regard to fundamental questions of this study, two different aspects can be distinguished: research objective and research questions.

The objective of this research project is stated as follows:

To design a methodology by which a manufacturing firm can develop its purchasing strategy to support its competitive business strategy.

This research objective implies development of the purchasing portfolio model in combination with an empirical study. Based on this research objective, four research questions addressed in this study are:

1) What are the criteria in the purchasing decision process for strategic purchasing?

When developing the purchasing strategy of a firm, the starting point should be a comprehensive strategy for the entire business. Therefore, this study will start by clarifying the nature of business strategy. It also includes a discussion and a review of manufacturing strategy with competitive priorities. This will be the basis of a purchasing strategy that is aligned with the business strategy. Based on this question, the author forms the theoretical compilation of the criteria for the purchasing decision process for further empirical research.

2) What are the critical components of a product under a company's business strategy?

The cost, quality, flexibility and delivery time of a final product is heavily influenced by those of its major components. Furthermore, non-critical items require about 80% of the purchasing transactions, although they represent less than 20% of the purchasing turnover (Caniels and Gelderman, 2007). Therefore, before developing a firm's purchasing strategy, it is necessary to recognise what the critical components of a product are under its business strategy. ABC analysis is an established model for classifying components by value of consumption. However, it is argued that value of consumption or cost is only one of the factors that should be considered when assessing which components are critical to a product. Therefore, the Analytic Hierarchy Process (AHP) is introduced to synthesise several factors that measure the importance of a component. The results obtained by this method are compared with those obtained with standard ABC analysis.

3) How can a firm develop a purchasing portfolio model for its purchasing strategy in order to support its business strategy?

As stated earlier, a portfolio model is a useful starting point for strategic analysis in purchasing. However, defining the dimensions is critical in developing the model. If suitable dimensions can be found and used, the portfolio model will provide an easy-to-grasp and usable tool for the strategic management of purchased components (Ahonen and Salmi, 2003). As the general form of a portfolio model has one dimension related to the importance of a purchase and one related to the nature of the supply, internal factors and external factors will be used as the two dimensions. Specifically, 'component value' and 'supply risk' are used here. Factors of 'component value' will be tackled by the first research question while factors of 'supply risk' will be concerned with risk assessment of the supply.

4) How can a firm develop its purchasing strategy according to its product type?

It can be argued that components of different product types (e.g. functional product and innovative product) and used in different manufacturing strategies (e.g. make-to-order (MTO) and make-to-stock (MTS)) can be managed with the same purchasing strategies. Each product type responds to distinctly different demand patterns and requires a different kind of supply chain and strategy (Mason-Jones et al., 2000a). According to Evans and Berman (2001), a differentiation by degree of product customisation is a key factor in determining the appropriate purchasing management. Therefore, it is important that companies understand the characteristics of their product and manufacturing systems. However, existing portfolio models overlook that this understanding will allow purchasing to make the right decisions to support the business strategy. This study will introduce the 'lean & agile component model' using the two dimensions, 'leanness' and 'agility'. A suitable purchasing strategy will be presented for each quadrant according to each component's characteristics.

1.5 Research methodology

Two major research methods are used in this thesis: an extensive literature study and a series of explorative case studies. The literature study covers three areas: (1) ABC classification and portfolio models in purchasing management, (2) Analytic Hierarchy Process (AHP) and (3) criteria in the purchasing decision process for strategic purchasing. After the review of the literature, five case studies are conducted in two different industries (electric elevators and electric water boilers). Figure 1.1 provides an overview of the two research methods. Each research method has its own characteristics and advantages, which gives us more appropriate answers for certain types of research questions.

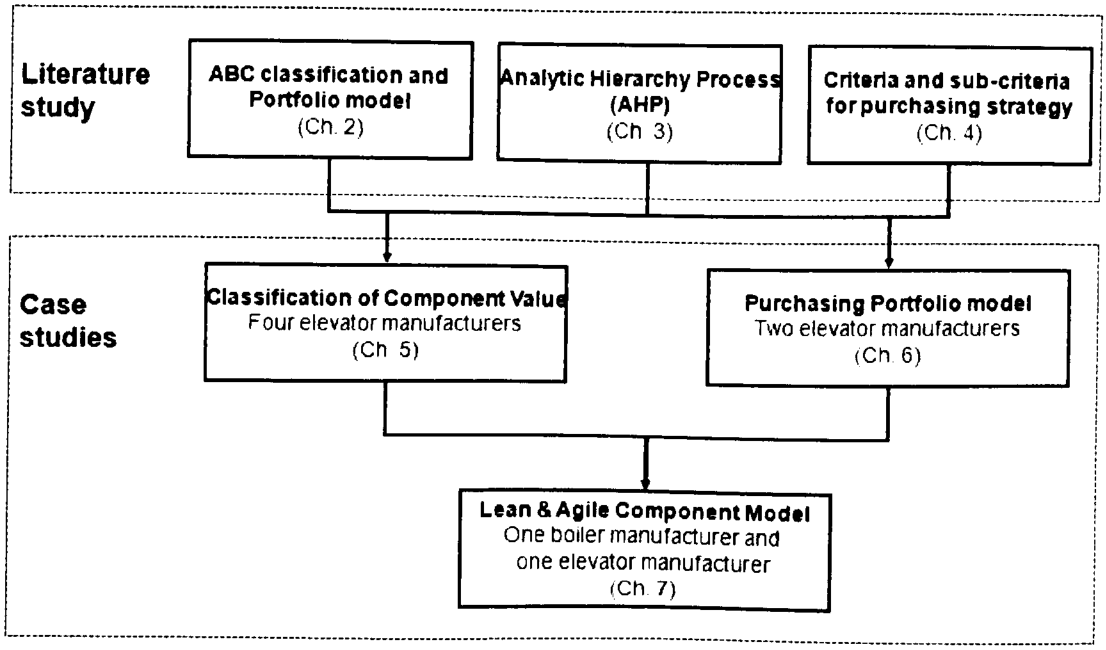


Figure 1.1 Overview of the two research methods

(a) Literature study

The literature study starts with a review of purchasing models, namely ABC classification and portfolio models. The main reason for starting with these areas is that the author wants to learn from the related purchasing strategies used in these existing models. It is argued that the AHP is a good candidate for prioritised components in respective of purchasing strategy because both qualitative and quantitative objectives have to be considered. For strategic purchasing, the criteria for the purchasing decision process will be identified and applied on the case studies. This step answers the first research question.

(b) Case studies

Case studies are used to identify and to describe advanced current practices with respect to purchasing models. The main purpose of each case study is to answer each research question. A case study research methodology is followed to evaluate the application of the AHP method to purchasing strategy in a manufacturing company. Although the case study methodology is a preferred way to examine contemporary events, a common concern about case studies is that they provide very little basis for scientific generalisation (Yin, 2003). However, multiple-case studies are used to build a general explanation of how various problems are tackled, even though the details of the cases will vary (Yin, 2003). This research consists of five case studies in South Korea, with participants from four elevator manufacturers and one electric water boiler manufacturer respectively. Two different industries are selected to compare purchasing strategies for two different product types. However, this research is not concerned with the analysis of the whole industry, but rather the purchasing strategy of the components purchased in each individual company. For this reason, the data from five companies are treated independently. Details of the methodology of case studies including the outline of AHP, background of industries, questionnaire, and interviews are described further in Chapter 3, Chapter 5 and Chapter 7.

1.6 Structure of the thesis

This thesis is divided into eight chapters. Its content and composition are summarised in Table 1.1.

The first chapter begins with an introduction to the research. This includes a discussion of the term purchasing and the importance of purchasing. After the general topic, the research objective and research questions are defined. Chapter 2 focuses on the existing literature on purchasing models, namely ABC classification and portfolio models. Due to the fragmented nature of the existing purchasing models researched, the chapter begins with an overview and analysis of these models. The purpose of this chapter is to critically appraise current purchasing portfolio models, showing why they cannot be used easily in practice. The empirical methods used in the thesis are introduced in Chapter 3, which provides a description of the AHP and the case study approach to research. The purpose of this chapter is to enable an evaluation of the quality of the research as far as the empirical methods are concerned. The criteria used to analyse characteristics of components for the formulation of the purchasing strategy are identified in Chapter 4, which provides answers to the first research question. These purchasing criteria are analysed to determine the importance of each of the criteria in the procurement of components in the case studies in the following chapters. The empirical research starts with Chapter 5, which reports four case studies and the use of the AHP method to analyse them. The purpose of this analysis is to identify the critical components under each company's purchasing strategy. This chapter provides answers to the second research question. In Chapter 6, the portfolio model for the purchasing strategy is developed using internal and external factors. After this, the portfolio model is used in two elevator firms to compare their purchasing strategies using sensitivity analysis. This chapter provides answers to the third research question. Chapter 7 includes elaboration of the answers to the last research question. It presents purchasing strategies for functional (lean) and innovative (agile) products on the basis of the theoretical and empirical analysis. For this, the 'lean & agile component model' is developed. Following this, the purchasing strategies are proposed in each category. The study is concluded in Chapter 8. This final part of the study includes a discussion of the outcomes and experiences from the research. First, a short summary of the study is presented. After this, conclusions of the study are presented. This is done by recalling the defined research questions at the beginning of the study and by giving answers to the questions. At the end, the limitations of this research are discussed and finally, some avenues for future research are presented.

Table 1.1 Summary of the structure and content of the thesis

Chapter	Outcome
1. Introduction	Research objective and research questions
2. From ABC Classification to Portfolio Approach	Review of current tools for purchasing components
3. Analytic Hierarchy Process (AHP)	Description of AHP and case studies
4. Criteria in Purchasing Decision Process for Strategic Purchasing	Identification of criteria in purchasing decision process for purchasing strategy and an answer to the first research question
5. Measurement and Classification of Component Value	Identification of critical components under purchasing strategy and an answer to the second research question
6. The Purchasing Portfolio Model	Development of the portfolio model for purchasing strategy based on two dimensions and an answer to the third research question
7. A Comparison of Lean & Agile Component Models for Different Productions	Development of the 'lean & agile component model' for two different types of products, functional and innovative, in lean and agile supply chains and an answer to the fourth research question
8. Conclusions	Conclusions & discussion

A journal paper and a conference paper reporting some of the content of this thesis are given in Appendix 1 and Appendix 2.

Chapter 2

From ABC Classification to Portfolio Approach

2.1 Introduction

ABC classification (based on Pareto Analysis) has been used in many companies as a tool for differentiating between purchases because it is simple to understand and easy to use. Kraljic (1983) introduced a portfolio approach to purchasing in which purchased items are classified on the basis of the two dimensions, 'importance of the purchase' and 'complexity of the supply market'. Items are classified by evaluating and positioning them into one of four quadrants of the portfolio model. The quadrants represent different purchasing strategies. Following on from Kraljic, several other researchers have developed similar portfolio models based on a two-dimensional framework, for example see (Bensaou, 1999) and (Olsen and Ellram, 1997). Purchasing portfolio models enable a business to identify the more important purchased items to focus on from the point of view of purchasing strategy, investing more time to build and maintain close relationships with the suppliers of these items. Taking a portfolio perspective in purchasing and supplier management can provide real advantage as it contributes to achieving a sustainable competitive edge and high profitability (Wagner and Johnson, 2004). So it is advocated that buyers should use a purchasing portfolio model in developing and implementing differentiated purchasing strategies (Gelderman and van Weele, 2005).

2.2 ABC classification

In any product that contains more than one component, some components will be more important to the company than others. Some, for example, might be of particularly high cost, so they would account for a large proportion of the total cost of the final product. To control the resource of a company most effectively, effort and controls should be based on a component's importance. One common way of organising and managing components is to use an ABC classification to rank components by the value of their usage (their annual usage rate multiplied by their individual value: dollar usage) (Slack et al., 2007). Components with a particularly high-value usage need to be closely managed, whereas those with low-value usage need not be treated so carefully. This method is very helpful if the majority of the purchase spend is usually caused by only a few material categories.

ABC classification developed by H Ford Dickey of USA in 1951 is a type of Pareto Analysis (Waller, 2003), sometimes referred to as the Pareto Law or 80-20 rule (Lysons and Gillingham, 2003). Especially in inventory management, this method has been a useful tool to control inventory. It has shown that about 20% of the quantity of inventory represents about 80% of the cost of inventory. Conversely, 80% of quantity contributes 20% of the cost. To use Pareto Analysis properly requires classification of stock by issue value. There are three classes A, B, and C as shown as Figure 2.1.

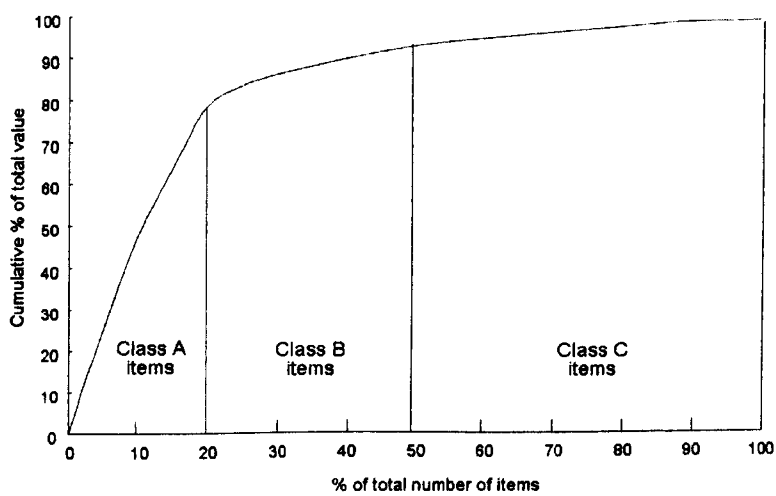


Figure 2.1 ABC classification for items in a warehouse (Slack et al., 2007)

Class A items require tight control to maintain stock at the lowest appropriate level, because the majority of cost savings in inventory management will be gained by decreasing stocks of these items. Class C should warrant no more than a loose control, such as a simple two-bin system that enables supply to be obtained with a minimum of administration. Finally, Class B items should have a control regime that lies between these two classes (Guvenir and Erel, 1998), possibly using statistics and forecasting models. The nature of the different systems of control used for the three categories of stock is shown in Table 2.1.

Table 2.1: ABC inventory control

Characteristics	**Policy**	**Methods**
Class A items	Tight control Personal supervision Balanced safety stock	Frequent monitoring Accurate demand forecast Detailed record keeping
Class B items	Classic stock control Lean stock policy	Rely on sophisticated system Calculated safety stocks
Class C items	Loose control Large orders Zero or high safety stock policy	Simple system (e.g. two bin) Avoid stock-out and excess Infrequent ordering

Source: Wild (1997)

ABC classification is also used elsewhere in operations management (Slack et al., 2007). For example, total productive maintenance (TPM) (Ireland and Dale, 2001), suppliers management (Waller, 2003), time-based competition for saving time (Wild, 1997), quality management (Miltenburg, 2005) and customer service (Grant et al., 2006).

ABC inventory analysis classifies the importance of components by financial value of consumption. This indicates priorities for inventory management and the important suppliers, but it does not provide any purchasing strategies for the categories, it merely provides information on the concentration of purchase spend (Gelderman and van Weele, 2005); typically, routine items require about 80% of the purchasing transactions, although they represent less than 20% of the purchasing turnover (Caniels and Gelderman, 2007). ABC analysis is easy to understand and therefore use, but it has major weaknesses (Flores et al., 1992). For example, it over-emphasizes items that have a high value of consumption but do not have critical effects on the production operation or the quality of the product. At the same time, it may under-emphasize items that have a low value of consumption but are critical to quality. The problem stems from ABC classification being based on a single measure, i.e. value of consumption, when there are other criteria such as inventory cost, obsolescence, durability and stock-out penalty cost that also represent important considerations for management (Ng, 2007; Partovi and Anandarajan, 2002).

In the last 20 years, multi-criterion inventory classification has been developed with different approaches: the cross-tabulate matrix (Flores and Whybark, 1987), cluster analysis (Ernst and Cohen, 1990), the analytic hierarchy process (AHP) (Flores et al., 1992; Partovi and Burton, 1993; Gajpal et al., 1994) and fuzzy AHP (Cakir and Canbolat, 2007), heuristic approaches based on artificial intelligence, such as genetic algorithms (GA) (Guvenir and Erel, 1998) and artificial neural networks (ANNs) (Partovi and Anandarajan, 2002), and weighted linear optimization models (Ramanathan, 2006; Ng, 2007). However, most research into multi-criterion inventory classification has focused on determining criteria and applying them in making categories of inventory items without formulating purchasing strategy.

2.3 Existing portfolio models

Markowitz (1952) originally developed portfolio theory for financial investment decision-making. Since then, the concept has been used widely in strategic planning and marketing. According to Gelderman and van Weele (2005), Kraljic (1983) introduced the first portfolio matrix for purchasing and supply management but until recently application within the field of purchasing had been limited (Nellore and Soderquist, 2000). Portfolio models have been applied in related areas such as supplier involvement in product development (Wynstra and Pierick, 2000), e-purchasing of materials (Bartezzaghi and Ronchi, 2004), the specification process (Nellore and Soderquist, 2000) and inter-organisational competence development (Moller et al., 2000).

In general, a purchasing portfolio model can be recognised by a matrix of two dimensions that is used for grouping components. After categorising components, each quadrant can be provided with a direction for a different purchasing strategy. Gelderman (2003) defined a portfolio model as a tool that uses two or more dimensions to define heterogeneous categories for which different strategic recommendations are provided. The basis of this approach is that purchasing managers need to develop separate strategies for their supply markets, because different suppliers represent dissimilar interests to the company (van Weele, 2005).

2.3.1 Kraljic's portfolio model

In Kraljic's portfolio approach, purchased items are classified on the basis of the two dimensions, the importance of purchasing and the complexity of the supply market. The importance of a particular purchase (component) can be defined in terms of the volume purchased, the percentage it represents of the total cost of purchases and the impact it has on product quality or competitive strategy. The complexity of the supply market can be assessed in terms of availability, the number of suppliers, competitive demand from others for the supplied item, make-or-buy opportunities, storage risks and substitution possibilities (alternatives) as listed in Table 2.2. Each dimension spans the values high and low, so that the segmented (2 x 2) matrix in Figure 2.2 is used to classify purchases into four categories (strategic, bottleneck, leverage and non-critical) that lay the foundations of the purchasing strategy.

Table 2.2 Classification dimensions of Kraljic purchasing portfolio model

Importance of purchasing	Complexity of supply market
volume purchased, percentage of total purchase cost, impact on product quality and business growth	availability, number of suppliers, competitive demand, make-or-buy opportunities, storage risks and substitution possibilities

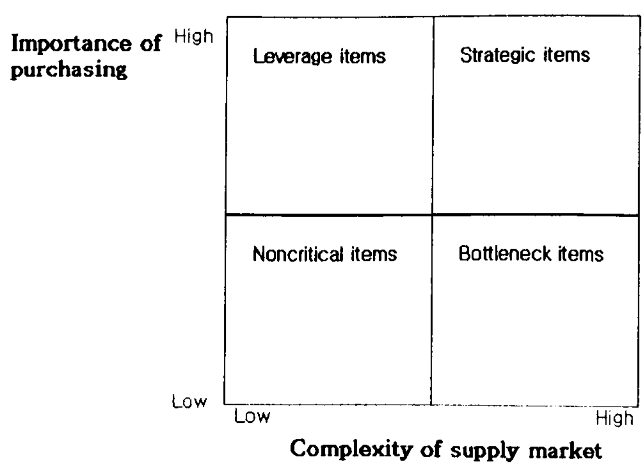


Figure 2.2 Kraljic purchasing portfolio model (modified from Kraljic, 1983)

These four categories are used for clarifying the purchase and setting directions for the purchasing strategy. Depending on the product segment of the portfolio model, the purchasing strategy will differ. Van Weele (2005) presents a possible strategy for each segment of the portfolio as follows.

Strategic items represent a considerable value to the company in terms of a large impact on profit and a high supply risk. Sometimes strategic items can only be bought from a single source, so the purchaser should strive for a partnership relationship with suppliers of these items. Examples are engines and gearboxes for automobile manufactures and turbines for the chemical industry. The purchasing strategy should be aimed at either partnership or collaboration with suppliers. This should lead to improvements in product quality, delivery reliability, lead times, product development, product design, and cost.

Leverage items have a relatively high share of the total cost of the end product and a low supply risk. A small change in cost here has a relatively strong effect on the total cost of the final product. In general, these items can be obtained from various suppliers at standard quality grades. Examples are steel and aluminum profiles, packaging and raw materials. A purchasing strategy based on the principles of competitive bidding or tendering can and should be pursued. Long-term supply contracts should be avoided because of the large number of potential suppliers and the impact of price. Buying at a minimum cost with maintenance of required quality and continuity of supply should get priority.

Bottleneck items have less influence on the financial results, but they are not easy to obtain. They can be obtained from few suppliers. In general the supplier is dominant in the relationship with the contractor, which may result in long delivery times and bad service. Examples are catalytic products for the chemical industry and pigments for the paint industry. The purchasing strategy should be focussed on assurance of supply. At the same time it is important to work at reducing dependency by developing alternative products and suppliers.

Non-critical items have a small value per item and there are many alternative suppliers. From a purchasing point of view, these items produce few technical or commercial problems. Usually, non-critical items require 80% of the purchasing department's time and energy, while they often represent less than 20% of the purchasing turnover. In practice, most items fall into this group. Examples include simple nuts and bolts. The purchasing strategy should be directed at the reduction of costs and complexity for administration and logistics. This can be done for instance by standardising the product range, reducing the number of suppliers, purchasing systems contracts for categories of MRO items, working with electronic catalogues, ordering through Internet-technology and using electronic payment. There is no need for long-term supply contracts if a better solution is found.

There have been several reports of empirical studies to test and develop Kraljic's model, for example see (Caniels and Gelderman, 2007), (Gelderman and van Weele, 2003) and (Wagner and Johnson, 2004). Kraljic offered an inconsistent view of the two dimensions. First, he said "A company's need for a supply strategy depends on two factors: (1) The strategic importance of purchasing in terms of the value added by product line, the percentage of raw materials in total costs and their impact on profitability, and so on.; and (2) the complexity of the supply market gauged by supply scarcity, pace of technology and/or materials substitution, entry barriers, logistics cost or complexity, and monopoly or oligopoly conditions" (Kraljic, 1983, p. 110). However, in the same paper he had a diagram with the dimensions "(1) criteria of importance of purchasing: cost of materials/total costs, value-added profile, profitability profile, and so on. (2) criteria of complexity of supply market: supply monopoly or oligopoly conditions, pace of technological advance, entry barriers, logistics cost and complexity, and so on" (Kraljic, 1983, p. 111, Exhibit I). Finally, he noted again "The profit impact of a given supply item can be defined in terms of the volume purchased, percentage of total purchase cost, or impact on product quality or business growth. Supply risk is assessed in terms of availability, number of supplier, competitive demand, make-or-buy opportunities, storage risks and substitution possibilities" (Kraljic, 1983, p. 112). Another criticism put forward by Gelderman (2003) is that it is not clear why Kraljic selected the particular dimensions used. However, endorsement is seen in the use of these dimensions in the work of others and in the use of effectively similar dimensions in the work reviewed below. This thesis makes a contribution through the interpretation and justification of these dimensions.

2.3.2 Olsen and Ellram's portfolio model

Based on the work of Kraljic (1983) and Fiocca (1982) and following on from the work of Narasimhan (1983), Olsen and Ellram (1997) proposed a portfolio model to assist in managing different kinds of supplier relationships. They renamed the vertical and horizontal dimensions in Figure 2.2, 'strategic importance of the purchase' and 'difficulty of the purchasing situation' respectively, although in effect there is little change in meaning.

They assess strategic importance using three factors internal to the firm: competence, economics and image. These factors then have three, four and two measures respectively, resulting in a total of nine. In the first group, competence factors, the company gets knowledge of the strategic importance of the purchase by finding out if the product purchased is close to the core competence in any way. Another contribution that comes with evaluating the competence factors is to see if it could improve the knowledge and technology within the firm. To describe the economic importance of a purchase in terms of the dollar value and the impact on the company's profits, the economic factors are used as the second group. They are supposed to capture the interdependencies between purchases, which can be achieved through knowledge about whether the purchased items are useful to get leverage with suppliers for other purchases or not. Finally, the image factors are used to describe the strategic importance of the purchase to the company's image among customers and suppliers.

The other dimension mentioned is the difficulty of managing the purchasing situation. It is assessed by three factors external to the company: product, supply market and environmental characteristics. Each of these factors has two measures, resulting in a total of six measures. In the first group, the product characteristics factors describe the novelty and the complexity of the item to be purchased. If it is new or complex, the company may have to pay more attention to the supplier relationship. The supply market factors describe the supplier's power (e.g. company size, the number of alternative suppliers, resource dependence etc) and the supplier's technical and commercial competence. The environmental factors describe the risk and uncertainty connected to a purchase situation.

The dimensions make up a portfolio model with the same four categories or matrix quadrants used by Kraljic. However, Olsen and Ellram have been criticised for not testing their model empirically (Zolkiewski and Turnbull, 2000). Moreover, a total of fifteen measures were used in their model, as listed in Table 2.3, although they argued that the listed factors are not comprehensive and they must be adjusted for particular companies. Moller et al. (2000) found that the model is impractical because it incorporates too many factors and measures to be considered, i.e. it is too elaborate for everyday usage in industry. The model presented here makes a contribution by addressing this issue.

Table 2.3 Classification dimensions of Olsen and Ellram purchasing portfolio model

Factors influencing the strategic importance of the purchase	**Factors describing the difficulty in managing the purchase situation**
Competence factors 1. The extent to which the purchase is part of the firm's core competencies 2. Purchase improves knowledge of buying organization 3. Purchase improved technological strength of buying organization	Product characteristics 1. Novelty 2. Complexity Supply market characteristics 1. Suppliers' power 2. Suppliers' technical and commercial competence
Economic factors 1. Volume or dollar value of purchases 2. The extent to which the purchase is part of a final product with a great value added 3. The extent to which the purchase is part of a final product with a good profitability 4. Criticality of the purchase to get leverage with the supplier for other buys	Environmental characteristics 1. Risk 2. Uncertainty
Image factors 1. Supplier critical image/brand name 2. Potential environmental/safety concerns	

2.3.3 Bensaou's portfolio model

Based on empirical data, Bensaou (1999) developed a portfolio model using the two dimensions, 'buyers' specific investments' and 'suppliers' specific investments', as listed in Table 2.4. Specific investments are broadly defined and can include anything from tangible to intangible resources developed to meet the needs of specific suppliers or customers. These investments are typically difficult or expensive to transfer to another relationship and may lose their value when redeployed to another supplier or customer. Bensaou's model consists of classifying supplier relationships into four categories: strategic partnership, captive supplier, captive buyer and market exchange - see Figure 2.3.

Table 2.4 Classification dimensions of Bensaou purchasing portfolio models

Buyer's specific investments	Supplier's specific investments
Tangible investments Buildings, tooling, equipment	Tangible investments Plant or warehouse location or layout, specialized facilities, dies
Intangible investments People, time, effort, best practice, knowledge	Intangible investments Sending guest engineers, developing information systems

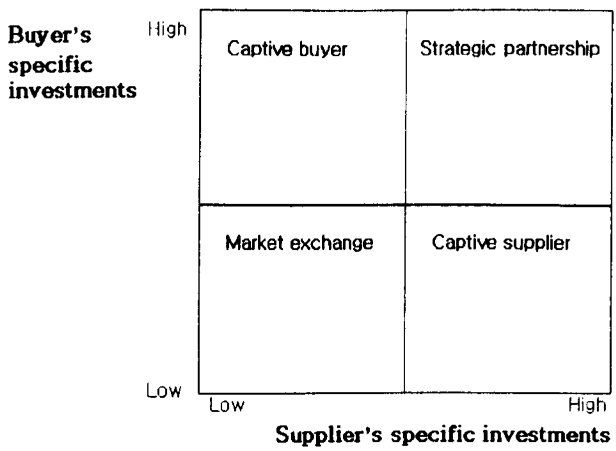


Figure 2.3 Bensaou purchasing portfolio model (modified from Bensaou, 1999)

Wasti et al. (2006) tested this model on a case study taken from the automotive industry in Turkey. No captive buyer relationships were identified as only captive supplier, market exchange and strategic partnership relationships were seen in the Turkish automotive industry. Comparing this result with what was reported by Bensaou, the Turkish situation resembles that seen in Japan were few captive buyer relationships are seen and it resembles the situation in the USA in respect of having fewer market exchange relationships compared to a higher number of strategic partnerships. Since Bensaou's model has been developed primarily for the automotive industry it does not provide sufficient guidance for practical use in other industries, which can be quite different, so it has not seen widespread application (Gelderman, 2003). Large automobile manufacturers sit at the top of supplier pyramids. The relationships between an automobile manufacturer at this focal tier and its major suppliers are generally closed and involve contracts for long periods of time so that the suppliers become very dependent on the manufacturer (the buyer). This is why the level of specific investments is important in determining strategy in Bensaou's automotive model.

2.3.4 Discussion

The existing approaches to purchasing portfolio models show that a common problem in defining the dimensions of a portfolio model is the synthesising of qualitative and quantitative measures (Ahone and Salmi, 2003). A decision making tool that can do this is required. Gelderman and van Weele (2003) argued that if a firm has problems discriminating between high and low on the dimensions then the classification of purchases will be arbitrary and so will be the resultant recommendations. The Analytic Hierarchy Process (AHP) is a decision making tool that can help people set priorities and make the best decisions when both qualitative and quantitative measures must be taken into consideration. It scores or weights alternative courses of action based on the decision makers' judgments concerning the relative importance of the criteria and the extent to which they are met by each alternative (Nydick and Hill, 1992). For this reason, it is introduced in the portfolio purchasing model presented in this thesis. This will be discussed in more detail in Chapter 3.

2.4 Summary

This chapter has discussed the purchasing tools in the literature, i.e. ABC analysis and the three main portfolio models. ABC analysis has been used to classify and manage components in many firms for a long time so that it has become a classic tool. It shows which components are more important than others in the context of inventory management. Although there are some benefits of this tool, it does not provide purchasing strategies for each group.

After Kraljic introduced the first portfolio model for purchasing management, the portfolio approach has been a useful tool to provide different purchasing strategies according to components in each quadrant of the two-dimensional model. However, there are still some critics of the actual application of portfolio models.

The literature reviewed supports the argument that defining the dimensions is a critical issue in the development of a purchasing model. However, the summary of existing approaches to the classification of components shows that it needs a combination of qualitative and quantitative measures. Therefore, a decision making tool that can take both perspectives into consideration is desired. For this reason, the AHP will be introduced in Chapter 3.

Chapter 3

The Analytic Hierarchy Process (AHP): a Tool for Strategic Decision Making in the Formulation of Purchasing Strategy

3.1 Introduction

The Analytic Hierarchy Process (AHP), developed by Saaty (1980), is a method for structuring and prioritising decision problems by relating alternatives to criteria and to objectives and then to an overall goal (Saaty, 2001). It is popular for multi-objective decision making and planning. The approach involves decomposing a complex and unstructured problem into a set of variables that are organized into a hierarchy (Chow and Luk, 2005). The AHP is a tool to help integrate and compare seemingly incomparable issues (Bhutta and Huq, 2002), because it is a flexible modelling tool that can deal with different types of data, e.g. tangible and intangible factors (Davies, 2001). Moreover, the AHP can be used to monitor easily the consistency with which a decision maker makes a judgement (Chan and Chan, 2004). The AHP is especially suitable when decision-making could encounter difficulties in accurately determining the various criteria weights and the evaluation of alternatives (Saaty, 1980).

Demonstrating its practicality and versatility, the application of the AHP has been reported in a variety of decision making and planning projects in many different areas (Vaidya and Kumar, 2006), e.g. marketing (Davies, 1994), production/manufacturing (Bayazit, 2005), purchasing (Bhutta and Huq, 2002; Cebi and Bayraktar, 2003; Chan and Chan, 2004; Dulmin and Mininno, 2003; Hou and Su, 2007; Muralidharan et al., 2002; Nydick and Hill, 1992; Sha and Che, 2006; Tam and Tummala, 2001; Udo, 2000; Vargas and Saaty, 1981; van de Water and van Peet, 2006), human resource management (Peters and Zelewski, 2007), financial management (Ho et al., 2006) and others (Chow and Luk, 2005; Law et al., 2006).

3.2 Application of the AHP to decision making in the purchasing process

The findings of a review of research into the future of purchasing and supply, commissioned by the Chartered Institute of Purchasing and Supply (CIPS) in the UK, was published recently (Zheng et al., 2007). It was found that purchasing is moving from being clerical to strategic, purchases that are less strategic are being automated or outsourced leaving a more strategic purchasing task to be tackled, and cross-functional and cross-enterprise teams will make joint decisions on purchasing and supply. Gelderman and van Weele (2003) also stress the need for teamwork when performing portfolio analysis stating, "The views of colleagues from different fields of expertise should be added to the more functional purchasing perspective." This leads to the need for methods, such as the AHP, that combine the inputs of several team members to prioritise components, i.e. to differentiate between strategic and non-strategic purchases.

On the use of the Kraljic (1983) matrix in the determination of purchasing strategy, Gelderman and van Weele (2003) state, "In-depth discussions on the positions in the matrix are considered as the most important phase of the analysis. Strategic discussions provide deeper in-sights and may lead more easily to consensus-based decisions." The AHP facilitates and encourages such consensus reaching discussion as it makes the decision-making process very transparent, highlighting misconceptions and acting as a catalyst for lively debate (Drake, 1998). As the AHP synthesises the perspectives of different people, counteracting the vested interests or restricted vision of individuals, it provides the triangulation that is desired when dealing with qualitative data in particular.

A central role that has been developed for the purchasing function is to develop and maintain a competitive advantage in the marketplace by selecting and managing the best suppliers for the organisation (Chan and Chan, 2004; Kannan and Tan, 2002). Consequently, there has been much research into supplier evaluation and selection using decision-making tools such as the AHP (Bhutta and Huq, 2002; Cebi and Bayraktar, 2003; Dulmin and Mininno, 2003; Hou and Su, 2007; Muralidharan et al., 2002; Nydick and Hill, 1992; Sha and Che, 2006; Tam and Tummala, 2001).

However, this thesis is not concerned with supplier evaluation and selection, but rather the strategic prioritisation of the components to be purchased. Van de Water and van Peet (2006) report the application of the AHP to the *make or buy* decision in manufacturing. They give a justification for using the AHP, explaining that it enables decision makers to set priorities, eliminates inconsistencies in prioritising, allows a hierarchy of decision layers to tackle complexity and explicitly takes into account the subjective nature of decision-making. These features are clearly exploited in the application presented here. More generally, van de Water and van Peet (2006) argue that practitioners need strategic frameworks that incorporate quantitative measures to assist in setting priorities, as seen here. Their introduction to the mechanics of the AHP is succinct, although they do reference complete books on the subject written by Saaty (1980; 2000). This chapter presents a more detailed but still concise introduction to the AHP aimed at people in manufacturing who are concerned with purchasing components and sub-assemblies.

The AHP and the specific model presented here may appear too elaborate to be applied by practitioners in manufacturing industry. However, the AHP is supported by proprietary software packages offering user-friendly interfaces and general support in the application of the method. Past research was frequently performed using the Export Choice proprietary software (e.g. Bayazit, 2005; Cebi and Bayraktar, 2003; Chan and Chan, 2004; Law et al., 2006; Tam and Tummala, 2001; Udo, 2000), which is also employed in this study.

3.3 The AHP procedure

The AHP process consists fundamentally of three steps: structuring the problem as a hierarchy, making pair-wise comparisons among criteria and subcriteria to determine the user's preferences, and calculating the weight of each alternative (Saaty, 1980).

3.3.1 Step 1: Structuring the problem as a hierarchy

The problem is decomposed into its independent elements and represented in a hierarchical structure (Schoenherr, 2004). Figure 3.1 presents a basic hierarchical structure consisting of three levels: the overall goal of the problem at the top level, criteria that define alternatives in the middle level, and competing alternatives at the bottom level. Each criterion in the hierarchical structure should contribute differently to the goal. The decision can be made on the relative importance among these criteria by making pair-wise comparisons at each level of the hierarchy.

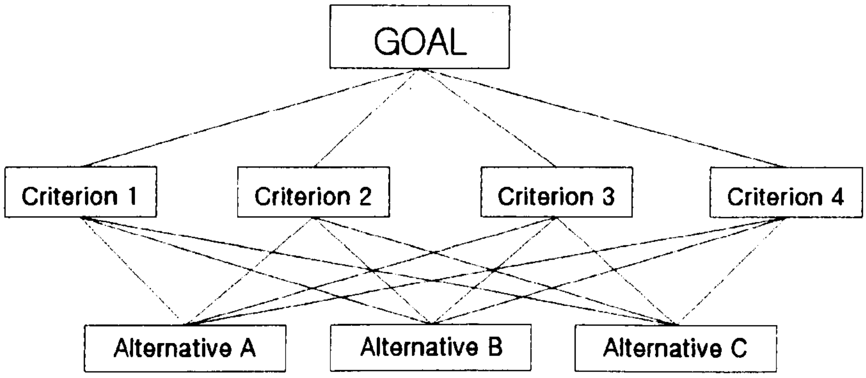


Figure 3.1 The basic structure of a hierarchy (Saaty and Vargas, 2001)

3.3.2 Step 2: Making the pair-wise comparison

Pair-wise comparisons express the relative importance of one item versus another in meeting the element (a goal or a criterion) directly above them in the hierarchy (Nydick and Hill, 1992). In pair-wise comparisons, the decision maker would need to compare two different criteria using scales that range from equality of preference or importance to extremely preferred or more important. Although there are many scales that can be used for quantifying managerial judgements, the nine-point numerical scale, created by Saaty (1980), is commonly used for AHP analysis (Bhutta and Huq, 2002). Table 3.1 shows the suggested numbers to express the degree of preference between two criteria, A and B.

Table 3.1 Nine-point scale for AHP preference

Intensity of importance	**Definition**	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one over another
5	Strong importance	Experience and judgement strongly favour one over another
7	Very strong importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent compromise between the priorities listed above
Reciprocals of above non-zero numbers	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Source: Saaty and Vargas (2001)

Comparison information for each component of the problem is represented by a pair-wise comparison matrix (Nydick and Hill, 1992). Let a_{ij} denote the comparison of criterion *i* against criterion *j*, the element of the comparison matrix at row *i*, column *j*. The pair-wise comparison matrix *A* can be created as shown below (Saaty, 1980):

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \qquad (3\text{-}1)$$

This matrix is referred to as a reciprocal matrix. The "reverse" comparisons simply use the reciprocal values in the matrix of comparisons that results. The a_{ij} element of this matrix is transformed to $1/a_{ij}$ or the reciprocal of the a_{ji} element. Moreover, in a reciprocal matrix, its principal diagonal elements are unity, as a factor compared to itself produces a judgement of "equal importance". Thus, values of 1 are placed down the leading diagonal, from the upper left corner to the lower right corner of the matrix. Therefore, if there are n factors that need to be compared for a given matrix, the number of judgements needed is $n(n-1)/2$ (Nydick and Hill, 1992). For example, if $n=4$, only 6 judgements are needed, whereas there are $n^2=16$ cells in the complete matrix.

However, if the number of alternatives to be evaluated is large (eight or more), these methods are generally computationally infeasible (Liberatore et al., 1992). For example, for 23 alternatives, $n(n-1)/2 = 253$ judgements are required for each criterion. For reducing this explosive number of pair-wise judgments required, Liberatore et al. (1992) suggested a five-point rating scale of: outstanding (O), good (G), average (A), fair (F), and poor (P). This was used to rate each alternative according to each criterion (Liberatore et al., 1992).

After the construction of the pair-wise comparison matrix, individual judgements should be combined to produce the group judgement results for the group decision-making. The geometric mean rather than the arithmetic mean should be conceptually more consistent (Harker and Vargas, 1990), because the arithmetic mean may not provide a good estimate of what most evaluators might consider is representative of their judgements, if the mean is affected by a small number of evaluators holding extremely high or low values (Davies, 2001). Geometric means of all individual judgements are then calculated with the following formula to produce the group judgement (Saaty and Vargas, 2001):

$$B = \sqrt[n]{b_1 \times b_2 \times \ldots \times b_n} \qquad (3\text{-}2)$$

where:

B = the combined judgment;

n = the number of individual judgments;

and b_1, b_2, . . . b_n = the individual judgments.

The AHP offers the opportunity to check the consistency of judgements in a matrix. To understand Saaty's (1980) treatment of inconsistency, the matrix A is called "consistent" if the following condition is satisfied:

$$a_{ik} \times a_{kj} = a_{ij} \qquad \forall i, j, k = 1, \ldots, n \qquad (3\text{-}3)$$

Based on this, Saaty then shows that for a pair-wise comparison matrix of size (n x n) to be "absolutely consistent", it must have one positive eigenvalue $\lambda_{max} = n$, while all other eigenvalues equal zero. However, in the real world, human evaluators do not typically achieve absolute consistency; so to be pragmatic Saaty introduces the consistency index (C.I.) to measure the "closeness to consistency":

$$\text{C.I.} = \frac{\lambda_{max} - n}{n - 1} \qquad (3\text{-}4)$$

where:

n = the number of factors being compared.

Then, the consistency ratio (C.R.) is used to assess whether a matrix is sufficiently consistent or not. This is the ratio of the C.I. to the random index (R.I.), which is the C.I. of a matrix of comparisons generated randomly:

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \qquad (3\text{-}5)$$

Random pair-wise comparisons have been simulated to produce average random indices (R.I.) for different sized matrices, as given in Table 3.2.

Table 3.2 Random Index (R.I.) values

N	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Saaty and Vergas (2001)

It is supposed that C.R. should be very small. For n=3 the C.R. should be less than 0.05, for n=4 it should be less than 0.08 and for $n \geq 5$ it should be less than 0.10 to get a sufficiently consistent matrix (Saaty, 2001).

3.3.3 Step 3: Calculating the weight of each alternative

There are potentially many ways in which to compute the 'priority vectors' to define the relative priorities of the criteria and sub-criteria. However, Saaty's (1980) consistency principle that $a_{ik} \times a_{kj} = a_{ij}$ and his subsequent argument for using the special case of the consistent matrix formed by elements $a_{ij} = w_i / w_j$, where w_i and w_j are the elements of the priority vector corresponding to criteria i and j (i.e.

their priorities), leads to the following method. In terms of matrix algebra, a priority vector is computed as the normalized, principal (largest) eigenvector of the consensus matrix of pair-wise comparisons. A more detailed mathematical description can be found in Saaty (1980). The calculation is complex and is normally executed using proprietary software such as Experts Choice. However, there are methods for calculating an approximate solution. For example, one can normalize the ratings in a consensus matrix by dividing each entry in a column by the sum of all the entries in that column, so that the entries in the column add up to one, and then average these normalized weights across the rows to give an average priority weight for each criterion. The normalization down the columns makes it statistically sound to compare and average scores across the columns to give row averages. The application of this algorithm is demonstrated in (Drake, 1998) and it can be implemented in a proprietary spreadsheet by a moderately experienced user.

3.4 Methodology of case studies

The methodology for applying the AHP consisted of three main stages. First, the problem background review covered the recent business environment of the elevator and electric boiler manufacturing industries, from which the case studies are drawn, the background of the case-study companies, their products and their competitive strategy. Second, the preliminary research included the primary interviews of the companies' staff and further analysis of the data so collected. Third, the development of the model includes establishing the criteria, construction of the AHP model, design of an evaluation questionnaire, respondent interviews, analysis of the questionnaire results and finally, determining the components' scores. Figure 3.2 presents an overview of the methodology for applying the AHP to the case studies.

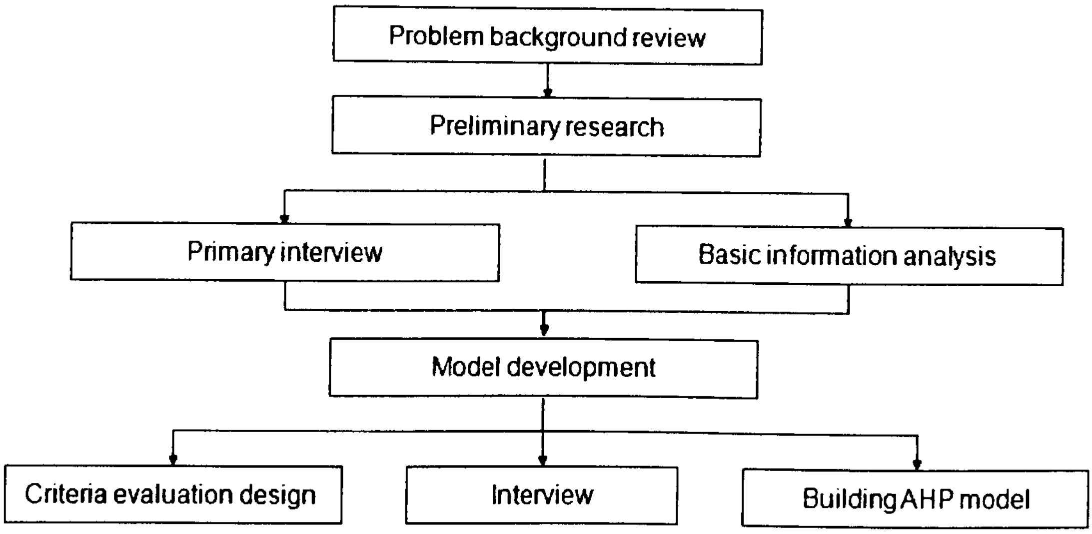


Figure 3.2 Overview of the methodology for case studies

3.4.1 Selection of the respondents

Selecting respondents for group decision making is an important part of the AHP (Saaty, 1980). Many purchasing decisions are taken or at least influenced by several departments within a business (van Weele, 2005). The various evaluators may be drawn from different functions of the company such as engineering, operations, accounting, etc. Ramanathan and Ganesh (1994) argued that all participants do not have equal expertise about the problem domain of a group decision. They should be selected based on their experience and knowledge about the various business functions of the company (Muralidharan et al., 2002).

In this research, between 3 and 5 individuals were selected from each case study company. They consisted of employees who are frequently involved directly or indirectly with component purchasing and came from the purchasing, engineering, operations management and accounting functions within the business. These samples give coverage of different functions and therefore perspectives. Nicholas (1998) referred to purchasing, manufacturing operations, engineering and accounting as the four key functions to have represented in a supplier selection team. The purchasing staff are more focused on the suppliers and the purchasing process, the engineers are more focused on the manufacturing technology and the product, the manufacturing operations managers are more focused on quality and customer service whilst the accountants are more focused on costs and profit.

3.4.2 Selection of criteria and sub-criteria

Four key criteria and twelve sub-criteria (three per criterion) are obtained through the literature review and the detailed argument developed in Chapter 4.

i. Quality (component durability, component reliability and component innovation);
ii. Cost (purchasing cost, inventory cost and quality cost);
iii. Availability (volume flexibility, modification flexibility and technological capability);
iv. Time (delivery speed, delivery reliability and development speed).

3.4.3 Questionnaire

The structured questionnaire is given in Appendix 3. The first and second sections are concerned with information about the company and its product respectively. They are used to analyse the environments of the companies and their industry, and the characteristics of their products. The third and fourth sections cover the pair-wise comparisons of the criteria and the purchased items in the AHP. In the third, a simple linear scale of 1 to 9 is applied whereas a five-point scale ranging from (1) very high to (5) very low is used for each alternative in the fourth section. The last question of the fourth section relates to the supply risk of each purchased item.

3.4.4 The interviews

The interviews were conducted from March to August 2006. In all cases, interviews with employees required visits to the companies to gather data 'face to face'. During each interview, the specific terminology of the decision criteria and the components of the elevator or boiler were explained to the staff if necessary. Special care was taken to avoid the pitfall of using leading questions when asking the staff for their evaluations. This means that members of the team do not have a preconception before making their assessments. This led the author to shun the use of a second evaluation round after the team members had been informed about their colleagues' scores, i.e. the AHP has been used to capture truly independent perceptions from different functions within the organisation.

The most common comment concerning the questions in two industries was difficulty in comparing qualitatively measured subcriteria (e.g. component durability and component reliability). Another comment from respondents was that the restriction of the five-point rating scale is bound to force inconsistencies on the respondent. For example, the *car set* is considered to be very high cost whereas the *limit switch* is extremely low, but the maximum difference between the two components can only be four increments on the five-point scale.

3.5 Summary

Although the AHP approach was originally developed for solving multi-criteria decision-making problems, its practicality and versatility has allowed it to be applied in the purchasing field. In particular, it has been used to combine qualitative and quantitative data, and to synthesise the perspectives of people from different functions within the business.

This chapter explains the AHP procedure based on three steps: 1) structuring the problem as a hierarchy, 2) making pair-wise comparisons among criteria and subcriteria to determine the user's preferences, and 3) calculating the weight of each alternative.

This chapter describes how the methodology of the AHP is applied in the five case studies. The case study methodology used consists of three stages: 1) problem background review, 2) preliminary research, and 3) AHP model development. The results of these empirical analyses are presented in Chapter 5, Chapter 6 and Chapter 7, respectively.

Chapter 4

Criteria in Purchasing Decision Process for Strategic Purchasing

4.1 Introduction

The commercial success or failure of any manufacturing firm is heavily influenced by the performance of its suppliers. This is because the cost, quality, flexibility and delivery time of products sold are directly related to the cost, quality, flexibility and delivery time of components purchased (Koh et al., 2007). For example, the failure of purchased components is often the major source of quality problems (Burt, 1989; Juran and Gryna, 1993; Watts et al., 1995), the good quality of purchased components gives to improve the substantial quality of the final product (Gadde and Snehota, 2000; Shin et al., 2000), the cost of purchased components can be the largest part of the total cost of a product (Hill, 2000; van Weele, 2005) and the performance of suppliers influences the company's ability to respond quickly to customers (Barbarosoglu and Yazgac, 1997). For this reason, the purchasing function has the potential to be critical in supporting and enabling a particular business strategy (Ellram and Carr, 1994).

Clearly and as noted by Watts et al. (1995), "Since the core of purchasing's role is to support the production and operations activities with an uninterrupted flow of materials and services, the purchasing and manufacturing strategies must be consistent with each other, and they must be able to support the corporate level competitive strategy." To take this a step further, there will be prerequisites of a business strategy that must be provided through the purchasing and manufacturing strategies. This means that when the purchasing strategy is developed, its objectives have to be the objectives of the business strategy rather than functional objectives. For example, an objective of purchasing might be to buy components at the lowest cost. Sometimes, the purchasing cost of any component from a new supplier might be lower than the cost of the component. However, if competitive strategy in the firm is concentrated on providing customers with high products quality, the new component may not run as efficiently through the production process to achieve high quality as the one from the existing supplier.

Porter (1986) highlighted the importance of the purchasing function and supplier management to achieving competitive success in the value chain. In summary, the purchasing function has become one of the most critical activities of a manufacturing business (Parikh and Joshi, 2005; Sarkis and Talluri, 2002). The purchasing strategy is required to be continuously updated to match changes in the business's strategic plans (Carr and Smeltzer, 1999). For example, changes in business strategy may require the use of different types of contracts or relationships with suppliers. Gelderman and van Weele (2003) demonstrate the link between business strategy and purchasing strategy by analysing case studies.

4.2 Purchasing decision process

The purchasing function is largely responsible for: determining the characteristics of components; selecting suppliers capable of providing the required items at the requisite levels of quality and price; managing transactions so that the goods or services are delivered in a timely manner (Krause et al., 2001). Although the purchasing process of each company is different for dissimilar products purchased and varies according to the company structure, there are some 'main' activities that are necessary and common.

Many researchers (Burt, 1989; Ghingold and Wilson, 1998; Kotteaku et al., 1995;

Laios and Moschuris, 2001; McWilliams et al., 1992; Smeltzer and Ogden, 2002; van Weele, 2005; Woodside and Samuel, 1981; Xideas and Moschuris, 1998) have tried to decompose the purchasing decision process into a number of phases, ranging from 3 to 15. Each phase includes discrete and directly observable activities. For example, according to van Weele (2005), the purchasing process should be divided into six activities. Figure 4.1 illustrates these six activities of the purchasing process chain. The first three activities, referred to as a tactical purchasing, are primarily of a technical – commercial nature while the three latter ones, called order function, are of a more logistics – administrative nature.

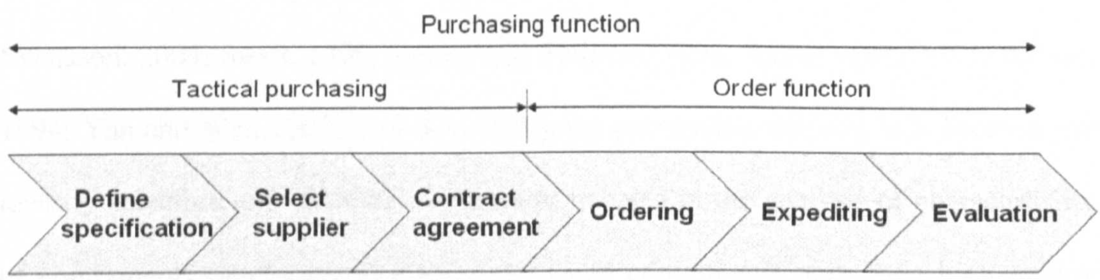


Figure 4.1 Purchasing process chain (van Weele, 2005)

Although the purchasing process has been divided into different numbers of stages by different researchers, the starting point of any purchasing process should be to define the component characteristics that can be used to describe or capture the whole of the user requirements in detail. For this reason, although supplier selection is an important decision making process (Ghodsypour and O'Brien, 1998; Nydick and Hill, 1992) and an important task for the purchasing department of a firm in particular (Sarkis and Talluri, 2002; Vokurka et al., 1996), the definition of component characteristics in the first step should be one of the most important stages in the purchasing process. Common sense tells us that deficiencies in one step will lead to problems in the next steps. Moreover, the desired or required component characteristics should become in turn the basis for the supplier selection (van Weele, 2005).

One limitation of the purchasing management literature, however, is that most criteria discussions take the perspective of supplier selection (e.g. Akarte et al., 2001; Craig et al., 1997; Deng and Wortzel, 1995; Gonzalez et al., 2004; Hirakubo and Kublin, 1998; Humphreys et al., 2003; Kannan and Tan, 2002; Katsikeas et al., 2004; Lee et al., 2001; Mummaleneni et al., 1996; Patton, 1996; Pearson and Ellram, 1995; Svensson, 2004; Swift, 1995; Verma and Pullman, 1998; Weber et al., 1991; Wilson, 1994; Yan and Wei, 2002). For developing the purchasing strategy, it is necessary to identify selection and evaluation criteria to be used in the analysis of characteristics of components purchased. For example, some components may have high quality characteristics required whereas others may have high variety required for a final product.

4.3 Strategic purchasing

Purchasing can have an impact on the firm's ability to achieve its chosen business strategies (Carr et al., 2000). For this reason, purchasing should be involved in the corporate strategic planning process (Carter and Narasimhan, 1996; Pearson and Gritzmacher, 1990). According to Carr and Pearson (1999) the purchasing function at Honda of America is totally integrated into its strategic planning process.

In general, the strategic role of purchasing is of two different types: rationalisation and development (Gadde and Hakansson, 2001). Purchasing can make a contribution to a company's competitive situation through rationalisation. This means that purchasing aims to decrease the total costs. The second strategic role of purchasing is to make sure that the company's and suppliers' research and development proceeds in the same direction. Attention should be paid to the advantage a supplier can create by being a developmental resource.

While there are many definitions of strategic purchasing and purchasing strategy, Ellram and Carr (1994) found that the phrases 'strategic purchasing' and 'purchasing strategy' are frequently thought to have the same meaning in the literature. Carr and Smeltzer (1997) defined strategic purchasing as "the process of planning, implementing, evaluating, and controlling strategic and operating purchasing decisions for directing all activities of the purchasing function toward opportunities consistent with the firm's capabilities to achieve its long-term goals".

It is necessary to consider first the concept of strategic management to understand strategic purchasing better (Freeman and Cavinato, 1990) because strategic purchasing exists to support a firm's strategy (Grant et al., 2006).

4.3.1 Strategic management

Many different definitions are used to describe strategic management both in reality and in the literature, but they all relate to actions necessary to achieve organizational goals (Carr and Smeltzer, 1997). Hill and Jones (1998) defined strategy as a pattern of decisions and actions that enables an organization to improve or maintain its performance.

Strategic management is the area of management studies concerned with decisions that help a firm obtain competitive advantage (Mol, 2003). In general, three basic hierarchical levels of a firm are involved in the strategic management process: corporate, business and functional (Hannagan, 2002).

The corporate strategy involves making decisions that set and guide resource allocations for the whole enterprise. It deals with the strategic question: *What business should a firm be in?* Once the corporate strategy decision is made, each business unit develops its own business plan for its products (Fredendall and Hill, 2001). The business strategy is the strategy for a single business unit. It attempts to answer the strategic question: *How should a firm compete in this particular business area?* The business strategy involves making decisions concerned with achieving and maintaining competitive advantage within the firm's industry by making the best use of the distinctive competences of the firm. The business strategy has to be supported by appropriate performance of all business functions (Rusjan, 2005). The third level of strategy is the functional strategy, which answers the strategic question: *How can a firm meet its business goals efficiently?* Functional strategies involve making decisions concerned with the formulation of action plans at the functional departments or divisions of organizations. Most firms have six main areas that constitute a business, namely marketing strategy, manufacturing strategy, purchasing strategy, technology strategy, human resources strategy and financial strategy (Lysons and Gillingham, 2003). Functional strategies are concerned with integrating activities within the functional area and linking the competitive business strategy and corporate strategy. Therefore, the purchasing strategy, at a functional level must be consistent with manufacturing strategy and it has to support the competitive business strategy of a firm, as shown in Figure 4.2 (Carr and Smeltzer, 1997; Watts et al., 1995). This thesis focuses on the relationship between business and functional level strategies.

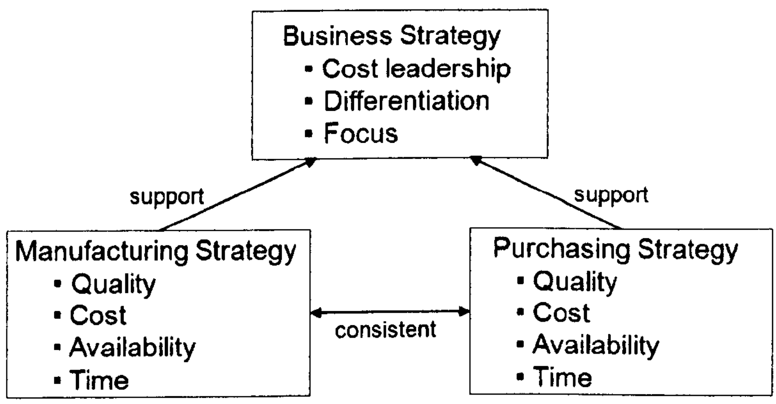


Figure 4.2 The linkage between business strategy and function level (modified from Watts et al., 1995)

4.3.2 Competitive advantage

All firms seek to gain an advantage over their competitors in the market. This competitive advantage means that there are some reasons why a customer would prefer to buy a similar product from one firm instead of others (Fredendall and Hill, 2001). Competitive advantage is developed at the business strategy level. A firm can obtain a competitive advantage over competitors in three basic strategies; cost leadership, differentiation or a focus strategy (Porter, 1985). Each strategy is a fundamentally different approach to creating and sustaining a firm's competitive advantage.

The cost leadership strategy in any market gains competitive advantage from being able to produce the product at the lowest cost. A company that applies this strategy will emphasize cost reduction at every point in its processes. This strategy also has to pay attention to bases of differentiation such as quality, but cost comes first (van Weele, 2005). These products are often highly standardised and not customised to individual customer's needs (Pitts and Lei, 2000). The problem with this strategy is that it could lead to the firm losing touch with the changing requirements of the customer (Bowman, 1990).

However, the differentiation strategy obtains a competitive advantage over competitors when a firm provides consumers unique value that makes the product distinct from that of its rivals. This strategy may be achieved in many ways that are valued. For example, the product may have a more innovative design, may be produced using high quality materials or process, or may be sold in some special channel (Pitts and Lei, 2000). The problem with this strategy is that there are likely to be extra costs incurred in providing the product (Hannagan, 2002), so the customer must be willing to pay more for the higher value.

The final strategy is known as a focus strategy, in which the firm may choose a specific niche market within an industry, competing on the basis of either low cost or differentiation. These niches could be a particular buyer group, a narrow segment, or a geographic or regional market (Pitts and Lei, 2000). The problem with this strategy is that the niche market may be small and specialist in nature, so that it could disappear over time (Hannagan, 2002).

Many firms frequently want to manage a cost leadership strategy with a differentiation strategy at the same time (van Weele, 2005). However, it is difficult for a company to pursue both strategies simultaneously, because these competitive strategies required different organizational structures, control procedures and systems (Porter, 1985). It could lead to problems, conflicts and compromises to meet the two strategies' requirements (Bowman, 1990). Moreover, there are dangers associated with being 'stuck in the middle' if a firm does focus on the competing clearly in one of these strategy areas (Porter, 1985).

The purchasing function can support a firm's strategic positioning (Landeros and Monczka, 1989; Spekman et al., 1994) because suppliers are one of the five forces that impact competition (Porter, 1985). Cost leadership and differentiation strategies require quite different types of purchasing strategies (Cousins, 2005) and organisational structures (David et al., 2002). For example, in the case of cost leadership, price and cost are central in the negotiations with the supplier in a centralised purchasing structure. However, in the case of the differentiation strategy, the emphasis is on close cooperation with the supplier in a decentralised purchasing structure. This cooperation can be in the area of process and product improvement, quality control, lead time reduction and exchange of information (van Weele, 2005).

4.4 Competitive priorities

If the purchasing strategy is to support the business strategy, it follows that the importance of a purchase is determined by the competitive priorities of the business. Hayes and Wheelwright (1984) introduced the term "competitive priorities" and defined it as strategic preferences. They suggested that companies compete in the marketplace by virtue of one or more of the four, core competitive priorities; cost, quality, delivery time and flexibility. Following their research, there has been a general consensus in the operations management literature that these are indeed the four main competitive priorities, for example see (Chan, 2005), (Dangayach and Deshmukh, 2001), (Fredendall and Hill, 2001), (Krajewski and Ritzman, 2005), (McCarthy, 2004), (Miller and Roth, 1994), (Morita and Flynn, 1997), (Shin et al., 2000), and (Sanchez and Perez, 2001). Any company, regardless of the industry in which it operates, should improve its product quality and service (flexibility or availability) and reduce lead times and cost simultaneously as illustrated in Figure 4.3 (Emmett and Crocker, 2006; Johansson et al., 1993), which portrays the calculation of the total value of the product to the customer. This figure gives further insight into what is covered by each of the four priorities.

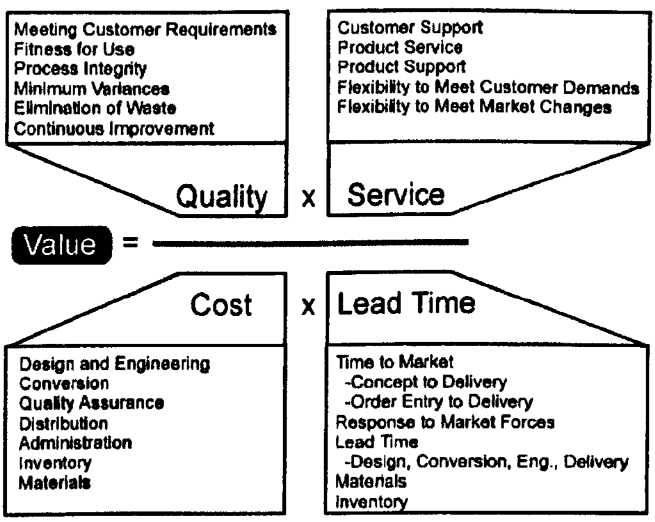


Figure 4.3 Johansson's total value metrics (Johansson et al., 1993)

According to Krause et al.'s (2001) empirical research, purchasing's competitive priorities are conceptualised as being similar to the competitive priorities in operations management. Manufacturers use materials, components and subassemblies sourced from external suppliers, so their products and customer service are affected significantly by the performance of their suppliers in terms of cost, quality, time and availability (Krause and Scannell, 2002). The different functional departments within a firm should be pursuing functional strategies that have similar priorities if they are pursuing the same goals (Krause et al., 2001), as shown in Figure 4.4. Looking in the real world, Nissan's purchasing strategy involved the selection of suppliers based on quality, cost, delivery and development capability criteria (Hannon, 2003). Note, in the literature the words service, flexibility and availability are effectively used interchangeably and availability is used from hereon in this thesis.

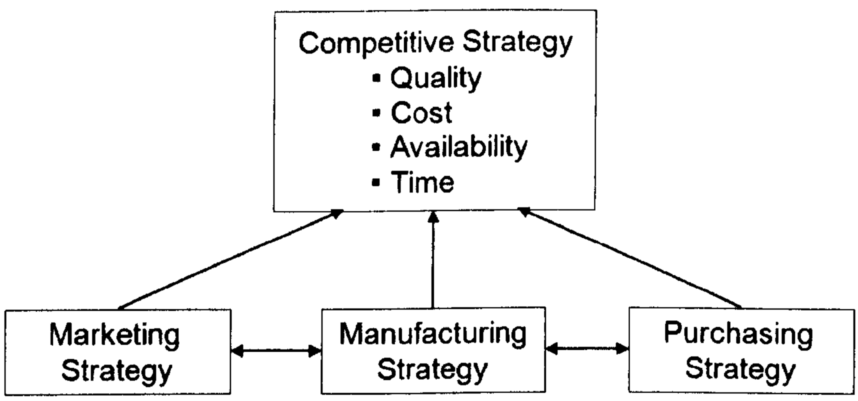


Figure 4.4 Relationship between competitive strategy and functional strategies (modified from Watts et al., 1995)

4.4.1 Quality

In manufacturing strategy, quality is associated with conformance to specifications and meeting the expectations of the customers (Dangayach and Deshmukh, 2001; Miltenburg, 2005; Slack and Lewis, 2002). Quality is a key criterion for obtaining and sustaining a firm's competitive advantage (Chao and Scheuing, 1994; Hannagan, 2002; Hill, 2000; Lo and Yeung, 2006; Pitts and Lei, 2000). A quality objective leads to certain actions in operations to provide a product that meets the customers' requirements (Schroeder, 2000). Total quality management (TQM) has been one of the important tools that manufacturing companies use to achieve high quality. The purchasing function has a critical role in TQM (e.g. Ahire et al., 1996; Carter and Narasimhan, 1994; Saraph et al., 1989). In order to achieve TQM, the quality of incoming materials and components must become as important as the quality of finished products delivered to customers (Sanchez-Rodriguez and Martinez-Lorente, 2004). A high quality product can be achievable only when it has been ensured that purchased materials and components meet quality requirements (Gottfredson et al, 2005; Nicholas, 1998; Scott, 1994). It should be true that a firm cannot provide its customers with product and service of better quality than the components received from its suppliers (Grant et al., 2006) without rework. Therefore, the assurance of an adequate supply of materials and components is one of the key elements of TQM policy (Gonzalez-Benito et al, 2003). Durability and reliability in particular must conform to the buying firm's specifications (Chan and Chan, 2004). In general they are often used as measures in quality in the literature (e.g. Krause et al., 2001; MacKenzie and Hardy, 1996; Park and Hartley, 2002; Shin, et al., 2000). Moreover, component innovation is one of the most important factors in product innovation. For example, most product innovation in the PC industry occurs in components and software, which are then incorporated by PC vendors (Dedrick and Kraemer, 2008). Bravard and Morgan (2006) argued that higher quality involves innovation from the supplier. Component innovation will give more competitive advantage because the high quality of purchased components is often the quickest and easiest way to improve the quality of the final product (Burt, 1989). In increasing the importance of purchasing, companies have to focus on not only internal quality issues, but also the quality of purchased components, which has to be managed carefully (Sila et al., 2006). When manufacturers select their suppliers, they can use supplier certification, which is granted to those suppliers that have demonstrated that they use statistical process control and other methods to achieve consistent quality performance (Schroeder, 2000). ISO 9000 is also a good example of supplier certification that companies are using to ensure quality (Miltenburg, 2005; Nicholas, 1998).

Quality is measured in this thesis on the basis of the importance of durability, reliability and innovation of component.

4.4.2 Cost

Low cost is the basic criterion to obtain a competitive advantage (Hannagan, 2002; Miltenburg, 2005; Spekman, 1988). It should be true that if firms can make products at low cost, they offer a low price and gain more of a competitive advantage than at a high price. With purchased materials and components accounting for approximately 50-70% of the total cost of a manufactured product (van Weele, 2005), the opportunities to reduce costs through purchasing are substantial (Hill, 2000). The purchasing cost of components has a great impact on the firm's potential profit (Dubois and Pedersen, 2002). Low purchasing costs can be achieved through economies of scale (Spekman et al., 1994). However, a major cost for many firms practicing low-cost leadership strategies is the amount of inspection and rework that accompanies mass production (Pitts and Lei, 2000). Companies must focus on the total overall cost rather than the lowest price of purchased materials and components (Burt, 1989), since this price is just one of the determinants of the total cost. Inventory cost is important in the context of supply chain management (Childerhouse and Towill, 2000). It is often expressed as a percentage of dollar value per unit time and, in practice, it is in the range of 15 to 35 % (Schroeder, 2000). The quality of components also has substantial implications for cost in a firm (Bowersox et al., 2002) because the purchasing of high quality components reduces the inventory cost (Nicholas, 1998) and production costs by eliminating rework, scrap and inspection in manufacturing processes (Pitts and Lei, 2000). A firm can improve its cost position by ensuring that the quality of purchased components meets its requirements (Porter, 1985). Quality assurance is extremely important in buying components and if the cost of incoming quality inspection of purchased items is reduced, then quality costs in the firm can be reduced (van Weele, 2005).

Cost is measured in this thesis on the basis of the importance of purchasing cost, inventory cost and quality cost.

4.4.3 Availability

Quality and cost will remain major competitiveness determinants, but manufacturing companies will increasingly need to provide greater product variety and customer focus (Alfnes and Strandhagen, 2000), so that availability has become an important factor to be used in a strategy for competitive advantage (Childerhouse et al., 2002; Christopher and Towill, 2000; Mason-Johnes et al., 2000a). Flexibility is the ability to change product volume or apply modifications in design with little penalty in time, cost or performance as a response of a firm to uncertainty in the business environment (Dangayach and Deshmukh, 2001; Jack and Raturi, 2002; Upton, 1997). Volume flexibility directly impacts customers' perceptions by preventing out of stock conditions when customers' demand is suddenly high. Modification flexibility is a value-adding attribute that is immediately visible to the customer (Vickery et al., 1999). In highly seasonal or one-off nature markets, the ability of a company to respond to increases in demand is an important factor in winning orders (Hill, 2000). Modification flexibility relates to the ability to meet the demands of high variety and personalised products. A high level of product diversification has been recognised already as an important factor in today's competitive markets (Hill, 2000). A company can achieve its competition by creating variety and customisation through flexible manufacturing systems (FMS) (Nicholas, 1998). Moreover, if the purchasing function of a firm can manage effectively its supplier capabilities, the result could be an increase in manufacturing flexibility (Clark, 1989; Narasimhan and Das, 1999). Technological change, and therefore technological capability, is one of the principal factors of competition (Porter, 1985) and new technologies present opportunities to enter into the market with a new product (Christensen and Bower, 1996). For these reasons, the technological capability of suppliers has received focal attention as a supplier selection criterion (Katsikeas et al., 2004).

Availability is measured in this thesis on the basis of the importance of volume flexibility, modification flexibility and technological capability.

4.4.4 Time

In recent times, the value of time has become a critical factor in obtaining competitive advantage (Beesley, 1997; Christopher et al., 2004; Grant et al., 2006; Kotler and Stonich 1991; Stalk and Hout, 1990; Towill, 1996). Customer expectations for delivery time and delivery time reliability have increased dramatically in recent years as a consequence of JIT manufacturing and supply chain management (Miltenburg, 2005). A firm can gain a competitive position through its ability to delivery more quickly than its rivals or to meet the delivery date the customers want when only some or even none of the competition can do so (Hill, 2000). However, industrial customers may accept longer lead times when delivery reliability is assured (Andries and Gelders, 1995). In general, the components of lead time that impact timely delivery are supplier lead time, manufacturing or production time, and delivery time performance (Davis, 1993). Many firms are attempting to gain or maintain a competitive advantage by purchasing items from suppliers who offer a reduction in the standard delivery time (Lee and Billington, 1992). Time to market with new product designs and developments can be also a crucial factor in competitive markets (Christopher and Towill, 2000; Hill, 2000). Stalk and Hout (1990) argued that there are two ways to compete through time-based competition (TBC). The first is that TBC can be implemented by faster throughput of existing products. The basic principle methods for doing this are quality management and JIT practices (Schroeder, 2000). JIT can reduce dramatically the lead time from raw materials through work in process to finished goods (Barker, 2001). TBC can also be used to introduce new products more quickly by reducing wasted time and unnecessary activities in the new-product development cycle (Schroeder, 2000). TBC can provide a competitive advantage by enabling the company to be the first to market (Beesley, 1997). According to Smith and Reinertson (1997), new products can often be introduced in half the normal time or less using this time based approach.

Time is measured in this thesis on the basis of the importance of delivery speed, delivery reliability and development speed.

4.4.5 Order winner and order qualifiers

Although some aspect of quality, cost, availability and time is a part of almost every company's competitive strategy, leading edge companies focus on just one of these four strategies as their basis of competition for winning in a chosen market (Cohen and Roussel, 2004). Hill (2000) introduced the concept of 'order winners' and 'order qualifiers' and these should be considered as such when determining manufacturing strategy. Order winners are competitive characteristics that directly and significantly contribute to winning business whereas order qualifiers may not be major competitive determinants of success, but are important competitive characteristics to get into or stay in a market. For example, to companies that compete directly on price, cost will be clearly their major competitive priority as order winner while other factors such as quality, availability and time are order qualifiers; the lowest price product will not win if its quality is not acceptable.

Figure 4.5 shows the benefits from order qualifiers and order winners as performance levels vary (Slack and Lewis, 2002). Competitive advantage can be increased by increasing performance in respect of order winners. However, once performance in respect of order qualifiers has reached the customers' or market's required level, no more is gained by further improvement. The advantage of order winners is that high levels of performance can provide positive competitive benefit. Firms must outperform their competitors in respect of the order winners. The competitive advantage will have to be achieved using the best resources available to an organization (Yusuf et al., 1999). Therefore, the firm should decide which resources are the best to support its competitive advantage and develop them more.

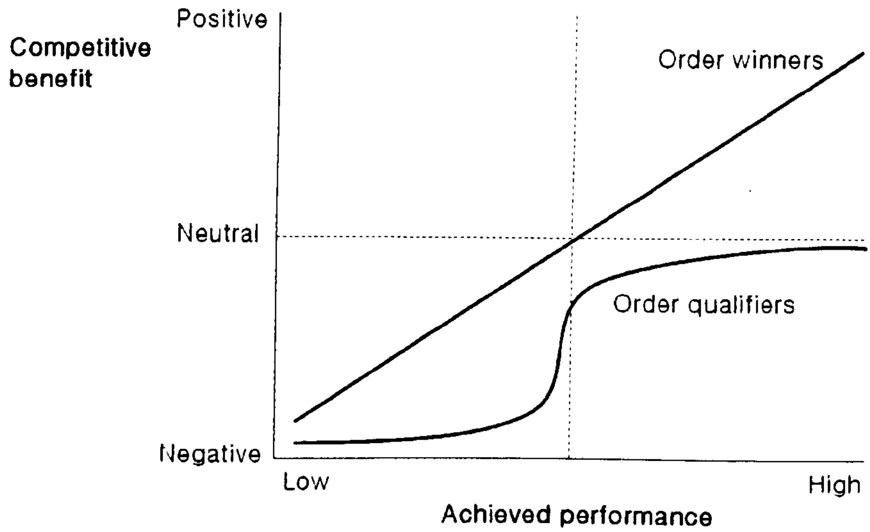


Figure 4.5 Order winners and order qualifiers (Slack and Lewis, 2002)

The order winners and qualifiers in a given market will change over time because markets are dynamic and competitors are moving targets (Hill, 2000). The order winner this year may not be the order winner next year (Fredendall and Hill, 2001; Johansson et al., 1993). Table 4.1 describes the transition in the various manufacturing practices from push manufacturing through pull manufacturing to the adaptive manufacturing of the 21st century. Christopher and Towill (2000) also showed this transition over 15-20 years in the personal computer market.

Table 4.1 Transition of manufacturing practices

Period	1970s	1980s	1990s	2000 &Beyond
Manufacturing practice	Push manufacturing	Pull manufacturing	Flexible manufacturing	Adaptive manufacturing
Order winner	Cost	Quality	Availability	Time
Order qualifiers	Quality Time Availability	Cost Time Availability	Time Cost Quality	Availability Quality Cost
Performance indicators	Production throughput	Cost management	Market share	Customer satisfaction
Characteristics	Mass production MRP system	TQM JIT system	Mass customisation TOC principle	Quick Response

Source: Authors based on SAP (2003)

In the 1970s, the dominant order winner was cost. This period was the era of mass production in push manufacturing. The goods were produced to forecast using material requirements planning (MRP) and capacity requirements planning (CRP). Maximising production throughput was a key focus in this time. This decade was followed by the pull manufacturing era. The focus of pull manufacturing was to minimise all forms of waste and produce quality products. In this period the order winner was quality because Western industry needed to respond to Japanese imports that were winning on far superior quality (Christopher and Towill, 2000). Next was the era of flexible manufacturing, a response to more volatile demand, high production variation and short product life cycles. As products were increasingly customised, availability was a key to maintaining sales and market share. Finally, time is now the order winner when the cost, quality and availability have all become order qualifiers. For example, the Dell computer company supplies what the individual customer selects or specifies within a maximum of seven days (Christopher and Towill, 2000). Adaptive manufacturing enables manufacturers to run at the speed of business and deliver superior performance through high visibility and responsiveness (SAP, 2003).

4.5 Conclusion

The starting point of the purchasing decision making process should be to define the required component characteristics. However, most previous research has focused on criteria by which to select suppliers, i.e. supply performance and capabilities. It is argued here that a critical process is the identification of the component characteristics to be used in purchasing decisions and the formulation of purchasing strategy. This gap in the research is addressed by this thesis.

The importance of a purchase is determined by the competitive priorities of the business. The literature reviewed supports the argument that a purchasing strategy is to support the business strategy for competitive success. Moreover, the purchasing strategy has to be consistent with manufacturing strategy simultaneously.

Competitive priorities have been used as a manufacturing strategy in operations management field. In addition, according to the literature review, they are conceptualised as being similar to purchasing's competitive priorities. To conclude, four competitive priorities (cost, quality, time and availability) have been identified as the selection and evaluation criteria for purchased components in the purchasing decision making process and each criterion has three measures respectively.

Chapter 5

Measurement and Classification of Component Value; the case of four elevator manufacturers

5.1 Introduction

The purchasing function has a significant impact on a firm's performance (Carr and Pearson, 2002; Chen et al., 2004; Narasimhan and Das, 2001; Sanchez-Rodriguez et al., 2006; Vereecke and Muylle, 2006) and the potential profit in firms (Dubois and Pedersen, 2002). An effective purchasing strategy can add up to 4% of sales value or 30% to profitability (Thompson, 1996). A manufacturing firm needs an effective purchasing strategy that emphasises identifying and developing suppliers for procurement of cheap components as well as other factors such as high quality and so on. Whilst perfection may be strived for, cost, time and other factors may constrain its ambitions. For example, the cost of quality cannot go beyond the level that the market is willing to pay and optimal performance may take years of continuous improvement. Suppliers cannot be expected to achieve optimal performance in respect of everything they do, so they must first focus on the priorities. Indeed, over-performance in low priority areas can be viewed as a waste. The purchasing function must make sure that suppliers have sufficient capabilities in the high priority areas, i.e. the basis for supplier selection and development is performance in these areas. This means that there is a need to prioritise requirements based on the needs and prerequisites of the business strategy, starting with the basic competitive elements such as quality, cost, flexibility and time.

Zheng et al (2007) state that, "There are widely differing views between purchasing professionals and their senior executives about the actual and potential strategic contribution of purchasing and supply to corporate success." Clearly, this contribution will be greatest in respect of the product components that have the greatest impact on achieving the business strategy, which in turn underlines the need for methods to prioritise components for strategic attention. The priorities of the components depend on the priorities of the competitive elements. For example, if quality is the basis of competition and therefore the highest priority element, then the components that define the level of quality of the product are the highest priority components in the context of purchasing.

The use of the Analytic Hierarchy Process (AHP) (Saaty, 1980; Saaty and Vargas, 2001) is introduced here to prioritise components used in assembling an electric traction elevator, according to their level of importance to or impact on the strategic priorities of the business. Priority groupings can then be established in respect of the business's purchasing strategy in a way that is analogous to *ABC analysis* in inventory management, where stock items are prioritised and grouped on the basis of the value of annual consumption, which is measured as unit-cost multiplied by unit-usage.

5.2 Case studies

As the cost of in-house manufacturing of components and sub-assemblies is much higher than the cost of outsourcing, elevator manufacturers in South Korea focus on design, assembly, marketing and sales and most in-house component manufacturing has ceased (van Weele, 2005). Discussions with several elevator manufacturers revealed that they spend typically more than 70% of each sales dollar on purchased components, so they should strive to improve not only availability but also to reduce costs. The key to success in this industry is the ability to embrace both efficiency and customisation (Peppers and Rogers, 2004). Elevator manufacturers are representative of many other manufacturers as they are noticing the criticality of purchased components, supplier performance and purchasing strategy to competitiveness (Carter and Narasimhan, 1996).

An elevator is a complex product with an average of 20,000 parts at the bottom level of its bill of materials (BOM) (Lu et al., 2005). Consequently, it is not a simple matter to manage effectively and efficiently the purchasing and supply of everything that is required. A first step in formulating a purchasing strategy for an elevator manufacturer must be to identify the characteristics of components of the elevator and prioritise the components on the basis of their impact on or contribution to the business strategy; the strategy for achieving competitive advantage. The purchasing strategy of the highest priority components must be addressed immediately as an integral part of, or prerequisite to, implementing the business strategy. Purchasing strategies are also required for the low priority components, but these are developed in the context of optimising the purchasing and supply processes with the fundamental aim of reducing costs; "Non-critical items require efficient processing, product standardisation, order volume and inventory optimalisation." (Gelderman and van Weele, 2003). Whilst this optimisation in respect of the low priority components may be desirable at day one, it is not a prerequisite of the business strategy but rather a matter for continuous improvement in the near future. This is in contrast to the need to achieve the core or critical requirements of the business strategy at day one in order to start competing in the marketplace. A description of the four elevator manufacturers that participated in the case studies is summarised in Table 5.1.

Table 5.1 Summary of the profiles of the four case-study elevator manufacturers

	Company-A	Company-B	Company-C	Company-D
Product	Elevator	Elevator	Elevator	Elevator
Product demand	Unpredictable	Unpredictable	Unpredictable	Unpredictable
Product Life cycle	1 year to 2 years	1 year to 2 years	1 year to 2 years	1 year to 2 years
Profit margins	10% to 20%	20% to 50%	20% to 50%	20% to 50%
Product variety	10-50 variants	More than 100 variants	More than 100 variants	More than 100 variants
Manufacturing process	Assemble-to-order (ATO) Make-to-order (MTO)	Make-to-order (MTO)	Make-to-order (MTO)	Make-to-order (MTO) Build-to-order (BTO)
Business strategy	Cost leadership	Differentiation	Differentiation	Focus
Order-winner	Cost	Availability	Availability	Availability
Level of customisation	Customised Standardisation	Customised Standardisation	Customised Standardisation	Tailed Customisation
Target Market	Housing estate	Housing estate, Hospital	Office building, Flat	Shopping centre, Hotel
Supply chain	Leagile	Leagile	Leagile	Agile
Turnover (2005)	£6.5M	£5M	£4.5M	£6M
Sales volume (2005)	480 units	350 units	280 units	300 units
Number of employees	57	53	47	62

As explained earlier in Chapter 3, the data for the AHP was gathered by questioning each company's staff who are frequently involved directly or indirectly with component purchasing, as shown in Table 5.2. In the case studies, the senior staff member was selected in each department. However, in Company-B and Company-D, one more staff in the purchasing department is also selected. In Company-C only three staff were available for questioning, but the member of staff from manufacturing operations was also responsible for the engineering function.

Table 5.2 Number of evaluators in the four elevator manufacturers

<table>
<tr><th>Department</th><th>Company-A</th><th>Company-B</th><th>Company-C</th><th>Company-D</th></tr>
<tr><td>Purchasing</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>Operations</td><td>1</td><td>1</td><td rowspan="2">1</td><td>1</td></tr>
<tr><td>Engineering</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Accounting</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Total</td><td>4</td><td>5</td><td>3</td><td>5</td></tr>
</table>

This thesis is not concerned with the analysis of the whole industry, but rather the individual companies. For this reason, an analysis is performed for each of the four companies to yield individual strategies and a basis for comparing the outcome of the analysis across different companies. To compare the components value among the four elevator manufacturers, the components should be common components that are used by all four elevator manufacturers. The common components that are characteristic of an elevator are included in the study presented here, e.g. the brake, the motor generator and the travelling cables. This allows for comparison across the companies of the purchasing strategies generated for the different components.

In selecting or sampling the components to be used in this study, quota sampling based on the ABC method of inventory classification was used. This means that 20% of components come from Class A and the remaining 80 % should be components of Class B and Class C, so that the sample reflects the values of the components.

Initially, between the two companies - A and B, the 37 components of the elevator were selected by a brainstorming approach involving the employees drawn from the different departments. After further evaluation, components with similar functions were removed (e.g. hoisting ropes and governor rope) and some were combined into their sub-systems. Finally, 23 components were decided as alternatives. Table 5.3 gives the final set of components of the elevator's BOM used in the analysis presented here.

Table 5.3 Components of the electric traction elevator

Location	Components	
Machine room	1. Brake 2. Control panel 3. Governor	4. Motor generator 5. Rope brake 6. Traction machine
Hoistway	1. Buffers 2. Compensating chain 3. Counterweights 4. Door operator 5. Guide rails 6. Guide shoes 7. Limit switch	8. Load weighing devices 9. Rail brackets 10. Roller guides 11. Ropes 12. Safety gear 13. Travelling cables
Car & hoistway entrances	1. Car set car, landing door, sill, etc 2. Door safety device	3. Operation fixtures operating panel, position indicator, hall button, etc 4. Interlock device

5.3 Building the AHP model for components value

Step 1 Structuring the purchased components prioritization problem

In this step a conceptual approach for structuring component prioritization problem using the AHP is introduced. A five level hierarchy decision process displayed in Figure 5.1 is described below.

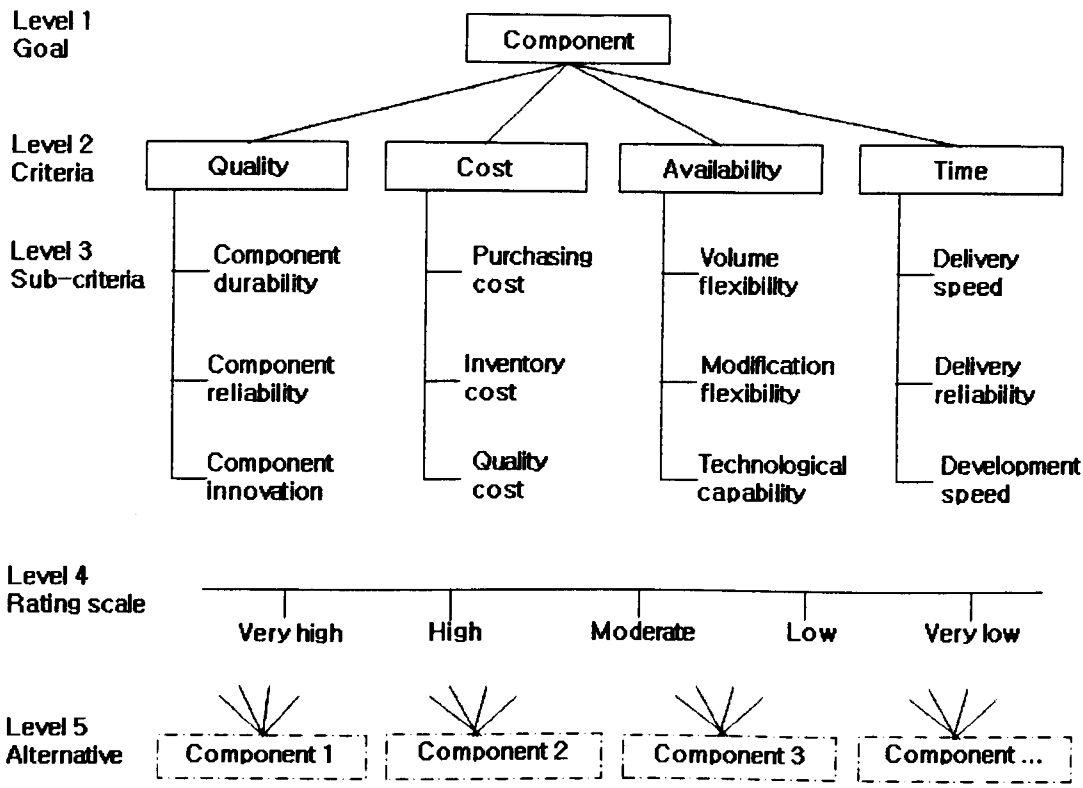


Figure 5.1 AHP model for analysis of components value

Level 1: The goal is placed at top of the AHP hierarchy. The goal in this application is the ranking and subsequent grouping of each component's impact on the competitive priorities of the business.

Level 2: It contains the purchasing's competitive priorities (criteria) introduced in Chapter 4.

Level 3: There are sub-criteria that are used to assess or 'measure' the criteria. The relative importance of the competitive criteria and sub-criteria to the business and the parent criteria respectively are rated using the basic AHP approach of pair-wise comparison.

Level 4: It contains the rating scale for assessing the impact of individual components on the sub-criteria. This is different from the usual AHP approach in that an absolute measurement is assigned to each sub-criterion for each component to be purchased, instead of pair-wise comparisons of the components on the basis of each sub-criterion. This direct approach avoids the large number of pair-wise comparisons and has been used in supplier selection studies (Chan and Chan, 2004; Tam and Tummala, 2001).

Level 5: It consists of the components of the elevator's bill of materials (BOM) to be evaluated.

Step 2 Measurement and data collection

In the first stage, evaluators were requested to assess the relative importance of the four criteria and their three sub-criteria in a pair-wise manner using a nine-point scale of intensity in Table 3.1. For example, if an evaluator decides that *quality* is moderately more important than *time*, then the former would be rated as '3' and the latter as '1/3' in this pair-wise comparison. Within each criterion, the sub-criteria are compared on a pair-wise basis to establish their relative importance to their parent criterion. For example, if *component durability* is considered absolutely (maximally) more important in determining quality compared to *component reliability*, then it is rated '9' whereas *component reliability* is rated '1/9' in this pair-wise comparison. As a result, matrices of pair-wise comparisons are obtained by the completion of all the pair-wise comparisons. These matrices are then used for calculating the relative importance of each criterion and each sub-criterion shown in levels 2 and 3 of Figure 5.1.

In the second stage, evaluators were requested to use absolute measurement to rate the strength of the impact of the individual elevator components on the sub-criteria using the five-point scale (VH=very high; H=high; M=moderate; L=low; VL=very low) suggested by Tam and Tummala (2001). For example, if an evaluator decides that *Control Panel* has a high impact on the component durability, it would be rated as 'high (H)'with respect to *component durability*. Absolute or direct measurement is used because there would otherwise be an intractable number of pair-wise comparisons to perform. There are 23 components to be rated against the 12 measures, as shown in Figure 5.1, resulting in ${}_{23}C_2$ = 23!/2!(23-2)! = 253 pair-wise comparisons for each of the 12 measures, giving a total of 253 x 12 = 3036 comparisons. Absolute measurement reduces this to 23 x 12 = 276 direct measurements. This difference would grow very rapidly with increases in numbers of components. Tam and Tummala (2001) and Chan and Chan (2004) also used direct measurement for this reason.

Step 3 Determination of normalized weights

As mentioned earlier, matrices of pair-wise ratings were obtained by the completion of all the pair-wise comparisons from the evaluators in the four elevator manufacturers. For each evaluator within each company there is a matrix of criteria comparisons and a matrix for each criterion to compare the sub-criteria. Table 5.4 is an example of one of these for Evaluator-1 in Company-A (See Tables A.1 to A.15 in Appendix 4 for others). The pair-wise comparison matrices for purchased components value shows criteria and sub-criteria at the top and on the left of each matrix in Table 5.4 (i.e. the columns and rows). Based on the judgments of the respondents, the matrix shows numerical values denoting the importance of the criteria on the left relative to the importance of the criteria at the top. A high value denotes that the criterion on the left is more important than the criterion at the top.

Table 5.4 Pair-wise comparison matrices of components value by Evaluator-1 in Company-A

Goal	Quality	Cost	Availability	Time
Quality	1	1	2	4
Cost	1	1	2	3
Availability	1/2	1/2	1	2
Time	1/4	1/3	1/2	1
				Consistency Ratio C.R.=0.00

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	3
Component reliability	1/2	1	2
Component innovation	1/3	1/2	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	7	2
Inventory cost	1/7	1	1/5
Quality cost	1/2	5	1
			C.R.=0.01

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/4	1/2
Modification flexibility	4	1	2
Technological capability	2	1/2	1
			C.R.=0.00

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	4
Delivery reliability	1	1	4
Development speed	1/4	1/4	1
			C.R.=0.00

The consistency ratio (C.R.) is used to assess whether a matrix is sufficiently consistent or not. For example, an evaluator may rate quality as '7' against cost, cost as '7' against time and time as '7' against quality. This would be extremely inconsistent as the first two 7s imply that quality must be rated more highly than time (See Saaty, 1980). Each pair-wise comparison matrix in Table 5.4 is presented with its C.R. and these satisfy the consistency test. However, for one of the other staff in Company-A the C.R. exceeded 0.08 for the (4x4) criteria comparison matrix (See

Table A.3 in Appendix 4), so his data was removed from the analysis; this was the representative of the engineering department. In Company-B one staff from the accounting department made the C.R.>0.08 for the (4x4) criteria comparison matrix (See Table A.8 in Appendix 4), so his data was also eliminated from the analysis.

These matrices are combined for the evaluators within each company using the geometric mean approach at each hierarchy level to obtain the corresponding consensus pair-wise comparison matrices. This yielded the five 'consensus matrices' for each company; one for the criteria and one for each of the four groups of sub-criteria within the criteria. Each of these matrices is then translated into the corresponding largest eigenvalue problem and is solved to find the normalized and unique priority weights for each criterion, as shown in Table 5.5 for Company-A, Table 5.6 for Company-B, Table 5.7 for Company-C and Table 5.8 for Company-D. The software, Expert Choice (2004), is used to calculate the normalized priority weights. A worked example of the normalisation and consistency index (C.I.) calculation are given in Appendix 5.

Table 5.5 Geometric mean of pair-wise comparison matrices of all evaluators for Company-A

Goal	Quality	Cost	Availability	Time	Priority weight
Quality	1	0.6	1.6	2.5	0.29
Cost	1.6	1	1.6	2.9	0.38
Availability	0.6	0.6	1	2.0	0.21
Time	0.4	0.3	0.5	1	0.12
					C.R.=0.01
Quality	**Component durability**	**Component reliability**	**Component innovation**	**Priority weight**	
Component durability	1	1.6	3.0	0.51	
Component reliability	0.6	1	2.0	0.33	
Component innovation	0.3	0.5	1	0.16	
				C.R.=0.00	
Cost	**Purchasing cost**	**Inventory cost**	**Quality cost**	**Priority weight**	
Purchasing cost	1	6.3	3.2	0.67	
Inventory cost	0.2	1	0.4	0.10	
Quality cost	0.3	2.7	1	0.23	
				C.R.=0.01	
Availability	**Volume flexibility**	**Modification flexibility**	**Technological capability**	**Priority weight**	
Volume flexibility	1	0.3	0.5	0.16	
Modification flexibility	3.3	1	2.0	0.55	
Technological capability	2.0	0.5	1	0.29	
				C.R.=0.00	
Time	**Delivery speed**	**Delivery reliability**	**Development speed**	**Priority weight**	
Delivery speed	1	0.6	2.9	0.35	
Delivery reliability	1.6	1	3.6	0.52	
Development speed	0.3	0.3	1	0.13	
				C.R.=0.01	

Table 5.6 Geometric mean of pair-wise comparison matrices of all evaluators for Company-B

Goal	Quality	Cost	Availability	Time	Priority weight
Quality	1	0.5	0.5	2.9	0.21
Cost	1.9	0.7	1	3.1	0.31
Availability	2.1	1	1.4	3.5	0.39
Time	0.3	0.3	0.3	1	0.09
					C.R.=0.02
Quality	**Component durability**	**Component reliability**	**Component innovation**		**Priority weight**
Component durability	1	1.4	3.9		0.51
Component reliability	0.7	1	2.7		0.36
Component innovation	0.3	0.4	1		0.13
					C.R. = 0.00
Cost	**Purchasing cost**	**Inventory cost**	**Quality cost**		**Priority weight**
Purchasing cost	1	5.9	3.7		0.69
Inventory cost	0.2	1	0.5		0.11
Quality cost	0.3	2.0	1		0.20
					C.R. = 0.01
Availability	**Volume flexibility**	**Modification flexibility**	**Technological capability**		**Priority weight**
Volume flexibility	1	0.3	0.5		0.14
Modification flexibility	3.9	1	2.4		0.59
Technological capability	2.2	0.4	1		0.27
					C.R.=0.00
Time	**Delivery speed**	**Delivery reliability**	**Development speed**		**Priority weight**
Delivery speed	1	0.5	3.0		0.31
Delivery reliability	1.9	1	6.3		0.59
Development speed	0.3	0.2	1		0.10
					C.R. = 0.00

Table 5.7 Geometric mean of pair-wise comparison matrices of all evaluators for Company-C

Goal	Quality	Cost	Availability	Time	Priority weight
Quality	1	0.6	1.0	2.6	0.26
Cost	1.0	0.6	1	2.6	0.26
Availability	1.6	1	1.6	2.9	0.37
Time	0.4	0.3	0.4	1	0.11
					C.R.=0.01
Quality	**Component durability**		**Component reliability**	**Component innovation**	**Priority weight**
Component durability	1		1.6	3.3	0.51
Component reliability	0.6		1	2.6	0.35
Component innovation	0.3		0.4	1	0.14
					C.R. = 0.01
Cost	**Purchasing cost**		**Inventory cost**	**Quality cost**	**Priority weight**
Purchasing cost	1		6.2	2.6	0.64
Inventory cost	0.2		1	0.3	0.09
Quality cost	0.4		3.1	1	0.27
					C.R. = 0.01
Availability	**Volume flexibility**		**Modification flexibility**	**Technological capability**	**Priority weight**
Volume flexibility	1		0.4	0.5	0.19
Modification flexibility	2.3		1	1.3	0.45
Technological capability	2.0		0.8	1	0.36
					C.R.=0.00
Time	**Delivery speed**		**Delivery reliability**	**Development speed**	**Priority weight**
Delivery speed	1		0.8	2.6	0.39
Delivery reliability	1.3		1	2.9	0.46
Development speed	0.4		0.3	1	0.15
					C.R. = 0.00

Table 5.8 Geometric mean of pair-wise comparison matrices of all evaluators for Company-D

Goal	Quality	Cost	Availability	Time	Priority weight
Quality	1	2.2	0.8	3.3	0.32
Cost	0.5	1	0.4	2.6	0.18
Availability	1.3	2.4	1	4.3	0.41
Time	0.3	0.4	0.2	1	0.09
					C.R.=0.01
Quality	**Component durability**	**Component reliability**	**Component innovation**		**Priority weight**
Component durability	1	1.3	2.9		0.47
Component reliability	0.8	1	2.4		0.37
Component innovation	0.3	0.4	1		0.16
					C.R.=0.00
Cost	**Purchasing cost**	**Inventory cost**	**Quality cost**		**Priority weight**
Purchasing cost	1	4.5	2.4		0.61
Inventory cost	0.2	1	0.5		0.13
Quality cost	0.4	2.0	1		0.26
					C.R.=0.00
Availability	**Volume flexibility**	**Modification flexibility**	**Technological capability**		**Priority weight**
Volume flexibility	1	0.3	0.5		0.15
Modification flexibility	3.4	1	2.2		0.56
Technological capability	2.2	0.5	1		0.29
					C.R.=0.01
Time	**Delivery speed**	**Delivery reliability**	**Development speed**		**Priority weight**
Delivery speed	1	0.8	3.1		0.38
Delivery reliability	1.3	1	3.6		0.49
Development speed	0.3	0.3	1		0.13
					C.R.=0.00

A five-point rating scale is used to determine the pair-wise comparison matrix. This matrix is then translated into the corresponding largest eigenvalue problem and is solved to find the normalized and unique weights for each rating scale. The resulting priority weights of very high (VH), high (H), moderate (M), low (L) and very low (VL) have their weights calculated as 0.51, 0.26, 0.13, 0.06 and 0.04 respectively as shown in Table 5.9.

Table 5.9 Pair-wise comparison judgment matrix for five-point rating scale

Rating scale	VH	H	M	L	VL	Priority weight
Very high (VH)	1	3	5	7	9	0.51
High (H)	1/3	1	3	5	7	0.26
Moderate (M)	1/5	1/3	1	3	5	0.13
Low (L)	1/7	1/5	1/3	1	3	0.06
Very low (VL)	1/9	1/7	1/5	1/3	1	0.04

Step 4 Synthesizing results

After computing the normalized priority weights for each pair-wise comparison matrix of the AHP hierarchy, the next step is to synthesize the solution for purchased components value. The normalized local priority weights of criteria and sub-criteria from the third step are combined together with respect to all successive hierarchical levels to obtain the global composite priority weights of all sub-criteria used in the third level of the AHP model.

5.4 An illustration of analysis of components value using the AHP model

The components are to be assessed by evaluation teams in each of the four case-study companies, using the following steps:

Step 1. To select the global weights set for purchased components, the values employed for the demonstration are shown in Table 5.10. Tables 5.5-5.8 are used within the AHP process to produce overall weights for the criteria and sub-criteria as given in Table 5.10. The criterion and sub-criterion weights are multiplied together to give a global weight for each sub-criterion, so that the importance or weight of a sub-criterion is measured by its importance to its parent criterion moderated by the importance of that criterion to the purchasing competitive priorities. For example, the global weight of component durability (0.15) in Company-A was gained from multiplying the local weight of quality (0.29) by the local weight of component durability (0.51).

Table 5.10 Combined criteria and sub-criteria weights in the four elevator manufacturers

Company	Strategic priority	Local weight	Strategic priority measures	Local weight	Global weight
	Quality	**0.29**	**Component durability**	**0.51**	**0.15**
			Component reliability	0.33	0.10
			Component innovation	0.16	0.05
	Cost	0.38	Purchasing cost	0.67	0.25
			Inventory cost	0.10	0.04
			Quality cost	0.23	0.09
Company-A	Availability	0.21	Volume flexibility	0.16	0.03
			Modification flexibility	0.55	0.12
			Technological capability	0.29	0.06
	Time	0.12	Delivery speed	0.35	0.04
			Delivery reliability	0.52	0.06
			Development speed	0.13	0.02
	Total	**1.00**	**Total**		**1.00**
	Quality	0.21	Component durability	0.51	0.11
			Component reliability	0.36	0.07
			Component innovation	0.13	0.03
	Cost	0.31	Purchasing cost	0.69	0.21
			Inventory cost	0.11	0.03
			Quality cost	0.20	0.06
Company-B	Availability	0.39	Volume flexibility	0.14	0.05
			Modification flexibility	0.59	0.23
			Technological capability	0.27	0.11
	Time	0.09	Delivery speed	0.31	0.03
			Delivery reliability	0.59	0.06
			Development speed	0.10	0.01
	Total	**1.00**	**Total**		**1.00**

Table 5.10 Combined criteria and sub-criteria weights in the four elevator manufacturers (continued)

Company	Strategic priority	Local weight	Strategic priority measures	Local weight	Global weight
	Quality	0.26	Component durability	0.51	0.13
			Component reliability	0.35	0.09
			Component innovation	0.14	0.04
	Cost	0.26	Purchasing cost	0.64	0.17
			Inventory cost	0.09	0.02
			Quality cost	0.27	0.07
Company-C	Availability	0.37	Volume flexibility	0.19	0.07
			Modification flexibility	0.45	0.17
			Technological capability	0.36	0.13
	Time	0.11	Delivery speed	0.39	0.04
			Delivery reliability	0.46	0.05
			Development speed	0.15	0.02
	Total	**1.00**	**Total**		**1.00**
	Quality	0.32	Component durability	0.47	0.15
			Component reliability	0.37	0.12
			Component innovation	0.16	0.05
	Cost	0.18	Purchasing cost	0.61	0.11
			Inventory cost	0.13	0.02
			Quality cost	0.26	0.05
Company-D	Availability	0.41	Volume flexibility	0.15	0.06
			Modification flexibility	0.56	0.23
			Technological capability	0.29	0.12
	Time	0.09	Delivery speed	0.38	0.03
			Delivery reliability	0.49	0.04
			Development speed	0.13	0.01
	Total	**1.00**	**Total**		**1.00**

Step 2. To evaluate the purchased components, evaluators were requested to use absolute measurement to rate 23 components of the elevator, as shown in Figure 5.1. Table 5.11 shows examples of the ratings obtained from the evaluators across the companies for the *control panel* component. For example, the *control panel* is deemed by Evaluator-1 in Company-A to have a high impact on component durability, but a low impact on volume flexibility.

Table 5.11 Absolute ratings given by four evaluators to the *control panel* component

Strategic priority	Component / Strategic Rating priority measures	Control panel			
		Company-A Evaluator-1	**Company-B Evaluator-1**	**Company-C Evaluator-1**	**Company-D Evaluator-1**
Quality	**Component durability**	**H**	H	H	H
	Component reliability	H	H	H	H
	Component innovation	VH	VH	VH	VH
Cost	Purchasing cost	VH	H	VH	H
	Inventory cost	VL	VL	VL	VL
	Quality cost	H	M	M	M
Availability	**Volume flexibility**	**L**	L	L	L
	Modification flexibility	H	H	H	H
	Technological capability	H	H	H	H
Time	Delivery speed	H	H	H	H
	Delivery reliability	H	H	H	H
	Development speed	H	H	H	H

Note: VH=very high; H=high; M=medium; L=low; VL=very low.

Step 3. Multiply the purchased components' global weights, which were determined from the AHP process, by the evaluators' ratings to obtain the total scores. The result of a five-point rating scale was then multiplied with the weights of the criteria and three sub-criteria as obtained in the first stage, and the consequent sum was the weight of purchased components of the elevator. The scores of each criterion are normalised using Equation 5-1.

$$C_{ij} = \frac{s_{ij}}{s_j} \times w_j \qquad (5\text{-}1)$$

C_{ij} = normalized criterion *j* score of component *i*;

s_{ij} = sum of sub-criterion scores within criterion *j* for component *i*;

s_j = sum of s_{ij} across all components;

w_j = sum of global weights of sub-criterion within criterion *j*.

The sum of these normalized scores of each criterion in all components is the local weight of each criterion in a company. After then, the sum of normalized scores of each criterion is the AHP score of this component. The sum of the AHP scores is 1. For gaining the ABC score for this component, the normalized cost score for each component is normalized again by dividing it by the sum of the normalized cost scores across all the components, so that the sum of the ABC scores is also 1. Table 5.12 shows an example of the computation process to obtain the total scores and normalised scores for the *control panel* component.

Table 5.12 Calculation of overall score for the *control panel* component in the elevator by Evaluator-1 in Company-A

		Control Panel Scoring		
Strategic priority measures	**Global weight (from Table 5.10)**	**Rate**	**Rating weight (from Table 5.9)**	**Global weight x Rating weight**
Quality				
Component durability	0.15	H	0.26	0.039
Component reliability	0.10	H	0.26	0.026
Component innovation	0.05	VH	0.51	0.026
Cost				
Purchasing cost	0.25	VH	0.51	0.128
Inventory cost	0.04	VL	0.04	0.002
Quality cost	0.09	H	0.26	0.023
Availability				
Volume flexibility	0.03	L	0.06	0.002
Modification flexibility	0.12	H	0.26	0.031
Technological capability	0.06	H	0.26	0.016
Time				
Delivery speed	0.04	H	0.26	0.010
Delivery reliability	0.06	H	0.26	0.016
Development speed	0.02	H	0.26	0.005
Total score				**0.321**

Normalized quality score
= (Quality score / Sum of quality scores across all components) X Sum of quality global weights
= (0.039+0.026+0.026 / 1.162) X 0.290 = **0.021**

Normalized cost score
= (Cost score / Sum of cost scores across all components) X Sum of cost global weights
= (0.128+0.002+0.023 / 0.958) X 0.377 = **0.059**

Normalized availability score
= (Availability score / Sum of availability scores across all components) X Sum of availability global weights
= (0.002 + 0.031+0.016 / 0.491) X 0.216 = **0.021**

Normalized time score
= Time score / Sum of time scores across all components) X Sum of time global weights
= (0.010+0.016+0.005 / 0.264) X 0.117 = **0.012**

AHP score
= Total score / Sum of total scores across all components
= 0.321/ 2.875 = **0.113**

ABC score
= Normalized cost score / Sum of normalized cost scores across all components
= 0.059 / 0.337 = **0.152**

Step 4. Finally, after the completion of the computation process of all scores of components from the *brake* to the *travelling cables* obtained from all evaluators in each company, their normalised each criterion, AHP and ABC scores can be computed simultaneously, as shown in Tables 5.13 to 5.16.

Table 5.13 Summary of normalized component mean scores of each criterion, AHP and ABC in Company-A

	Evaluator-1						Evaluator-2						Evaluator-3						Mean Score					
Component	**Q**	**C**	**A**	**T**	**AHP**	**ABC**	**Q**	**C**	**A**	**T**	**AHP**	**ABC**	**Q**	**C**	**A**	**T**	**AHP**	**ABC**	**Q**	**C**	**A**	**T**	**AHP**	**ABC**
Brake	0.018	0.016	0.014	0.009	0.057	0.041	0.013	0.016	0.007	0.006	0.042	0.043	0.019	0.017	0.015	0.006	0.057	0.045	0.016	0.016	0.012	0.006	0.050	0.042
Buffers	0.007	0.010	0.004	0.002	0.023	0.026	0.006	0.009	0.004	0.005	0.024	0.024	0.005	0.007	0.004	0.002	0.018	0.019	0.006	0.009	0.004	0.003	0.022	0.023
Car Set	0.018	0.059	0.019	0.006	0.102	0.152	0.013	0.061	0.011	0.006	0.091	0.164	0.019	0.054	0.021	0.006	0.100	0.143	0.016	0.058	0.016	0.006	0.096	0.151
Compensating Chain	0.008	0.011	0.006	0.002	0.027	0.028	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.011	0.006	0.003	0.030	0.029	0.010	0.011	0.007	0.004	0.032	0.029
Control Panel	**0.021**	**0.059**	**0.021**	**0.012**	**0.113**	**0.152**	0.015	0.038	0.014	0.006	0.073	0.102	0.019	0.058	0.022	0.011	0.110	0.153	0.018	0.052	0.018	0.009	0.097	0.135
Counterweights	0.007	0.012	0.005	0.002	0.026	0.031	0.006	0.009	0.007	0.006	0.028	0.024	0.009	0.011	0.005	0.003	0.028	0.029	0.008	0.011	0.006	0.004	0.029	0.029
Door Operator	0.018	0.020	0.006	0.002	0.046	0.051	0.013	0.016	0.007	0.006	0.042	0.043	0.010	0.015	0.008	0.005	0.038	0.040	0.014	0.017	0.008	0.004	0.043	0.044
Door Safety Devices	0.016	0.014	0.006	0.002	0.038	0.036	0.013	0.016	0.007	0.006	0.042	0.043	0.010	0.015	0.006	0.005	0.036	0.040	0.013	0.015	0.007	0.004	0.039	0.039
Governor	0.018	0.016	0.016	0.011	0.061	0.041	0.013	0.016	0.007	0.006	0.042	0.043	0.019	0.010	0.008	0.006	0.043	0.026	**0.016**	**0.014**	0.011	0.007	0.048	0.036
Guide Rails	0.015	0.016	0.006	0.013	0.050	0.041	0.013	0.016	0.007	0.010	0.046	0.043	0.018	0.010	0.006	0.011	0.045	0.026	0.014	0.014	0.007	0.012	0.047	0.036
Guide Shoes	0.008	0.007	0.006	0.002	0.023	0.018	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.007	0.006	0.003	0.026	0.019	0.010	0.008	0.007	0.004	0.029	0.021
Interlock Devices	0.015	0.011	0.006	0.002	0.034	0.028	0.013	0.010	0.007	0.006	0.036	0.027	0.010	0.015	0.006	0.003	0.034	0.040	0.012	0.012	0.007	0.004	0.035	0.031
Limit Switch	0.008	0.007	0.006	0.002	0.023	0.018	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.007	0.006	0.003	0.026	0.019	0.010	0.008	0.007	0.004	0.029	0.021
Load Weighing Devices	0.008	0.006	0.006	0.002	0.022	0.015	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.006	0.006	0.003	0.025	0.016	0.010	0.007	0.007	0.004	0.028	0.018
Motor Generator	0.018	0.030	0.014	0.012	0.074	0.077	0.013	0.031	0.007	0.006	0.057	0.083	0.016	0.034	0.012	0.011	0.073	0.090	0.015	0.032	0.011	0.009	0.067	0.083
Operation Fixtures	0.013	0.016	0.019	0.002	0.050	0.041	0.009	0.013	0.023	0.005	0.050	0.035	0.010	0.013	0.014	0.003	0.040	0.034	0.011	0.015	0.019	0.004	0.049	0.039
Rail Brackets	0.008	0.006	0.006	0.002	0.022	0.015	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.006	0.006	0.003	0.025	0.016	0.010	0.007	0.007	0.004	0.028	0.018
Roller Guides	0.008	0.006	0.006	0.002	0.022	0.015	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.006	0.006	0.003	0.025	0.016	0.010	0.007	0.007	0.004	0.028	0.018
Rope Brake	0.008	0.006	0.006	0.004	0.024	0.015	0.013	0.009	0.007	0.005	0.034	0.024	0.010	0.010	0.006	0.005	0.031	0.026	0.010	0.008	0.007	0.004	0.029	0.021
Ropes	0.016	0.013	0.011	0.005	0.045	0.033	0.013	0.009	0.007	0.006	0.035	0.024	0.018	0.014	0.008	0.006	0.046	0.037	0.015	0.012	0.009	0.006	0.042	0.031
Safety Gear	0.008	0.007	0.006	0.002	0.023	0.018	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.007	0.006	0.003	0.026	0.019	0.010	0.008	0.007	0.004	0.029	0.021
Traction Machine	0.018	0.030	0.021	0.011	0.080	0.077	0.013	0.031	0.014	0.006	0.064	0.083	0.019	0.034	0.022	0.011	0.086	0.090	0.016	0.032	0.018	0.009	0.075	0.083
Travelling Cable	0.008	0.011	0.005	0.005	0.029	0.028	0.013	0.009	0.007	0.006	0.035	0.024	0.010	0.011	0.005	0.003	0.029	0.029	0.010	0.011	0.006	0.005	0.032	0.029
Total	**0.290**	**0.377**	**0.216**	**0.117**	**1.000**	**1.000**	**0.290**	**0.377**	**0.216**	**0.117**	**1.000**	**1.000**	**0.290**	**0.377**	**0.216**	**0.117**	**1.000**	**1.000**	**0.290**	**0.377**	**0.216**	**0.117**	**1.000**	**1.000**

Note: Q=Quality; C=Cost; A=Availability; T=Time

Table 5.14 Summary of normalized component mean scores of each criterion, AHP and ABC in Company-B

	Evaluator-1						Evaluator-2						Evaluator-3						Evaluator-4						Mean Score					
Component	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC
Brake	0.012	0.013	0.018	0.007	0.050	0.041	0.011	0.015	0.014	0.006	0.046	0.050	0.014	0.010	0.019	0.009	0.052	0.032	0.013	0.016	0.023	0.006	0.058	0.050	0.012	0.014	0.018	0.007	0.051	0.046
Buffers	0.005	0.009	0.006	0.002	0.022	0.028	0.005	0.006	0.007	0.001	0.019	0.020	0.003	0.007	0.007	0.002	0.019	0.022	0.006	0.007	0.010	0.002	0.025	0.022	0.005	0.006	0.007	0.002	0.020	0.020
Car Set	0.012	0.057	0.035	0.005	0.109	0.180	0.008	0.049	0.035	0.006	0.098	0.163	0.014	0.035	0.032	0.002	0.083	0.110	0.013	0.042	0.040	0.006	0.101	0.132	0.012	0.046	0.035	0.005	0.098	0.151
Compensating Chain	0.005	0.01	0.009	0.002	0.026	0.032	0.005	0.006	0.011	0.003	0.025	0.020	0.006	0.010	0.009	0.002	0.027	0.032	0.006	0.008	0.012	0.009	0.035	0.025	0.006	0.008	0.010	0.004	0.028	0.026
Control Panel	0.014	0.034	0.038	0.010	0.096	0.107	0.016	0.027	0.039	0.006	0.088	0.090	0.014	0.035	0.036	0.008	0.093	0.110	0.013	0.045	0.023	0.006	0.087	0.142	0.015	0.036	0.034	0.007	0.092	0.118
Counterweights	0.005	0.011	0.006	0.002	0.024	0.035	0.005	0.006	0.008	0.003	0.022	0.020	0.003	0.010	0.007	0.002	0.022	0.032	0.006	0.007	0.009	0.002	0.024	0.022	0.005	0.008	0.007	0.002	0.022	0.026
Door Operator	0.012	0.015	0.015	0.002	0.044	0.047	0.011	0.016	0.023	0.003	0.053	0.053	0.014	0.011	0.016	0.002	0.043	0.035	0.013	0.017	0.013	0.002	0.045	0.054	0.012	0.015	0.016	0.002	0.045	0.049
Door Safety Devices	0.012	0.013	0.013	0.002	0.040	0.041	0.010	0.009	0.018	0.004	0.041	0.030	0.011	0.011	0.016	0.002	0.040	0.035	0.010	0.012	0.013	0.002	0.037	0.038	0.011	0.011	0.015	0.002	0.039	0.036
Governor	0.012	0.01	0.027	0.004	0.053	0.032	0.010	0.015	0.021	0.006	0.052	0.050	0.014	0.010	0.027	0.008	0.059	0.032	0.013	0.013	0.025	0.006	0.057	0.041	0.012	0.012	0.026	0.006	0.056	0.039
Guide Rails	0.010	0.010	0.010	0.011	0.041	0.032	0.005	0.014	0.020	0.010	0.049	0.047	0.006	0.010	0.010	0.008	0.034	0.032	0.009	0.013	0.013	0.009	0.044	0.041	0.009	0.012	0.014	0.010	0.045	0.039
Guide Shoes	0.005	0.007	0.010	0.002	0.024	0.022	0.010	0.006	0.011	0.003	0.030	0.020	0.006	0.007	0.010	0.002	0.025	0.022	0.006	0.007	0.013	0.002	0.028	0.022	0.008	0.006	0.011	0.002	0.027	0.020
Interlock Devices	0.011	0.013	0.013	0.002	0.039	0.041	0.010	0.009	0.014	0.003	0.036	0.030	0.009	0.011	0.016	0.002	0.038	0.035	0.009	0.012	0.013	0.002	0.036	0.038	0.010	0.011	0.014	0.002	0.037	0.036
Limit Switch	0.005	0.006	0.010	0.002	0.023	0.019	0.010	0.006	0.011	0.003	0.030	0.020	0.006	0.007	0.010	0.002	0.025	0.022	0.006	0.006	0.013	0.002	0.027	0.019	0.008	0.005	0.011	0.002	0.026	0.016
Load Weighing Devices	0.005	0.006	0.009	0.002	0.022	0.019	0.010	0.007	0.011	0.003	0.031	0.023	0.006	0.007	0.009	0.002	0.024	0.022	0.006	0.005	0.012	0.002	0.025	0.016	0.008	0.006	0.010	0.002	0.026	0.020
Motor Generator	0.012	0.020	0.025	0.010	0.067	0.063	0.011	0.027	0.014	0.005	0.057	0.090	0.014	0.035	0.030	0.008	0.087	0.110	0.013	0.026	0.020	0.006	0.065	0.082	0.012	0.027	0.023	0.007	0.069	0.089
Operation Fixtures	0.007	0.015	0.035	0.002	0.059	0.047	0.006	0.011	0.033	0.002	0.052	0.037	0.006	0.018	0.032	0.002	0.058	0.057	0.007	0.011	0.040	0.002	0.060	0.035	0.007	0.013	0.035	0.002	0.057	0.043
Rail Brackets	0.005	0.006	0.010	0.002	0.023	0.019	0.010	0.006	0.011	0.003	0.030	0.020	0.006	0.007	0.010	0.002	0.025	0.022	0.006	0.006	0.013	0.002	0.027	0.019	0.008	0.005	0.011	0.002	0.026	0.016
Roller Guides	0.005	0.006	0.010	0.002	0.023	0.019	0.010	0.006	0.011	0.003	0.030	0.020	0.006	0.007	0.010	0.002	0.025	0.022	0.006	0.005	0.013	0.002	0.026	0.016	0.008	0.005	0.011	0.002	0.026	0.016
Rope Brake	0.005	0.010	0.010	0.004	0.029	0.032	0.010	0.007	0.013	0.003	0.033	0.023	0.006	0.007	0.010	0.002	0.025	0.022	0.006	0.006	0.013	0.002	0.027	0.019	0.008	0.007	0.012	0.003	0.030	0.023
Ropes	0.011	0.010	0.012	0.004	0.037	0.032	0.010	0.014	0.020	0.010	0.054	0.047	0.013	0.010	0.018	0.004	0.045	0.032	0.009	0.008	0.015	0.005	0.037	0.025	0.011	0.010	0.016	0.006	0.043	0.033
Safety Gear	0.005	0.006	0.010	0.002	0.023	0.019	0.010	0.006	0.011	0.003	0.030	0.020	0.006	0.007	0.010	0.002	0.025	0.022	0.006	0.006	0.013	0.002	0.027	0.019	0.008	0.005	0.011	0.002	0.026	0.016
Traction Machine	0.012	0.02	0.038	0.010	0.080	0.063	0.011	0.027	0.027	0.006	0.071	0.090	0.014	0.035	0.036	0.008	0.093	0.110	0.013	0.026	0.023	0.006	0.068	0.082	0.012	0.027	0.031	0.007	0.077	0.089
Travelling Cable	0.005	0.010	0.007	0.004	0.026	0.032	0.005	0.006	0.011	0.003	0.025	0.020	0.006	0.010	0.008	0.004	0.028	0.032	0.006	0.009	0.010	0.005	0.030	0.028	0.006	0.008	0.009	0.004	0.027	0.026
Total	**0.206**	**0.311**	**0.390**	**0.093**	**1.000**	**1.000**	**0.206**	**0.311**	**0.390**	**0.093**	**1.000**	**1.000**	**0.206**	**0.311**	**0.390**	**0.093**	**1.000**	**1.000**	**0.206**	**0.311**	**0.390**	**0.093**	**1.000**	**1.000**	**0.206**	**0.311**	**0.390**	**0.093**	**1.000**	**1.000**

Note: Q=Quality; C=Cost; A=Availability; T=Time

Table 5.15 Summary of normalized component mean scores of each criterion, AHP and ABC in Company-C

	Evaluator-1						Evaluator-2						Evaluator-3						Mean Score					
Component	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC	Q	C	A	T	AHP	ABC
Brake	0.016	0.011	0.033	0.007	0.067	0.041	0.016	0.013	0.023	0.007	0.059	0.050	0.018	0.018	0.024	0.006	0.066	0.068	0.016	0.014	0.027	0.007	0.064	0.054
Buffers	0.008	0.006	0.009	0.003	0.026	0.022	0.007	0.004	0.007	0.004	0.022	0.015	0.007	0.005	0.007	0.003	0.022	0.019	0.008	0.005	0.008	0.003	0.024	0.019
Car Set	0.016	0.034	0.029	0.008	0.087	0.127	0.016	0.042	0.028	0.004	0.09	0.162	0.018	0.029	0.030	0.006	0.083	0.110	0.016	0.034	0.029	0.006	0.085	0.132
Compensating Chain	0.008	0.008	0.008	0.003	0.027	0.030	0.008	0.008	0.008	0.004	0.028	0.031	0.008	0.004	0.008	0.003	0.023	0.015	0.008	0.006	0.008	0.004	0.026	0.023
Control Panel	0.016	0.036	0.033	0.008	0.093	0.134	0.016	0.025	0.031	0.007	0.079	0.097	0.018	0.029	0.033	0.006	0.086	0.110	0.016	0.030	0.033	0.007	0.086	0.116
Counterweights	0.008	0.009	0.008	0.003	0.028	0.034	0.007	0.006	0.006	0.004	0.023	0.023	0.007	0.005	0.006	0.003	0.021	0.019	0.008	0.007	0.007	0.004	0.025	0.027
Door Operator	0.014	0.011	0.013	0.003	0.041	0.041	0.016	0.010	0.023	0.004	0.053	0.039	0.017	0.012	0.010	0.003	0.042	0.045	0.015	0.011	0.015	0.004	0.045	0.043
Door Safety Devices	0.015	0.008	0.013	0.003	0.039	0.030	0.015	0.008	0.017	0.004	0.044	0.031	0.013	0.009	0.010	0.003	0.035	0.034	0.014	0.008	0.012	0.004	0.039	0.031
Governor	0.016	0.011	0.023	0.007	0.057	0.041	0.016	0.008	0.026	0.004	0.054	0.031	0.018	0.014	0.027	0.006	0.065	0.053	0.016	0.011	0.026	0.005	0.059	0.043
Guide Rails	0.014	0.011	0.010	0.006	0.041	0.041	0.014	0.008	0.010	0.014	0.046	0.031	0.008	0.008	0.010	0.012	0.038	0.030	0.012	0.009	0.010	0.010	0.041	0.035
Guide Shoes	0.008	0.006	0.010	0.003	0.027	0.022	0.008	0.006	0.010	0.004	0.028	0.023	0.008	0.004	0.010	0.003	0.025	0.015	0.008	0.005	0.010	0.004	0.027	0.019
Interlock Devices	0.015	0.008	0.013	0.003	0.039	0.030	0.015	0.008	0.013	0.004	0.040	0.031	0.014	0.009	0.010	0.003	0.036	0.034	0.014	0.008	0.010	0.004	0.038	0.031
Limit Switch	0.008	0.006	0.010	0.003	0.027	0.022	0.008	0.006	0.01	0.004	0.028	0.023	0.008	0.004	0.010	0.003	0.025	0.015	0.008	0.005	0.010	0.004	0.027	0.019
Load Weighing Devices	0.008	0.006	0.008	0.003	0.025	0.022	0.008	0.006	0.008	0.004	0.026	0.023	0.008	0.004	0.008	0.003	0.023	0.015	0.008	0.005	0.008	0.004	0.025	0.019
Motor Generator	0.016	0.021	0.033	0.008	0.078	0.078	0.016	0.025	0.031	0.007	0.079	0.097	0.018	0.029	0.033	0.006	0.086	0.110	0.016	0.025	0.033	0.007	0.081	0.097
Operation Fixtures	0.016	0.015	0.029	0.005	0.065	0.056	0.010	0.011	0.028	0.003	0.052	0.042	0.010	0.014	0.036	0.005	0.065	0.053	0.012	0.013	0.032	0.004	0.061	0.050
Rail Brackets	0.008	0.006	0.010	0.003	0.027	0.022	0.008	0.006	0.010	0.004	0.028	0.023	0.008	0.004	0.010	0.003	0.025	0.015	0.008	0.005	0.010	0.004	0.027	0.019
Roller Guides	0.008	0.006	0.010	0.003	0.027	0.022	0.008	0.006	0.010	0.004	0.028	0.023	0.008	0.004	0.010	0.003	0.025	0.015	0.008	0.005	0.010	0.004	0.027	0.019
Rope Brake	0.008	0.006	0.010	0.003	0.027	0.022	0.008	0.006	0.010	0.004	0.028	0.023	0.008	0.009	0.010	0.006	0.033	0.034	0.008	0.006	0.010	0.005	0.029	0.023
Ropes	0.015	0.008	0.013	0.006	0.042	0.030	0.015	0.008	0.017	0.004	0.044	0.031	0.008	0.009	0.017	0.006	0.040	0.034	0.012	0.008	0.016	0.006	0.042	0.031
Safety Gear	0.008	0.006	0.010	0.003	0.027	0.022	0.008	0.006	0.010	0.004	0.028	0.023	0.008	0.004	0.010	0.003	0.025	0.015	0.008	0.005	0.010	0.004	0.027	0.019
Traction Machine	0.016	0.021	0.033	0.008	0.078	0.078	0.016	0.025	0.031	0.007	0.079	0.097	0.018	0.029	0.033	0.006	0.086	0.110	0.016	0.025	0.033	0.007	0.081	0.097
Travelling Cable	0.008	0.008	0.010	0.003	0.029	0.030	0.008	0.008	0.008	0.007	0.031	0.031	0.008	0.008	0.008	0.006	0.030	0.030	0.008	0.008	0.009	0.006	0.031	0.031
Total	**0.258**	**0.258**	**0.375**	**0.108**	**1.000**	**1.000**	**0.258**	**0.258**	**0.375**	**0.108**	**1.000**	**1.000**	**0.258**	**0.258**	**0.375**	**0.108**	**1.000**	**1.000**	**0.258**	**0.258**	**0.375**	**0.108**	**1.000**	**1.000**

Note: Q=Quality; C=Cost; A=Availability; T=Time

Table 5.16 Summary of normalized component mean scores of each criterion, AHP and ABC in Company-D

	Evaluator-1						Evaluator-2					
Component	**Q**	**C**	**A**	**T**	**AHP**	**ABC**	**Q**	**C**	**A**	**T**	**AHP**	**ABC**
Brake	0.020	0.013	0.024	0.006	0.063	0.070	0.016	0.008	0.023	0.003	0.050	0.047
Buffers	0.009	0.005	0.006	0.002	0.022	0.027	0.014	0.005	0.012	0.003	0.034	0.029
Car Set	0.020	0.026	0.033	0.004	0.083	0.140	0.016	0.023	0.036	0.003	0.078	0.135
Compensating Chain	0.009	0.006	0.009	0.002	0.026	0.032	0.014	0.005	0.012	0.003	0.034	0.029
Control Panel	0.024	0.015	0.035	0.008	0.082	0.081	0.016	0.013	0.043	0.003	0.075	0.076
Counterweights	0.009	0.006	0.007	0.002	0.024	0.032	0.014	0.005	0.012	0.003	0.034	0.029
Door Operator	0.018	0.007	0.019	0.003	0.047	0.038	0.014	0.005	0.023	0.003	0.045	0.029
Door Safety Devices	0.018	0.007	0.019	0.002	0.046	0.038	0.014	0.005	0.023	0.003	0.045	0.029
Governor	0.020	0.009	0.027	0.008	0.064	0.048	0.014	0.008	0.019	0.003	0.044	0.047
Guide Rails	0.017	0.009	0.010	0.009	0.045	0.048	0.014	0.008	0.012	0.007	0.041	0.047
Guide Shoes	0.009	0.004	0.010	0.002	0.025	0.022	0.014	0.005	0.012	0.003	0.034	0.029
Interlock Devices	0.018	0.006	0.010	0.002	0.036	0.032	0.014	0.005	0.016	0.003	0.038	0.029
Limit Switch	0.009	0.003	0.010	0.002	0.024	0.016	0.014	0.005	0.012	0.003	0.034	0.029
Load Weighing Devices	0.009	0.003	0.009	0.002	0.023	0.016	0.014	0.005	0.010	0.003	0.032	0.029
Motor Generator	0.020	0.015	0.035	0.008	0.078	0.081	0.016	0.013	0.023	0.003	0.055	0.076
Operation Fixtures	0.012	0.010	0.033	0.003	0.058	0.054	0.014	0.007	0.023	0.003	0.047	0.041
Rail Brackets	0.009	0.003	0.010	0.002	0.024	0.016	0.014	0.005	0.012	0.003	0.034	0.029
Roller Guides	0.009	0.003	0.010	0.002	0.024	0.016	0.014	0.005	0.012	0.003	0.034	0.029
Rope Brake	0.009	0.005	0.010	0.003	0.027	0.027	0.014	0.005	0.012	0.003	0.034	0.029
Ropes	0.018	0.007	0.019	0.003	0.047	0.038	0.014	0.008	0.012	0.003	0.037	0.047
Safety Gear	0.009	0.003	0.010	0.002	0.024	0.016	0.014	0.005	0.012	0.003	0.034	0.029
Traction Machine	0.020	0.015	0.035	0.008	0.078	0.081	0.016	0.013	0.023	0.003	0.055	0.076
Travelling Cable	0.009	0.006	0.008	0.003	0.026	0.032	0.014	0.005	0.012	0.003	0.034	0.029
Total	**0.325**	**0.180**	**0.407**	**0.087**	**1.000**	**1.000**	**0.325**	**0.180**	**0.407**	**0.087**	**1.000**	**1.000**

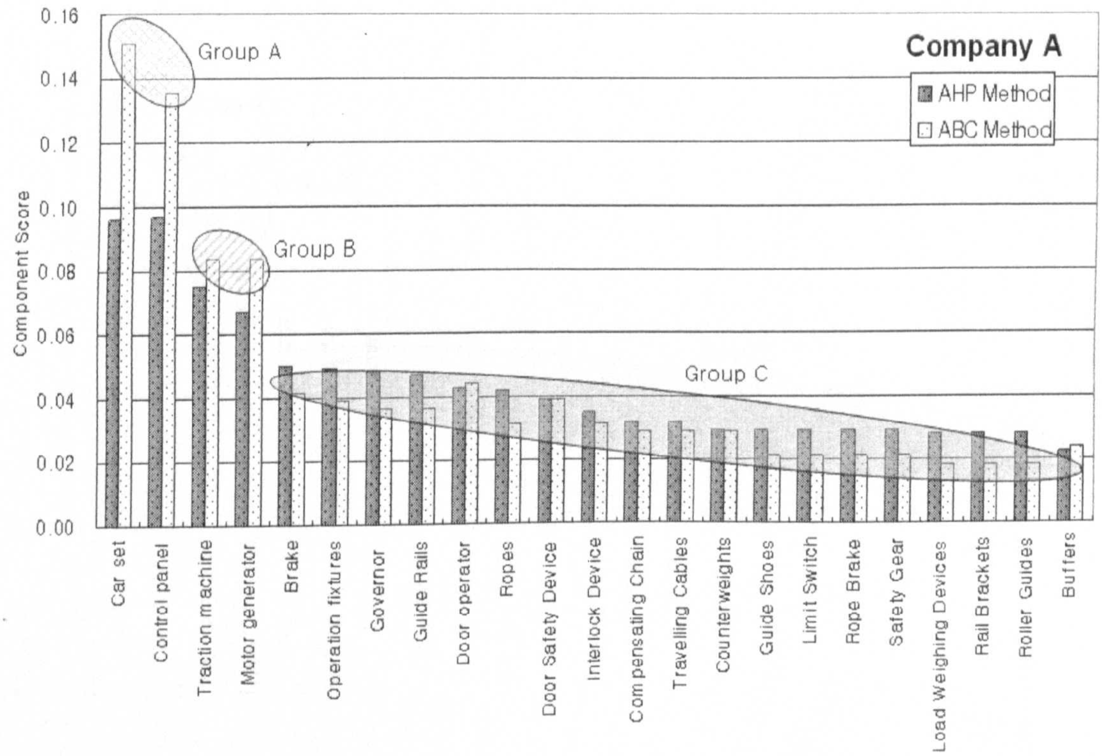
	Evaluator-3						Evaluator-4					
Component	**Q**	**C**	**A**	**T**	**AHP**	**ABC**	**Q**	**C**	**A**	**T**	**AHP**	**ABC**
Brake	0.025	0.011	0.021	0.006	0.063	0.059	0.014	0.010	0.026	0.006	0.056	0.054
Buffers	0.007	0.005	0.010	0.002	0.024	0.027	0.008	0.004	0.008	0.002	0.022	0.022
Car Set	0.039	0.026	0.021	0.008	0.094	0.141	0.014	0.033	0.036	0.005	0.088	0.179
Compensating Chain	0.009	0.006	0.010	0.002	0.027	0.032	0.014	0.004	0.011	0.002	0.031	0.022
Control Panel	0.037	0.016	0.037	0.008	0.098	0.086	0.016	0.017	0.038	0.005	0.076	0.092
Counterweights	0.007	0.005	0.010	0.002	0.024	0.027	0.008	0.005	0.008	0.002	0.023	0.027
Door Operator	0.020	0.008	0.018	0.002	0.048	0.043	0.016	0.007	0.021	0.002	0.046	0.038
Door Safety Devices	0.011	0.006	0.017	0.002	0.036	0.032	0.016	0.007	0.018	0.002	0.043	0.038
Governor	0.019	0.009	0.010	0.007	0.045	0.049	0.016	0.004	0.026	0.006	0.052	0.022
Guide Rails	0.011	0.009	0.017	0.007	0.044	0.049	0.014	0.005	0.011	0.009	0.039	0.027
Guide Shoes	0.011	0.004	0.010	0.002	0.027	0.022	0.014	0.004	0.011	0.002	0.031	0.022
Interlock Devices	0.017	0.005	0.010	0.002	0.034	0.027	0.014	0.005	0.012	0.002	0.033	0.027
Limit Switch	0.011	0.003	0.010	0.002	0.026	0.016	0.014	0.004	0.011	0.002	0.031	0.022
Load Weighing Devices	0.009	0.003	0.010	0.002	0.024	0.016	0.014	0.004	0.011	0.002	0.031	0.022
Motor Generator	0.037	0.016	0.021	0.008	0.082	0.086	0.014	0.017	0.027	0.006	0.064	0.092
Operation Fixtures	0.032	0.010	0.014	0.001	0.057	0.054	0.016	0.009	0.029	0.002	0.056	0.049
Rail Brackets	0.011	0.003	0.010	0.002	0.026	0.016	0.014	0.004	0.012	0.002	0.032	0.022
Roller Guides	0.011	0.003	0.010	0.002	0.026	0.016	0.014	0.004	0.011	0.002	0.031	0.022
Rope Brake	0.011	0.006	0.010	0.003	0.030	0.032	0.014	0.006	0.011	0.003	0.034	0.033
Ropes	0.019	0.006	0.018	0.007	0.050	0.032	0.014	0.006	0.018	0.005	0.043	0.033
Safety Gear	0.011	0.003	0.010	0.002	0.026	0.016	0.014	0.004	0.011	0.002	0.031	0.022
Traction Machine	0.037	0.016	0.021	0.008	0.082	0.086	0.014	0.017	0.038	0.006	0.075	0.092
Travelling Cable	0.009	0.006	0.010	0.003	0.028	0.032	0.014	0.004	0.008	0.006	0.032	0.022
Total	**0.325**	**0.180**	**0.407**	**0.087**	**1.000**	**1.000**	**0.325**	**0.180**	**0.407**	**0.087**	**1.000**	**1.000**

	Evaluator-5						Mean Sco			
Component	**Q**	**C**	**A**	**T**	**AHP**	**ABC**	**Q**	**C**	**A**	**T**
Brake	0.022	0.013	0.012	0.005	0.052	0.070	0.018	0.011	0.023	0.00
Buffers	0.006	0.005	0.009	0.002	0.022	0.027	0.008	0.005	0.009	0.00
Car Set	0.025	0.027	0.039	0.010	0.101	0.145	0.018	0.027	0.037	0.00
Compensating Chain	0.011	0.006	0.011	0.003	0.031	0.032	0.011	0.006	0.011	0.00
Control Panel	0.022	0.015	0.036	0.010	0.083	0.081	0.023	0.016	0.039	0.00
Counterweights	0.005	0.006	0.008	0.003	0.022	0.032	0.008	0.006	0.009	0.00
Door Operator	0.020	0.007	0.018	0.004	0.049	0.038	0.016	0.007	0.021	0.00
Door Safety Devices	0.016	0.007	0.012	0.003	0.038	0.038	0.016	0.007	0.016	0.00
Governor	0.020	0.009	0.015	0.005	0.049	0.048	0.016	0.008	0.021	0.00
Guide Rails	0.020	0.009	0.012	0.010	0.051	0.048	0.015	0.008	0.011	0.00
Guide Shoes	0.011	0.004	0.012	0.003	0.030	0.022	0.011	0.005	0.011	0.00
Interlock Devices	0.015	0.006	0.012	0.003	0.036	0.032	0.015	0.005	0.014	0.00
Limit Switch	0.006	0.003	0.012	0.003	0.024	0.016	0.010	0.004	0.011	0.00
Load Weighing Devices	0.011	0.003	0.011	0.003	0.028	0.016	0.011	0.004	0.010	0.00
Motor Generator	0.022	0.015	0.036	0.005	0.078	0.081	0.018	0.016	0.032	0.00
Operation Fixtures	0.011	0.009	0.034	0.003	0.057	0.048	0.013	0.009	0.030	0.00
Rail Brackets	0.011	0.003	0.012	0.003	0.029	0.016	0.011	0.004	0.012	0.00
Roller Guides	0.011	0.003	0.012	0.003	0.029	0.016	0.011	0.004	0.011	0.00
Rope Brake	0.011	0.005	0.012	0.003	0.031	0.027	0.011	0.006	0.011	0.00
Ropes	0.020	0.007	0.012	0.005	0.044	0.038	0.016	0.007	0.016	0.00
Safety Gear	0.011	0.003	0.012	0.003	0.029	0.016	0.011	0.004	0.011	0.00
Traction Machine	0.022	0.015	0.036	0.005	0.078	0.081	0.018	0.016	0.034	0.00
Travelling Cable	0.011	0.006	0.009	0.003	0.029	0.032	0.011	0.006	0.009	0.00
Total	**0.325**	**0.180**	**0.407**	**0.087**	**1.000**	**1.000**	**0.325**	**0.180**	**0.407**	**0.08**

Note: Q=Quality; C=Cost; A=Availability; T=Time

5.5 Multi-criteria classification and criterion groups

As many SMEs still use ABC classification as a tool to control their components, elevator manufacturers also have done this tool to mange their components. However, in ABC classification, components should be ranked by the value of their usage (Slack et al., 2007). Figure 5.2 illustrates the components' AHP and ABC scores from Tables 5.13 to 5.16. The ABC score includes the scores of purchasing cost, inventory cost and quality cost, as shown in Figure 5.1. For this score, raw data is not used but five rating levels, defined as 'very high', 'high', 'moderate', 'low' and 'very low' in Table 5.12. Partovi and Burton (1993) also used these cost rating levels to classify inventory items using the AHP process for ABC analysis. To decipher the large array of priorities, they are sorted and placed in groups. For example, in Figure 5.2 the components are split (by eye, searching for natural breaks in the data) into three groups. It should be noted that in this particular example three groups have been formed, but there could be more groups, especially when the number of components is larger and more natural breaks are seen in the scores.



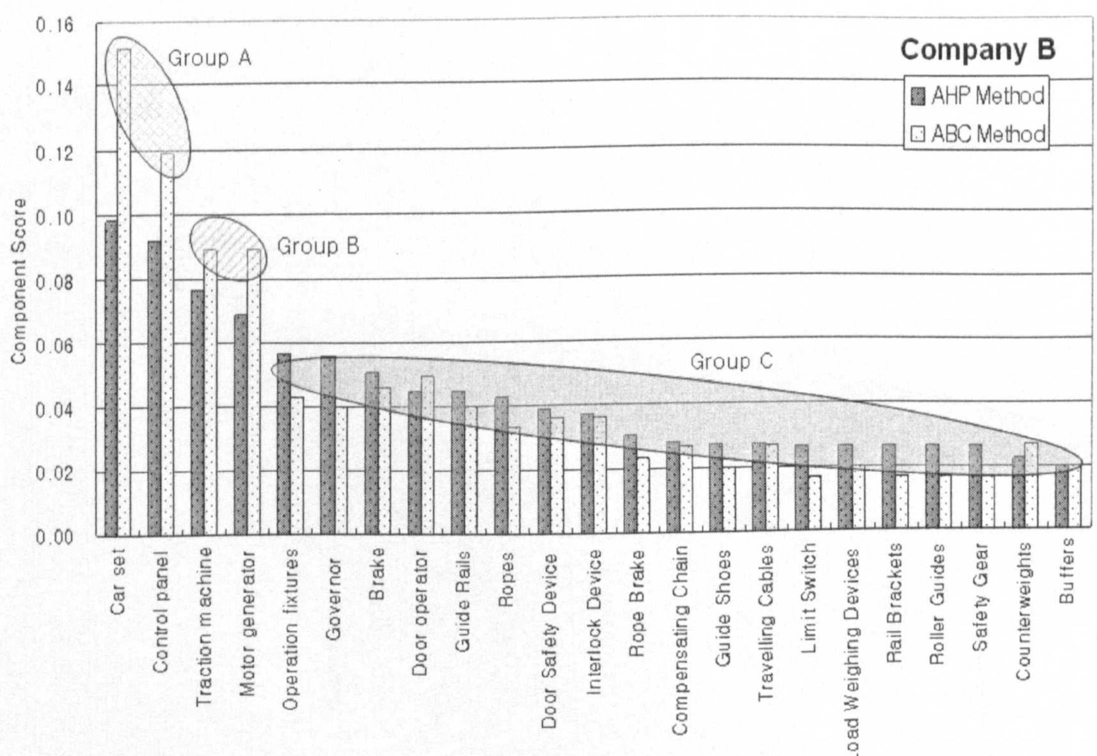
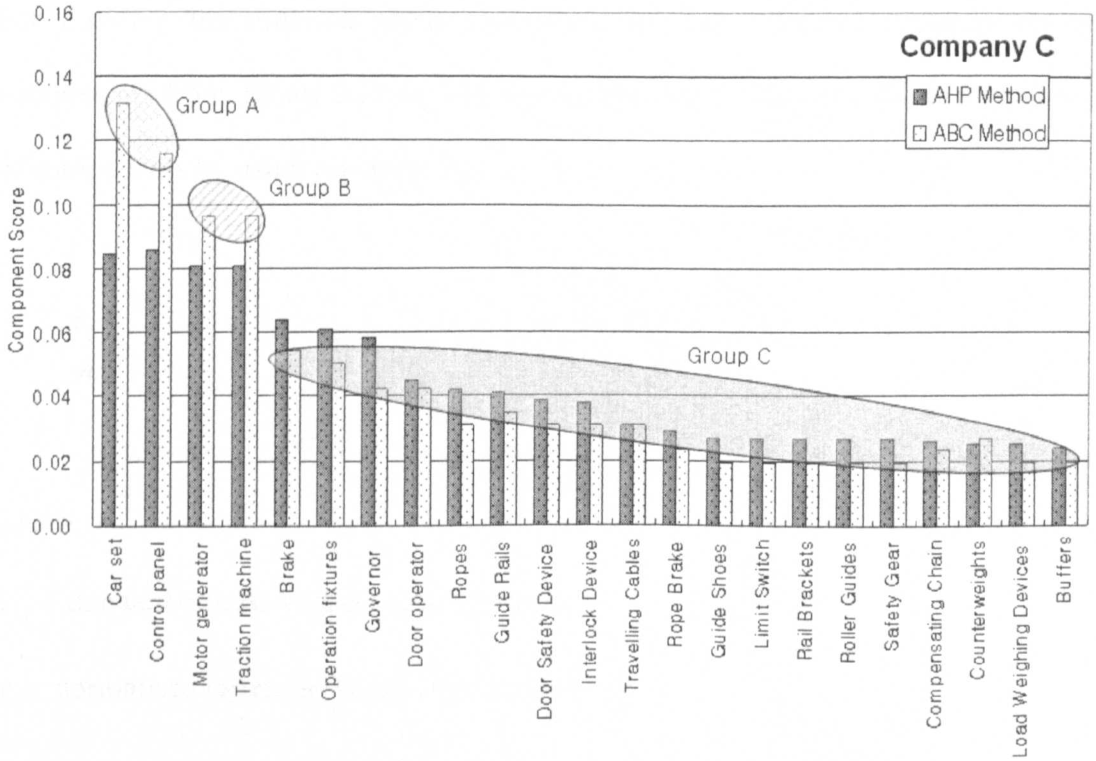


Figure 5.2 AHP and ABC score of components of the electric traction elevator in the four manufacturers (continued)



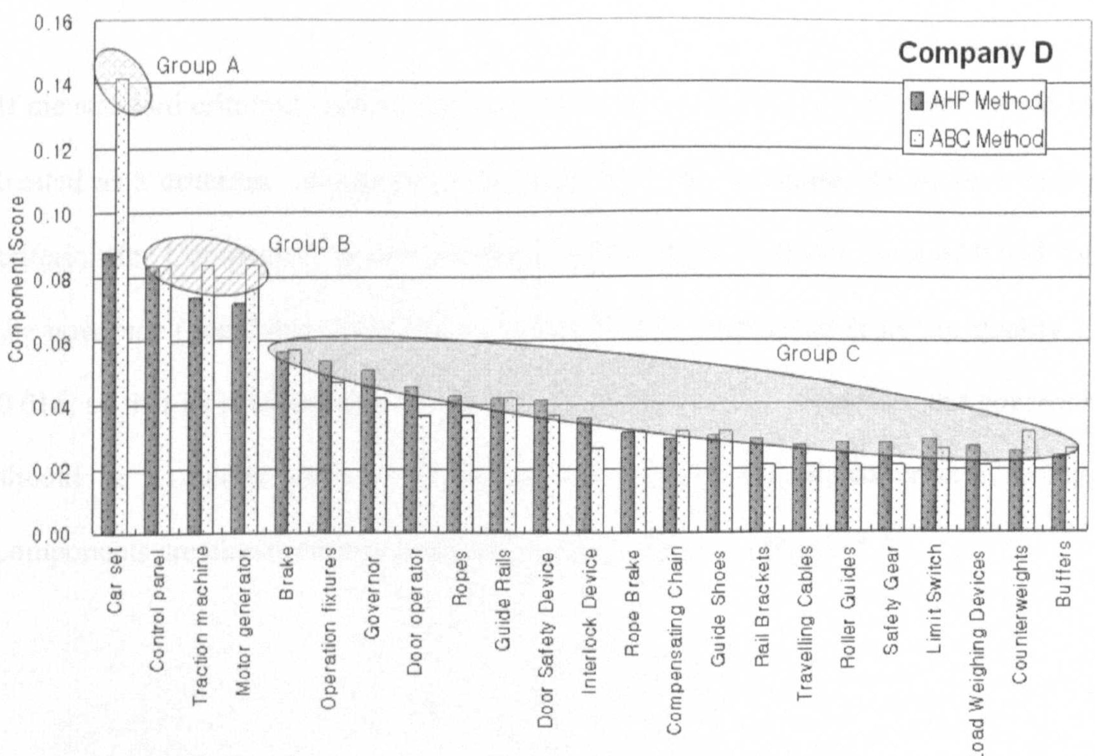


Figure 5.2 AHP and ABC score of components of the electric traction elevator in the four manufacturers (continued)

For deciding the criterion groups, all the normalized criterion mean scores of components from Tables 5.13 to 5.16 were transformed to standard criterion scores of components by using Equation 5-2.

$$Z_{ij} = \frac{c_{ij}}{m_i} \qquad (5\text{-}2)$$

where:

Z_{ij} = standard criterion j score of component i;

c_{ij} = normalised criterion j score of component i;

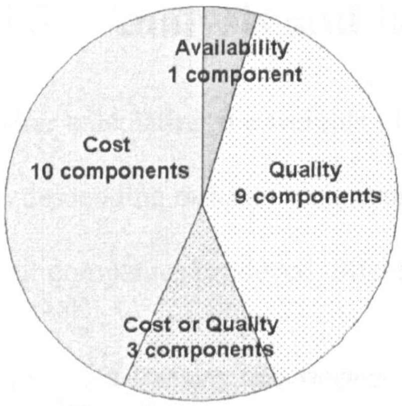
m_i = order-winner score of component i in a company.

If the standard criterion j score of component i is more than 1, component i should be treated as a criterion j component; see Table 5.17. For example, the order-winning criterion for Company-A is cost and this has a normalised mean score of 0.014 for the *governor* (See Table 5.13).The *governor*'s normalised mean score for quality is 0.016, so that its standard quality score is 0.016/0.014 = 1.1. Therefore the *governor* should be a quality item. After converting to their normalized criteria scores, components are classified into criterion groups as shown in Figure 5.3.

Table 5.17 Summary of standard criterion scores of quality, cost, availability and time of components in the four elevator manufacturers

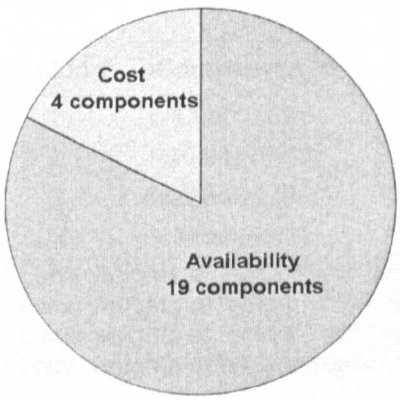
	Company-A				Company-B				Company-C				Company-D			
Component	**Q**	**C**	**A**	T	**Q**	**C**	**A**	T	**Q**	**C**	**A**	T	**Q**	**C**	**A**	T
Brake	1.0	1.0	0.8	0.4	0.7	0.8	1.0	0.4	0.6	0.5	1.0	0.3	0.8	0.5	1.0	0.3
Buffers	0.7	1.0	0.4	0.3	0.7	0.9	1.0	0.3	1.0	0.6	1.0	0.4	0.9	0.6	1.0	0.2
Car Set	0.3	1.0	0.3	0.1	0.3	1.3	1.0	0.1	0.6	1.2	1.0	0.2	0.5	0.7	1.0	0.2
Compensating Chain	0.9	1.0	0.6	0.4	0.6	0.8	1.0	0.4	1.0	0.8	1.0	0.5	1.0	0.5	1.0	0.2
Control Panel	0.3	1.0	0.3	0.2	0.4	1.1	1.0	0.2	0.5	0.9	1.0	0.2	0.6	0.4	1.0	0.2
Counterweights	0.7	1.0	0.5	0.4	0.7	1.1	1.0	0.3	1.1	1.0	1.0	0.6	0.9	0.7	1.0	0.2
Door Operator	0.8	1.0	0.5	0.2	0.8	0.9	1.0	0.1	1.0	0.7	1.0	0.3	0.8	0.3	1.0	0.1
Door Safety Devices	0.9	1.0	0.5	0.3	0.7	0.7	1.0	0.1	1.2	0.7	1.0	0.3	1.0	0.4	1.0	0.1
Governor	**1.1**	**1.0**	**0.8**	**0.5**	0.5	0.5	1.0	0.2	0.6	0.4	1.0	0.2	0.8	0.4	1.0	0.3
Guide Rails	1.0	1.0	0.5	0.9	0.6	0.9	1.0	0.7	1.2	0.9	1.0	1.0	1.4	0.7	1.0	0.7
Guide Shoes	1.3	1.0	0.9	0.5	0.7	0.5	1.0	0.2	0.8	0.5	1.0	0.4	1.0	0.5	1.0	0.2
Interlock Devices	1.0	1.0	0.6	0.3	0.7	0.8	1.0	0.1	1.4	0.8	1.0	0.4	1.1	0.4	1.0	0.1
Limit Switch	1.3	1.0	0.9	0.5	0.7	0.5	1.0	0.2	0.8	0.5	1.0	0.4	0.9	0.4	1.0	0.2
Load Weighing Devices	1.4	1.0	1.0	0.6	0.8	0.6	1.0	0.2	1.0	0.6	1.0	0.5	1.1	0.4	1.0	0.2
Motor Generator	0.5	1.0	0.3	0.3	0.5	1.2	1.0	0.3	0.5	0.8	1.0	0.2	0.6	0.5	1.0	0.2
Operation Fixtures	0.7	1.0	1.3	0.3	0.2	0.4	1.0	0.1	0.4	0.4	1.0	0.1	0.4	0.3	1.0	0.1
Rail Brackets	1.4	1.0	1.0	0.6	0.7	0.5	1.0	0.2	0.8	0.5	1.0	0.4	0.9	0.3	1.0	0.2
Roller Guides	1.4	1.0	1.0	0.6	0.7	0.5	1.0	0.2	0.8	0.5	1.0	0.4	1.0	0.4	1.0	0.2
Rope Brake	1.3	1.0	0.9	0.5	0.7	0.6	1.0	0.3	0.8	0.6	1.0	0.5	1.0	0.5	1.0	0.3
Ropes	1.3	1.0	0.8	0.5	0.7	0.6	1.0	0.4	0.8	0.5	1.0	0.4	1.0	0.4	1.0	0.3
Safety Gear	1.3	1.0	0.9	0.5	0.7	0.5	1.0	0.2	0.8	0.5	1.0	0.4	1.0	0.4	1.0	0.2
Traction Machine	0.5	1.0	0.6	0.3	0.4	0.9	1.0	0.2	0.5	0.8	1.0	0.2	0.5	0.5	1.0	0.2
Travelling Cable	0.9	1.0	0.5	0.5	0.7	0.9	1.0	0.4	0.9	0.9	1.0	0.7	1.2	0.7	1.0	0.3

Note: Q=Quality; C=Cost; A=Availability; T=Time



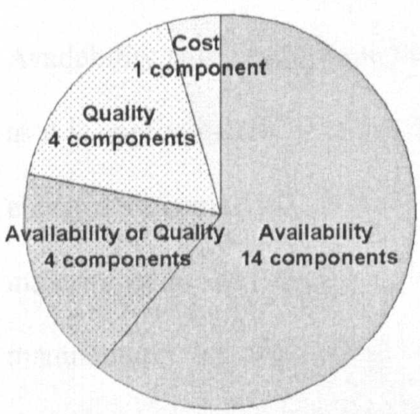
Company-A

Business strategy	Cost leadership
Order winner	Cost
Order qualifiers	Quality Availability Time



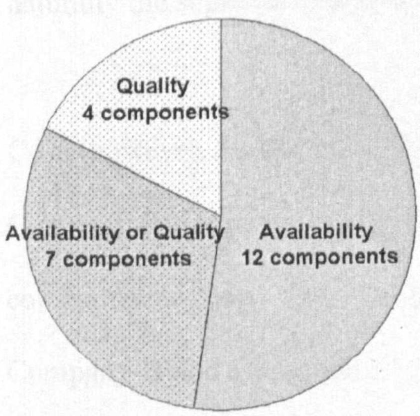
Company-B

Business strategy	Differentiation
Order winner	Availability
Order qualifiers	Cost Quality Time



Company-C

Business strategy	Differentiation
Order winner	Availability
Order qualifiers	Quality Cost Time



Company-D

Business strategy	Focus
Order winner	Availability
Order qualifiers	Quality Cost Time

Figure 5.3 Criterion groups in the four elevator manufacturers

5.6 Analysis and interpretation of results

After calculating the weights of each criterion at the second level, they are arranged in descending order of weight or priority, as shown in Table 5.18. This shows that the four companies produced different weights for the strategic priorities.

Table 5.18 Ranking and weights of strategic priorities of components in the four elevator manufacturers

	Strategic priorities (local weight)			
Ranking	**Company-A** [1)]	**Company-B** [2)]	**Company-C** [3)]	**Company-D** [4)]
1	Cost (0.38)	Availability (0.39)	Availability (0.37)	Availability (0.41)
2	Quality (0.29)	Cost (0.31)	Cost (0.26)	Quality (0.32)
3	Availability (0.21)	Quality (0.21)	Quality (0.26)	Cost (0.18)
4	Time (0.12)	Time (0.09)	Time (0.11)	Time (0.09)

1) Local weights of factors from Table 5.5
2) Local weights of factors from Table 5.6
3) Local weights of factors from Table 5.7
4) Local weights of factors from Table 5.8

Availability is the most important strategic priority of three companies - B, C and D, as it is approximately four times as heavily weighted as time by these companies. An elevator is comprised of both standardised and customised components, with the majority being customised to meet the needs of the customer. Since the elevator manufacturer has adopted the make-to-order (MTO) process, availability is quite naturally the supreme competitive priority.

Cost, however, is the most important strategic priority for Company-A, because Company-A has a cost leadership strategy, which makes it more sensitive than other companies to cost. Cost is also the next most important strategic priority for Company-B and Company-C. As elevator manufacturers typically spend more than 70% of each sales dollar on purchased materials and components, the high weighting given to cost is to be expected.

Whilst availability and cost dominate the priorities in this MTO, high variety and highly competitive market, quality still maintains a significant weight for safety reasons, i.e. an elevator is potentially dangerous and could injure or cause death to the user. In general, elevators are built to strict quality standards such as ASME A17 for the U.S.A. and the EN 81 series for Europe. Quality is given an especially high weight at Company-D because it produces a particularly high quality product a niche mark.

Time has the lowest weight of all priorities for all the companies. This is a consequence of the overriding importance of availability, cost and quality rather than time being unimportant per se. This low weight given to time agrees with the results of Quayle's (2003) survey that found that the highest priority requirements placed on suppliers by SMEs are pricing, quality and capability, while time to market and procurement have lower importance.

Figure 5.2 shows that the four companies have a similar allocation of components to the three groups using the ABC method. This result can be justified by them having similar cost structures for their components. For example, the *car set* is one of the most expensive components in elevator manufacture while the *roller guides* are one of the cheapest components. Group A is the most critical or high-priority component group consisting of the *car set* and the *control panel*. Group B is the second most important group containing the *traction machine* and the *motor generator*. Group C contains the least critical components, from the *operation fixtures* to the *buffers*. The only deviation from this group assignment is seen for Company-D which has the *control panel* in Group B.

It also shows that Company-A and Company-B have similar grouping results between using the ABC method and the AHP method while Company-C and Company-D have difference component groups. This should come from the result of different weights of cost in each company. Table 5.18 indicates a greater emphasis on cost in Company-A and Company-B and there is an explanation. In Company-A and Company-B, target markets are mainly housing estates and hospitals, while office buildings and flats for Company-C and shopping centres and hotels for Company-D. Typically, the order batch size for Company-A and Company-B is larger than for Company-C and Company-D. This is because the order batch size for housing estates is normally more then 10, while office buildings generally have a batch size less than 5. As they are ordering in large batches, existing and potential customers of Company-A and Company-B expect a quantity discount before ordering, i.e. the customers' minds are set on forcing prices down.

Figure 5.3 shows each company has a different number of components in each criterion group. Components are placed in the group for the criterion upon which they have the greatest impact, as determined by Table 5.17. For example, the components in the cost group have a higher impact on the cost of the end product. These items should be managed to minimise cost. The groups are related to a firm's business strategy and the order-winning features of the end-product. For example, Company-A has a cost leadership strategy with cost as the order-winner, so more components belong to the cost group. Company-B and Company-C have the same differentiation strategy with the same order-winner: availability. However, their criterion groups are very different. Company-B has more components in the cost group because cost is a very important order qualifier. Company-C and Company-D have similar criterion groups, except Company-C has one cost component whereas Company-D has none. This similarity is to be expected as they have the same order-winner, availability and order-qualifiers.

The four components of the higher priority Group A and Group B have a considerable impact on the value of the end-product, as discussed before, so they must be analysed in more detail. Table 5.19 shows how these four components are assigned to the criterion groups for the four elevator manufacturers. In Company-A, all the components are in the cost group so Company-A should manage the components to reduce cost. Company-B, however, has 3 cost components and 1 availability component. It should be noted that although Company-B has a differentiation strategy, Company-B has to consider cost is also one of the important criteria. Company-C has 3 availability components and 1 cost component while Company-D has 4 availability components. This means that Company-C and Company-D have to focus on availability to achieve their business strategy. But in Company-C, the *car set* should be managed carefully as a cost item because it represents a large proportion of the total cost of an elevator.

Table 5.19 Components of criterion groups in Group A and Group B

Company	Quality group	Cost group	Availability group	Time group
Company-A		Car set Control panel Motor generator Traction machine		
Company-B		Car set Control panel Motor generator	Traction machine	
Company-C		Car set	Control panel Motor generator Traction machine	
Company-D			Car set Control panel Motor generator Traction machine	

5.7 Conclusions

The literature conveys the importance of aligning purchasing strategy with business strategy for achieving competitive success. This chapter has made a pragmatic contribution to achieving this by prioritising components on the basis of their impact on the competitive priorities of the business. In particular, the Analytic Hierarchy Process (AHP) has been applied to the prioritisation and subsequent grouping of the components of an electric traction elevator according to their impact on the business strategy. This information can be used to guide and prioritise the work of those forming the purchasing strategy required to support the business strategy. The purchasing strategy of the highest priority components must be given immediate attention as an integral part of implementing the business strategy, whilst the purchasing strategy for the lower priority components can be developed in due course, perhaps viewed as a matter for continuous improvement. The component priorities also indicate priorities for supplier development.

The literature reviewed supports the argument that contemporary strategic purchasing requires team working and the synthesis of the views of staff from different fields of expertise. The AHP is a synthesiser that facilitates consensus and makes the decision-making process very transparent.

The result of this chapter is a good starting point to a further study o f purchasing strategy using criterion groups to improve a company's competitiveness. A purchasing focus on cost or any other dimension is one of the main determinants of competitiveness for many manufacturing companies. Therefore, analysing criterion groups is one of the gaps to be filled in order to develop the purchasing strategy in the manufacturing area. Besides, this result shows that companies with the same business strategy may place a given component into different criterion groups, so that these components will then have different purchasing strategies.

In the analysis presented in this chapter only data internal to the companies has been used. However, when a company decides upon its purchasing strategy, external data must also be considered as the supply market environment will have a significant impact on the purchasing and supply of components. So, in the next chapter the external supply situation faced is brought into the analysis. Furthermore, to choose the best mix of competitive objectives according to the types of market will be one of the most critical choices in the future. Some companies already combined two competitive factors as high quality and low cost using a lean strategy, or quick response and focus on customer order with an agile strategy. This will be explained in Chapter 7.

Chapter 6

The Purchasing Portfolio Model; the case of two elevator manufacturers

6.1 Introduction

Recently, purchasing portfolio models have received a great deal of attention both in the academic and business fields and been used as a tool and a reference. They are easy to understand and they give practical guidelines on how to manage different purchased items, suppliers and supplier relationships (Dubois and Pedersen, 2002). Kraljic's approach is now being presented in textbooks on purchasing, e.g. (Gadde and Hakansson, 2001), (Lysons and Gillingham, 2003) and (van Weele, 2005). Surveys have found that 74% of Dutch purchasers (Gelderman, 2003) and 55% of French purchasers (Kibbeling, 2005) in the manufacturing and engineering sectors use purchasing portfolio analysis. In a survey of 122 companies in the UK across the manufacturing, service and other industry sectors, purchasing portfolio analysis was found to be the second most used of 65 purchasing and supply tools; the top five being vendor rating, purchasing portfolio analysis, enterprise resource planning (ERP) systems, supplier development and service-level agreements (Cox and Watson, 2004).

Major manufacturers such as Motorola, Honda and Toyota have benefited from strategically managing purchasing and relationships with their suppliers (Liker and Choi, 2004; Metty et al., 2005; Pressey et al., 2007). They have attained higher quality, increased operational flexibility, shorter lead-times and cost reductions as a result of close, collaborative relationships with suppliers (Janda and Seshadri, 2001). Strategic purchasing can benefit not only large firms but also small firms (Carr and Pearson, 2002). However, small and medium size enterprises' (SMEs') use of portfolio models is much lower than that of larger enterprises (Gelderman and van Weele, 2005). Instead, purchasing decisions in small firms are generally made either by the owner or by a chosen few on the basis of intuition and personal experience (Cagliano and Spina, 2002) (or possibly misconception) and this can lead naturally to poor performance. Moreover, small firms may find it difficult to gain interest in development and collaboration from their suppliers because they order small volumes and they normally lack the management resource to find and develop alternative suppliers and solutions (Gadde and Hakansson, 2001). Small businesses suffer from having little purchasing power (Quayle, 2002) unlike large businesses, which have considerable negotiating power over suppliers since their volume of purchases is much greater (Gonzalez-Benito et al, 2003). Most previous research into purchasing strategy has been in the context of large companies (Cagliano and Spina, 2002), so that little has been reported on purchasing strategy for SMEs in particular. This chapter reports the development of a portfolio model for purchasing strategy and applies it in two SME case studies. The focus is on the development of a practical approach that is simple enough for SMEs to implement with their limited resources and limited access to supplier data (they have less power), although the approach is still intended to be valid for all sizes of enterprises.

6.2 Development of the purchasing portfolio model

As mentioned earlier, the application presented concerns the production-related items (e.g. raw materials and components) used in assembling a final product, i.e. strategic purchases. These have a different purchasing structure and strategy compared with non-production-related items such as MRO items, i.e. non-strategic purchases. Xideas and Moschuris (1998) have already argued that firms have different structures for the purchasing functions and processes for different types of purchased items.

It has been seen that the general form of a purchasing portfolio model has one dimension related to the importance of a purchase and one related to the nature of the supply. The importance of a purchase depends on the product of which it will be part; is the purchase critical to the product's quality, competitive stance and profitability? The supply dimension is fundamentally concerned with risk assessment and here it is given the title 'supply risk'. It relates to the performance of the suppliers and factors outside the control of the buyer. For example, a component that has only one supplier who in turn is financially unstable is higher risk than a component that has numerous, stable suppliers.

For developing the purchasing portfolio model, four competitive priorities are measured on the basis of the importance of the factors in Table 6.1 to the process of purchasing components. These factors are adopted here in measuring the importance dimension which in turn is referred to as the 'component value' in line with Johansson et al. (1993), as the fundamental importance of a component of a manufactured product is determined by its contribution to the 'value' of the product, as discussed in Chapter 4.

As discussed earlier in Chapter 3, to combine these measures to give an overall measure for the 'component value' dimension the AHP is used as described in Chapter 5. To achieve the aims and objectives set by the business strategy one must focus on the strategic or competitive priorities, i.e. that which contributes most, and 'priority' is a relative measure. This means that 'component value' is a relative rather than absolute measure. For example, the impact of a component on cost depends on its proportion of the overall cost of the end-product, i.e. its costs relative to the cost of the other components. This makes the AHP appropriate.

Table 6.1 Factors influencing the component value

Quality factors 1. Component durability 2. Component reliability 3. Component innovation
Availability factors 1. Volume flexibility 2. Modification flexibility 3. Technological capability
Cost factors 1. Purchasing cost 2. Inventory cost 3. Quality cost
Time factors 1. Delivery speed 2. Delivery reliability 3. Development speed

However, 'supply risk' is quite different. If a component fails to be delivered then the final product cannot be completed. High risk purchases must be managed accordingly irrespective of whether other components are more or less risky. Consider for example the number of suppliers; having only one or two suppliers is high risk. However, having many suppliers is low risk. If two components had, say, 20 and 100 potential suppliers respectively, then both are low risk on an absolute basis. If a relative view was taken, 20 is much smaller than 100 so would be classed, incorrectly, as high risk. This has ramifications for the method of measurement used. The AHP is not appropriate as the risk associated with an individual component should be measured independently or directly. This difference between how 'component value' and 'supply risk' are measured (relative versus absolute) is important to appreciate as it results in different treatments in the model presented here.

The dimension of 'supply risk' is based on the similar dimensions used by Kraljic (1983) and Olsen and Ellram (1997). Kraljic used the following factors in measuring the 'complexity of the supply market': availability; number of potential suppliers; competitive demand; make-or-buy opportunities; storage risks; substitution possibilities. Olsen and Ellram used three factors with six sub-factors for measuring 'difficulty of the purchasing situation': product characteristics (sub-factors: novelty and complexity); supply market characteristics (sub-factors: suppliers' power, and suppliers' technical and commercial competence); environmental characteristics (sub-factors: risk and uncertainty). These measures require the acquisition of data external to the business. It is not easy to get all the required data for either of these sets of factors using a business's internal resources as much time and expense may be required. Rajagopal and Sanchez (2005) argued that data is only available from the closest suppliers and even when it is available, it can be incorrect due to reasons such as the commitment of the supplier and the fundamental size and complexity of the task of data acquisition. It may be particularly difficult for an SME to acquire accurate data from suppliers as SMEs do not have the 'power' of large customers to command the attention of suppliers. In the SME case studies introduced in the following section, the staff reported that they certainly did not have the data required. Furthermore, even though Olsen and Ellram used several factors and sub-factors they still noted that the list was not comprehensive and it may need to vary for individual businesses. It is reiterated that Moller et al. (2000) found Olsen and Ellram's model to be impractical because it is too elaborated for everyday usage in industry. The argument subscribed to in this chapter is that the over elaboration of the measurement of this dimension is neither immediately helpful nor practical.

It is proposed here that two simple factors can be used to help assess the 'supply risk'. First, 'size of the supplier' is an objective and quantifiable way of measuring the 'supplier's power' as used by Olsen and Ellram, on the assumption that power is typically related to size. Second, the measure 'number of suppliers' is used to combine and simplify Olsen and Ellram's use of 'product characteristics' and 'environmental characteristics'. Looking at the sub-factors, if a purchase exhibits 'novelty' or 'complexity' then it will typically be available from only one or very few suppliers, which means that there are monopoly or at best oligopoly conditions creating risk.

The supply risk model in Figure 6.1 combines the two factors, 'size of supplier' and 'number of suppliers' to score the 'supply risk' in the range 1 to 9. As with the AHP, the supply risk model converts the qualitative measurement of the factors into a quantitative measurement or score to use with the purchasing portfolio model.

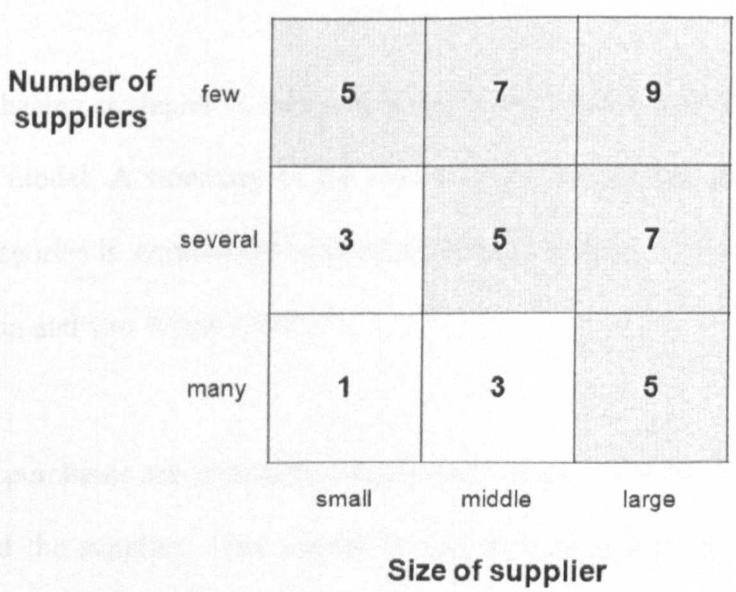


Figure 6.1 Supply risk model

Based on the two dimensions, 'component value' and 'supply risk', four types of purchased items are demarcated in the purchasing portfolio model; strategic items, bottleneck items, leverage items and non-critical items as shown in Figure 6.2.

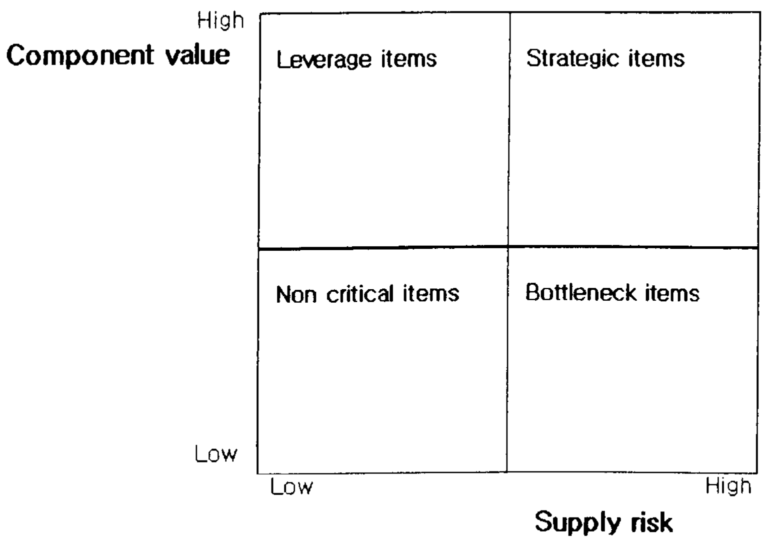


Figure 6.2 Purchasing portfolio model (Based on Kraljic's matrix with renamed axes)

The purchasing strategies of components will vary according to their position in this portfolio model. A summary of the nature of the purchasing strategies implied by these categories is synthesised below from Kraljic (1983), de Boer et al. (2001) and Gelderman and van Weele (2005).

Strategic purchases are critical to success and require close interactions between the buyer and the supplier. They cannot be left to the vagaries of open-market based supply. The purchasing strategy is to maintain a strategic partnership, so the manufacturer should manage these purchases by regular information exchanges with suppliers, frequent visits from both partners and long-term supply relationships, perhaps moving towards virtual integration. The manufacturer could involve the supplier in its product development.

Leverage purchases are easy to manage but have high strategic importance. They could be obtained from various suppliers, so the general recommendation is to exploit purchasing power, managing these purchases by supplier selection, product substitution and targeted pricing negotiations. The purchasing strategy could be based upon the principle of competitive bidding.

Bottleneck purchases are difficult to manage but have low strategic importance. They cause significant problems and risks because suppliers are scarce. The core of the purchasing strategy is to ensure the volume of components, so these purchases should be managed by supplier control, safety stock and backup plans. Alternative suppliers could be found.

Non-critical purchases are easy to manage and have low strategic importance. They cause only few technical or commercial problems from the point of view of purchasing. However, they are ordered frequently from many suppliers, so their logistical and administrative costs are high. Therefore, the focus of the purchasing strategy is to reduce transaction costs through efficient processing, product standardisation and the optimisation of order volumes and inventory levels. The number of suppliers could be reduced through category management.

6.3 Application of purchasing portfolio model

Two South Korean electric elevator manufacturers, Company-B and Company-C, are used as case studies. As these companies are similar (see Table 5.1), they provide a test to see how different or similar portfolio models may be produced to meet the needs of ostensibly similar businesses. The AHP data for the portfolio mapping exercise from Chapter 5 is re-used.

For the application of the purchasing model, all the mean AHP scores for components for Company-B and Company-C from Table 5.14 and Table 5.15 were converted into standard scores of components by using Equation 6-1.

$$Z_i = \frac{y_i - y_{min}}{y_{max} - y_{min}} \qquad (6\text{-}1)$$

where:

Z_i = standard score of component *i*;

y_i = AHP score of component *i*;

y_{min} = minimum normalised score across all components;

y_{max} = maximum normalised score across all components.

These standardised scores range from 0 to 1. When the normalized score of a component is the minimum score, the standard score is 0 and when the normalized score of component is the maximum, the standard score is one.

Then, as the AHP is based on the 1 to 9 weighting scale the component standard scores are transformed onto this scale for consistency using Equation 6-2.

$$V_i = 8 \times Z_i + 1 \qquad (6\text{-}2)$$

where:

V_i = transformed score of component *i*;

Z_i = standard score of component *i*.

The 'component value' scores are gained by applying Equations 6-1 and 6-2, and are given in Figure 6.3 for Company-B and Company-C. For example, the component value of the *control panel* in Company-B is 8.38 when its AHP score is 0.092, y_{min} is 0.020 and y_{max} is 0.098. The scaled scores are used in positioning the components in the purchasing portfolio matrix.

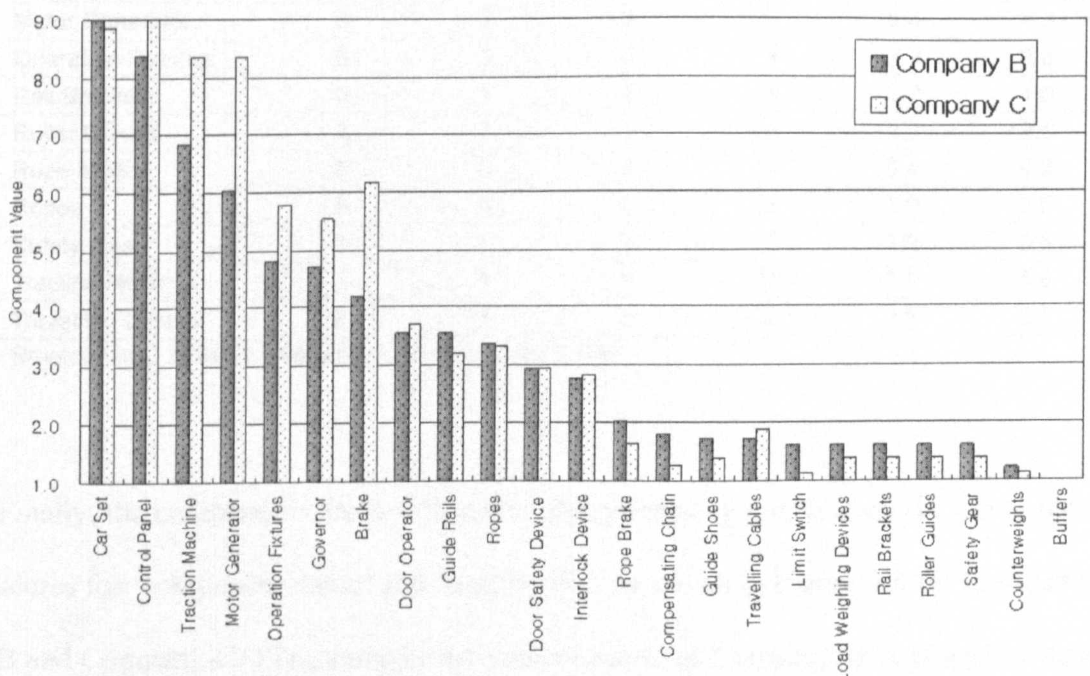


Figure 6.3 Component value scores in Company-B and Company-C

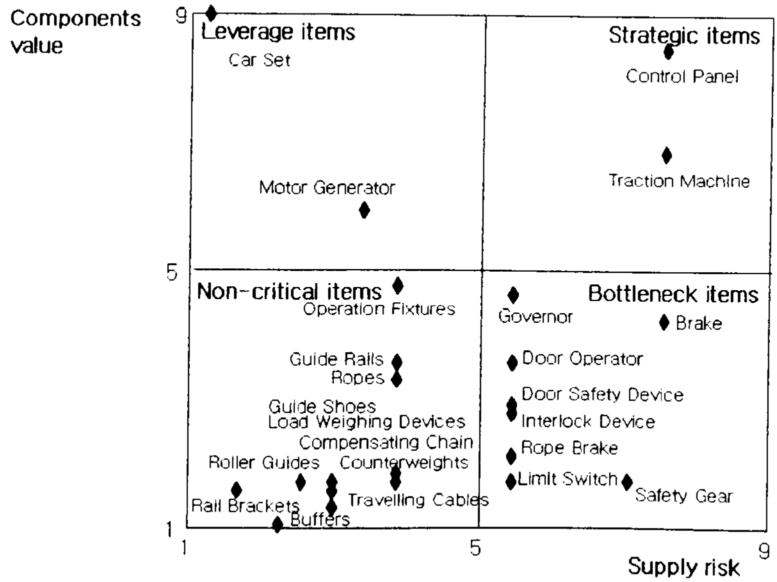
After scoring 'component value', the 'supply risk' is scored by the evaluators using the supply risk scoring model in Figure 6.1, giving the results in Table 6.2. For example, the mean score of supply risk of the *control panel* in Company-B is $\sqrt[4]{(7+9+7+7)}=7.5$ using Equation (3-2).

Table 6.2 Summary of supply risk scores of components in Company-B and Company-C

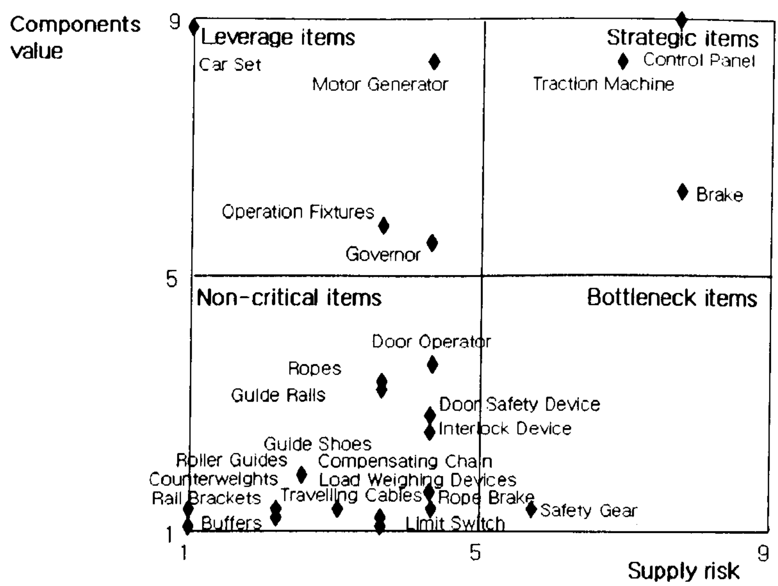
Component	Company-B					Company-C
	Evaluator-1 score	Evaluator-2 score	Evaluator-3 score	Evaluator-4 score	Mean score	mean score
Brake	7	7	7	9	7.5	7.6
Buffers	3	1	3	3	2.3	1.0
Car Set	1	1	3	1	1.3	1.0
Compensating Chain	5	3	3	5	3.9	3.6
Control Panel	**7**	**9**	**7**	**7**	**7.5**	7.6
Counterweights	3	3	3	3	3.0	2.1
Door Operator	5	5	5	7	5.4	4.2
Door Safety Device	5	5	5	7	5.4	4.2
Governor	5	5	5	7	5.4	4.2
Guide Rails	5	5	3	3	3.9	3.6
Guide Shoes	3	3	3	3	3.0	3.0
Interlock Device	5	5	5	7	5.4	4.2
Limit Switch	5	5	5	7	5.4	4.2
Load Weighing Devices	3	3	3	3	3.0	3.6
Motor Generator	3	3	3	5	3.4	4.2
Operation Fixtures	5	3	5	3	3.9	3.6
Rail Brackets	3	1	3	1	1.7	1.0
Roller Guides	3	1	3	5	2.6	2.1
Rope Brake	5	5	5	7	5.4	4.2
Ropes	5	5	3	3	3.9	3.6
Safety Gear	7	7	7	7	7.0	5.6
Traction Machine	7	7	7	9	7.5	6.8
Travelling Cables	5	3	3	5	3.9	2.5

9=very high; 7=high; 5=medium; 3=low; 1=very low

Finally, the components are positioned in the purchasing portfolio model using their scores for 'component value' and 'supply risk', as shown in Figure 6.4 for Company-B and Company-C. For example, the *control panel* in Company-B is placed at 8.38 on the component value scale and 7.5 on the supply risk scale in Figure 6.4.



Company-B



Company-C

Figure 6.4 Purchasing portfolio models in two elevator manufacturers

6.4 Analysis of results

Figure 6.3 shows the histogram of the component value scores. A key observation that can be made is that whilst there is quite good agreement on the ordering of the 'component value' scores, it is most notable that Company-C has produced much higher values for some of the higher-value components (from traction machine to brake in the histogram). This is then seen in Figure 6.4 displaying more components in the leverage and strategic categories.

There are also different relationships with suppliers in the two companies. In Company-B, most of the relationships with suppliers are short-term based on the lowest price as one of the main criteria of supplier selection, while Company-C has long-term relationships with some of its suppliers because quality, as well as cost, is important in Company C as shown in Table 5.17.

Figure 6.4 shows the final result; the positioning of the components within the purchasing portfolio for both companies. Company-C has a large number of components in the low value, low risk, non-critical items category, whereas Company-B has moved several of these further along the 'supply risk' dimension into the bottleneck category. Company-C has placed more components than Company-B into the high levels of 'component value'.

Company-B has a clear natural-break in its 'supply risk' values in the region of the middle value of 5. This is important because the use of this middle value as a rigid cut-off point between low and high values has no real justification, whereas a natural break in the data is an intuitively more reasoned boundary between different strategic groupings. Company-B has two components just under 5 on the 'component value' scale so there is no natural brake at 5. However, a natural break does begin to appear moving up the value scale beyond 5 towards the position of the *motor generator*. Company-C appears to have a natural break in its scores for 'supply risk' and 'component value' in the region of 5. It is also noted that the high scores for 'component value' break into two groups for both companies – high and very high.

Due to the differences noted above, differences exist in the implied purchasing strategies. Both companies have a large cluster of non-critical items to be managed accordingly. Company-B also has several low-value components that it deems should be managed on the basis of high 'supply risk', i.e. bottleneck items, whereas Company-C has only one such item. Company-C has classified more components as clearly high value. These findings lead to recommendations for the purchasing strategies in section 6.6.

6.5 Sensitivity analysis

There is a need to conduct an analysis of the sensitivity of the results to the weights assigned to the competitive priorities, because these weights are based on subjective expert assessments (Udo, 2000), i.e. qualitative assessments are being converted to precise, quantitative scores. Figure 6.5 shows the 'gradient sensitivity analysis' for the quality criterion for Company-B. It shows how the 'component value' changes for each of the components as the weight of quality is adjusted, with the value used in the purchasing portfolio model above being highlighted by a vertical bar. As the weight of quality is changed the weights of the other criteria are adjusted proportionately, so that the sum of the weights remains equal to one. It can be seen that varying the weight of quality causes the ranking of the components to change and it would alter their position in the purchasing portfolio matrix.

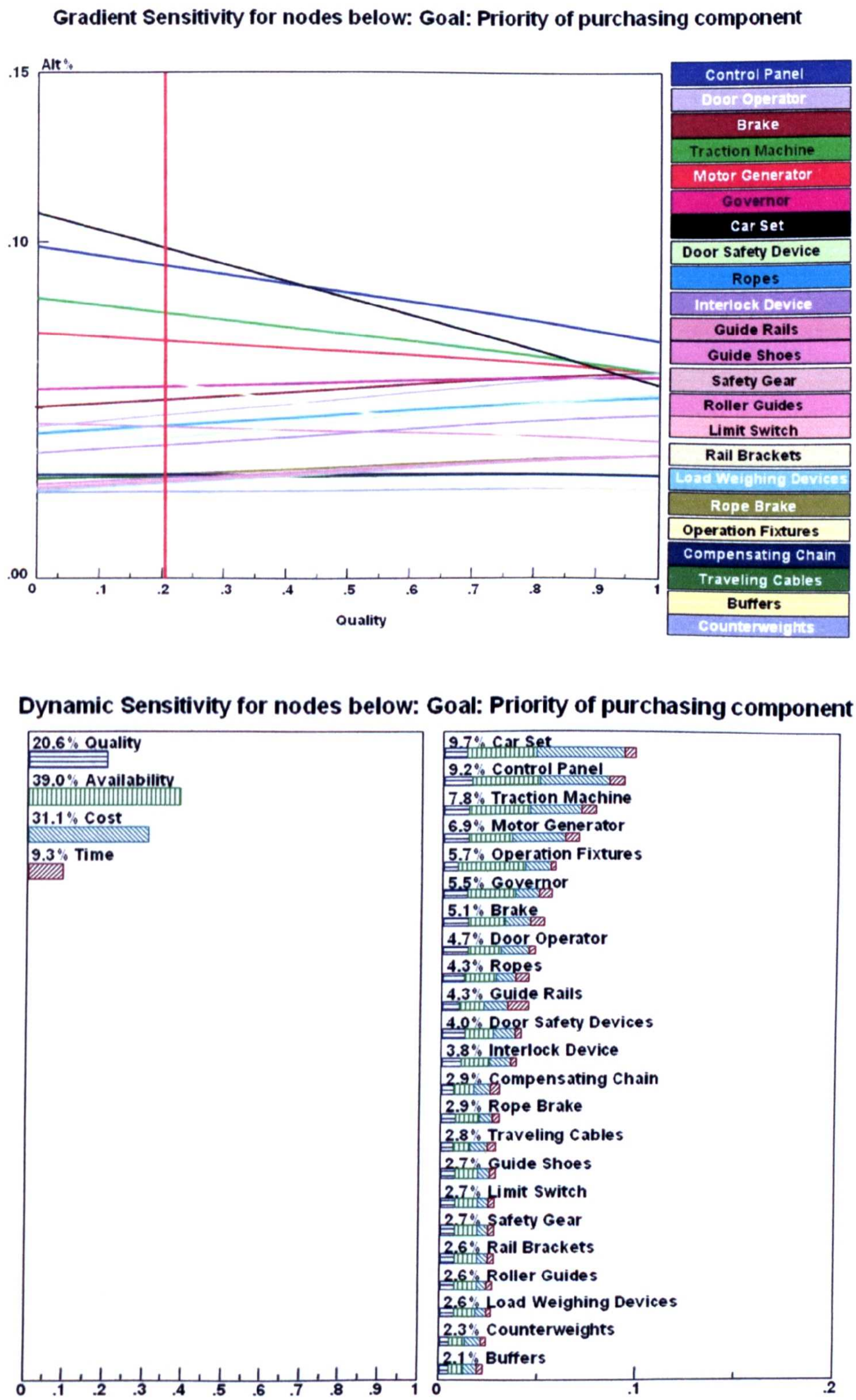


Figure 6.5 Sensitivity analysis in Company-B

As the 'component value' weights change, the important change is when a component moves between the low-value and high-value categories, either up or down. This means moving from the 'leverage' or 'strategic' categories to the 'non-critical' or 'bottleneck' categories, or vice-versa. This would cause a major change in the procurement strategy, whereas simply repositioning components within a category is not significant. So, the sensitivity analysis used here identifies how much a criterion weight must be increased or decreased before a component moves between low and high 'component value'. Note, as a criterion weight is varied, not only are the other criterion weights adjusted to keep the sum equal to 1, the component values must be re-normalised using equations 6-1 and 6-2. As discussed previously, the middle value 5 provides a boundary between low and high 'component value', so the sensitivity to a criterion weight is determined by adjusting it until the 'component value' of one of the components first crosses this boundary between low and high, in either direction.

Figures 6.6 to 6.13 show the effects of changing the weights of the criteria (quality, cost, availability and time) for Company-B and Company-C. The original weight of each criterion is marked with a vertical line labelled "Baseline". A second vertical line labelled "Group reversal" marks the first criterion weight at which one of the components shifts from its original category (in Figure 6.4) to another category as the weight is moved up and down, i.e. it shows the sensitivity to changing the weight. The components included in the figures are the original high 'component value' components for the company concerned, plus the component that is the first to switch between the low and high categories, which may be one of the original high value components.

Looking at Figures 6.6 to 6.9, the overall finding for Company-B is that the original results are not sensitive to changes in the weights of quality and time but they are sensitive to the weights of availability and cost. The weight of quality (Figure 6.6) needs to be increased from 0.21 to 0.34, an increase of 62%, before the *governor* component switches from being a bottleneck item to being a strategic item, i.e. from low value to high value. The weight of time (Figure 6.9) needs to be increased from 0.09 to 0.22 (144%) before a change is seen. However, when the weight of cost (Figure 6.7) is decreased a small amount from 0.31 to 0.29 (6%), the *operation fixtures* switches from being a non-critical item to a leverage item. The weight of availability (Figure 6.8) also gives a sensitive result with the change required being from 0.39 to 0.42 (8%).

The above results were obtained using the value 5 as the boundary between low and high. However, as mentioned earlier, the middle value 5 on the 'component value' scale of Company-B is not the natural-break, see Figure 6.4. The natural-break is the middle point between the *operation fixtures* and the *motor generator*, which is calculated as 5.4. The sensitivity analysis shows that the gap in the weights of all criteria from 'Baseline' to 'Group reversal' is increased when this natural-brake is used for the boundary between low and high 'component value'. Now the weights of quality and time need to be increased from 0.21 to 0.44 (110%) and from 0.09 to 0.27 (200%) respectively, for the *governor* to change from being a bottleneck item to being a strategic item. Whilst the weights of cost and availability need to be changed from 0.31 to 0.24 (23%) and from 0.39 to 0.48 (23%) respectively, for the *operation fixtures* to become a leverage item. So, using the natural-brake between high and low 'component value' results in fairly low sensitivity.

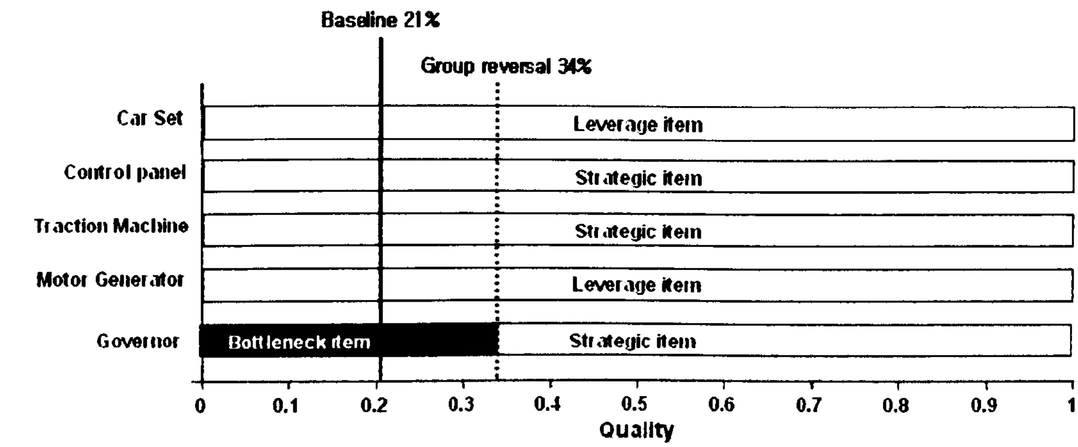


Figure 6.6 Sensitivity analysis in changing weight of quality in Company-B

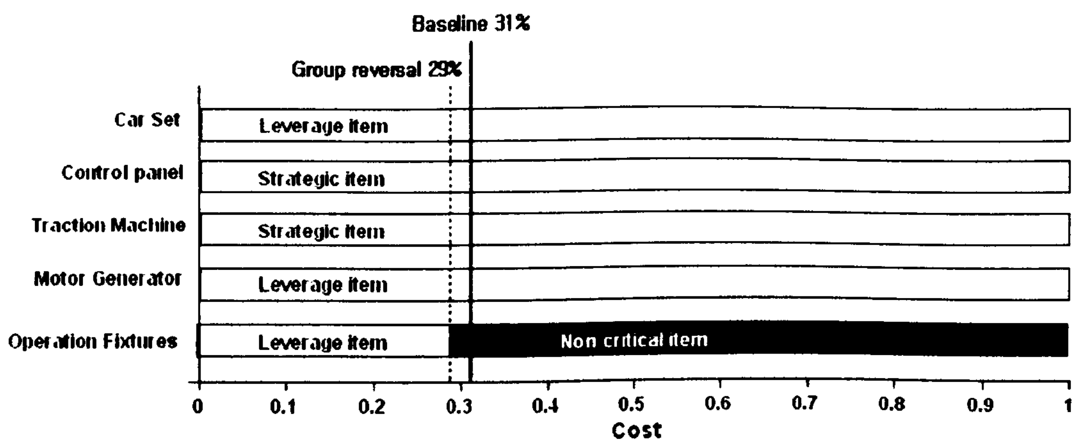


Figure 6.7 Sensitivity analysis in changing weight of cost in Company-B

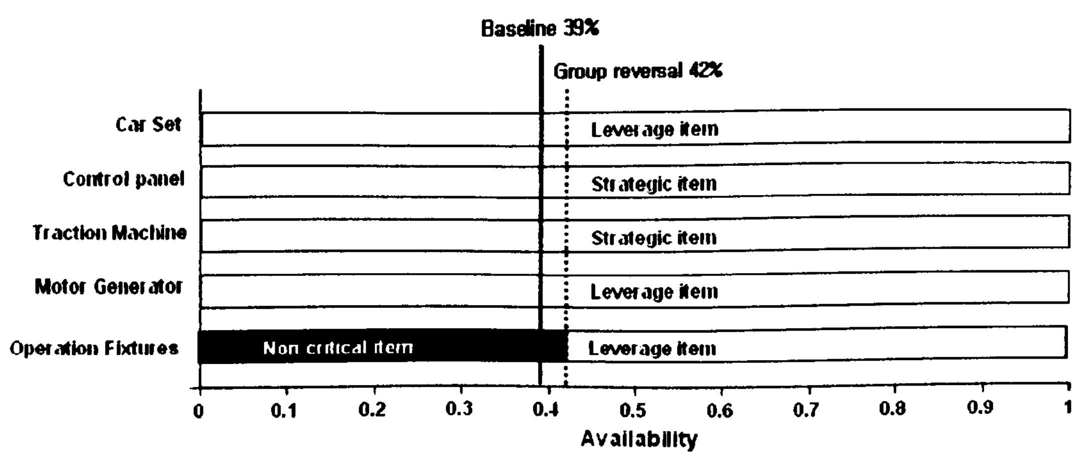


Figure 6.8 Sensitivity analysis in changing weight of availability in Company-B

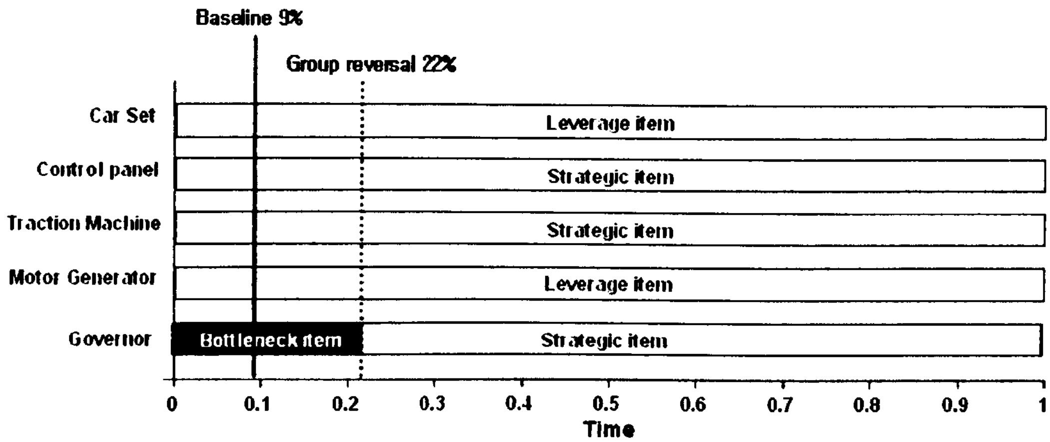


Figure 6.9 Sensitivity analysis in changing weight of time in Company-B

Figures 6.10 to 6.13 show the effects of changing the criterion weights for Company-C and the component values show much less sensitivity for Company-C than for Company-B. Cost and availability again show the greatest sensitivities, but the changes required to change the classifications are from 0.26 to 0.37 and 0.24 to 0.37, i.e. 42% and 55%, respectively. These are relatively large changes, so the sensitivity is not high, indicating an intrinsic robustness of the results for Company-C.

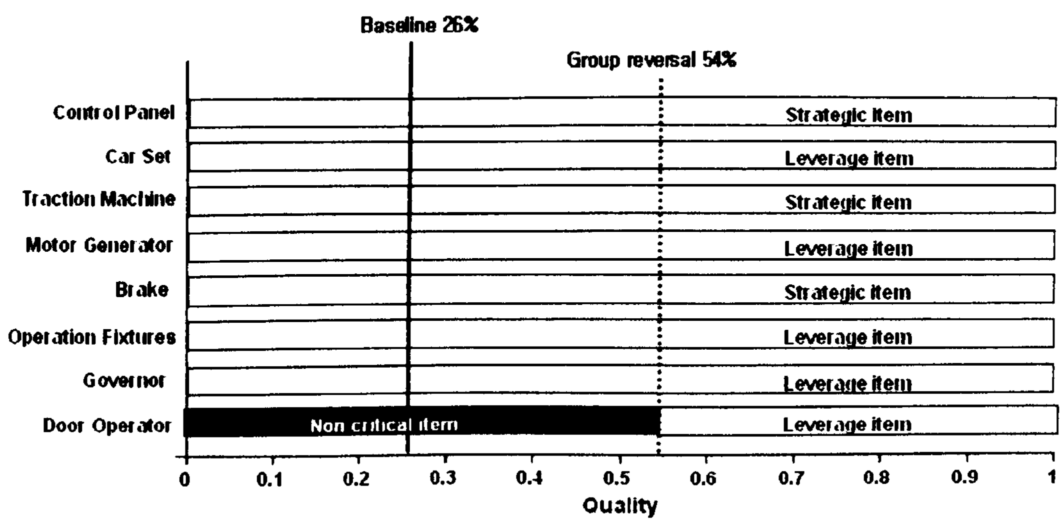


Figure 6.10 Sensitivity analysis in changing weight of quality in Company-C

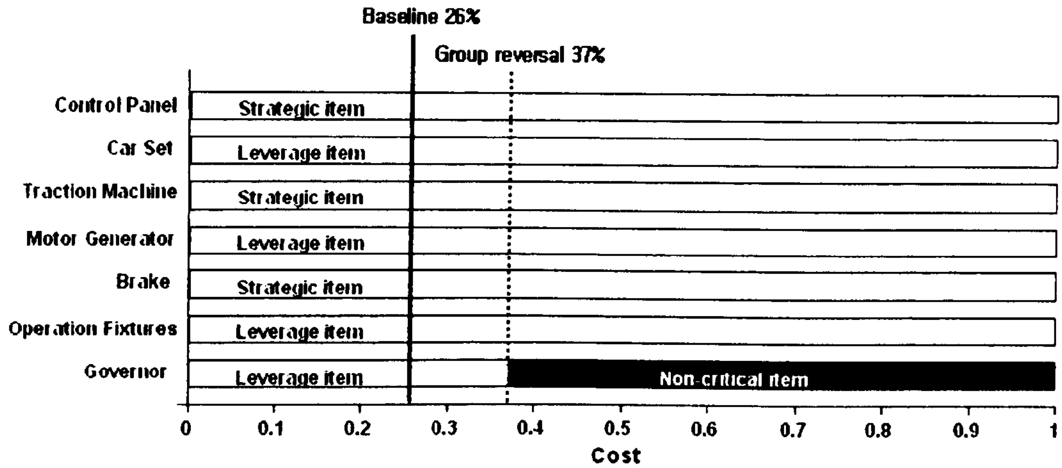


Figure 6.11 Sensitivity analysis in changing weight of cost in Company-C

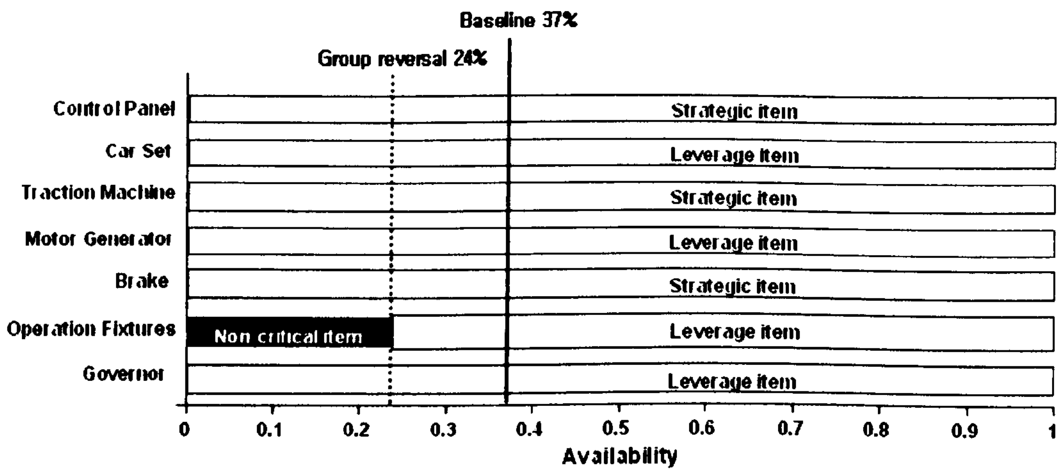


Figure 6.12 Sensitivity analysis in changing weight of availability in Company-C

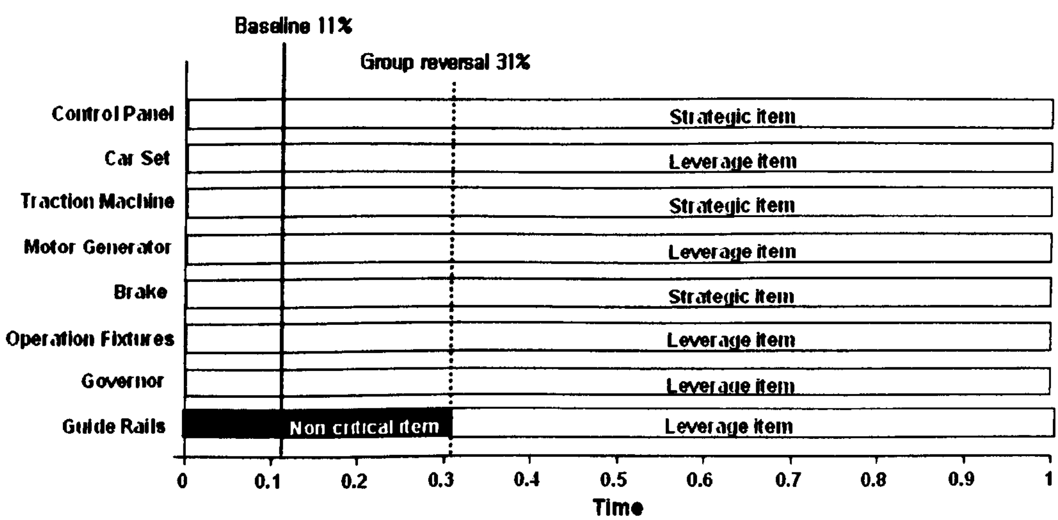


Figure 6.13 Sensitivity analysis in changing weight of time in Company-C

6.6 Recommendations to companies

With so many components in the high 'supply risk' category, Company-B should focus on reducing this risk. For its large number of bottleneck items, it should develop supplier control, use safety stocks and backup plans and seek alternative suppliers. For the strategic items it should ensure close relationships and frequent information exchange with its suppliers, involving them in product and supply chain development. For its large number of non-critical items it can continue with its underlying strategy of competing on price discussed above. This can be done through efficient, low-cost transactions, product standardisation and optimised inventory management. As Company-B has few components in the high component value category, it should consider more carefully which components have high impact on achieving the company's competitive strategies in case some important impacts are being underestimated.

As Company-C has a very large concentration of components in the non-critical category, it has the opportunity to pursue lower costs. It has been identified that Company-C attaches equally high weight to cost and quality in its competitive priorities. However, what the purchasing portfolio matrix is showing is that Company-C has a number of very high value components that need to be managed for quality and a large number of non-critical components that need to be managed for cost. This is what the equal importance of cost and quality mean, rather than every component should be managed on the basis of high quality and cost. So whilst Company-C is focused on close relationships with its suppliers to achieve high quality, it should not ignore the opportunity to reduce the cost of its many non-critical items by exploiting market-based supply for these components, whilst maintaining high quality through partnership for the other high value components. Generally, for its non-critical items Company-C should aim to reduce transaction costs through efficient processing, product standardisation and the optimisation of order volumes and inventory levels, whilst the number of suppliers could be reduced through category management. Having seen Company-B rate far more components as high 'supply risk', Company-C should consider whether it is being complacent in assessing its own risk as being lower or reassure itself that its own risk is indeed lower.

6.7 Conclusion

The case for aligning purchasing strategy with business strategy has been argued. Purchasing portfolio models have received great attention in both the academic and business fields recently and the evidence suggests that they are effective tools for developing differentiated purchasing strategies that are aligned with business strategy. However, their application still has some limitations, so this chapter has presented a purchasing portfolio modelling approach to address some of these limitations.

Based on the dimensions of Kraljic's purchasing portfolio model in Chapter 2 and the factors and their measures for defining competitive priorities in Chapter 4, two dimensions, 'component value' and 'supply risk', have been provided. The positioning of purchases on the 'component value' scale has been made systematic by the application of the AHP to consolidate the qualitative measures of the competitive priorities into a single quantitative measure of a component's impact on the value of the end-product. The positioning of purchases on the 'supply risk' scale has been made simple by the use of the supply risk model which quantifies the risk based on a qualitative assessment of 'monopoly conditions' and the 'size of the supplier'. As justified in the thesis, measurement is direct for each purchased component in respect of 'supply risk' but relative to other components in respect of 'component value'. The use of methods based on the users' qualitative judgments rather than hard, quantitative data is of particular value to SMEs that lack the power and resource to acquire the large quantity of quantitative data required, which may in any case lack integrity.

The purchasing portfolio approach developed here has been applied to two South Korean elevator manufacturers using face-to-face interviews with their staff. This has yielded some notable differences in the positioning of their purchased components in the purchasing portfolio matrix, even though these companies have ostensibly similar situations. These differences have been analysed and related to the business strategies of the companies so that recommendations have been made for the future purchasing strategies of the companies.

Chapter 7

A Comparison of Lean & Agile Component Models for Different Products; the case of one boiler manufacturer and one elevator manufacturer

7.1 Introduction

Since Kraljic (1983) introduced a portfolio approach, purchasing portfolio models have been adopted widely in many different industries for developing and implementing purchasing strategies (Lysons and Gillingham, 2003). However, despite the importance of the purchasing portfolio approach, the literature is still deficient in some important ways. Fisher (1997) argued that products can be either functional or innovative with each requiring a distinctly different kind of supply chain strategy. A product with a predictable demand and a reliable source of supply should be managed in a different way to one with an unpredictable demand and an unreliable source of supply (Lee, 2002). Li and O'Brien (2001) presented a quantitative analysis of the relationships between product types and supply chain strategies. They endorsed the findings of Fisher. Kaipia and Holmstrom (2007) emphasised the firm should decide its supply chain planning approach (e.g. CRP, VMI, JIT, MRP, etc) on the basis of the product types and their demand characteristics. Gonzalez-Benito (2002) argued that JIT purchasing is not applicable to all purchased products. Therefore, it is important that before purchasing strategy is developed, the nature of the product and supply chain must be established and subsequently taken into consideration.

The type of manufacturing strategy used such as buy-to-order (BTO), assemble-to-order (ATO), make-to-order (MTO) and make-to-stock (MTS) is another factor affecting purchasing actives such as supplier selection (Sonmez, 2006). For example, the purchasing operations for a manufacturer producing cars in large batches may differ greatly from a ship manufacturer who has a new project for every order. The former should manage inventory by a materials requirements planning (MRP) system with a stable demand, whereas the latter should obtain materials from a vast, frequently changing, supplier base on a single transaction basis (van Weele, 2005). Cakravastia et al. (2002) and Li and O'Brien (1999) argued that different manufacturing strategies may impact on the selection of suppliers in the supply chain. Therefore, if a firm has a different manufacturing strategy, its purchasing strategy should be different.

A firm should align its purchasing strategy with its business strategy depending on how it defines its supply chain strategy to achieve a competitive advantage (Cousins, 2005). For example, if the business strategy is concentrated on providing customers with low price products, then the manufacturing and purchasing strategies must also focus on cost. Whereas, if business strategy is concentrated on high variety products, then both strategies must also focus on availability. Clearly, purchasing strategies will differ between manufacturers to be in line with business strategies (van Weele, 2005). The buyer must determine and manage the purchasing strategy on the basis of the company's business strategy and a deep understanding of its products (Watts et al., 1995; van Weele, 2005) to achieve what is termed "strategic purchasing".

7.2 Development of the lean & agile component model

Fisher (1997) classified products into two types as functional or innovative. He suggested that functional products are characterized by stable demand and long life cycles, low profit margins and low variety and they require a physically efficient process, whereas innovative products have volatile demand, short life cycles, high profit margins and high variety and they need a market responsive process. Table 7.1 illustrates the comparison of characteristics between functional and innovative product types.

Table 7.1 Characteristics for functional versus innovative product types

	Functional product	Innovative product
Demand	Predictable	Unpredictable
Product Life cycle	Long	Short
Profit margins	Low	High
Product variety	Low	High
Average stockout rate	Low	High
Process	Physically efficient	Market responsive

Source: Fisher (1997) modified.

These two product types have distinctly different demand patterns and hence require a different supply chain to address their specific characteristics (Mason-Jones et al., 2000b). Functional products are very well suited to a lean supply chain as demand is relatively predictable with forecast-driven planning, while innovative products are more suited to an agile supply chain to deal with the unpredictability of demand-driven planning (Childerhouse and Towill, 2000; Lysons and Gillingham, 2003).

The concept of lean manufacturing was derived originally from the Toyota Production system (TPS) (Womack et al., 1990). Its core concept is the elimination of waste. Womack and Jones (1996) extended this idea to a business concept called lean enterprise. There are two major tools of lean manufacturing, Just in Time (JIT) and Total Quality Management (TQM) (Adeleye and Yusuf, 2006). To use lean manufacturing, all of the components must be of the highest product quality standard (Groover, 2008). The production volumes of functional goods in a lean supply chain are stable and predictable because they are forecast-driven. So, the JIT system is appropriate in a lean strategy (Naylor et al., 1999).

Agile manufacturing was first introduced in the Iacocca Institute (1991) report entitled *21st Century Manufacturing Enterprise Strategy*. Agility as a business concept was derived from flexible manufacturing systems (FMSs) (Christopher, 2000). Agile manufacturing is closely related to a strategy associated with the idea of flexibility and time; being able to respond quickly to any given customer need (Zhang and Sharifi, 2007). In the agile supply chain, production volumes are unpredictable and volatile because they are demand-driven. The JIT system may be unsuitable in an agile strategy because it is for managing components with steady demand (Chandra and Grabis, 2004). Therefore, a firm may combine MRP for planning with a discrete orders system for execution, because MRP has a focus on product flexibility in the production process with a high level of order tracking (Plenert, 1999).

Robertson and Jones (1999) stated, "Whereas lean methods offer customers good quality products at low price by removing inventory and waste from manufacturing, agile manufacturing is a strategy for entering niche markets rapidly and being able to cater for the specific needs of ever more demanding customers on an individual basis." Therefore, cost and quality are important factors in lean manufacturing, whereas availability and time are key characteristics of agile manufacturing. Table 7.2 emphases the attributes of the lean and agile strategies.

Table 7.2 Distinguishing attributes of lean and agile strategies

	Lean strategy	**Agile strategy**
Products type	Functional product	Innovative product
Marketplace demand	Predictable	Unpredictable
Key characteristics	Quality and cost	Availability and time
Procurement	Kanban (JIT)	Discrete orders (MRP)

However, Selldin and Olhager (2007) found that some firms' situations do not fit into these types of products and supply chains. They illustrate this phenomenon when firms may try to turn traditional functional products into innovative products or adopt new manufacturing concepts such as quick response and agile manufacturing with functional products. In practice, most supply chains and processes are driven by a mixture of push and pull systems (Smith, 2002). Therefore, leanness and agility can be combined with the strategic use of a strategic stock holding decoupling point in the supply chain, namely a leagile supply chain (Bruce et al., 2004). The leagile supply chain can adopt lean manufacturing in order to enable cost-effectiveness on the upstream side of the decoupling point, while simultaneously adopting agile manufacturing in order to achieve a high service level in a volatile marketplace on the downstream side (Mason-Jones et al., 2000b).

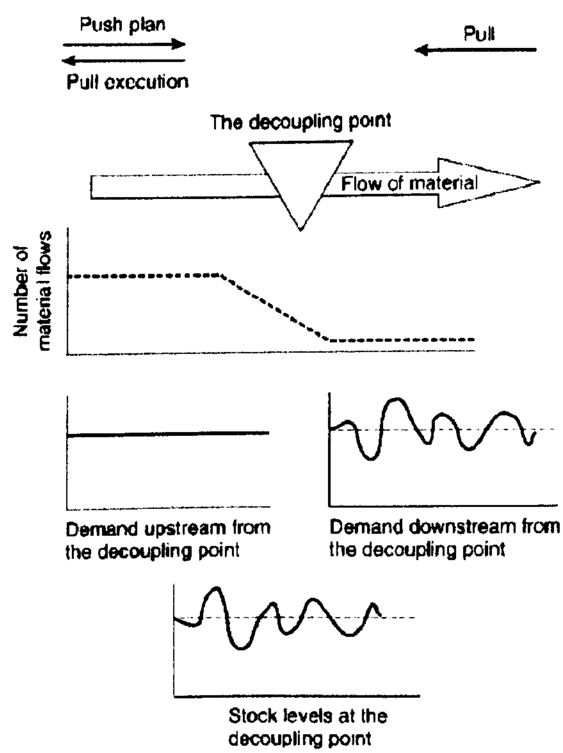


Figure 7.1 The role of the decoupling point in the supply chain (Naylor et al., 1999)

As shown in Figure 7.1, at the decoupling point is a stock of raw materials and components providing a buffer that absorbs downstream demand, providing a smother demand pattern for the upstream processes. However, minimum reasonable inventory (MRI) buffer stocks are needed to cope with unavoidable uncertainties in the supply chain (Childerhouse et al., 2003). For this, standard common components are desirable as they can be assembled into a range of different products. The downstream side of the decoupling point in the supply chain is primarily demand driven with highly variability, while the upstream side is forecast driven with reduced variety. Therefore, the agile paradigm must be applied downstream from the decoupling point, while the lean manufacturing paradigm can be adopted in the upstream side with level scheduling and Kanban (Mason-Jones et al., 2000b; Naylor et al., 1999). The decoupling point separates the part of the supply chain where manufacturing is based on customers' orders from the part of the supply chain based on planning and level control (Hoekstra and Romme, 1992). Therefore, the position of the decoupling point defines where the strategic stocks are kept in the supply chain. Figure 7.2 shows how different manufacturing strategies determine where the decoupling point is located.

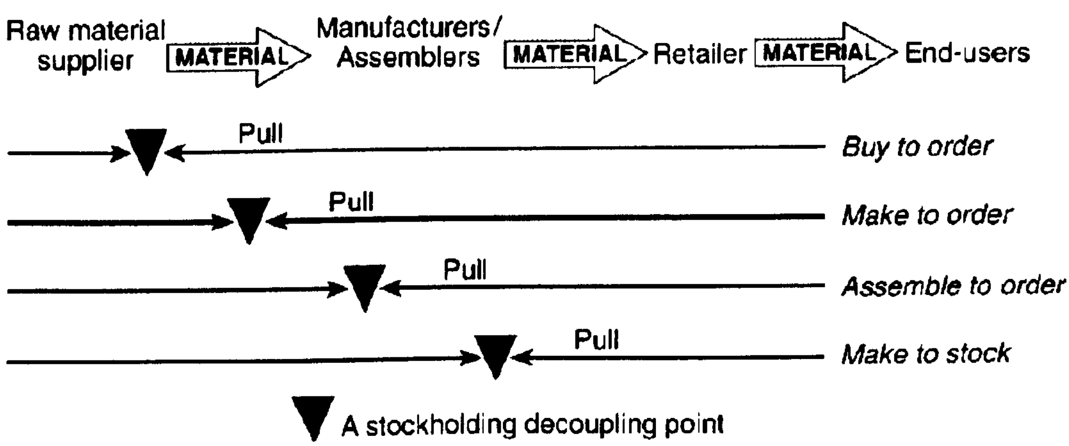


Figure 7.2 Supply chain structures and manufacturing strategies with the decoupling point (Hoekstra and Romme, 1992)

In the buy-to-order (BTO) manufacturing strategy, products are designed and assembled to meet a specific customer's needs. It is suitable when all the products manufactured are unique and yield long lead times (Naylor et al., 1999). In principle, there is no stock at all and the purchase and order of materials take place on the basis of the specific customer order (van Weele, 2005).

The make-to-order (MTO) and assemble-to-order (ATO) strategies have similar characteristics. The major difference between them is the degree of product variability. ATO has defined product families to produce while no typical product families are defined in MTO (Samandhi and Hoang, 1995). In both strategies there are two parts, push and pull. In the push part, raw materials and components are manufactured or purchased to forecasts whereas in the pull part, final products are assembled only after the receipt of a customer order. Therefore, only raw materials and components are kept in stock.

In the make-to-stock (MTS) strategy, standard products are manufactured and stocked according to forecasts. Customers will be served from an end-product inventory. Products are often manufactured to large volumes for economies of scale (Porter et al., 1999). Table 7.3 summarises the distinguishing features of the different manufacturing strategies.

Table 7.3 Distinguishing features of the manufacturing strategies

	BTO	MTO	ATO	MTS
Product	Fully customised	No typical product family customised	Defined product family	Standard
Product demand	Cannot be forecast	-	-	Can be forecast
Capacity	Cannot be planned	-	-	Can be planned
Production lead-time	Most important	Most important	Important	Unimportant to customer

Source: Samandhi and Hoang (1995) modified

Firms have different product types with different manufacturing strategies in different supply chains depending on the nature of the demand, such as whether it is forecast-driven or demand-driven. This is a reason why each firm needs its own different purchasing strategy. The role and issues facing purchasing will vary in each of the manufacturing strategies described above.

In the BTO strategy, most of the components are specific to an order because every product is unique. For this reason, it is difficult to forecast their demand in advance. When the firm selects suppliers, availability and time should be considered more important than price. Moreover, each order needs to be discussed with suppliers in detail. Purchasing for this strategy strongly resembles a project base (van Weele, 2005). However, in the MTS strategy, purchased components should be 'standards', the purchasing planning of quantities of them is also predictable and their price can be negotiated with suppliers based on expected volumes. JIT delivery can be adopted based on the production planning. In the MTO and ATO strategies, a wide variety of raw material and subassemblies are purchased, or produced and are kept as inventories, and then assembled into finished products as customers demand. For this reason, the firm needs standard common components as well as specific components for the variety of products (Hendry, 1998). Therefore, important questions to be addressed are, "Which components should be kept as inventories before final demand is known?", and "What quantities of these components should be purchased?"

In line with the Pareto Law (80/20 rule), Christopher and Towill (2001) argued that 20% of manufactured products will cover 80% of total demand. These products will be treated by lean principles whereas the slow moving 80% will require a more agile management. Barker's case study (2001) identified a similar pattern at the component level, with a customer order for a customised product, approximately 80% of components are from standard and the remaining 20% are specifically designed. Standard components are produced based on specifications provided by the supplier whereas specific components are produced according to designs, specified by the buyer (Lysons and Gillingham, 2003). It can be argued that the standard components should be purchased using lean supply while the specific components should be purchased using agile supply. Table 7.4 presents some of characteristics of standard and specific components.

Table 7.4 Characteristics of standard and specific components

	Standard component	**Specific component**
Demand	Predictable	Unpredictable
Product Life cycle	Long	Short
Product variety	Low	High
Product volume	High	Low
Purchasing policy	Quality and cost	Availability and time

The characteristics of final products affect the characteristics of their components. For example, if the variety of an end-product is low and the demand is predictable, the variety of its components and their demand are also low and predictable. Moreover, these items need their purchasing strategy to be aligned with the business strategy. For example, if a firm uses the MTO strategy, it must focus on the common standard components that are purchased in the upstream side of the supply chain to reduce the cost of the product, while simultaneously focusing on the specific components to enhance the availability of the product. This has important implications when considering the development of purchasing strategy.

In this chapter, the four competitive priorities used previously are applied in order to analyse components' leanness and agility, as shown in Table 7.5. Leanness refers to a component's impact on quality and cost in the end-product, whereas agility reflects the impact on availability and time, with respect to the final product. After calculating the purchased components' scores using the AHP, the components are now classified into four groups as lean, agile, hybrid and non-strategic items in the 'lean & agile component model' as shown in Figure 7.3. The calculations are considered in detail in Section 7.5.

Table 7.5 Two dimensions of the lean & agile component model

Factors influencing leanness	Factors influencing agility
Quality factors 1. Component durability 2. Component reliability 3. Component innovation	Availability factors 1. Volume flexibility 2. Modification flexibility 3. Technological capability
Cost factors 1. Purchasing cost 2. Inventory cost 3. Quality cost	Time factors 1. Delivery speed 2. Delivery reliability 3. Development speed

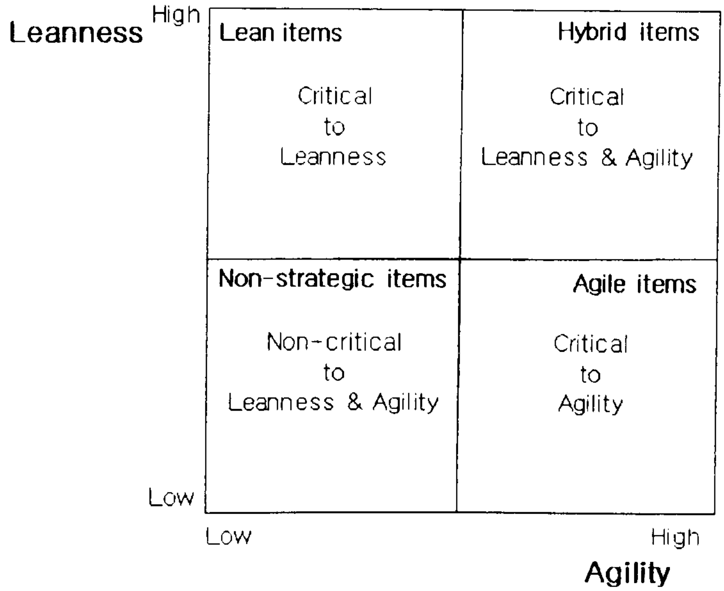


Figure 7.3 Lean & Agile component model

From the strategic point of view, some purchases should have a greater impact on the business strategy; the strategy for achieving competitive advantage. For example, if the firm has cost leadership as the business strategy, a high cost component will have more impact on the cost of the end-product, whereas a high variety component will be more important than others when the business strategy is concentrated on providing customers with high variety products. The components have to be managed differently according to their characteristics.

Lean items represent components with high leanness. These items have a considerable impact on the quality and cost of the final product. The firm should focus on reducing cost and improving quality in respect of these components. For this, the firm should change these items to standard components applied to various final products. They can reduce the component stock levels and production costs because of the increase in batch production sizes and the use of more efficient components (Benton and Krajewski, 1990; Berry et al., 1992; Persona et al., 2007). Moreover, standard components could be bought in large quantities by global sourcing in order to benefit from economics of scale (Jin, 2004; Smith, 2002) and to ensure better quality, providing immediate and dramatic improvements in cost and quality (Lysons and Gillingham, 2003; Monczka et al., 2002). If the demand for these items is stable and predictable, a push production system is more appropriate than a pull system. However, the firm can use JIT when the final production schedule is calculated and executed at the low level, although the forecast is calculated at the planning level by using a push system (push planning, pull execution) (Naylor et al., 1999). So, JIT rather than MRP should be more suitable in the procurement of these items. The re-order point stock control method can be a useful method for managing globally sourced components (Chandra and Grabis, 2004).

Agile items represent components with high agility. These items have a great impact on the availability and time of the end-product. The firm should consider these items for increasing availability and shortening time. Some items could be purchased from local suppliers for high flexibility, if the components are changed or modified often. Close relationships with local suppliers enhance the ability of a firm to make wide changes in its final product (Patti, 2006). For example, Zara and Benetton achieved high levels of availability in their final products by working closely with local suppliers (Christopher et al., 2004). Moreover, local suppliers can significantly reduce the delivery time of components. According to Monczka et al. (2002), firms using only local suppliers performed better in on-time delivery and lead times than other firms. Small suppliers are also good sources for these items because they usually pay more attention to buyer's requirements and the response to requests for special assistance from the buyer can be more rapid than with a large firm (Lysons and Gillingham, 2003). Discrete orders should be used in the MRP for procurement of these items.

Hybrid items represent components with high leanness and agility. These items are critical to achieving effective agility. However, they are also critical to achieving the order qualifiers, i.e. quality and cost. This means that as we develop availability and time factors (the order winners) in respect of these components, it is essential that this is done with regard for quality and cost (the order qualifiers) also, as these components have a high impact on quality and cost. This contrasts with components that are 'pure' agile items that do not have such a high impact on quality and cost, and therefore have less constraint in improving availability and time.

Non-strategic items represent components with low impact on leanness and agility, i.e. little impact on the competitive advantage of the end-product. The firm should leave them with simple loose control, although many items fall into this category. The firm could control these items as mainly common components. According to Hiller (2002), the use of the common item as backup, when the specific item stocks out, is convenient even if its purchasing cost is up to two or three times more expensive. Some of these items could be controlled using simple systems such as the two-bin stock control system.

7.3 Case studies

To apply the 'lean & agile component model', an electric water boiler manufacturer and the electric elevator manufacturer, Company-D from Chapter 4, were selected.

The electric boiler is an example of a functional product according to Fisher's classification whereas the electric elevator satisfies the innovative class, as summarised in Table 7.6. This choice of case studies allows comparison of the purchasing strategies produced for products in the two different classes. For the electric elevator, Company-D was selected because it shows more typical innovative product characteristics than the others, i.e. it requires a more agile supply chain (See Table 5.1).

In South Korea, the domestic electric water boiler is associated with off-peak night time electricity. It generally heats the water during the night, when economy off-peak tariffs are available, and releases the heated water during the day. So, the electric boiler firm offers a moderate boiler range awarded with the Korea Electric Power Corporation (KEPCO) standards. The size of electric boiler depends on the capacity requirement for the application. A characteristic of an electric boiler is industry standard sizes that are suitable for any application. For this reason, competition in the electric boiler market is very much on price rather than strategic positioning.

By contrast, an elevator is designed for a specific building, taking into account such factors as the height of the building, the number of users on each floor, and the expected usage periods. The numbers of components varies with the number of stories and the complexity of the design of the elevator. A job begins with a list of the customer's functional requirements such as speed and capacity, desired style options and a set of blueprints describing the dimensions of the building. An appropriate set of elevator components is specified and ordered from the component suppliers for subsequent assembly and installation in the recipient building. This is a high-variety, low-volume market in which competition is very high. The differences in the situations of the electric boiler and elevator manufacturers are summarised in Table 7.6.

Table 7.6 The electric boiler and elevator product manufacturers

	Electric Boiler Company	**Electric Elevator Company-D**
Demand	Predictable	Unpredictable
Product Life cycle	More than 2 years	1 year to 2 years
Profit margins	10% to 20%	20% to 50%
Product variety	10-50 variants	More than 100 variants
Average stockout rate	2% to 10%	10% to 40%
Order winner	Cost	Availability
Level of customisation	Standardisation	Tailored customisation
Manufacturing system	MTS	MTO/BTO
Supply chain	Lean	Agile

The evaluators (staff) from the electric boiler manufacture decided upon 13 components of the electric boiler product for the study presented here, as shown in Table 7.7, according to the same logic presented in Section 5.2. For the elevator manufacturer, see Table 5.3.

Table 7.7 Components of the electric boiler

Components	
1. Diffuser	8. Magnesium Bar
2. Electric Control Box	9. Rubber Packing
3. External Steel Sheet	10. Sensor
4. Floating Valve	11. Socket
5. Heater	12. Thermometer
6. Internal Steel Sheet	13. Thermostat
7. Lagging	

7.4 Analysis of the lean & agile value of components using the AHP

As explained earlier in Chapter 3, the data for the AHP was gathered by questioning three of the electric boiler manufacturer's staff who came from the purchasing, the manufacturing operations and engineering, and the accounting departments. For the elevator manufacturer, Company-D, the AHP data from Chapter 5 is re-used.

The AHP procedures used before are applied to the electric boiler company. Table 7.8 shows the pair-wise comparison matrices for the competitive priorities produced by Evaluator-1. The geometric mean of the pair-wise comparison matrices of all the evaluators are shown in Table 7.9.

Table 7.8 Pair-wise comparison matrices of the competitive priorities by Evaluator-1 in the electric boiler manufacturer

Goal	Quality	Cost	Availability	Time
Quality	1	2	4	4
Cost	1/2	1	4	4
Availability	1/4	1/4	1	2
Time	1/4	1/4	1/2	1
				Consistency Ratio C.R.=0.05

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	3
Component reliability	1/2	1	2
Component innovation	1/3	1/2	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	4	5
Inventory cost	1/4	1	1
Quality cost	1/5	1	1
			C.R.=0.01

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	3	3
Modification flexibility	1/3	1	1
Technological capability	1/3	1	1
			C.R.=0.00

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/3	2
Delivery reliability	3	1	5
Development speed	1/2	1/5	1
			C.R.=0.00

Table 7.9 Geometric mean of pair-wise comparison matrices of the competitive priorities for all evaluators for the electric boiler manufacturer

Goal	Quality	Cost	Availability	Time	Priority weight
Quality	1	1.3	3.9	3.3	0.42
Cost	0.8	1	1	2.9	0.35
Availability	0.3	0.3	3.3	1.3	0.12
Time	0.3	0.3	0.8	1	0.11
					C.R.=0.01
Quality	**Component durability**	**Component reliability**	**Component innovation**		**Priority weight**
Component durability	1	1.3	3.3		0.48
Component reliability	0.8	1	2.6		0.38
Component innovation	0.3	0.4	1		0.14
					C.R.=0.00
Cost	**Purchasing cost**	**Inventory cost**	**Quality cost**		**Priority weight**
Purchasing cost	1	3.3	3.1		0.61
Inventory cost	0.3	1	1.3		0.21
Quality cost	0.3	0.8	1		0.18
					C.R.=0.01
Availability	**Volume flexibility**	**Modification flexibility**	**Technological capability**		**Priority weight**
Volume flexibility	1	2.6	2.6		0.57
Modification flexibility	0.4	1	1.3		0.23
Technological capability	0.4	0.8	1		0.20
					C.R.=0.01
Time	**Delivery speed**	**Delivery reliability**	**Development speed**		**Priority weight**
Delivery speed	1	0.4	2.3		0.29
Delivery reliability	2.3	1	3.6		0.57
Development speed	0.4	0.3	1		0.14
					C.R.=0.02

The priority vectors in Table 7.9 are used to produce overall or global weights for the sub-criteria as given in Table 7.10. The corresponding criterion and sub-criterion weights are multiplied together to give a global weight for each sub-criterion, so that the importance or weight of a sub-criterion is measured by its importance to its parent criterion weighted by the importance of the parent criterion to the business strategy.

Table 7.10 Combined criteria and sub-criteria weights in the electric boiler manufacturer

Strategic priority	Local weight	Strategic priority measures	Local weight	Global weight
Quality	0.42	Component durability	0.48	0.20
		Component reliability	0.38	0.16
		Component innovation	0.14	0.06
Cost	0.35	Purchasing cost	0.61	0.21
		Inventory cost	0.22	0.08
		Quality cost	0.17	0.06
Availability	0.12	Volume flexibility	0.57	0.07
		Modification flexibility	0.23	0.03
		Technological capability	0.20	0.02
Time	0.11	Delivery speed	0.29	0.03
		Delivery reliability	0.57	0.06
		Development speed	0.14	0.02
Total	1.00	Total		1.00

In the second stage, evaluators were requested to use absolute measurement to rate the strength of the impact of the individual electric boiler components on the sub-criteria using the five-point scale (VH=very high; H=high; M=medium; L=low; VL=very low); see Table 7.11 for examples.

Table 7.11 Example absolute ratings given by Evaluator-1 to some of the components in the electric boiler

	Component Rating	Evaluator-1			
Strategic priority	Strategic priority measures	Internal Steel Sheet	Lagging	Socket	Rubber Packing
Quality	Component durability	H	M	M	M
	Component reliability	H	H	M	L
	Component innovation	H	L	L	VL
Cost	Purchasing cost	VH	M	M	VL
	Inventory cost	H	M	L	VL
	Quality cost	L	VL	VL	VL
Availability	Volume flexibility	H	H	L	L
	Modification flexibility	M	H	L	VL
	Technological capability	H	L	M	L
Time	Delivery speed	H	M	M	L
	Delivery reliability	H	M	H	L
	Development speed	VL	L	L	VL

VH=very high; H=high; M=medium; L=low; VL=very low

For each component, the results obtained with the five-point rating scale were multiplied by the weights of the sub-criteria and summed, as shown in Table 7.12 for the *Internal street sheet* component in the electric boiler. The total score for each component is normalized by dividing it by the sum of the total scores across all the components, so that the sum of the normalized scores is 1. The lean and agile scores are normalised using Equation 7-1.

$$C_i = \frac{s_i}{s} \times w \qquad (7\text{-}1)$$

where:

C_i = normalized lean (agile) score of component i;

s_i = sum of sub-criterion scores within criteria of quality and cost (availability and time) for component i;

s = sum of s_i across all components;

w = sum of global weights of sub-criterion within criteria of quality and cost (availability and time).

Equation 7.1 is similar to Equation 5-1. The normalized, lean, agile and total scores for each component from each evaluator are then combined using the geometric mean to give the results in the final three columns of Table 7.13 for the electric boiler and Table 7.14 for the elevator.

Table 7.12 Calculation of overall score for the *internal steel sheet* component in the electric boiler by Evaluator-1

Strategic priority measures	Global weight (from Table 7.10)	*Internal Steel Sheet* Scoring: Rate	Rating weight (from Table 5.9)	Global weight x Rating weight
Quality				
Component durability	0.20	H	0.26	0.052
Component reliability	0.16	H	0.26	0.042
Component innovation	0.06	H	0.26	0.016
Cost				
Purchasing cost	0.21	VH	0.51	0.107
Inventory cost	0.08	H	0.26	0.021
Quality cost	0.06	L	0.06	0.004
Availability				
Volume flexibility	0.07	H	0.26	0.018
Modification flexibility	0.03	M	0.13	0.004
Technological capability	0.02	H	0.26	0.005
Time				
Delivery speed	0.03	H	0.26	0.008
Delivery reliability	0.06	H	0.26	0.016
Development speed	0.02	VL	0.04	0.001
Total score				**0.292**
Normalized total score = Total score / Sum of total score across all components				**0.152**
Normalized lean score = (Score of quality and cost / Sum of quality and cost scores across all components) X Sum of quality and cost global weights				**0.122**
Normalized agile score = (Score of availability and time / Sum of availability and time score across all components) X Sum of availability and time global weights				**0.030**

Table 7.13 Summary of normalized scores of lean, agile and total of all components in the electric boiler manufacturer

Electric Boiler Component	Evaluator-1			Evaluator-2			Evaluator-3			Mean score		
	Lean	Agile	Total	Lean	Agile	Total	Lean	Agile	Total	Lean	Agile	Total
Diffuser	0.041	0.013	0.054	0.039	0.017	0.056	0.056	0.019	0.075	0.045	0.016	0.061
Electric Control Box	0.117	0.031	0.148	0.117	0.029	0.146	0.105	0.026	0.131	0.113	0.029	0.141
External Steel Sheet	0.096	0.028	0.124	0.089	0.018	0.107	0.083	0.025	0.108	0.089	0.023	0.112
Floating Valve	0.019	0.006	0.025	0.027	0.007	0.034	0.024	0.011	0.035	0.023	0.008	0.031
Heater	0.086	0.027	0.113	0.080	0.022	0.102	0.068	0.020	0.088	0.078	0.023	0.100
Internal Steel Sheet	0.122	0.030	0.152	0.131	0.024	0.155	0.106	0.025	0.131	0.119	0.026	0.145
Lagging	0.055	0.024	0.079	0.047	0.024	0.071	0.060	0.016	0.076	0.054	0.021	0.075
Magnesium Bar	0.056	0.017	0.073	0.042	0.021	0.063	0.060	0.021	0.081	0.052	0.020	0.072
Rubber Packing	0.025	0.008	0.033	0.024	0.009	0.033	0.025	0.013	0.038	0.025	0.010	0.034
Sensor	0.050	0.013	0.063	0.051	0.012	0.063	0.056	0.011	0.067	0.052	0.012	0.064
Socket	0.041	0.017	0.058	0.042	0.022	0.064	0.060	0.022	0.082	0.047	0.020	0.067
Thermometer	0.023	0.008	0.031	0.040	0.012	0.052	0.035	0.011	0.046	0.032	0.010	0.042
Thermostat	0.037	0.010	0.047	0.041	0.011	0.052	0.037	0.011	0.048	0.038	0.011	0.049
Total	**0.769**	**0.231**	**1.000**	**0.769**	**0.231**	**1.000**	**0.769**	**0.231**	**1.000**	**0.769**	**0.231**	**1.000**

Table 7.14 Summary of normalized scores of lean, agile and total of all components in the elevator manufacturer (Company-D)

Elevator component	Evaluator-1			Evaluator-2			Evaluator-3			Evaluator-4			Evaluator-5			Mean score		
	Lean	Agile	Total	Lean	Agile	Total	Lean	Agile	Total	Lean	Agile	Total	Lean	Agile	Total	Lean	Agile	Total
Brake	0.033	0.030	0.063	0.024	0.026	0.050	0.032	0.031	0.063	0.024	0.032	0.056	0.035	0.017	0.052	0.029	0.028	0.057
Buffers	0.014	0.008	0.022	0.019	0.015	0.034	0.015	0.009	0.024	0.012	0.010	0.022	0.011	0.011	0.022	0.013	0.011	0.024
Car Set	0.046	0.037	0.083	0.039	0.039	0.078	0.047	0.047	0.094	0.047	0.041	0.088	0.052	0.049	0.101	0.045	0.043	0.088
Compensating Chain	0.015	0.011	0.026	0.019	0.015	0.034	0.016	0.011	0.027	0.018	0.013	0.031	0.017	0.014	0.031	0.017	0.013	0.030
Control Panel	0.039	0.043	0.082	0.029	0.046	0.075	0.053	0.045	0.098	0.033	0.043	0.076	0.037	0.046	0.083	0.039	0.045	0.084
Counterweights	0.015	0.009	0.024	0.019	0.015	0.034	0.015	0.009	0.024	0.013	0.010	0.023	0.011	0.011	0.022	0.014	0.011	0.025
Door Operator	0.025	0.022	0.047	0.019	0.026	0.045	0.026	0.022	0.048	0.023	0.023	0.046	0.027	0.022	0.049	0.023	0.023	0.046
Door Safety Devices	0.025	0.021	0.046	0.019	0.026	0.045	0.023	0.013	0.036	0.023	0.020	0.043	0.023	0.015	0.038	0.023	0.018	0.041
Governor	0.029	0.035	0.064	0.022	0.022	0.044	0.019	0.026	0.045	0.020	0.032	0.052	0.029	0.020	0.049	0.024	0.027	0.051
Guide Rails	0.026	0.019	0.045	0.022	0.019	0.041	0.026	0.018	0.044	0.019	0.020	0.039	0.029	0.022	0.051	0.023	0.019	0.042
Guide Shoes	0.013	0.012	0.025	0.019	0.015	0.034	0.014	0.013	0.027	0.018	0.013	0.031	0.015	0.015	0.030	0.016	0.013	0.029
Interlock Devices	0.024	0.012	0.036	0.019	0.019	0.038	0.015	0.019	0.034	0.019	0.014	0.033	0.021	0.015	0.036	0.020	0.016	0.036
Limit Switch	0.012	0.012	0.024	0.019	0.015	0.034	0.013	0.013	0.026	0.018	0.013	0.031	0.009	0.015	0.024	0.014	0.013	0.027
Load Weighing Devices	0.012	0.011	0.023	0.019	0.013	0.032	0.013	0.011	0.024	0.018	0.013	0.031	0.014	0.014	0.028	0.015	0.012	0.027
Motor Generator	0.035	0.043	0.078	0.029	0.026	0.055	0.037	0.045	0.082	0.031	0.033	0.064	0.037	0.041	0.078	0.034	0.038	0.072
Operation Fixtures	0.022	0.036	0.058	0.021	0.026	0.047	0.024	0.033	0.057	0.025	0.031	0.056	0.020	0.037	0.057	0.022	0.032	0.054
Rail Brackets	0.012	0.012	0.024	0.019	0.015	0.034	0.013	0.013	0.026	0.018	0.014	0.032	0.014	0.015	0.029	0.015	0.014	0.029
Roller Guides	0.012	0.012	0.024	0.019	0.015	0.034	0.013	0.013	0.026	0.018	0.013	0.031	0.014	0.015	0.029	0.015	0.013	0.028
Rope Brake	0.014	0.013	0.027	0.019	0.015	0.034	0.016	0.014	0.030	0.020	0.014	0.034	0.016	0.015	0.031	0.017	0.014	0.031
Ropes	0.025	0.022	0.047	0.022	0.015	0.037	0.024	0.026	0.050	0.020	0.023	0.043	0.027	0.017	0.044	0.023	0.020	0.043
Safety Gear	0.012	0.012	0.024	0.019	0.015	0.034	0.013	0.013	0.026	0.018	0.013	0.031	0.014	0.015	0.029	0.015	0.013	0.028
Traction Machine	0.035	0.043	0.078	0.029	0.026	0.055	0.037	0.045	0.082	0.031	0.044	0.075	0.037	0.041	0.078	0.034	0.040	0.074
Travelling Cable	0.015	0.011	0.026	0.019	0.015	0.034	0.016	0.012	0.028	0.018	0.014	0.032	0.017	0.012	0.029	0.017	0.012	0.029
Total	**0.505**	**0.494**	**1.000**	**0.505**	**0.494**	**1.000**	**0.505**	**0.494**	**1.000**	**0.505**	**0.494**	**1.000**	**0.505**	**0.494**	**1.000**	**0.505**	**0.494**	**1.000**

7.5 Application of the lean & agile component model

The standardised lean and agile scores for the components were calculated using Equation 7-2, with the results given in Figure 7.4 and 7.5. Equation 7.2 is similar to Equation 6-1, except that the meaning of y_{min}, y_{max}, Z_i and y_i are revised in the light of categorising the components into lean and agile.

$$Z_i = \frac{y_i - y_{min}}{y_{max} - y_{min}} \qquad (7\text{-}2)$$

where:

Z_i = standard lean (agile) score of the component *i*;

y_i = normalised lean (agile) score of the component *i*;

y_{min} = minimum normalised score between lean and agile across all components;

y_{max} = maximum normalised score between lean and agile across all components.

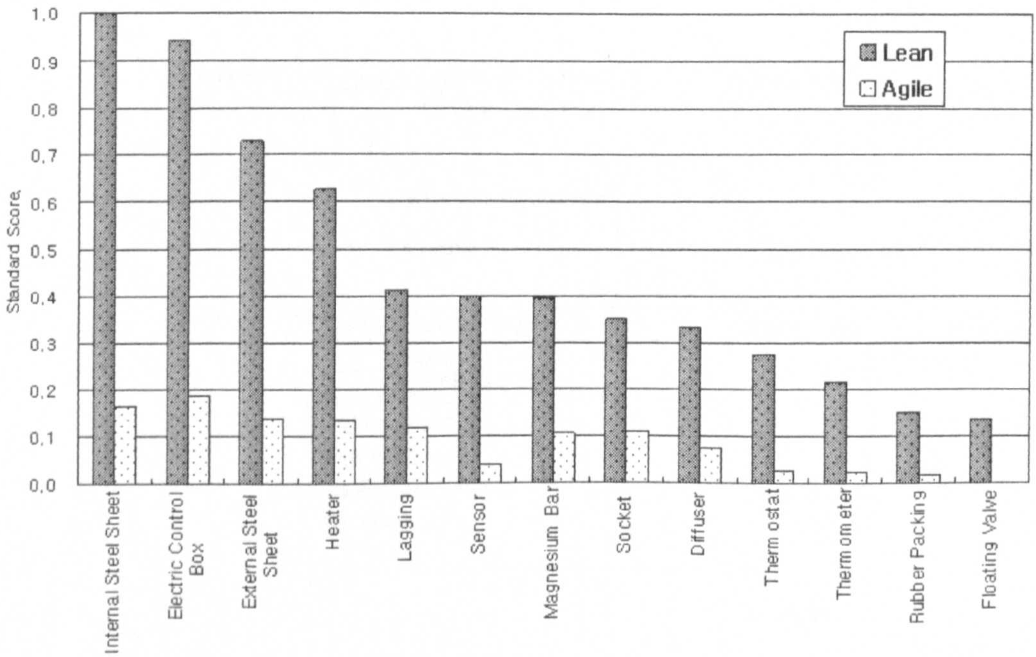


Figure 7.4 Standard lean and agile scores of components in the electric boiler

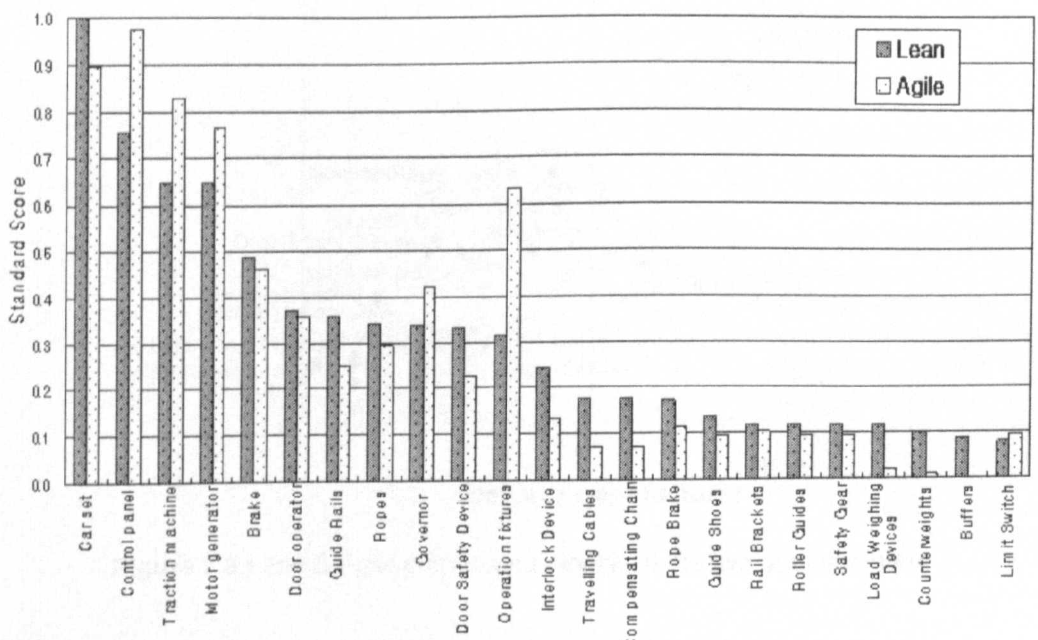
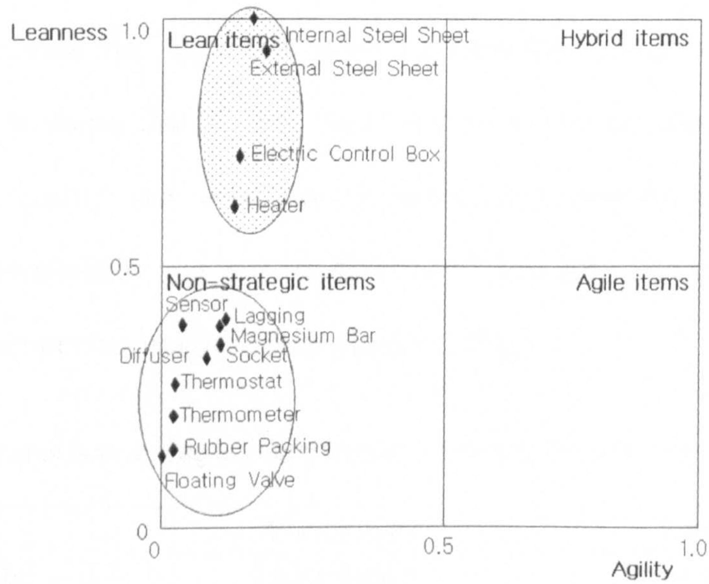
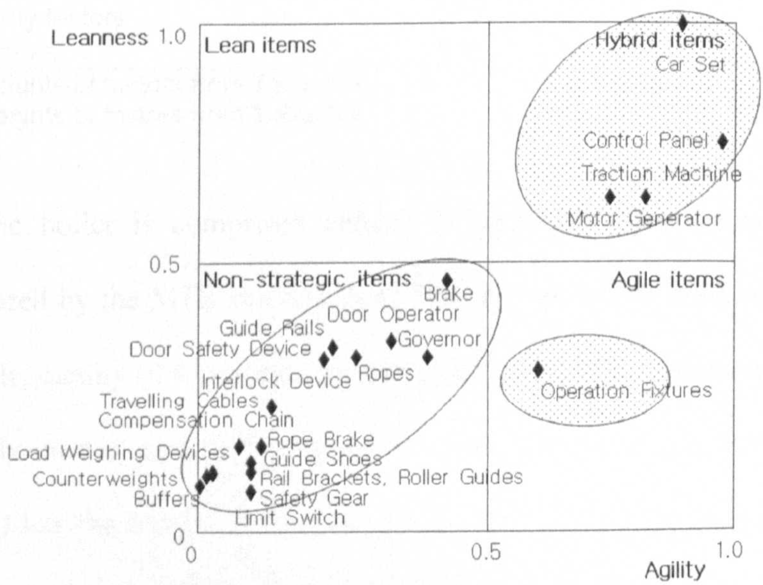


Figure 7.5 Standard lean and agile scores of components in the elevator (Company-D)

The standard scores of lean and agile in Figures 7.4 and 7.5 are used to position each component in the lean & agile component models in Figure 7.6.



Electric boiler manufacturer



Elevator manufacturer

Figure 7.6 Lean & Agile component models in the two manufacturers

7.6 Analysis of results

Table 7.15 presents the lean and agile characteristics weights for the two manufacturers. It shows that for the 'lean' electric boiler manufacturer the lean characteristics (quality and cost) are weighted more heavily than the agile characteristics (availability and time) in the ratio 77% to 23%. However, the 'agile' elevator manufacturer has weighted both equally (50%).

Table 7.15 Weights of lean and agile characteristics in the two manufacturers

Strategic priority	Electric boiler Local weight [1]	Elevator Local weight [2]
Lean characteristics	0.77	0.50
Quality factors	0.42	0.32
Cost factors	0.35	0.18
Agile characteristics	0.23	0.50
Availability factors	0.12	0.41
Time factors	0.11	0.09

1) Local weights of factors from Table 7.9
2) Local weights of factors from Table 5.8

An electric boiler is comprised entirely of standard components and is mostly manufactured by the MTS strategy. Since the electric boiler must be extremely safe and reliable, quality (0.42) is the supreme strategic priority. However, as competition is primarily on cost and profit margins are low, cost cutting is a major activity and cost (0.35) has the second highest weight in Table 7.15. Due to these two weights, the electric boiler should be classed as a functional product suited to a lean supply chain. Therefore, the electric boiler firm's purchasing strategies should focus on lean characteristics.

In contrast, an elevator is comprised of both standardised and specific components, with the majority of the elevators being customised to meet the needs of the customer. Consequently, availability (0.41) is quite naturally the highest competitive priority when the elevator is made using the MTO strategy. However, quality (0.32) has a high position in competitive priorities for safety reasons, i.e. an elevator is potentially very dangerous. Although the elevator has characteristics of an innovative product which implies using an agile supply chain, the elevator firm should focus on both lean characteristics and agile characteristics as it has weighted them equally. The case has been argued that although many firms are in an agile supply chain, they have still adopted lean manufacturing as a business practice (Bruce et al., 2004; Childerhouse and Towill, 2000; Christopher and Towill, 2001; van Hoek, 2000; Mason-Jones et al., 2000a; Naylor et al., 1999)

Figure 7.4 and Figure 7.5 show the histograms of the component standard scores of lean and agile for the electric boiler and elevator respectively. There are different patterns between the two companies. In the case of the electric boiler, the standard lean scores are much higher than the standard agile scores for all components. Moreover, the standard agile scores of all components are clearly very low. This is then seen in Figure 7.6 displaying no component of the electric boiler in the high agility categories. However, the elevator company has some components with much higher standard agile scores, and all but one of these also have higher lean scores. This is then reflected in Figure 7.6 displaying more components of the elevator in the hybrid items category.

Figure 7.6 shows the positioning of components within the 'lean & agile component models' for both companies. As mentioned above, the electric boiler has no component in the high agility categories, which is in line with the electric boiler being a functional product. Instead, it has several non-strategic items and a cluster of lean items. In contrast, the elevator has a component in the agile category as well as several in the hybrid category. The presence of several hybrid items means that although the elevator is an innovative product with agile strategy, it is also important to reduce or control cost and improve quality for some components that are also important to agility, i.e. to availability and time. This result is evidence that a firm should focus on lean manufacturing even though it produces an innovative product using an agile strategy. In the elevator manufacturer, some components should be managed in order to reduce cost and improve quality on the upstream side of the decoupling point, while others should be managed in order to increase availability and shorten time on the downstream side of the supply chain. Both companies have a very large concentration of components in the non-strategic category. This large group of non-strategic items is normally expected in the corresponding C category when using traditional ABC analysis.

As mentioned earlier in Chapter 6, it may be difficult to discriminate in general between categories in a matrix model. Looking at Figure 7.6, the electric boiler has a clear natural-break in its 'lean value' in the region of the middle value of 0.5. However, the elevator has one component (*brake*) just under the 0.5 boundary for 'lean value', but a natural-break between low and high is seen further up the lean value scale beyond 0.5 at about 0.6.

7.7 Conclusion

Purchasing strategy is crucially more important to the success of a manufacturing firm to support its competitive advantage. The literature conveys a firm needs different purchasing strategies on the basis of the product types and their demand characteristics. Moreover, purchasing strategies differ between manufacturers to be in line with their business strategies. For developing differentiated purchasing strategies, purchasing portfolio models are effective tools. Recently, purchasing portfolio models have been adopted widely in many different industries for developing and implementing purchasing strategies. However, the actual use of them has some limitations in supporting the achievement of competitive advantage. This chapter has presented the 'lean & agile component model' to address some of these limitations.

The 'lean & agile component model' has been developed based on two dimensions, 'leanness' and 'agility'. The positioning of leanness and agility scales has been achieved by the application of the AHP to analyse the four competitive priorities used previously.

The 'lean & agile component model' has been applied to two South Korean manufacturers, an electric boiler manufacturer and an elevator manufacturer. This has revealed some notable differences in the component characteristics in the 'lean & agile component models' of the two manufacturers that have different product types and business strategies. This result shows why component characteristics and their impact on competitive advantage should be considered in developing the purchasing strategy for achieving competitive advantage.

Chapter 8

Conclusions

8.1 Summary of the research

This thesis has concentrated on the area of purchasing management with the main focus being on purchasing portfolio models in manufacturing firms. There is a considerable amount of literature on strategic purchasing, written from both the theoretical and practical perspectives. Purchasing is an important, contemporary area of research and several major reports have been published during the last two decades. However, the practical model of purchasing management in manufacturing firms is still deficient. Some companies have bought their components often not in a strategic way but through clerical decisions. In addition, the purchasing decision has typically been based at the functional level without considering the business strategy.

This study started with the fundamental questions, "What is the purchasing strategy to improve the business strategy?" and "How can a firm develop and use this purchasing strategy?" With regard to the fundamental questions of this study, the objective of this research project is addressed as follows:

To design a methodology by which a manufacturing firm can develop its purchasing strategy to support its competitive business strategy.

In line with this objective, four research questions have been posed. In order to answer these questions, two research methods have been combined: a literature study and a series of explorative case studies at four electric elevator manufacturers and one electric boiler manufacturer, all in South Korea. The methods were used in a complementary way. The results of the literature study were inputs to the design of the questionnaire used in the case studies. Each research method has its own characteristics and its own strong points, which make it more appropriate for answering certain types of research questions. The main conclusions of this thesis are presented according to the research questions.

Research question 1

What are the criteria in the purchasing decision process for strategic purchasing?

The literature reviewed shows the purchasing decision process has been decomposed into several stages with different activities. However, the starting point of any purchasing decision process is to define the components' specifications. To develop the purchasing strategy, it should be necessary to identify the criteria to be used in the purchasing process for component specification. Moreover, the purchasing strategy must be consistent with manufacturing strategy and support the competitive business strategy. For this the importance of a purchase is determined by the competitive priorities of the business.

Based on the literature review, four criteria in the purchasing decision process are identified based on the competitive priorities: quality, cost, availability and time. This concurs with Krause et al.'s (2001) conclusions, which were that purchasing's competitive priorities affect significantly the buyers' final products and customer service. They are also connected to the manufacturing priorities in support of business strategy. There are three measures for each criterion, as given in Table 6.1. The result of this research question is used as an input in the empirical research.

Research question 2

What are the critical components of a product under a company's business strategy?

The literature reviewed shows that traditional ABC classification has been used in many companies as a tool for differentiating between components. However, this ABC classification being based on a single measure, namely value of consumption, is inadequate. For example, it over-emphasizes or under-emphasizes items based on value of consumption without considering their fundamental impact on the competitive priorities. For this reason, multi-criteria classification has been developed with different approaches (e.g. Cakir and Canbolat, 2007; Ernst and Cohen, 1990; Flores and Whybark, 1987; Flores et al., 1992; Gajpal et al., 1994; Guvenir and Erel, 1998; Partovi and Burton, 1993; Partovi and Anandarajan, 2002; Ramanathan, 2006; Ng, 2007). However, most researchers have focused on determining criteria and applying them to inventory management rather than purchasing management.

Applying the AHP, the four case studies showed that each company attaches different weights for the competitive priorities according to their business strategies. For example, availability is the most important strategic priority for three companies while cost is the most important strategic priority for one. In order to find the critical components for a firm's business strategy, the AHP was applied using the weighted competitive priorities. To decipher the large array of priorities, the components are sorted and placed into groups. In this thesis, they were split into three groups according to their strategic importance. When cost has a relatively low impact on competitive advantage as in two companies, the results show that using the multi-criteria in the AHP produces different results from using just the value of consumption in the ABC method. .

Criterion groups were introduced to classify components according to their criterion with the greatest impact on business strategy. The groups then lead to different purchasing strategies. The case study results show that each elevator manufacturer has a different number of components in each criterion group. It becomes clear from this study that although some companies purchase the same components as each other for their final products, these components may need different purchasing strategies according to the individual company's business strategy and the order winning and order qualifying characteristics of the end-product.

Research question 3

How can a firm develop a purchasing portfolio model for its purchasing strategy in order to support its business strategy?

The literature reviewed argues that a portfolio approach is an effective tool for strategic analysis in purchasing management. It has been seen that the general form of a purchasing portfolio model has one dimension related to the importance of a purchase and one related to the nature of the supply. The importance of a purchased component depends on the end-product and the importance of the component to this end-product, whereas the nature of the supply is concerned with supply risk assessment. If suitable dimensions could be found and used in the portfolio model, it would be easy to understand and provide practical guidelines on how to manage the purchasing of different items. Therefore, defining the dimensions has been a critical issue in the development of portfolio models (e.g. Bensaou, 1999; Kraljic, 1983; Nellore and Soderquist, 2000; Olsen and Ellram, 1997). Moreover, the literature shows that one of the common problems with dimensions is the synthesising of qualitative and quantitative measures. It would be a great help for purchasing managers if a decision making tool is provided to systematically measure the dimensions for individual purchases. This need was addressed in this thesis.

In two case studies a purchasing portfolio model was applied using the two dimensions; 'component value' and 'supply risk'. The importance dimension, 'component value', was measured on the basis of the importance of four competitive priorities; quality, cost, availability and time. The weight of each priority was determined by its contribution or impact on achieving competitive advantage in the end-product, i.e. the business strategy. It was argued that 'component value' is a relative rather than absolute measure. To combine these measures to give an overall measure for this dimension the AHP tool was used. However, the supply dimension, supply risk, relates to the performance of the suppliers and factors outside the immediate control of the buyer (although the buyer can design a purchasing strategy to mitigate this risk). The risk associated with an individual component was measured independently or directly as it was argued that 'supply risk' is an absolute rather than relative measure, i.e. a high risk item is high risk, irrespective of how risky other items are. The supply risk was assessed using two factors; size of the supplier and monopoly conditions, which are combined in the supply risk model. Based on the 'component value' and 'supply risk' dimensions, purchased components were classified into four categories in the purchasing portfolio model; strategic items, bottleneck items, leverage items and non-critical items. Each of these categories has a general form of purchasing strategy associated with it.

The case studies show different distributions of the components across the categories in the purchasing portfolio model. One company has placed more components into the high levels of 'component value'. This company also has a large number of components in the non-critical items category, whereas another company has moved several of these further along the 'supply risk' dimension into the bottleneck category. These differences are related to the relative importance of the competitive priorities and the supply risk of the components in each company, so that some components' purchasing strategies are different in order to support the different business strategies, even though these two companies have ostensibly similar situations.

Research question 4

How can a firm develop its purchasing strategy according to its product type?

There are two types of products, functional and innovative, depending on their characteristics such as demand pattern and market expectations (Fisher, 1997). A functional product requires a physically efficient supply chain whereas an innovative product needs a market-responsive supply chain. Similar approaches for matching Fisher's product types and supply chain types are found in many references, e.g. (Childerhouse et al. 2002), (Huang et al., 2002), (Lee, 2002), (Ramdas and Spekman, 2000), and (Selldin and Olhager, 2007). The literature study confirmed that these types of products require distinguishable purchasing strategies in different supply chains to address their specific characteristics and market demand.

The view of functional and innovative products was found to be associated with the lean and agile manufacturing strategies respectively, in line with the findings of Naylor et al. (1999). The literature shows that lean manufacturing is concentrated on reducing cost and improving quality whereas agile manufacturing is closely related a strategy associated with increasing availability and shortening time. However, in practice a mixture of lean manufacturing and agile manufacturing was found in many supply chains. A stock-holding decoupling point in the supply chain can be used to combine these two strategies in the leagile supply chain (Bruce et al., 2004). The location of this point is a key defining feature of the manufacturing strategy, e.g. make-to-stock (MTS), make-to-order (MTO).

On the basis of the literature study, the 'lean & agile component model' was developed to analyse the leanness (cost and quality) and agility (availability and time) of components. Then, appropriate purchasing strategies based upon the position of a component within the model were suggested.

Two case studies were presented to demonstrate the application of the 'lean & agile component model' to different product types. The result shows that each product has different component characteristics according to the product's characteristics and the business strategy. In the electric boiler, a functional product, there are four lean items while there is no component in the high agile categories. However, the elevator, an innovative product, has four hybrid items and one agile item. Therefore, the electric boiler manufacturer must focus more on leanness whereas the elevator manufacturer has to consider both leanness and agility, with agility considered to be the order winner and leanness the order qualifier. The case studies support the argument that when purchasing strategies are developed, a manufacturer must consider its components' characteristics to support its business strategy, and therefore its manufacturing strategy, for competitive advantage.

8.3 List of contributions

This thesis has made the following contributions.

i. Existing purchasing portfolio models and ABC analysis, for use in formulating purchasing strategy, have been critically appraised. Weaknesses of existing models, especially Kraljic's, have been identified and addressed in this thesis.

ii. The Analytic Hierarchy Process (AHP) has been introduced to weight the competitive priorities of a business and to assess the relative contribution of individual purchased components to achieving these priorities and therefore the overall business strategy.

iii. Based on a review of relevant literature, the factors (criteria) to be used in determining the competitive priorities and the measures (sub-criteria) to be used in assessing the contribution of purchased components to the priorities have been established.

iv. The results of applying the AHP in four elevator manufacturers to assess 'component value' were compared with conventional ABC analysis, showing improved classifications in respect of purchasing strategy, particularly when cost was not weighted as highly as the other competitive priorities.

v. Criterion groups have been introduced to classify components according to their characteristics that have the greatest impact on achieving business strategy. These groups make a high contribution to their corresponding competitive priority in the end-product, so they are related to business strategy and the order winning features of the end-product. The groups show which components should be managed most carefully to achieve a firm's competitive advantage.

vi. A purchasing portfolio modelling approach to address the weaknesses identified in existing approaches has been presented. This has used the two dimensions, 'component value' and 'supply risk', to divide the purchases into four purchasing strategy categories. It has been argued that 'component value' is a relative measure based on qualitative measurement, so the AHP is suited. In contrast, 'supply risk' is an absolute measure, so a suitable yet simple method of measuring it has been justified.

vii. Based on the application of the new purchasing portfolio modelling approach in two elevator manufacturers, these two companies actually faced different situations which resulted in differences in the purchasing strategies produced by the analysis, although they originally looked like they had the same situation, e.g. business strategy, order winners and type of supply chain etc.

viii. Sensitivity analysis allows companies to expose inconsistency between purchasing strategy and business strategy. It has been performed to identify how much a criterion weight has to be increased or decreased for a component to move between high and low on the 'component value' scale.

ix. The purchasing portfolio modelling approach has been enhanced to divide high component value into the factors impacting leanness and those impacting agility, in line with the view that products are functional or innovative and thereby suited to lean or agile supply chains, respectively.

x. The enhanced lean/agile approach has been demonstrated for an elevator manufacture and an electric boiler manufacturer, which gave examples of innovative and functional products, respectively. For the functional product (electric boiler) it was found that all of the high component value products were classed as 'lean'. However, for the innovative product (elevator) several of the components were classed as 'hybrid', having high agile and lean values. It has been argued that this highlights the key role of the leagile supply chain for innovative products. Purchasing strategies have been derived based upon the position of components in the 'lean & agile component model'.

8.4 Limitations of the study and suggestions for further research

Even though the study has contributed to the development and understanding of purchasing portfolio models, there are some limitations to the study, which raise the need for further research.

A limitation of this research is the volume and scope of five case studies. The study has been executed with a focus on SMEs in South Korea, although the research approach is still intended to be valid for all sizes of enterprises. Also, this study has focused on two product types, namely functional and innovative products. The electric boiler has characteristics of functional products that are characterized by stable demand and long life cycles, low profit margins and low variety, whereas the elevator represents innovative products that have volatile demand, short life cycles, high profit margins and high variety. Based on these arguments the electric boiler and the elevator have been selected in this research. However, further research should look at other products. In order to validate the results on a broader basis, this research should be rolled out for other products, other sizes of companies and other countries.

Another limitation of this study pertains to the application of purchasing models to a single product category. The findings of the case studies are based on one product category in each company. However, in general, all components are not used in only one product. The selection of the single-product case study naturally brings some limitations as far as the generalisation of the results of the study is concerned. Thus, further research should look at the multi-product case. Furthermore, the author has not investigated the actual effects of the purchasing portfolio model in terms of the development of purchasing strategy or opportunities to benefit from strategic purchasing. The author has not carried out any 'before' and 'after' studies at a particular company, which could have measured some of these effects. However, it should be true that all the effects of a purchasing model are not readily measurable. Future research could include an empirical study of the actual effects of the application of the purchasing portfolio model. The research should begin with the development of measures of the effects. This could be done in the form of longitudinal case studies, in which firms carry out an implementation by using the purchasing model.

An additional limitation concerns problems about discriminating between categories in the portfolio model. The results of the case studies show that some components are positioned near a demarcation line. Although two methods (middle value and natural break) have been considered to decide the distinction between 'high' and 'low' value in the dimensions in this study, there should be more research into the demarcation problem. The supply risk matrix in this study uses two dimensions, 'size of supplier' and 'number of suppliers', with values ranging from low to high. Using this matrix, a score of supply risk is obtained. Further research should also consider the supply risk scores allocated to different sets of coordinates within the matrix. For example, see Figure 8.1

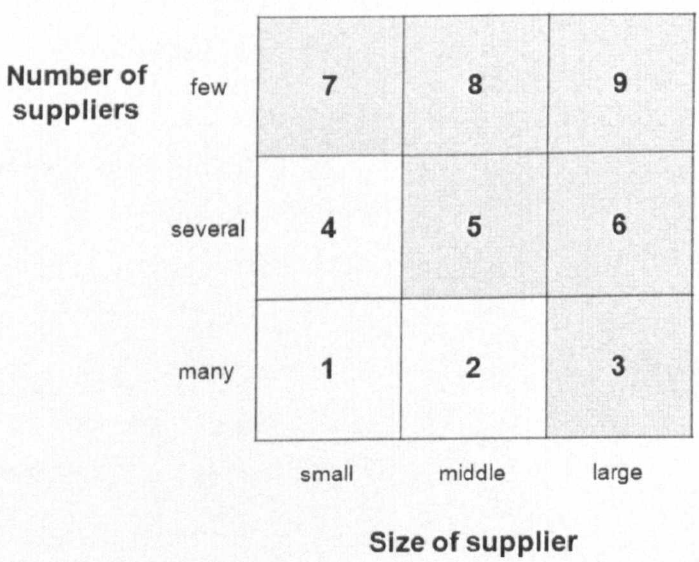


Figure 8.1 An example of different feasible values in supply risk model

The final limitation is the 'lean & agile component model'. Although this model has been developed for two types of products as functional and innovative, there is a need to combine the supply market environment as supply risk for deciding upon a company's purchasing strategy. For this, further research should consider a two-step approach as a framework for developing purchasing strategies. The first step might be to develop the 'lean & agile component model' with leanness and agility. The second step might then be to develop the 'lean & agile purchasing portfolio model' using the 'lean & agile component model' and the 'supply risk model' as two dimensions.

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Appendix 1

Component Prioritisation for Strategic Purchasing and the case study of a South Korean Elevator Manufacturer.

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Component Prioritisation for Strategic Purchasing and the case study of a South Korean Elevator Manufacturer.

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Abstract

The importance of aligning purchasing strategy with business strategy is argued using a substantial literature review. However, some purchases will have a greater impact on the strategic priorities of the business and suppliers cannot be expected to achieve optimal performance in everything they do, especially at day one. This paper presents the application of the Analytic Hierarchy Process (AHP) to prioritise the components of an electric traction elevator in the context of their importance to the business strategy of the manufacturer. This is the first step in the formulation of the manufacturer's purchasing strategy. The relative importance of the competitive elements in the form of quality, cost, availability and time are first established for the manufacturer's business strategy, along with the relative importance of the sub-criteria used to measure these elements. The components of the elevator are then assessed to see which have the greatest impact on these sub-criterion measures to establish component priorities and groupings to guide those forming the purchasing strategy. The paper includes a justification of the criteria and sub-criterion measures used, based on a literature review.

Keywords: Purchasing strategy; business strategy; supply chain management; AHP.

1 Introduction

Manufacturers use materials, components and subassemblies sourced from external suppliers so that their products and customer service are affected significantly by the performance of these suppliers in terms of quality, cost, flexibility and time [1]. The failure of purchased components is often the major source of quality problems [2], the cost of purchased components can be the largest part of the total cost of a product [3] and the availability and delivery time of purchased components can be critical factors in the commercial success of the final product [4]. The purchasing function is largely responsible for: determining the characteristics of purchased materials, components and services; selecting suppliers capable of providing the required items at the requisite levels of quality and price; managing transactions so that the goods or services are delivered in a timely manner [5]. All of these activities have the potential to be critical in supporting and enabling a particular business strategy.

Clearly and as noted by Watts et al.[2], "Since the core of purchasing's role is to support the production and operations activities with an uninterrupted flow of materials and services, the purchasing and manufacturing strategies must be consistent with each other, and they must be able to support the corporate level competitive strategy." To take this a step further, there will be prerequisites of a business strategy that must be provided through the purchasing and manufacturing strategies. For example, changes in business strategy may require the use of different types of contracts or relationships with suppliers and, if one decides to compete on cost, then the purchasing and manufacturing strategies must seek to minimize costs as a priority. Porter [6] highlighted the importance of the purchasing function and supplier management to achieving competitive success in the value chain. In summary, the purchasing function has become one of the most critical activities of a manufacturing business [7]. The buyer must determine and manage the purchasing strategy on the basis of the company's business strategy and a deep understanding of its products to achieve strategic purchasing [2][3]. Gelderman and van Weele [8] demonstrate the link between business strategy and purchasing strategy by analysing case studies.

Whilst perfection may be strived for, cost, time and other factors may constrain our ambitions. For example, the cost of quality cannot go beyond the level that the market is willing to pay and optimal performance may take years of continuous improvement. Suppliers cannot be expected to achieve optimal performance in respect of everything they do, so they must first focus on the priorities. Indeed, over-performance in low priority areas can be viewed as a waste. The purchasing function must make sure that suppliers have sufficient capabilities in the high priority areas, i.e. the basis for supplier selection and development is performance in these areas. This means that there is a need to prioritise requirements based on the needs and prerequisites of the business strategy, starting with the basic competitive elements such as quality, cost, flexibility and time.

Zheng et al [9] state that, "There are widely differing views between purchasing professionals and their senior executives about the actual and potential strategic contribution of purchasing and supply to corporate success." Clearly, this contribution will be greatest in respect of the product components that have the greatest impact on the business strategy, which in turn underlines the need for methods to prioritise components for strategic attention.

The priorities of the components depend on the priorities of the competitive elements. For example, if quality is the basis of competition and therefore the highest priority element, then the components that define the level of quality of the product are the highest priority components in the context of purchasing.

2 The Elevator Industry

This paper reports the first steps in the development of a purchasing strategy for a South Korean elevator manufacturer that has 53 employees and had a turnover of £5M in 2005. Its demand is unpredictable, there are more than 100 product variants, the product lifecycle is between one and two years and profit margins range between 20% and 50%. Its business strategy is focused on availability and the manufacturing strategy is make-to-order. In this case study, the term availability refers to the flexibility of the suppliers in respect of the order quantities they will accept, their ability to supply modified components and their ability to adopt new technologies.

The use of the Analytic Hierarchy Process (AHP) [10][11] is introduced here to prioritise components used in assembling an electric traction elevator, according to their level of importance to or impact on the strategic priorities of the business. Priority groupings can then be established in respect of the business's purchasing strategy in a way that is analogous to *ABC analysis* in inventory management where stock items are prioritised and grouped on the basis of the value of annual consumption, measured as unit cost multiplied by unit usage. For an introduction to *ABC analysis* see, for example, [12][13]. The case for using the AHP is given in Section 3 and a detailed introduction is given in later sections. The AHP is a multi-criteria decision making process that weights the relative importance of the criteria and then ranks alternative decision alternatives on the basis of these weighted criteria. In the application presented here, the multi-criteria are the strategic priorities of the business and the decision alternatives are the components of the elevator that need to be prioritised, in the context of their contribution to achieving the strategic priorities. Furthermore, the AHP can handle subjective as well as objective comparison data which makes it most suitable to this application.

An elevator is designed for a specific building, taking into account such factors as the height of the building, the number of users on each floor, and the expected usage periods. The numbers of components varies with the number of stories and the complexity of the design of the elevator. A job begins with a list of the customer's functional requirements such as speed and capacity, desired style options and a set of blueprints describing the dimensions of the building. An appropriate set of elevator components is specified and ordered from the component suppliers for subsequent assembly and installation in the recipient building. This is a high-variety, low-volume market in which competition is very high. As the cost of in-house manufacturing of components and sub-assemblies is much higher than the cost of outsourcing, elevator manufacturers focus on design, assembly, marketing and sales and most in-house component manufacturing has ceased [3]. Discussions with several elevator manufacturers revealed that they spend typically more than 70% of each sales dollar on purchased components, so they should strive to improve not only availability but also to reduce costs. The key to success in this industry is the ability to embrace both efficiency and customisation. Elevator manufacturers are representative of many other manufacturers as they are noticing the criticality of purchased components, supplier performance and purchasing strategy to competitiveness.

An elevator is a complex product with an average of 20,000 parts at the bottom level of its bill of materials (BOM) [14]. Consequently, it is not a simple matter to manage effectively and efficiently the purchasing and supply of everything that is required. A first step in formulating a purchasing strategy for an elevator manufacturer must be to prioritise or rank the components of the elevator on the basis of their impact on or contribution to the business strategy; the strategy for achieving competitive advantage. The purchasing strategy of the highest priority components must be addressed immediately as an integral part of, or prerequisite to, implementing the business strategy. Purchasing strategies are also required for the low priority components, but these are developed in the context of optimising the purchasing and supply processes with the fundamental aim of reducing costs; "Non-critical items require efficient processing, product standardisation, order volume and inventory optimalization." [8]. Whilst this optimisation in respect of the low priority components may be desirable at day one, it is not a prerequisite of the business strategy but rather a matter for continuous improvement in the near future. This is in contrast to the need to achieve the core or critical requirements of the business strategy at day one in order to start competing in the marketplace.

3 The case for using the AHP

The findings of a review of research into the future of purchasing and supply, commissioned by the Chartered Institute of Purchasing and Supply (CIPS) in the UK, were published recently [9]. It was found that purchasing is moving from being clerical to strategic, purchases that are less strategic are being automated or outsourced leaving a more strategic purchasing task to be tackled and cross-functional and cross-enterprise teams will make joint decisions on purchasing and supply. Gelderman and van Weele [8] also stress the need for teamwork when performing portfolio analysis stating, "The views of colleagues from different fields of expertise should be added to the more functional purchasing perspective." This leads to the need for methods, such as the AHP, that combine the inputs of several team members to prioritise components, i.e. to differentiate between the strategic and non-strategic purchases.

On the use of the Kraljic matrix [15] in the determination of purchasing strategy, Gelderman and van Weele [8] state, "In-depth discussions on the positions in the matrix are considered as the most important phase of the analysis. Strategic discussions provide deeper in-sights and may lead more easily to consensus-based decisions." The AHP facilitates and encourages such consensus reaching discussion as it makes the decision-making process very transparent, highlighting misconceptions and acting as a catalyst for lively debate [16].

A central role that has been developed for the purchasing function is to develop and maintain a competitive advantage in the marketplace by selecting and managing the best suppliers for the organisation [17][18]. Consequently, there has been much research into supplier selection using decision-making tools such as the AHP, e.g. [4][19][20][21]. However, this paper is not concerned with supplier selection, but rather the strategic prioritisation of the components to be purchased. Van de Water and van Peet [22] report the application of the AHP to the *make or buy* decision in manufacturing. They give a justification for using the AHP, explaining that it enables decision makers to set priorities, eliminates inconsistencies in prioritising, allows a hierarchy of decision layers to tackle complexity and explicitly takes into account the subjective nature of decision-making. These features are clearly exploited in the application presented here. More generally, van de Water and van Peet argue that practitioners need strategic frameworks that incorporate quantitative measures to assist in setting priorities, as seen here. Their introduction to the mechanics of the AHP is succinct, although they do reference complete books on the subject written by Saaty [10][23]. This paper presents a more detailed but still concise introduction to the AHP aimed at people in manufacturing who are concerned with purchasing components and sub-assemblies.

The AHP and the specific model presented here may appear too elaborate to be applied by practitioners in manufacturing industry. However, the AHP is supported by proprietary software packages that aim to offer user-friendly interfaces and general support in the application of the method, for example see [24].

4 Structuring the component prioritisation problem for the AHP

The AHP is explained in detail by Saaty and Vargas [11] and a succinct introduction with worked examples is given by Drake [16]. An introduction in the context of the elevator application is given here.

The goal is placed at Level 1 of the AHP hierarchy, as shown in Figure 1. The goal in this application is the ranking and subsequent grouping of the components according to their level of impact on the strategic priorities of the business. Level 2 of the hierarchy contains the ranking criteria or purchasing's competitive priorities, which are conceptualized as being similar to those of operations management [5]. The purchasing competitive priorities and their measures given by Krajewski and Ritzman [25] are adopted here at *Levels 2 and 3* respectively. Each of the competitive priorities can be classified as a 'market qualifier' or a 'market qualifier' depending on the market served and its supply chains [26] and, in the context of the AHP, the relevant importance of these criteria will vary with the market served and the business strategy developed to compete in that market. The relative importance of the criteria and sub-criteria to the business and the parent criteria respectively are assessed or rated using the basic AHP approach of pair-wise comparison.

Level 4 of the hierarchy contains the rating scale for assessing the impact of individual components of the elevator on the sub-criteria. This is different from the usual AHP approach in that an absolute measurement is assigned to each sub-criterion for each component to be purchased, instead of pair-wise comparisons of the components on the basis of each sub-criterion. Absolute (or direct) measurement is used because there would be an intractable number of pair-wise comparisons to perform. In the case studies presented here, there are 23 components to be rated against the 12 strategic priority measures. This would result in ${}_{23}C_2 = 23!/2!(23-2)! =$ 253 pair-wise comparisons for each of the 12 measures, giving a total of 253 x 12 = 3036 comparisons. If absolute measurement is used, this number is reduced to 23 x 12 = 276 absolute measurements. This difference would grow very rapidly with increases in numbers of components. This direct approach has been used in supplier selection [17][27].

The last level of the hierarchy consists of the components to be evaluated. Table 1 gives the major components in the elevator's BOM used in the analysis presented here.

In summary, the AHP proceeds as follows, with the details of the calculations given in the following sections:

i. Select the criteria and their sub-criteria (measures) according to which the components are to be prioritized; these encapsulate the competitive priorities of the business.

ii. Weight the relative importance of the criteria using pair-wise comparisons based on a '1 to 9' relative importance scale as described below.

iii. Weight the relative importance of the sub-criteria within each criterion using pair-wise comparisons and the '1 to 9' scale and multiply these weights by their parent criterion weights to get overall sub-criterion weights.

iv. Score the impact of each component on each sub-criterion using the direct rating scale described below and weight these scores using the sub-criterion weights before summing to give an overall score for the component.

5 Selection of Criteria and Sub-Criteria

The importance of a purchase is determined by the competitive priorities of the business. The literature reviewed supports the argument that a purchasing strategy is to support the business strategy for competitive success. Moreover, the purchasing strategy has to be consistent with manufacturing strategy simultaneously [28].

Since Hayes and Wheelwright [29] introduced competitive priorities, they have been used as a manufacturing strategy in the operations management field [25]. According to Krause et al.'s [5] empirical research, purchasing's competitive priorities are conceptualised as being similar to the competitive priorities in operations management. To conclude, four competitive priorities (cost, quality, availability and time) are identified as the criteria to be used in prioritising the purchased components and each criterion has three measures as discussed below.

According to Chao and Scheuing [30] quality is the most important concern for strategic supplier management. The assurance of an adequate supply of materials and components is certainly one of the key elements of total quality management policy [31]. The quality of purchased components is a major determinant of the quality of the final product [32]. Quality is measured in this thesis on the basis of the importance of durability, reliability and innovation of the component. Quality is associated with conformance to specifications and meeting the expectations of the customers [33][34][35] and durability and reliability in particular must conform to the buying firm's specifications [17]. In general, these two measures are often used as measures of quality in the literature, e.g. [5] [36][37][38]. Innovation is included as a measure of quality as it can be central to achieving competitive advantage, and high innovation or quality in purchased components is often the quickest and easiest way to improve the quality of the final product [39].

Availability is measured on the basis of the importance of volume flexibility, modification flexibility and technological capability. Volume flexibility directly impacts customers' perceptions by preventing out of stock conditions of products when demand is suddenly high and modification flexibility is a value-adding attribute that is immediately visible to the customer [40]. Modification flexibility relates to the ability to meet the demands of high variety and personalised products. If the purchasing function of a firm can manage effectively its supplier capabilities, the result could be an increase in manufacturing flexibility [41][42]. Technological change, and therefore technological capability, is one of the principal factors of competition [43] and new technologies present opportunities to enter into the market with a new product [44]. For these reasons, technological capability has received focal attention as a supplier selection criterion [45].

Cost is measured on the basis of the importance of purchasing cost, inventory cost and quality assurance. The purchasing cost is clearly one of the major and fundamental factors in assessing the importance of purchasing [15] [46]. Inventory cost is important in the context of supply chain management [26]. If the cost of incoming and quality inspection of purchased items is reduced, then quality costs in the firm can be low [3].

Time is measured on the basis of the importance of delivery speed, delivery reliability and development speed. These times can be a crucial factor in determining the success of a product [26]. Many businesses are attempting to gain or maintain a competitive advantage by purchasing items from suppliers who offer a reduction in the standard delivery time [47].

6 Weighting criteria by pair-wise comparison and rating components against criteria.

The data for the AHP was gathered by questioning five of the elevator manufacturer's staff who are frequently involved directly or indirectly with component purchasing; two from the purchasing department, one from engineering, one from operations management and one from accounting. This sample gives coverage of different functions and therefore perspectives. Ramanathan and Ganesh [48] argued that all participants do not have equal expertise about the problem domain in the group decision. The numbers should be selected based on their experience and knowledge about various business functions of the company [49]. Nicholas [50] referred to purchasing, manufacturing operations, engineering and accounting as the four key functions to have represented in a supplier selection team. The purchasing staff are more focused on the suppliers, the engineer is more focused on the manufacturing technology and the product, the operations manager is more focused on quality and customer service whilst the accountant is more focused on costs and profit.

In general the number of staff in some departments or functions of SMEs is small (e.g. 2-3 persons). In the case study company, two staff work in purchasing, so both of them were selected for data gathering. However, in the case of the other departments there are more staff, so the senior staff member was selected in each case.

Interviews with the staff required visits to the company to gather data 'face to face'. During each interview, the specific terminology of the decision criteria and the components of the elevator were explained to the staff if necessary. Special care was taken to avoid the pitfall of using leading questions when asking the staff for their evaluations. This means that members of the team do not have a preconception before making their assessments. This led the authors to shun the use of a second evaluation round after the team members had been informed about their colleagues' scores, i.e. the AHP has been used to capture truly independent perceptions from different functions within the organisation.

The staff were then the 'evaluators' for the purposes of the AHP, which was implemented using the Expert Choice software [24]. In general, interviews are not absolutely necessary to gather data as one can use other methods such as questionnaires on paper or access over an intranet in a company. However, 'face to face' interviews enable the interviewee to provide deeper explanations of the method immediately in response to feedback from interviewees and it is perceived that this approach provides more reliable data.

The nine-point scale in Table 2, suggested by Saaty and Vargas [11], is used to quantify the pair-wise comparisons of the criteria. For example, if an evaluator decides that *quality* is moderately more important than *time*, then the former would be rated as '3' and the latter as '1/3' in this pair-wise comparison. Within each criterion, the sub-criteria are compared on a pair-wise basis to establish their relative importance to their parent criterion. For example, if *component durability* is considered absolutely (maximally) more important in determining quality compared to *component reliability*, then it is rated '9' whereas *component reliability* is rated '1/9' in this pair-wise comparison. Matrices of pair-wise comparisons are obtained by the completion of all the pair-wise comparisons. Table 3 gives the five comparison matrices for *evaluator-1*, one for the criteria and one for each of the four groups of sub-criteria within the criteria.

There is the possibility of inconsistency in the pair-wise comparisons. For example, an evaluator may rate quality as '7' against cost, cost as '7' against time and time as '7' against quality. This would be extremely inconsistent as the first two 7s imply that quality must be rated more highly than time. To understand Saaty's [10] treatment of inconsistency, let a_{ij} denote the comparison of criterion i against criterion j, the element of the comparison matrix at row i, column j. A matrix is then called "consistent" if $a_{ik} = a_{ij} . a_{jk}$, for all i, j, k. Based on this, Saaty then shows that for a pair-wise comparison matrix of size (n x n) to be "absolutely consistent", it must have one positive eigenvalue $\lambda_{max}= n$, while all other eigenvalues equal zero. In the real world, human evaluators do not typically achieve absolute consistency; so to be pragmatic Saaty introduces the consistency index (C.I.) to measure the "closeness to consistency":

$$C.I. = (\lambda_{max} - n) / (n - 1) \quad (1)$$

Then, the consistency ratio (C.R.) is used to assess whether a matrix is sufficiently consistent or not. This is the ratio of the C.I. to the random index (R.I.), which is the C.I. of a matrix of comparisons generated randomly:

$$C.R. = C.I. / R.I. \quad (2)$$

Random pair-wise comparisons have been simulated to produce average random indices (R.I.) for different sized matrices. In Saaty and Vargas [11] for $n = 3$ to 10 the R.I. values given are 0.52, 0.89, 1.11, 1.25, 1.35, 1.4, 1.45 and 1.49 respectively.

For n=3 the C.R. should be less than 0.05, for n=4 it should be less than 0.08 and for $n \geq 5$ it should be <0.10. Each pair-wise comparison matrix in Table 3 is presented with its C.R. and these satisfy the consistency test. However, for one of the other staff the C.R. exceeded 0.08 for the comparison of the criteria, so his data was removed from the analysis; this was the representative of the accounting department. A C.R. close to 0.05 for the (3x3) cost and time comparison matrices provided further support for the removal of his data.

As suggested by Saaty and Vargas [11], the geometric mean (the n^{th} root of the product of n items), rather than the arithmetic mean, is used to consolidate the pair-wise comparison matrices of the individual staff (evaluators) questioned. This yields the five 'consensus matrices' in Table 4. The next step is to compute the 'priority vectors' to define the relative priorities of the criteria and sub-criteria (the final column of Table 4). There are potentially many ways in which this might be done. However, Saaty's [10] consistency principle that $a_{ik} = a_{ij} . a_{jk}$ and his subsequent argument for using the special case of the consistent matrix formed by elements $a_{ij} = w_i/w_j$, where w_i and w_j are the elements of the priority vector corresponding to criteria i and j (i.e. their priorities), leads to the following method. In terms of matrix algebra, a priority vector is computed as the normalized, principal (largest) eigenvector of the consensus matrix of pair-wise comparisons. This calculation is complex and is normally executed using proprietary software. However, there are methods for calculating an approximate solution. For example, normalize the ratings in a consensus matrix by dividing each entry in a column by the sum of all the entries in that column, so that the entries in the column add up to one, and then average these normalized weights across the rows to give an average priority weight for each criterion. The normalization down the columns makes it statistically sound to compare and average scores across the columns to give row averages. The application of this algorithm is demonstrated by Drake [16] and it can be implemented in a proprietary spreadsheet by a moderately experienced user.

The priority vectors in Table 4 are used to produce overall or global weights for the sub-criteria as given in Table 5. The corresponding criterion and sub-criterion weights are multiplied together to give a global weight for each sub-criterion, so that the importance or weight of a sub-criterion is measured by its importance to its parent criterion weighted by the importance of the parent criterion to the business strategy.

In the second stage, evaluators were requested to use absolute measurement to rate the strength of the impact of the individual elevator components on the sub-criteria using the five-point scale (VH=very high; H=high; M=medium; L=low; VL=very low) suggested by Tam and Tummala [27]; see Table 6. For example, the control panel is deemed to have a high impact on component durability, but a low impact on volume flexibility. Table 7 shows the normalized weights calculated for the five-point scale using the AHP procedure described earlier in this section.

For each component, the results obtained with the five-point rating scale were multiplied by the weights of the sub-criteria and summed, as shown in Table 8 for the *control panel* component. The total score for each component is normalized by dividing it by the sum of the total scores across all the components, so that the sum of the normalized scores is 1. The normalized, total scores for each component from each evaluator are then combined using the geometric mean to give the results in the final two columns of Table 9.

7 Analysis and interpretation of results

The priority weights of the four criteria in the matrix at the top of Table 4 show that availability and cost are the most important strategic priorities to be considered when prioritising the elevator's components.

Availability (0.39) is nearly twice as heavily weighted as quality (0.21) and over four times more heavily weighted than time (0.09). An elevator is comprised of both standardised and customised components, with the majority being customised to meet the needs of the customer. Since the elevator manufacturer has adopted the make-to-order (MTO) strategy, availability is quite naturally the supreme competitive priority. Cost (0.31) is the next most important strategic priority, with its weight just below that of availability. As the elevator manufacturer spends more than 70% of each sales dollar on purchased materials and components, the high weighting given to cost is to be expected also. Whilst availability and cost dominate the priorities in this make-to-order, high variety and highly competitive market, quality still maintains a significant weight for safety reasons, i.e. an elevator is potentially dangerous and could injure or cause death to the user. Time has the lowest weight. This is a consequence of the overriding importance of availability and cost rather than time being unimportant per se.

The global weights of each sub-criterion at Level 3 are arranged in descending order of priority in Table 10. It can be seen that measures of availability (modification flexibility and technological capability) achieve the 1st and 3rd= rankings. A cost measure (purchasing cost) is ranked 2nd whilst a quality measure (durability) is ranked 3rd=. The highest ranked time measure (delivery reliability) is ranked 6th=.

It is noted that whilst availability and cost are the most important strategic priorities, two of the top five strategic priority measures are measures of quality. The reason for this is that availability and cost are both dominated by one of their measures (sub-criteria) in Table 5, i.e. they each have one measure with a dominant weight. This means that the other measures of availability and cost fall down the priority list. However, quality has two measures with relatively high weights and these are the two coming into the top five positions of Table 10.

Figure 2 illustrates the component priorities or scores in the penultimate column of Table 9. To decipher the large array of priorities, they can be sorted and placed in groups. For example, in Figure 2 the components are split (by eye, searching for natural breaks in the data) into three groups. Group A is the most critical or high-priority component group consisting of the *car set*, the *control panel*, the *traction machine* and the *motor generator*. Group B is the second most important group containing components from the *operation fixtures* to the *interlock device*. Group C contains the least critical components, from the *rope brake* to the *buffers*. It should be noted that in this particular example three groups have been formed, but there could be more groups, especially when the number of components being analysed is larger and more natural breaks are seen in the scores.

Grouping is not essential. The sorted list of priorities is in itself a guide to the purchasing strategist; an essential piece of information required in formulating purchasing strategy when faced with a large number of different items to purchase.

In the columns in Figure 2, each component's score is broken down into its contribution in respect of each criterion: time; quality; cost; availability. This shows the purchasing priorities with respect to each criterion. For example, the *operation fixtures* have the greatest impact on availability, whereas the *guide rails* have the greatest impact on time. This information would be of value, for example, when seeking to improve performance within individual criteria. It also indicates how the groupings would change if the company's strategic priorities in Table 10 were to change.

It should be noted that the numerical values in the tables, derived from the evaluators' responses, represent subjective data that have sample character and that these values do not apply to other applications.

8 Sensitivity Analysis

Sensitivity analysis is performed to examine the sensitivity of the results to the weights of the strategic priorities or criteria. To examine the sensitivity of the AHP results to the weight of a particular criterion, the weight is increased and decreased and the weights of the remaining criteria are adjusted proportionately, so that the sum of the weights remains equals to 1. This causes linear changes in the scores of the components. Whilst this results in changes in the rankings of the components, the critical changes are when the strategic groupings in Figure 2 are changed or, in particular, when a component from one group changes rank order with a component from another group, as this would require a significant change in the fundamental purchasing strategy. For quality with original weight 0.21, this does not happen until the weight is increased to 0.94, when the score for the *car set* (Group A) becomes less than that of the *brake* (Group B). For time with original weight 0.09, the weight must be increased to 0.53, when the *car set* (Group A) is ranked lower than the *guide rails* (Group B). Clearly, the substantive output of the analysis is not sensitive to the weights assigned to quality and time.

For cost and availability with original weights 0.31 and 0.39 respectively, a change occurs when the weight is increased to 0.45 and 0.55 respectively, when for both criteria the *motor generator* (Group A) is ranked lower than the *operation fixtures* (Group B). These results do not represent very high sensitivity as the changes required in percentage terms are 45% and 41% respectively in a result obtained by averaging the independent results of four evaluators.

Hill [51] introduced the concept of 'order winners' and 'order qualifiers' against which it is maintained that manufacturing strategy should be determined. Order winners are competitive characteristics that directly and significantly contribute to winning business whereas order qualifiers may not be major competitive determinants of success, but are important competitive characteristics to get into or stay in a market. For example, when companies compete directly on price, cost is the order winner whereas other factors such as quality, availability and time will tend to be order qualifiers. In the analysis presented here, cost and availability were clearly the most highly weighted criteria, so they would appear to correspond to order winners, whereas time and availability correspond to order qualifiers. It is noted that, increasing the weights of the order winners beyond their already relatively high levels changes the groupings. Setting the weights of the order winners very high corresponds to setting the weights of the order qualifiers very low, tending towards ignoring them all together. In this respect, the sensitivity analysis demonstrates the importance of the lower-weight criteria in capturing the order qualifying criteria and one should not be tempted to focus solely on the highest priority, order-winning criteria in performing strategic analysis.

9 Conclusion

The importance of aligning purchasing strategy with business strategy for achieving competitive success has been argued using a substantial literature review. A pragmatic contribution has been made towards achieving this alignment, by prioritising the components of a manufactured product on the basis of their impact on the competitive priorities of the business. In particular, the Analytic Hierarchy Process (AHP) has been applied to the prioritisation and subsequent grouping of the components of an electric traction elevator according to their impact on the business strategy. This information can be used to guide and prioritise the work of those forming the purchasing strategy required to support the business strategy. The purchasing strategy for the highest priority components must be given immediate attention as an integral part of implementing the business strategy, whilst the purchasing strategy for the lower priority components can be developed in due course, perhaps viewed as a matter for continuous improvement. The component priorities also indicate priorities for supplier development.

The literature reviewed supports the argument that contemporary strategic purchasing requires team working and the synthesis of the views of staff from different fields of expertise. The AHP is a synthesiser that facilitates consensus and makes the decision-making process very transparent.

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Location	Components	
Machine room	1. Control panel (CP) 2. Motor generator (MG) 3. Traction machine (TM)	4. Brake (B) 5. Rope brake (RB) 6. Governor (G)
Hoistway	1. Travelling cables (TC) 2. Ropes (R) 3. Compensating chain (CC) 4. Counterweights (C) 5. Load weighing devices (LW) 6. Guide rails (GR) 7. Rail brackets (RBs)	8. Buffers (Bfs) 9. Limit switch (LS) 10. Roller guides (RG) 11. Door operator (DO) 12. Safety gear (SG) 13. Guide shoes (GS)
Car & hoistway entrances	1. Car set (CS) car, sill, landing door, etc 2. Operation fixtures (OF) operating panel, position indicator, hall button, etc	3. Door safety device (DS) 4. Interlock device (ID)

Table 1: List of major components of the electric traction elevator

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one over another
5	Strong importance	Experience and judgement strongly favour one over another
7	Very strong importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Compromises between the priorities listed above
Reciprocals of the above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Table 2: One to nine scale for AHP preference

Goal	Quality	Availability	Cost	Time
Quality	1	1/2	1/2	2
Availability	2	1	2	3
Cost	2	1/2	1	2
Time	1/2	1/3	1/2	1
			Consistency Ratio C.R. = 0.03	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	5
Component reliability	1/2	1	3
Component innovation	1/5	1/3	1
			C.R. = 0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/5	1/3
Modification flexibility	5	1	2
Technological capability	3	1/2	1
			C.R. = 0.00

Cost	Purchasing cost	Inventory cost	Quality assurance
Purchasing cost	1	7	4
Inventory cost	1/7	1	1/2
Quality assurance	1/4	2	1
			C.R. = 0.00

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	8
Development speed	1/3	1/8	1
			C.R. = 0.01

Table 3: Pair-wise comparison matrices for *evaluator-1*

Goal	Quality	Availability	Cost	Time	Priority weight
Quality	1	0.5	0.5	2.9	0.21
Availability	2.1	1	1.4	3.5	0.39
Cost	1.9	0.7	1	3.1	0.31
Time	0.3	0.3	0.3	1	0.09
				C.R. = 0.02	

Quality	Component durability	Component reliability	Component innovation	Priority weight
Component durability	1	1.4	3.9	0.51
Component reliability	0.7	1	2.7	0.36
Component innovation	0.3	0.4	1	0.13
			C.R. = 0.00	

Availability	Volume flexibility	Modification flexibility	Technological capability	Priority weight
Volume flexibility	1	0.3	0.5	0.14
Modification flexibility	3.9	1	2.4	0.59
Technological capability	2.2	0.4	1	0.27
			C.R. = 0.01	

Cost	Purchasing cost	Inventory cost	Quality assurance	Priority weight
Purchasing cost	1	5.9	3.7	0.69
Inventory cost	0.2	1	0.5	0.11
Quality assurance	0.3	2.0	1	0.20
			C.R. = 0.01	

Time	Delivery speed	Delivery reliability	Development speed	Priority weight
Delivery speed	1	0.5	3.0	0.31
Delivery reliability	1.9	1	6.3	0.59
Development speed	0.3	0.2	1	0.10
			C.R. = 0.00	

Table 4: Geometric mean of pair-wise comparison matrices of all *evaluators*.

Strategic priority	Local weight	Strategic priority measures	Local weight	Global weight
Quality	0.21	Component durability	0.51	0.11
		Component reliability	0.36	0.07
		Component innovation	0.13	0.03
Availability	0.39	Volume flexibility	0.14	0.05
		Modification flexibility	0.59	0.23
		Technological capability	0.27	0.11
Cost	0.31	Purchasing cost	0.69	0.21
		Inventory cost	0.11	0.03
		Quality assurance	0.20	0.06
Time	0.09	Delivery speed	0.31	0.03
		Delivery reliability	0.59	0.06
		Development speed	0.10	0.01
Total	**1.00**	**Total**		**1.00**

Table 5: Combined criteria and sub-criteria *weights*

Strategic Priority Measure \ Component	Control panel	Motor generator	Traction machine	Brake	Rope brake	Governor
Quality						
Component durability	H	H	H	H	M	H
Component reliability	H	H	H	H	M	H
Component innovation	VH	H	H	H	L	H
Availability						
Volume flexibility	L	L	L	L	L	M
Modification flexibility	H	M	H	L	L	M
Technological capability	H	H	H	H	L	H
Cost						
Purchasing cost	H	M	M	L	VL	L
Inventory cost	VL	VL	VL	VL	VL	VL
Quality assurance	M	M	M	M	M	L
Time						
Delivery speed	H	H	H	H	L	M
Delivery reliability	H	H	H	M	M	M
Development speed	H	H	M	M	L	L

VH=very high; H=high; M=medium; L=low; VL=very low

Table 6: Absolute ratings given by the evaluator-1 to some of the components

Rating scale	VH	H	M	L	VL	Rating weight
Very high (VH)	1	3	5	7	9	0.51
High (H)	1/3	1	3	5	7	0.26
Moderate (M)	1/5	1/3	1	3	5	0.13
Low (L)	1/7	1/5	1/3	1	3	0.06
Very low (VL)	1/9	1/7	1/5	1/3	1	0.04

Table 7: Pair-wise comparison judgment matrix for five-point rating scale

Strategic Priority Measures	Global weight (from Table 5)	*Control Panel* Scoring		
		Rating	Rating weight (from Table 7)	Global weight x Rating weight
Quality				
Component durability	0.11	H	0.26	0.03
Component reliability	0.07	H	0.26	0.02
Component innovation	0.03	VH	0.51	0.01
Availability				
Volume flexibility	0.05	L	0.06	0.00
Modification flexibility	0.23	H	0.26	0.06
Technological capability	0.11	H	0.26	0.03
Cost				
Purchasing cost	0.21	H	0.26	0.06
Inventory cost	0.03	VL	0.04	0.00
Quality assurance	0.06	M	0.13	0.01
Time				
Delivery speed	0.03	H	0.26	0.01
Delivery reliability	0.06	H	0.26	0.01
Development speed	0.01	H	0.26	0.00
			Total Score	0.24
			Normalised Total = Total Score / Sum of Total Scores across components	**0.10**

Table 8: Calculation of overall score for the *control panel* component for evaluator-1

Component \ Evaluator	1		2		3		4		Combined	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Control Panel	0.10	2	0.09	2	0.09	1=	0.09	2	0.09	2
Motor Generator	0.07	4	0.06	4	0.09	1=	0.06	4	0.07	4
Traction Machine	0.08	3	0.07	3	0.09	1=	0.07	3	0.08	3
Brake	0.05	5	0.05	5	0.05	7	0.06	4	0.05	7
Rope Brake	0.03	13	0.03	13	0.03	13	0.03	14	0.03	13
Governor	0.05	5	0.05	5	0.06	5	0.06	4	0.06	5
Travelling Cables	0.03	13	0.03	13	0.03	13	0.03	14	0.03	13
Ropes	0.04	8	0.05	5	0.04	8	0.04	10	0.04	9
Compensating Chain	0.03	13	0.03	13	0.03	13	0.04	10	0.03	13
Counterweights	0.03	13	0.02	22	0.02	22	0.02	23	0.02	22
Load Weighing Devices	0.02	23	0.03	13	0.03	13	0.03	14	0.03	13
Guide Rails	0.04	8	0.05	5	0.04	8	0.05	8	0.04	9
Rail Brackets	0.02	20	0.03	13	0.03	13	0.03	14	0.03	13
Buffers	0.02	20	0.02	22	0.02	23	0.03	14	0.02	22
Limit Switch	0.03	13	0.03	13	0.03	13	0.03	14	0.03	13
Roller Guides	0.02	20	0.03	13	0.03	13	0.03	14	0.03	13
Door Operator	0.04	8	0.05	5	0.04	8	0.05	8	0.05	7
Safety Gear	0.03	13	0.03	13	0.03	13	0.03	14	0.03	13
Guide Shoes	0.03	13	0.03	13	0.03	13	0.03	14	0.03	13
Car Set	0.11	1	0.10	1	0.08	4	0.10	1	0.10	1
Operation Fixtures	0.06	5	0.05	5	0.06	5	0.06	4	0.06	5
Door Safety Device	0.04	8	0.04	11	0.04	8	0.04	10	0.04	9
Interlock Device	0.04	8	0.04	11	0.04	8	0.04	10	0.04	9
Total	1.00		1.00		1.00		1.00		1.00	

Table 9: Summary of scores and rank of components in the electric traction elevator

Rank	Strategic priority measure	Global weight
1	Modification flexibility	0.23
2	Purchasing cost	0.21
3=	Component durability	0.11
3=	Technological capability	0.11
5	Component reliability	0.07
6=	Quality assurance	0.06
6=	Delivery reliability	0.06
8	Volume flexibility	0.05
9=	Inventory cost	0.03
9=	Delivery speed	0.03
9=	Component innovation	0.03
12	Development speed	0.01

Table 10: Ranking of strategic priority measures

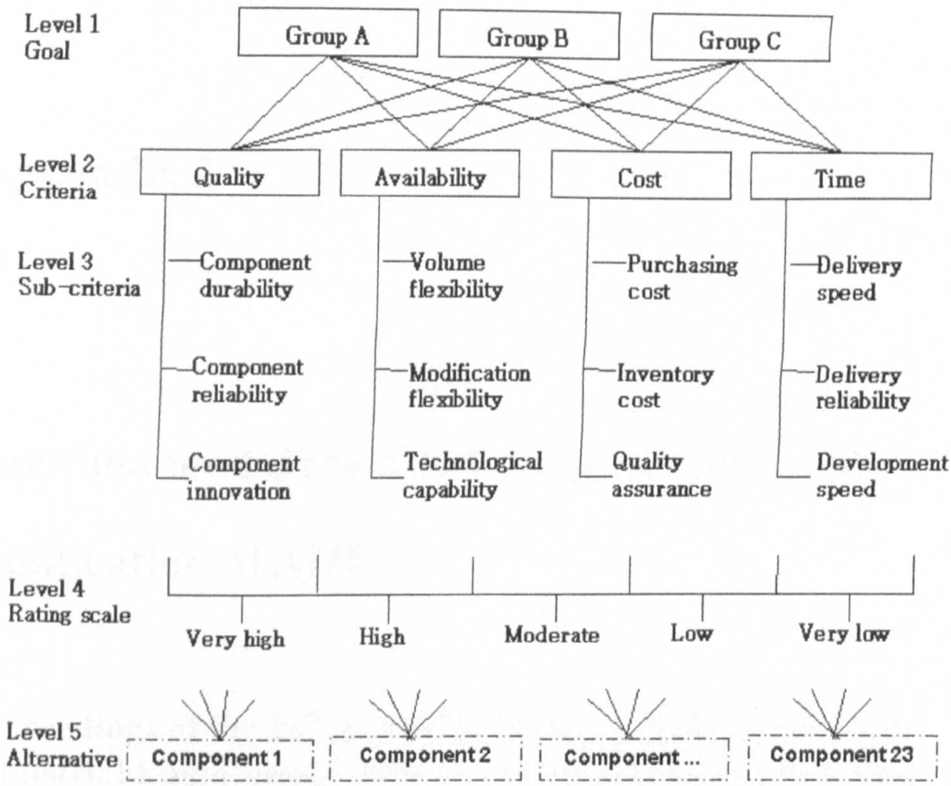

Figure 1: AHP component-grouping model for the elevator manufacturer

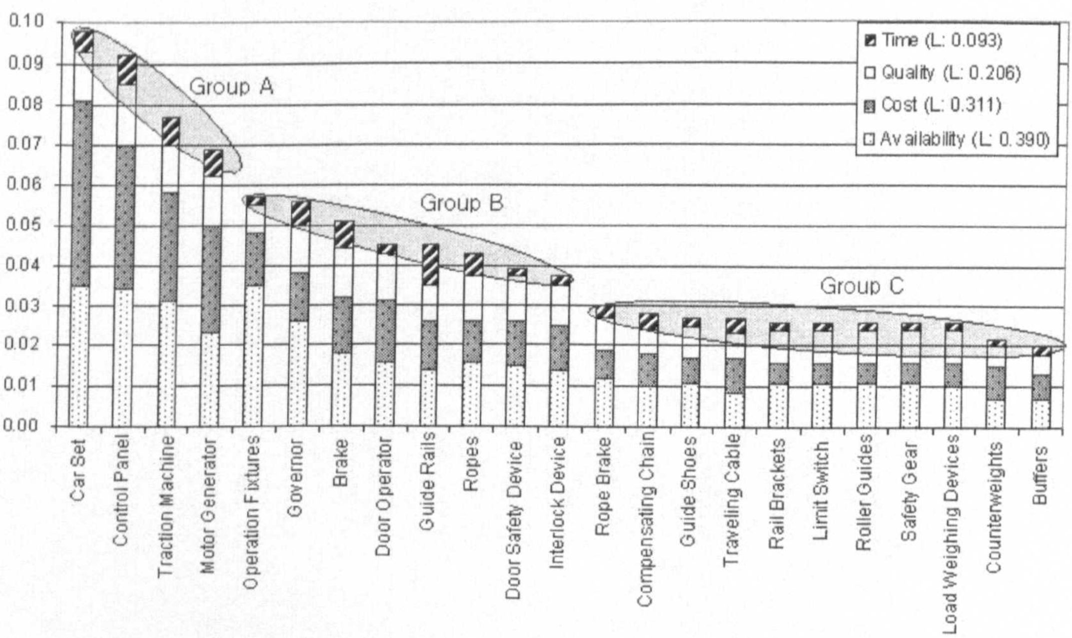

Figure 2: Combined score of components in the electric traction elevator

Appendix 2

Portfolio model for Purchasing Strategy with Application of AHP

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PORTFOLIO MODEL FOR PURCHASING STRATEGY WITH APPLICATION OF AHP

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Abstract: The environment of manufacturing companies change rapidly due to competitive nature of the global marketplace. An appropriate strategic purchasing component can provide a manufacturing firm with a competitive advantage. The buyer should determine and manage the purchasing strategy on the basis of its products and services for competing successfully in the market. The purchasing department has shifted its focus from an administrative scope to a strategic role in order to increase the competitive advantage of the organization. Therefore, purchasing strategies differ among manufacturers and need to be in line with business strategies. In this paper, a case study is reported to illustrate an innovative model which adopts AHP in the Purchasing model. The proposed model can provide a framework for firms to purchase component.

Keywords: Portfolio models; Purchasing strategy; AHP; components and BOM; Supply chain;

1. INTRODUCTION

Enterprises in all branches of industry are being forced to react to the growing individualization of demand, yet, at the same time, increasing competitive pressure dictates that costs must also continue to decrease. Companies have to adopt strategies which embrace both efficiency and customization. Companies in any industry should manage their components more than before. Since the many manufacturing firms spend approximately 60 percent of each sales dollar on purchased components, materials and services from external suppliers, the manufacturing firm's final products are significantly affected by the performance of external suppliers in terms of cost, quality, time, and availability. This will result in a need of effective analysis of components, strategy of purchasing and selection of suppliers. But, most of researchers, they usually developed purchasing model without any analysis of components. So they overlooked that each company has its own product in a different business environment. Although some of previous studies classified components before development of purchasing strategies, their dimensions were not easy to understand and needed extra information as suppliers' specific investments or supply market environment. The aim of this proposal is to analysis and group components those assemble one kind of product for purchasing strategy with application of Analytic Hierarchy Process.

2. LITERATURE REVIEW

Ellram and Carr (1994) summarized research work pertaining to the role of the purchasing function in supporting a firm's strategy. The work explores the broad issue of communicating and integrating purchasing strategy into corporate strategy and examines how purchasing strategies and activities can support or detract from the strategies of the firm.

Portfolio models have been used in strategic planning and marketing, but their application to the field of purchasing has been limited (Nellore and Soderquist, 2000). Recently, purchasing portfolio models have received considerable attention from academic and business world. Contrary to the growing number of academic publications on purchasing portfolio models, little is known about their actual use. Obviously, not all products and not all buyer supplier relationships are to be managed in the same way at different supply chains.

The Analytic Hierarchy Process (AHP) is a powerful and flexible decision making process to help people set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. AHP has been applied successfully for supplier evaluation and selection (Chan and Chan, 2004). The AHP offers a methodology to rank alternatives courses of action based on the decision maker's judgments concerning the importance of the criteria and the extent to which they are met by each alternative (Nydick and Hill, 1992). For this reason, AHP is ideally suited for analysis of components for grouping.

3. RESEARCH METHODOLOGY

The methodology adopted for the research consisted of 4 main stages. (See Figure 1)

1. A problem background review covered the recent business environment of the boiler manufacturing industry, the company background, the products and its competitive strategy.
2. A literature review for building the portfolio model of component covered 4 main topics, namely supply chain management, portfolio model, purchasing strategy and AHP.
3. Preliminary research included the primary interview of company's staff and further analysis of the data so collected.
4. Development of the component portfolio model includes the criteria, construction of the AHP model, design of an evaluation questionnaire, respondent interview, analysis of the questionnaire result, grouping components and finally, building the portfolio model.

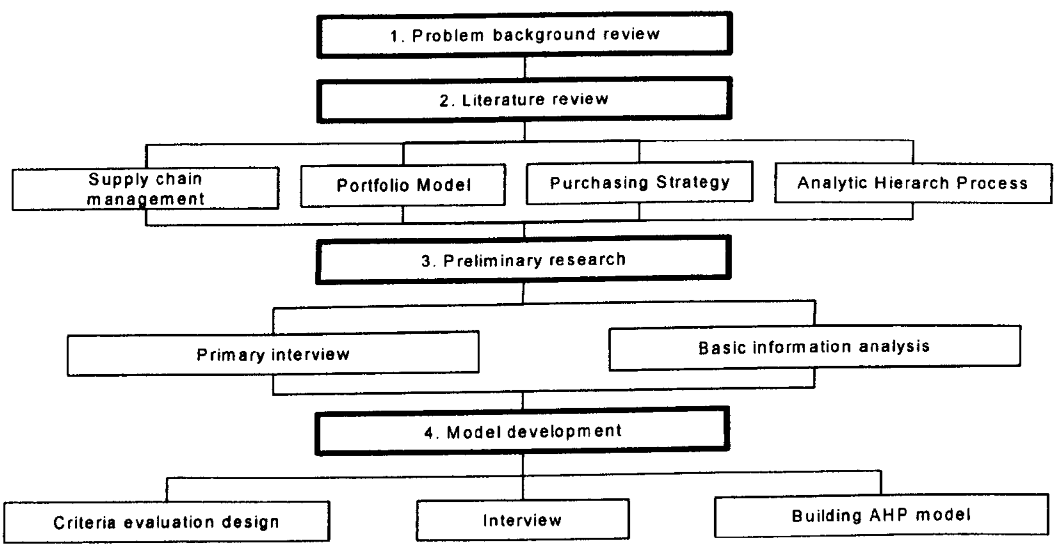

Figure 1. Overview of the Research Methodology

4. DEVELOPMENT OF COMPONENTS GROUPING MODEL

4.1 Formation of components grouping criteria

In this work, the purchasing competitive priorities and its measures given by Krajewski and Ritzman (2005) and have been adopted as the criteria. The quality, cost, lead time, and service level of final product in supply chain depend on its components those are listed on the bill of materials. Therefore four main criteria as quality, cost, lead time, and service in components level are also important competitive criteria. Christopher and Towill (2000) explained the issues related to the concepts of "market qualifier" and "market winner" in different supply chains and identified quality, cost, lead time, and availability as four prime performance measures. For a lean supply chain, cost is the market winner, while the other factors are market qualifiers. In case of an agile supply chain, the winner in market is availability, and quality, cost and lead time are market qualifiers.

	Market Qualifiers	Market Winners
Customisation (Agile Supply)	Quality Cost Lead time	Availability (Service level)
Standardisation (Lean Supply)	Quality Lead time Availability (Service level)	Cost

Figure 2. Market Winners-Qualifiers Matrix for Agile, Leagile and Lean Supply

4.1.1 Quality

Product quality is an issue closely related to manufacture because if components are incorrectly made or purchased, or defective raw material is used there is a probability of product failure (Wainwright, 1995). The supply function is an important dimension of quality management in final product because materials and purchased parts are the source of half the quality problems (Burt, 1989). The quality factor has been measured on the basic of the importance of the quality dimensions in the purchasing components process: durability, reliability and innovation of component.

4.1.2 Cost

We can know the importance of purchasing by analysing of the cost structure of manufacturing companies. Manufacturing industry over the years became more dependent on suppliers. The purchasing value in relation to cost of goods sold in approximately 50 per cent. If the other business costs, which have an important purchasing component, are added to the purchasing value, the total amounts to approximately 68 per cent (van Wheel 2005, pp.16-17). Thus the purchasing function has a substantial impact on the total cost of a firm and thereby on the potential profit (Dubois and Pedersen, 2002). The cost factor has been measured on the basic of the importance of following cost dimensions in the purchasing components process: purchasing cost, inventory cost, and quality assurance.

4.1.3 Time

The components that impact timely delivery are supplier lead-time, manufacturing or production time, and delivery time performance (Davis, 1993). The time factor has been measured on the basic of the importance of following time dimensions in the purchasing components process: delivery speed, delivery reliability, and development speed.

4.1.4 Availability

Through the application of technology and new management methods, the company can achieve their competition by creating variety and customisation through flexibility and quick responsiveness (Pine II, 1993). The availability factor has been measured on the basic of the importance of following availability dimensions in the purchasing components process: volume flexibility, modification flexibility, and technological capability.

4.2 Building the AHP model and Discussion

The AHP modelling process involves three steps, namely structuring components grouping problem, performing paired comparisons between elements/decision alternatives, and synthesis-finding solution to the problem. Using this three steps approach, an AHP model is formulated for grouping of components. The AHP methodology is explained in Saaty's book (1980). Below we give enough of the general approach to enable the reader to follow the paper with ease.

Step 1. Structuring the hierarchy

Group related components and arrange them into a hierarchical order that reflects functional dependence of one component or a group of components on another. The approach of the AHP involves the structuring of any complex problem into different hierarchy levels with a view to accomplishing the stated objective of a problem. The goal is placed on the 1st level of the hierarchy. The 2nd level of the hierarchy occupies the criteria. Examples of the criteria are competitive priorities that might be used are quality, availability, cost, and lead time. The 3rd level is sub-criteria. They have related with respective criteria. The four level of the hierarchy contains the rating scale. The five-point rating scale of Very High (VH), High (H), Moderate (M), Low (L) and Very Low (VL) is used to determine the pairwise comparison matrices. The last level of the hierarchy consists of the alternatives, namely the different components. The alternatives are the components those are listed on the bill of materials (BOM) of one kind of product.

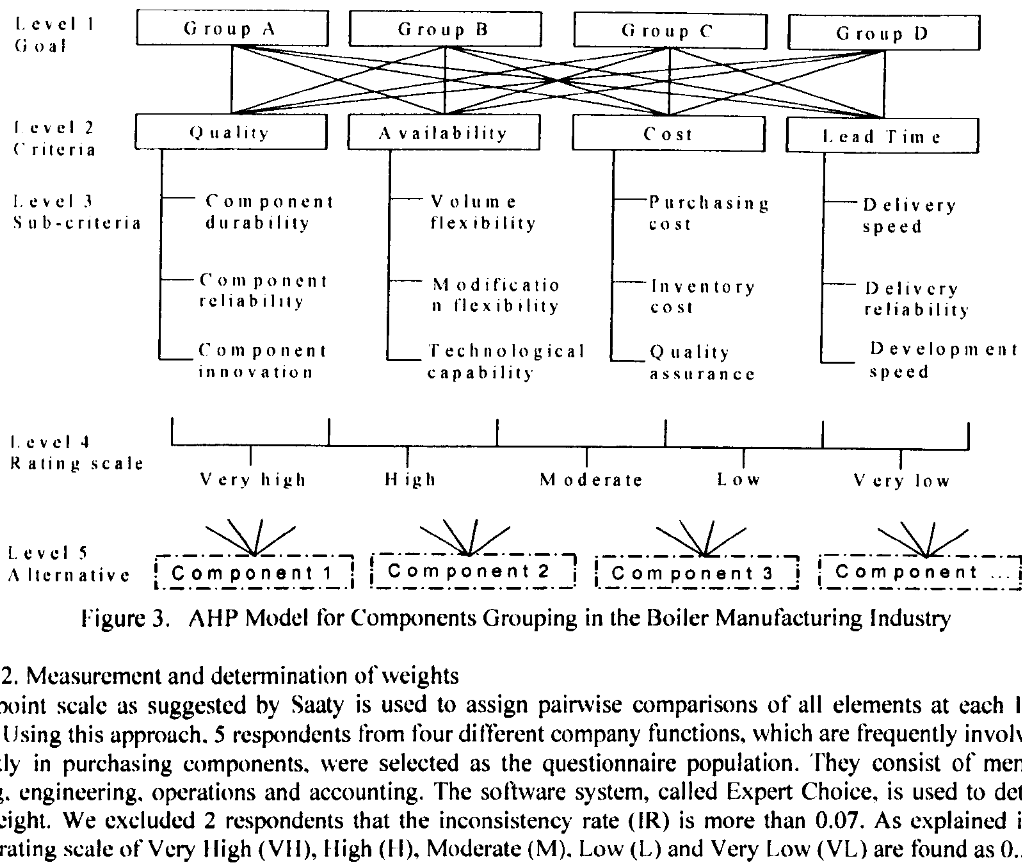

Figure 3. AHP Model for Components Grouping in the Boiler Manufacturing Industry

Step 2. Measurement and determination of weights
The nine-point scale as suggested by Saaty is used to assign pairwise comparisons of all elements at each level of the hierarchy. Using this approach, 5 respondents from four different company functions, which are frequently involved directly or indirectly in purchasing components, were selected as the questionnaire population. They consist of members from purchasing, engineering, operations and accounting. The software system, called Expert Choice, is used to determine the priority weight. We excluded 2 respondents that the inconsistency rate (IR) is more than 0.07. As explained in step 1, a five-point rating scale of Very High (VH), High (H), Moderate (M), Low (L) and Very Low (VL) are found as 0.513, 0.261, 0.129, 0.063 and 0.034 respectively.

The weights of the each criterion of second level and the global weights of each sub-criterion of level 3 are shown in Table 1. In the case of the criterion, quality (0.421) and cost (0.348) occupy the first and second ranks, followed by availability (0.118) and the last is time (0.113). The result shows that quality and cost are the most important strategic priorities to be considered in grouping component problem, representing more than 76 percent of total weights. It can be seen that the purchasing cost occupy the top ranking in the strategic priority measures, followed by component durability and component reliability. They are more than 57 percent of total global weight. Table 2 shows that example of the computation process to obtain the total scores of Brazing Filler Metal and Internal Steel Sheet.

Step 3. Synthesizing results
After the completion of the computation process of all scores of components from brazing filler metal to thermostat obtained from evaluators 1 to 3, their total scores can be computed simultaneously. Table 3 summarises the result.

Finally components can be categorized to four groups by total score compared with five-point rating scale score. Group A, the score is more than 0.30, means the critical component group that consists of internal steel sheet and electric control box. The second important group is B. External steel sheet, heater and brazing filler metal those score is over 0.20 are members of Group B. Following is Group C those members, lagging, magnesium bar, socket, sensor and diffuser, are bigger than 0.13. The last group is D. Group D has non-critical components those are thermostat, thermometer, rubber packing and floating value. The score are less than 0.129. This is illustrated in the hierarchy of strategic importance components groups in Figure 4.

Table 1. Composite Priority Weights for Strategic Priority Measures

Strategic Priority (criterion)	Local weight	IR	Strategic Priority Measures (sub-criterion)	Local weight	IR	Global weight	Rank
Quality	0.421		Component durability	0.477		0.201	2
			Component reliability	0.378	0.00	0.159	3
			Component innovation	0.145		0.061	7
Availability	0.118		Volume flexibility	0.566		0.067	5
			Modification flexibility	0.233	0.01	0.027	10
		0.01	Technological capability	0.201		0.024	11
Cost	0.348		Purchasing cost	0.613		0.213	1
			Inventory cost	0.221	0.03	0.077	4
			Quality assurance	0.166		0.058	8
Time	0.113		Delivery speed	0.286		0.032	9
			Delivery reliability	0.572	0.02	0.065	6
			Development speed	0.142		0.016	12
Total	1.000		Total			1.000	

Table 2. Computation Spreadsheet of Total Scores given to Brazing Filler Metal and Internal Steel Sheet by Evaluator 1

Strategic Priority	Strategic Priority Measures	Global weight	Brazing Filler Metal			Internal Steel Sheet		
			Rating	Score	Score x global weight	Rating	Score	Score x global weight
Quality	Component durability	0.201	H	0.261	0.052	H	0.261	0.052
	Component reliability	0.159	H	0.261	0.041	H	0.261	0.041
	Component innovation	0.061	H	0.261	0.016	H	0.261	0.016
Availability	Volume flexibility	0.067	H	0.261	0.017	H	0.261	0.017
	Modification flexibility	0.027	M	0.129	0.003	M	0.129	0.003
	Technological capability	0.024	H	0.261	0.006	H	0.261	0.006
Cost	Purchasing cost	0.213	H	0.261	0.056	VH	0.513	0.109
	Inventory cost	0.077	H	0.261	0.020	H	0.261	0.020
	Quality assurance	0.058	L	0.063	0.004	L	0.063	0.004
Time	Delivery speed	0.032	H	0.261	0.008	H	0.261	0.008
	Delivery reliability	0.065	H	0.261	0.017	H	0.261	0.017
	Development speed	0.016	M	0.129	0.002	VL	0.034	0.001
Total scores					0.242			0.294

Table 3. Summary of Scores and Ranking of Components in Electric Boiler

Component	Evaluator 1		Evaluator 2		Evaluator 3		Total	
	Score	Rank	Score	Rank	Score	Rank	Mean score	Rank
Brazing Filler Metal	0.242	3	0.178	5	0.216	4	0.212	5
Internal Steel Sheet	0.294	1	0.347	1	0.291	1	0.311	1
External Steel Sheet	0.242	3	0.239	3	0.239	3	0.240	3
Heater	0.216	5	0.231	4	0.197	5	0.215	4
Lagging	0.152	6	0.162	6	0.166	8	0.160	6
Rubber Packing	0.073	12	0.076	14	0.080	13	0.076	13
Magnesium Bar	0.143	7	0.145	8	0.175	7	0.154	7
Sensor	0.123	8	0.145	8	0.149	10	0.139	9
Socket	0.116	9	0.148	7	0.180	6	0.148	8
Diffuser	0.107	10	0.130	10	0.166	8	0.134	10
Electric Control Box	0.287	2	0.327	2	0.288	2	0.301	2
Thermometer	0.073	12	0.118	11	0.107	12	0.099	12
Floating Valve	0.052	14	0.079	13	0.078	14	0.070	14
Thermostat	0.093	11	0.118	11	0.110	11	0.107	11
Total	2.213		2.443		2.441		2.366	

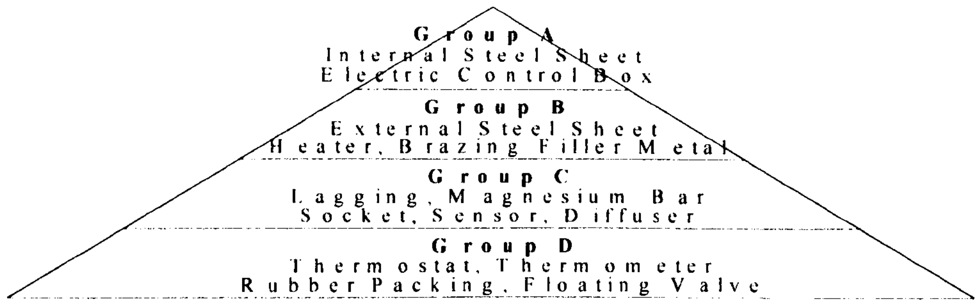

Figure 4. Hierarchy of Components Groups

5. CONCLUSION

Today's manufacturers usually assemble purchased components including materials. Purchasing components is viewed as critical activity for assembly equipment manufacturing industry. First, in this paper, four strategic priorities were identified as criteria, and the priority measures as the sub-criteria, and then an AHP model was formulated to group the component. The proposed AHP model is applicable to any problem of grouping components. After finding the global priority weights, they can be used to determine the final composite priority weights of component occupying the last level hierarchy.

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Appendix 3

The questionnaire

Section A: Company Data

(A1) What is the name of your Industry?

____

(A2) What is the position of your company in the supply chain?

____

(A3). Indicate the type of manufacturing process of your company.

_____Lean (mass production with no customisation or specialization available)

_____Agile (volume production with customisation and specialization available)

_____Hybrid (combination of Lean and Agile manufacturing processes)

(A4) What is the process complexity of *your company*?

_____Very High _____High _____Moderate _____Low _____Very Low

(A5) What is the level of competition in your industry?

_____Very High _____High _____Moderate _____Low _____Very Low

(A6) What is the rate of innovation in your industry?

_____Very High _____High _____Moderate _____Low _____Very Low

(A7) What is the size of your company based on Market Capital (2005 year)?

____

(A8) What is the size of your company based on labour force?

____

(A9) Your current job title?

____Purchasing Manager ____General Manager ____Other Purchasing Job

____Other (   )

(A10) Experience as the current job?

_____< 5 years _____5~10 years _____10~15 years _____> 15 years

Section B: Product Data

(B1) What is the name of your product(s)/category?

____

(B2) Indicate the type of product(s)/category of your company.

_____Make to Stock

_____Assembling to Order

_____Make to Order

_____Engineering to Order

(B3) What is the market winner in competitive priorities of your product(s)?

_____ Quality _____ Cost _____ Availability _____ Time

(B4) What is variety of product based on one category?

____ < 10 goods ____ 10~50 goods ____ 50~100 goods ____ > 100 goods

(B5) What is the sales volume of your product(s) at last year?

_____ < 1 Thousand _____ 1~100 Thousand _____ > 100 Thousand

(B6) What is the life cycle of your product(s)?

_____ < 3 months _____ 3~12 months _____ 1~2 years _____ > 2 years

(B7) What is the level of stockout rate in your product(s)?

_____ < 2 % _____ 2~10 % _____ 10~40 % _____ > 40 %

(B8) What is the level of purchasing component charge rate in your product(s)?

_____ < 20 % _____ 20~40 % _____ 40~70 % _____ > 70 %

(B9) What is the level of margin rate in your product(s)?

_____ < 10 % _____ 10~20 % _____ 20~50 % _____ > 50 %

Section C: Criteria and Sub-criteria Data

Circle the desired number of Intensity of importance between 0 and 9 in the table.

(C1) Decide which of the two criteria, left or right criterion considered when you purchase a component is more important, and how much more important it is:

Criteria	Importance ←								Equality	→ Importance								Criteria
Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time
Availability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time
Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Time

(C2) Decide which of the two sub-criteria, left or right sub-criterion in **quality** considered when you purchase a component is more important, and how much more important it is:

Sub-criteria	Importance ←								Equality	→ Importance								Sub-criteria
Component durability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Component reliability
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Component innovation
Component reliability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Component innovation

(C3) Decide which of the two sub-criteria, left or right sub-criterion in **availability** considered when you purchase a component is more important, and how much more important it is:

Sub-criteria	Importance ⟵								Equality							⟶	Importance	Sub-criteria
Volume flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Modification flexibility
Volume flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological capability
Modification flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological capability

(C4) Decide which of the two sub-criteria, left or right sub-criterion in **cost** considered when you purchase a component is more important, and how much more important it is:

Sub-criteria	Importance ⟵								Equality							⟶	Importance	Sub-criteria
Purchasing cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Inventory cost
Purchasing cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quality cost
Inventory cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quality cost

(C5) Decide which of the two sub-criteria, left or right sub-criterion in **time** considered when you purchase a component is more important, and how much more important it is:

Sub-criteria	Importance ⟵								Equality							⟶	Importance	Sub-criteria
Delivery speed	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Delivery reliability
Delivery speed	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Development speed
Delivery reliability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Development speed

Section D: Component Data

(Q) What is the name of component?

____

D1. Quality

(D1.1) What is the rate of durability of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D1.2) What is the rate of reliability of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D1.3) What is the rate of innovation of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

D2. Availability

(D2.1) What is the rate of volume flexibility of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D2.2) What is the rate of modification flexibility of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D2.3) What is the rate of technological capabilities of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

D3. Cost

(D3.1) What is the rate of purchasing cost of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D3.2) What is the rate of inventory cost of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D3.3) What is the rate of quality cost of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

D4. Time

(D4.1) What is the rate of delivery speed of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D4.2) What is the rate of delivery reliability of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

(D4.3) What is the rate of development speed of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

D5. Supply risk

(D5.1) What is the risk of supply market of the above component in your product(s)?

_____Very High _____High _____Moderate _____Low _____Very Low

Appendix 4

Pair-wise comparison matrices

Table A.1 Pair-wise comparison matrices of components value by Evaluator-2 in Company-A

Goal	Quality	Cost	Availability	Time
Quality	1	1/2	1	2
Cost	2	1	1	2
Availability	1/2	1/2	1	2
Time	1/2	1/2	1/2	1
				Consistency Ratio C.R.=0.02

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	3
Component reliability	1/2	1	2
Component innovation	1/2	1/2	1
			C.R.=0.02

Cost	Purchasing cost	Inventory cost	*Quality* cost
Purchasing cost	1	5	4
Inventory cost	1/5	1	1/2
Quality cost	1/4	2	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/3	1/2
Modification flexibility	3	1	2
Technological capability	2	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	4
Development speed	1/3	1/4	1
			C.R.=0.02

Table A.2 Pair-wise comparison matrices of components value by Evaluator-3 in Company-A

Goal	Quality	Cost	Availability	Time
Quality	1	1/2	2	2
Cost	2	1	2	4
Availability	1/2	1/2	1	2
Time	1/2	1/4	1/2	1
				Consistency Ratio C.R.=0.02

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	3
Component reliability	1/2	1	2
Component innovation	1/3	1/2	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	7	4
Inventory cost	1/7	1	1/2
Quality cost	1/4	2	1
			C.R.=0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/3	1/2
Modification flexibility	3	1	2
Technological capability	2	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	2
Delivery reliability	2	1	3
Development speed	1/2	1/3	1
			C.R.=0.01

Table A.3 Pair-wise comparison matrices of components value by Evaluator-4 in Company-A

Goal	Quality	Cost	Availability	Time
Quality	1	1	2	2
Cost	1	1	5	5
Availability	1/2	1/5	1	3
Time	1/2	1/5	1/3	1
			Consistency Ratio C.R.=0.10	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	3
Component reliability	1	1	2
Component innovation	1/3	1/2	1
			C.R.=0.02

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	4	2
Inventory cost	1/4	1	1/3
Quality cost	1/2	3	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/4	1/2
Modification flexibility	4	1	3
Technological capability	2	1/3	1
			C.R.=0.02

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	2
Delivery reliability	1	1	3
Development speed	1/2	1/3	1
			C.R.=0.02

Table A.4 Pair-wise comparison matrices of components value by Evaluator-1 in Company-B

Goal	Quality	Cost	Availability	Time
Quality	1	1/2	1/2	2
Cost	2	1	1/2	2
Availability	2	2	1	3
Time	1/2	1/3	1/2	1
			Consistency Ratio C.R.=0.03	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	5
Component reliability	1/2	1	3
Component innovation	1/5	1/3	1
			C.R.=0.00

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	7	4
Inventory cost	1/7	1	1/2
Quality cost	1/4	2	1
			C.R.=0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/5	1/3
Modification flexibility	5	1	2
Technological capability	3	1/2	1
			C.R.=0.00

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	8
Development speed	1/3	1/8	1
			C.R.=0.01

Table A.5 Pair-wise comparison matrices of components value by Evaluator-2 in Company-B

Goal	Quality	Cost	Availability	Time
Quality	1	1	1	3
Cost	1	1	1	3
Availability	1	1	1	2
Time	1/3	1/3	1/2	1
				Consistency Ratio C.R.=0.01

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	3
Component reliability	1	1	3
Component innovation	1/3	1/3	1
			C.R.=0.00

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	5	4
Inventory cost	1/5	1	1/2
Quality cost	1/4	2	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/4	1/2
Modification flexibility	4	1	3
Technological capability	2	1/3	1
			C.R.=0.02

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	8
Development speed	1/3	1/8	1
			C.R.=0.01

Table A.6 Pair-wise comparison matrices of components value by Evaluator-3 in Company-B

Goal	Quality	Cost	Availability	Time
Quality	1	1/3	1/3	4
Cost	3	1	1	5
Availability	3	1	1	6
Time	1/4	1/5	1/6	1
				Consistency Ratio C.R.=0.03

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	4
Component reliability	1	1	3
Component innovation	1/4	1/3	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	5	3
Inventory cost	1/5	1	1/2
Quality cost	1/3	2	1
			C.R.=0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/3	1/2
Modification flexibility	3	1	2
Technological capability	2	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	3
Delivery reliability	1	1	4
Development speed	1/3	1/4	1
			C.R.=0.01

Table A.7 Pair-wise comparison matrices of components value by Evaluator-4 in Company-B

Goal	Quality	Cost	Availability	Time
Quality	1	1/2	1/3	3
Cost	2	1	1/2	3
Availability	3	2	1	4
Time	1/3	1/3	1/4	1
				Consistency Ratio C.R.=0.03

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	4
Component reliability	1/2	1	2
Component innovation	1/4	1/2	1
			C.R.=0.00

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	7	4
Inventory cost	1/7	1	1/2
Quality cost	1/4	2	1
			C.R.=0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/4	1/2
Modification flexibility	4	1	3
Technological capability	2	1/3	1
			C.R.=0.02

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/3	3
Delivery reliability	3	1	6
Development speed	1/3	1/6	1
			C.R.=0.02

Table A.8 Pair-wise comparison matrices of components value by Evaluator-5 in Company-B

Goal	Quality	Cost	Availability	Time
Quality	1	1/5	3	4
Cost	5	1	5	5
Availability	1/3	1/5	1	2
Time	1/4	1/5	1/2	1
			Consistency Ratio C.R.=0.09	
Quality	**Component durability**	**Component reliability**	**Component innovation**	
Component durability	1	1	1	
Component reliability	1	1	1	
Component innovation	1	1	1	
			C.R.=0.00	
Cost	**Purchasing cost**	**Inventory cost**	**Quality cost**	
Purchasing cost	1	7	7	
Inventory cost	1/7	1	2	
Quality cost	1/7	1/2	1	
			C.R.=0.05	
Availability	**Volume flexibility**	**Modification flexibility**	**Technological capability**	
Volume flexibility	1	3	2	
Modification flexibility	1/3	1	1	
Technological capability	1/2	1	1	
			C.R.=0.02	
Time	**Delivery speed**	**Delivery reliability**	**Development speed**	
Delivery speed	1	1/5	1/5	
Delivery reliability	5	1	2	
Development speed	5	1/2	1	
			C.R.=0.05	

Table A.9 Pair-wise comparison matrices of components value by Evaluator-1 in Company-C

Goal	Quality	Cost	Availability	Time
Quality	1	1	1/2	3
Cost	1	1	1/2	2
Availability	2	2	1	4
Time	1/3	1/2	1/4	1
			Consistency Ratio C.R.=0.01	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	4
Component reliability	1/2	1	3
Component innovation	1/4	1/3	1
			C.R.=0.02

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	6	3
Inventory cost	1/6	1	1/3
Quality cost	1/3	3	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/3	1/2
Modification flexibility	3	1	2
Technological capability	2	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	3
Development speed	1/3	1/3	1
			C.R.=0.05

Table A.10 Pair-wise comparison matrices of components value by Evaluator-2 in Company-C

Goal	Quality	Cost	Availability	Time
Quality	1	1	1	2
Cost	1	1	1	3
Availability	1	1	1	2
Time	1/2	1/3	1/2	1
			Consistency Ratio C.R.=0.01	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	3
Component reliability	1	1	3
Component innovation	1/3	1/3	1
			C.R.=0.00

Cost	Purchasing cost	*Inventory* cost	*Quality* cost
Purchasing cost	1	8	3
Inventory cost	1/8	1	1/5
Quality cost	1/3	5	1
			C.R.=0.04

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/2	1/2
Modification flexibility	2	1	1
Technological capability	2	1	1
			C.R.=0.00

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	2
Delivery reliability	1	1	2
Development speed	1/2	1/2	1
			C.R.=0.00

Table A.11 Pair-wise comparison matrices of components value by Evaluator-3 in Company-C

Goal	Quality	Cost	Availability	Time
Quality	1	1	1/2	3
Cost	1	1	1/2	3
Availability	2	2	1	3
Time	1/3	1/3	1/3	1
			Consistency Ratio C.R.=0.02	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	3
Component reliability	1/2	1	2
Component innovation	1/3	1/2	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	5	2
Inventory cost	1/5	1	1/2
Quality cost	1/2	2	1
			C.R.=0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/2	1/2
Modification flexibility	2	1	1
Technological capability	2	1	1
			C.R.=0.00

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	3
Delivery reliability	1	1	4
Development speed	1/3	1/4	1
			C.R.=0.01

Table A.12 Pair-wise comparison matrices of components value by Evaluator-1 in Company-D

Goal	Quality	Cost	Availability	Time
Quality	1	2	1	3
Cost	1/2	1	1/3	2
Availability	1	3	1	5
Time	1/3	1/2	1/5	1
			Consistency Ratio C.R.=0.01	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	2
Component reliability	1	1	2
Component innovation	1/2	1/2	1
			C.R.=0.00

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	6	2
Inventory cost	1/6	1	1/2
Quality cost	1/2	2	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/4	1/2
Modification flexibility	4	1	3
Technological capability	2	1/3	1
			C.R.=0.02

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	4
Delivery reliability	1	1	3
Development speed	1/4	1/3	1
			C.R.=0.01

Table A.13 Pair-wise comparison matrices of components value by Evaluator-2 in Company-D

Goal	Quality	Cost	Availability	Time
Quality	1	2	1/2	3
Cost	1/2	1	1/3	3
Availability	2	3	1	5
Time	1/3	1/3	1/5	1
			Consistency Ratio C.R.=0.02	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	4
Component reliability	1	1	3
Component innovation	1/4	1/3	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	4	2
Inventory cost	1/4	1	1/2
Quality cost	1/2	2	1
			C.R.=0.00

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/3	1/2
Modification flexibility	3	1	2
Technological capability	2	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	4
Delivery reliability	1	1	4
Development speed	1/4	1/4	1
			C.R.=0.00

Table A.14 Pair-wise comparison matrices of components value by Evaluator-3 in Company-D

Goal	Quality	Cost	Availability	Time
Quality	1	2	1	3
Cost	1/2	1	1/2	3
Availability	1	2	1	3
Time	1/3	1/3	1/3	1
				Consistency Ratio C.R.=0.02

Quality	Component durability	Component reliability	Component innovation
Component durability	1	2	3
Component reliability	1/2	1	2
Component innovation	1/3	1/2	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	4	3
Inventory cost	1/4	1	1/5
Quality cost	1/3	5	1
			C.R.=0.01

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/3	1/2
Modification flexibility	3	1	2
Technological capability	2	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1	2
Delivery reliability	1	1	3
Development speed	1/2	1/3	1
			C.R.=0.02

Table A.15 Pair-wise comparison matrices of components value by Evaluator-4 in Company-D

Goal	Quality	Cost	Availability	Time
Quality	1	3	1	5
Cost	1/3	1	1/2	2
Availability	1	2	1	5
Time	1/5	1/2	1/5	1
			Consistency Ratio C.R.=0.01	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	3
Component reliability	1	1	3
Component innovation	1/3	1/3	1
			C.R.=0.00

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	4	2
Inventory cost	1/4	1	1/3
Quality cost	1/2	3	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	1/4	1/3
Modification flexibility	4	1	2
Technological capability	3	1/2	1
			C.R.=0.02

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	4
Development speed	1/3	1/4	1
			C.R.=0.02

Table A.16 Pair-wise comparison matrices of the competitive priorities by Evaluator-2 in the electric boiler manufacturer

Goal	Quality	Cost	Availability	Time
Quality	1	1	3	3
Cost	1	1	3	3
Availability	1/3	1/3	1	1
Time	1/3	1/3	1	1
			Consistency Ratio C.R.=0.00	

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	4
Component reliability	1	1	3
Component innovation	1/4	1/3	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	3	3
Inventory cost	1/3	1	2
Quality cost	1/3	1/2	1
			C.R.=0.05

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	2	3
Modification flexibility	1/2	1	2
Technological capability	1/3	1/2	1
			C.R.=0.01

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	2
Delivery reliability	2	1	3
Development speed	1/2	1/3	1
			C.R.=0.01

Table A.17 Pair-wise comparison matrices of the competitive priorities by Evaluator-3 in the electric boiler manufacturer

Goal	Quality	Cost	Availability	Time
Quality	1	1	5	3
Cost	1	1	3	2
Availability	1/5	1/3	1	1
Time	1/3	1/2	1	1
				Consistency Ratio C.R.=0.02

Quality	Component durability	Component reliability	Component innovation
Component durability	1	1	3
Component reliability	1	1	3
Component innovation	1/3	1/3	1
			C.R.=0.01

Cost	Purchasing cost	Inventory cost	Quality cost
Purchasing cost	1	3	2
Inventory cost	1/3	1	1
Quality cost	1/2	1	1
			C.R.=0.02

Availability	Volume flexibility	Modification flexibility	Technological capability
Volume flexibility	1	3	2
Modification flexibility	1/3	1	2
Technological capability	1/2	1	1
			C.R.=0.02

Time	Delivery speed	Delivery reliability	Development speed
Delivery speed	1	1/2	3
Delivery reliability	2	1	3
Development speed	1/3	1/3	1
			C.R.=0.05

Appendix 5

An example of demonstration of AHP calculation

Demonstration of AHP calculation for four criteria in Company-A

Using the geometric mean approach from Equation (3-2), the corresponding consensus pair-wise comparison matrix of four criteria in Company-A is obtained from Table 5.4 and Tables A.1-A.2, as shown in Table A.18.

Table A.18 Pair-wise comparison matrix of four criteria in Company-A from Table 5.5

Goal	Quality	Cost	Availability	Time
Quality	1	0.6	1.6	2.5
Cost	1.6	1	1.6	2.9
Availability	0.6	0.6	1	2.0
Time	0.4	0.3	0.5	1
Column sum	3.61	4.69	2.60	8.42

The weightings in Table A.18 are then normalised, by dividing each entry in a column by the sum of all the entries in that column, so that they add up to one. For example, considering a_{11}, so a_{11} = 1/3.61 = 0.277. Similarly, other elements of matrix are performed and shown in Table A.19. Following normalisation, the weights are averaged across the rows to give an average weight for each criterion. For example, for row 1, average is (0.277 + 0.242 + 0.340 + 0.330)/4 = 0.289. Similarly, average for the remaining rows are calculated and shown in Table A.19.

Table A.19 Normalised pair-wise comparison matrix of four criteria in Company-A

Goal	Quality	Cost	Availability	Time	Row average
Quality	0.277	0.242	0.340	0.300	0.289
Cost	0.439	0.384	0.340	0.343	0.376
Availability	0.174	0.242	0.214	0.238	0.217
Time	0.110	0.133	0.107	0.119	0.117
Column sum	1.000	1.000	1.000	1.000	1.000

Multiply the matrix of comparisons in Table A.18 with the row average in Table A.19 to get the weights related to each attribute:

$$\begin{matrix} Quality \\ Cost \\ Availability \\ Time \end{matrix} = 0.289\begin{bmatrix} 1.0 \\ 1.6 \\ 0.6 \\ 0.4 \end{bmatrix} + 0.376\begin{bmatrix} 0.6 \\ 1.0 \\ 0.6 \\ 0.3 \end{bmatrix} + 0.217\begin{bmatrix} 1.6 \\ 1.6 \\ 1.0 \\ 0.5 \end{bmatrix} + 0.117\begin{bmatrix} 2.5 \\ 2.9 \\ 2.0 \\ 1.0 \end{bmatrix} = \begin{bmatrix} 1.166 \\ 1.518 \\ 0.871 \\ 0.471 \end{bmatrix}$$

Divide each element of the above matrix expression with their respective row average shown in Table A.19 to get the individual weight of the attributes:

$$\begin{matrix} Quality \\ Cost \\ Availability \\ Time \end{matrix} = \begin{bmatrix} 1.166/0.289 \\ 1.518/0.376 \\ 0.871/0.217 \\ 0.471/0.117 \end{bmatrix} = \begin{bmatrix} 4.029 \\ 4.034 \\ 4.014 \\ 4.019 \end{bmatrix}$$

The average of these values is called eigenvalue λ_{max}:

$$\lambda_{max} = \frac{4.029 + 4.034 + 4.014 + 4.019}{4} = 4.024$$

The consistency index of this matrix is calculated using Equation (3-4):

$$C.I. = \frac{\lambda_{max} - n}{n - 1} = \frac{4.024 - 4}{4 - 1} = 0.008$$

For matrix of size 4, the value of the random index (I.R.) = 0.89 (Table 3.2), and the consistency ratio (C.R.) of this matrix is obtained using Equation (3-5):

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.008}{0.89} = 0.01$$

Since, C.R. < 0.08 for n=4, the judgments made are acceptable.