A Decision Tool for Supplier Selection That Takes into Account Power and Performance

Thesis

A DECISION TOOL FOR SUPPLIER SELECTION THAT TAKES INTO ACCOUNT POWER AND PERFORMANCE

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Abstract

Companies select their suppliers to provide required performance while being successful partners. An important aspect of collaboration is the power relationship between the company and its suppliers. Although the significance of power in supplier selection is acknowledged, published work rarely includes assessment of power. An empirical study on selecting suppliers for new product developments in a major European diesel engine manufacturing company, supported by three smaller studies with electronic engineering companies, frames overall questions regarding the importance of incorporating power into supplier selection and how this might be achieved.

This research proposes an approach that assesses both performance and power and integrates the assessment results by modelling the relative effects of power and performance. It positions the suppliers into six scenarios (ideal, satisfying, tolerable, unfavourable, risky and tough) which depict to what extent a supplier is 'suitable' to work with. A reverse analysis reviews the relationship when several suppliers appear suitable.

An assessment method is developed incorporating both subjective and objective data for qualitative and quantitative criteria. It combines two decision making methods, AHP and TOPSIS, with triangular fuzzy numbers. Multiple judgements from several decision makers are synthesised. This method is adapted for performance assessment of single, group and cross-group suppliers. Weights are calculated for the criteria, and combined with calculations of supplier performance against each criterion to provide an overall assessment and supplier profile. Power is quantified against a set of power determinants and power relations (supplier dominance, buyer dominance and balanced) are determined. The effects of supplier perceptions (objective, optimistic and pessimistic) are estimated in the calculation.

The proposed approach involves complex calculations and a prototype software tool is developed with graphical interfaces. The tool includes performance criteria and power determinants collected from literature and allows users to define new ones. Application to an agriculture case enables the sustainable performance of suppliers (farmers) to be evaluated and compared.

To my mum, Xiaojing Liu

Thank you for all your support, love and friendship

感谢我的母亲柳晓静

谢谢你无私的爱和支持

Declaration

This thesis is the result of my own research and does not include the outcome of work done in collaboration, except where otherwise stated. This thesis has not been submitted in whole or part for consideration for any other degree.

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List of Acronyms

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ANP	Analytic Network Process
BD	Buyer Dependence
BOM	Bill of Material
BP	Buyer Power
DEA	Data Envelopment Analysis
DRM	Design Research Methodology
ECM	Electronic Control Module
ELECTRE	ELimination Et Choix Traduisant la REalité
FBBI	Feature Based Business Intelligence
FIS	Fuzzy Inference System
GA	Genetic Algorithm
GP	Goal Programming
GSND	Global Supply Network Division
KPI	Key Performance Indicator
JIT	Just-In-Time
LP	Linear Programming
MCDM	Multiple Criteria Decision Making
MIP	Mixed Integer Programming
MP	Mathematical Programming
NIS	Negative Ideal Solution
NPI	New Product Introduction
OEM	Original equipment manufacturer
PIS	Positive Ideal Solution
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
TFN	Triangular Fuzzy Number
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
SD	Supplier Dependence
SME	Small and Medium-sized Enterprise
SP	Supplier Power
STEEP	Social, Technological, Economic, Environmental and Political
TQM	Total Quality Management
VMI	Vendor Managed Inventory

List of notations

A^*	the positive ideal solution
A^-	the negative ideal solution
C_i^*	the relative similarity to the ideal solutions of supplier *i*
$\tilde{c}_{ij}$	the relative importance of criterion *i* over another *j*
D_i^*	the distance to the positive ideal solution of supplier *i*
D_i^-	the distance to the negative ideal solution of supplier *i*
D(X/Y)	X's dependence on Y
D(Y/X)	Y's dependence on X
$F(\tilde{w}_i)$	the function that calculates the crisp value associated with the TFN $\tilde{w}_i$
P(X/Y)	the power of X over Y
P(Y/X)	the power of Y over X
PA(X/Y)	the power advantage of X over Y
Pfull(X/Y)	a full estimation of the power of X over Y
Pposs(X/Y)	an estimation of the power of X over Y, taking into account the perspective of Y
U(X/Y)	the dependence-irrelevant power of X
U(Y/X)	the dependence-irrelevant power of Y
$V(\tilde{w}_1 \geq \tilde{w}_2)$	the degree of possibility of $\tilde{w}_1 \geq \tilde{w}_2$
$\tilde{w}_i$	the fuzzy weight of criterion *i*
w_i	the crisp weight of criterion *i*

Chapter 1 Introduction

Competition has shifted from company versus company to supply chain versus supply chain (Christopher, 2011). The performance from suppliers is a key factor in the efficiency and effectiveness of a supply chain. Working with suppliers of high capability plays a significant role in the success of a company's business (Johnsen, 2009; Echtelt et al., 2008). Therefore, selecting suitable suppliers is critical. However, it is a complex decision process. There are 'hard' criteria for selection like quality, price, delivery, technology and financial status, which reflect the potential performance a supplier could offer. There are also 'soft' factors, which influence what the company can actually obtain, such as available alternative suppliers, purchased volume, switching cost or the importance of the purchased product. These factors reflect the ability to influence the supplier as well as the buyer in a relationship. The factors also give the buyer and supplier a degree of power over each other. These factors should also be taken into account during supplier selection.

This thesis proposes a supplier selection approach supported by a software tool, which considers both hard performance criteria and soft factors in the power relationship between the buyer and the supplier. Petersen et al. (2005, p. 372) describe the supplier selection problem with a metaphor:

"*Suppliers are like fish in the ocean. We (the buyers) are the fishermen. The key challenge facing us is how to put out the right bait, so that we can pull up the right suppliers at the right time and get them to help us develop our products. There are several problems associated with fishing: How do we know we are using the right bait? How do we know the right kinds of fish are in the water? Most importantly, when we catch a fish, how do we know whether it is the right fish, and whether we should keep it or throw it back in the water? Finally, how do we know the fish will follow through with its commitments if we decide to keep it?*"

To ‘catch’ a suitable supplier can be seen as the most crucial step in collaboration, because the company and the supplier will work together to create value and good supplier performance increases the chances of successfully delivering the product into the market. This thesis addresses the question of how to select a ***suitable*** supplier in terms of both ‘hard’ criteria and ‘soft’ factors. In order to introduce this question and its complexity the first section examines these hard criteria and soft factors in terms of how they contribute to the power relationship between supplier and buyer.

1.1 Problem illustration

The importance of power relationships between supplier and buyer is illustrated by a recent highly published problem in the production of Volkswagen (VW) cars.

On 17th August 2016, VW announced that the production of its top-selling Golf model at Wolfsburg was curtailed because supplier ES Automobilguss GmbH refused to deliver cast iron parts needed to make gearboxes[1]. Earlier in the same month, supplier Car Trim GmbH, a sister company of ES Automobilguss, had stopped the deliveries of seat covers to VW’s Emden plant in northern Germany. About 28,000 workers at six of VW’s German factories were affected by this supplier dispute. It was estimated that one-week production halt at its Wolfsburg headquarters would lead to about 100 million euros in lost gross profits. The reason of the dispute according to the suppliers was that VW had refused to offer compensation after cancelling the contracts without giving a reason.

After more than 20 hours negotiation, VW and the two automotive parts suppliers reached agreement announced on 23rd August. The suppliers agreed to resume the deliveries. The supplier ES Automobilguss announced a long-term partnership (at least another six years) had been decided that would secure more than 600 jobs at the company. Though the dispute had been resolved, it had knock-on effects to other suppliers.

[1] Source: a series of news reports on Volkswagen’s two key suppliers stopping deliveries, from Reuter News Agency http://www.reuters.com/

As Europe's largest automotive manufacturer, VW is considered to be in a powerful position. However, this dispute warned VW that they might not have as much power over their suppliers as they had assumed. For example, VW had previously indicated it would seek price cuts from its suppliers to mitigate the costs of an emission-test cheating scandal. However, VW should not have assumed that the suppliers would accept any demand without resisting. This dispute has shown that it can be the buyer (VW) rather than the supplier who suffers the consequences. VW has power because of its size, brand effect and market share. But ES Automobilguss also has power, because of the importance of its product and the time it would take any other supplier to set up production.

Possessing power over suppliers does not necessarily mean a company will use the power. People in the industry had not expected that a supplier would seek open conflict with VW. However, if intending to exert power, a company needs to know who, the supplier or itself, has greater power in the relationship. The earlier they know this relative position, the better they can deal with the buyer-supplier relationship. The question emerges: what is this relative position and how can it be used in supplier analysis.

1.2 Research Motivation

This PhD research grew out of the author's involvement with the European Framework 7 CONVERGE project (2009-2011), where she participated as a researcher in Bordeaux, France. The aim of this project was to support collaboration on both the strategic and tactical levels by ensuring that communication across the supply chains is based on relevant and up-to-date information from the network partners.

Four electronic manufacturers were industry partners who provided case studies. The project investigated their supply chains, organisation and IT structures, their information exchange with customers and suppliers as well as the problems and requirements for communication. Interviews with the project partners led to the following observations:

- The quality of the supplier plays a significant role in the quality of the product. All manufacturers put significant efforts into establishing the quality of their suppliers. One manufacturer in automotive industry, who produces electronic systems, established an audit for suppliers in order to detect problems and conflicts in terms of quality and production capabilities. Another innovative SME (Small and Medium-sized Enterprise) evaluated and tracked its supplier performance in terms of the provided product quality and technical and economic solutions.
- Power relationships exist between the manufacturers and their suppliers/customers. Power relationships influence both communication and collaboration. The automotive industry manufacturer had a ‘balanced’ position with its suppliers, which enhanced the communication. However, the relationship with some of its customers seemed less balanced, as some long-term customers often changed their requirements, which increased the financial cost. This required reallocation of resources and renegotiation with suppliers. As these are predominantly ‘important’ customers for the manufacturer, most of these customers’ requests were accommodated.

A company increases its chances of successful collaboration, if it understands what performance can be offered by a supplier and who is in a relatively advantageous position. But the question is how can a company assess this in the selection stage? The aim of this thesis is to address this question.

1.3 Preliminary research questions

This thesis is based on two preliminary research questions. The first is the starting point for the work and has prompted a detailed examination on the existing research. The results of the examination have supported the second preliminary research question by identifying the gaps in the literature and further refined the research questions (see Chapter 2 for details). The first preliminary research question is to understand the supplier selection problem.

Preliminary research question 1 (Q1): How are suppliers assessed and selected?

This question leads to the exploration of supplier selection in terms of criteria, methods used, and the effects of power considerations. Five supporting sub-research questions are:

- What are the criteria to assess and select suppliers?
- What techniques or methods exist to assess suppliers?
- How is power defined in a supply chain?
- What determines the power relationship?
- How does the power relationship influence supplier selection?

Selection based on best performance against hard criteria does not necessarily result in a suitable supplier to work with. As illustrated in VW's problem with its suppliers and observed in the cases of the previous project, the power relationship plays a role. The second research question arises to bridge supplier selection and the power relationship.

Preliminary research question 2 (Q2): how can supplier selection be enhanced by including the considerations of power relationship?

This leads to the following sub-questions:

- How does power interact with supplier performance?
- How can the power relationship be incorporated into the analysis of suppliers?

Broadly speaking, the objective of this research is to provide an alternative perspective for decisions about supplier selection. The results of the research can also be applied for tasks such as supplier monitoring and supplier development. The work sets out to develop new knowledge in the area of supply chain design that would benefit industry and academia.

1.4 Thesis structure

In the light of the primary research questions outlined in the previous section, the thesis proceeds as follows. Supplier performance and power relationship are reviewed through both literature and empirical studies. An approach to supplier selection that takes into account assessment of both power and performance is proposed. It is implemented in a software tool, which is evaluated by a practical case as well as being applied to an illustrative case.

The chapters are organised as shown in Figure 1-1. Chapter 2 describes a comprehensive literature review on the supply chain context, supplier assessment and selection criteria, decision making techniques used for assessment, supporting tools and the complexity of decision making in supplier assessment and selection. It also includes a literature review on power concepts, related theories and its measurement. Chapter 3 presents the methodology for this research. Chapter 4 provides a description of supplier assessment and power understanding in industry, based on interviews performed at a European engine company and other three smaller interviews at electronic engineering companies. Building on the results of the literature review and the empirical studies, an approach is proposed in Chapter 5 for supplier selection which analyses the relative position between the buyer and the supplier in terms of power and performance. Assessment methods are proposed in Chapter 6 that quantify supplier performance and power relationships. The assessment methods are implemented in a software tool, described in Chapter 7. The application of the tool and a discussion on the validation are presented in Chapter 8. Conclusions and further research are covered in Chapter 9.

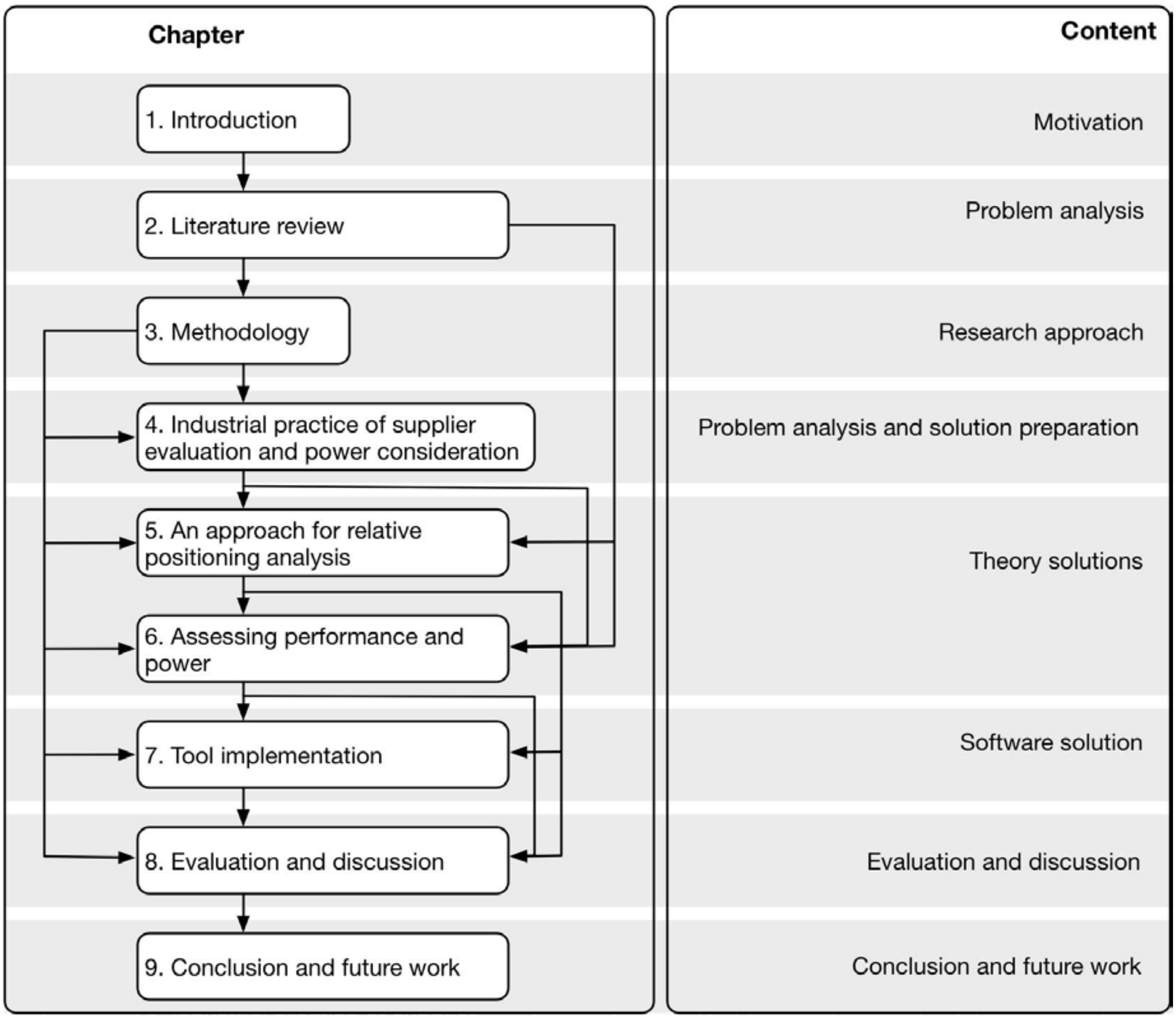


Figure 1-1 Thesis structure

Chapter 2 Literature review

Supplier selection is a decision problem with the purpose of identifying suppliers with high potential of offering what a company needs. Most research focuses on 'hard' performance criteria that reflect what a supplier could offer. A comprehensive literature review explores what criteria have been considered in supplier selection and how suppliers are measured according to different criteria. However, a supplier with top ranked performance might have less interest in collaboration, bargain for more profits, and even lower their performance for specific customers. Cox (2001) argues that buyer-supplier relationships operate in an environment of relative buyer and supplier power. This relative position influences the behaviours of suppliers in terms of the leverage they have before and after establishing a relationship. Thus, a literature review on power in supply chains is also conducted starting in section 2.7. Figure 2-1 presents an overview of this chapter, signposting the key definitions and tables.

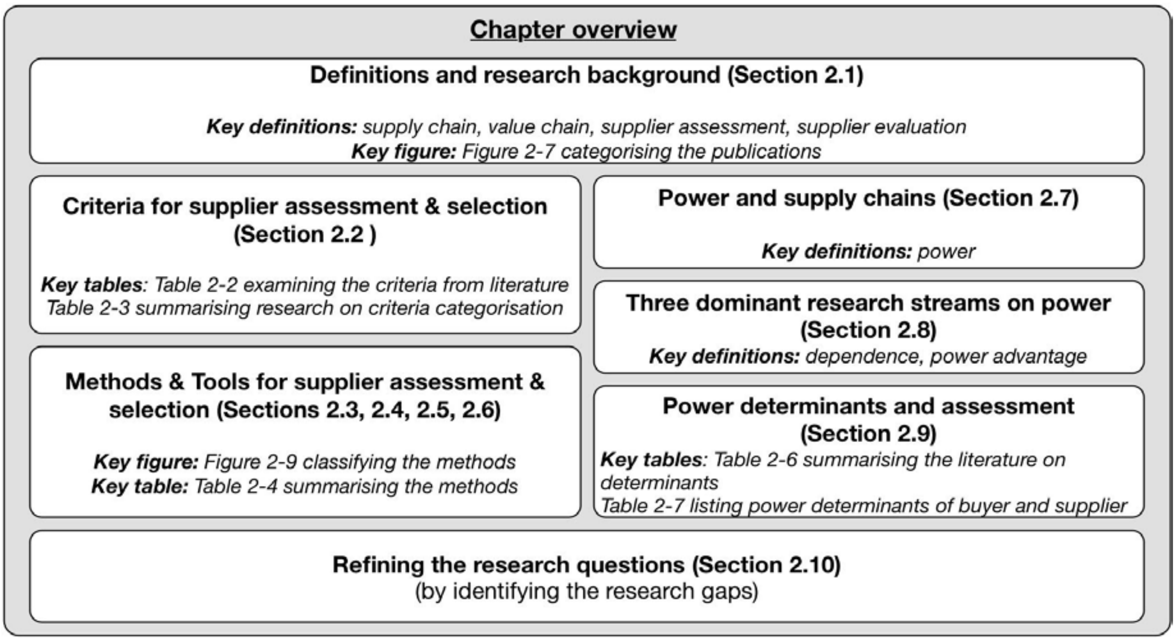


Figure 2-1 Chapter overview

This chapter starts with a description of supply chains. It introduces the problem of supplier selection in general and provides an overview of the published academic literature on this topic. Next, the criteria for supplier selection are examined. The available techniques and methods for assessment are then discussed with regard to their data requirements and ease of use to find suitable techniques to build a straightforward and practical method. Software tools to support the available methods are identified along with the methods exploration.

This chapter then focuses on the literature on power and its application in the supply chain in terms of: (1) how power influences supplier performance and the buyer-supplier relationship; (2) if and how power is considered in supplier selection. The literature analysis identifies the factors that determine power and the ways to measure power based on the main theories. The chapter concludes with the discussion on the research gaps.

2.1 Definitions and research background

The selection of suppliers to collaborate with is regarded as a critical decision (Viswanadham and Samvedi, 2013). To understand this decision-making problem, this section introduces the key definitions and the research background in terms of supply chain, supplier selection and the decision process. It also overviews the published research on this topic. Collaboration is considered as a broad and encompassing term (Barratt, 2004). For the purpose of this research, we adopt the definition from Simatupang and Sridharan (2002) that collaboration is defined as *two or more companies working jointly to plan and execute supply chain operations*. Definitions and key concepts used by the thesis are highlighted with italic styles and quotation marks “” are used if they are directly quoted from literature. There are different depths measuring the integration with partners and different scopes referring to the collaboration areas, which leads to different forms of relationships (Skjoett-Larsen et al., 2003).

2.1.1 Supply chains and their structure

A supply chain is a set of connected and interdependent entities directly involved in the upstream and downstream flows of products, services, finances and/or information (La Londe and Masters, 1994; Mentzer et al., 2001; Harland, 1996). Figure 2-2 shows an example of a manufacturing supply chain from (Mentzer et al., 2001). In this supply chain suppliers provide raw materials and components to support product development and manufacturing; a third party financial provider offers financing and financial advice; a third party logistics provider performs the logistics activities between the organisation and its customers; and a market research organisation investigates consumers' behaviour for the company. A service supply chain is similar in that the exchanged product is a service instead of a physical product.

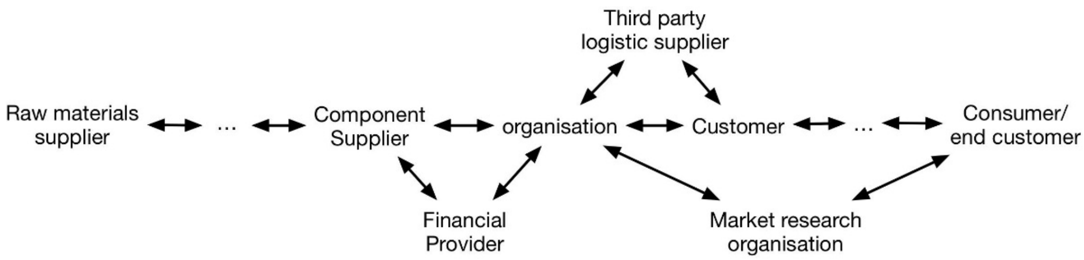


Figure 2-2 A manufacturing supply chain example, adapted from Mentzer et al. (2001)

Along with the flows of the resources in the supply chain, a series of exchange between buyers and suppliers occur, which adds value to the product or service as perceived by the buyer and ultimately by the consumer (Cox et al., 2001). The activities of 'adding value' invoke another perspective on the same chains – the value chain. Following Kaplinsky and Morris (2001, p. 9), *"the value chain describes the full range of activities which are required to bring a product or service from conception, through the different phases of production, delivery to final consumers and final disposal after use."* The value chain describes the flow of revenue from the consumer to the initial supplier. This flow provides the value stream for each stage of the supply chain (Cox, 1999). The supply chain and the value chain have the same structure and Figure 2-3 illustrates the 'exchange' relationship between supply chain and value chain, which links supplied resources and their value.

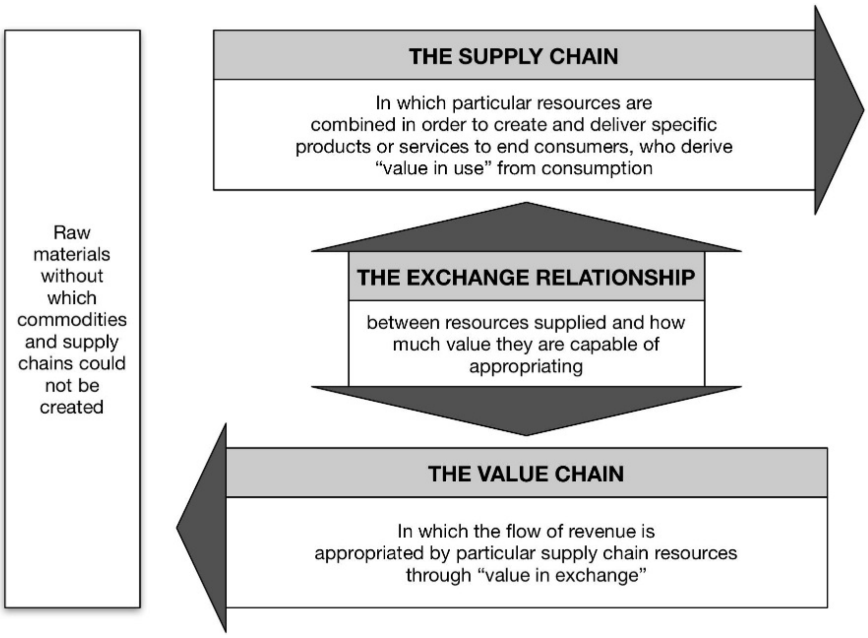


Figure 2-3 Supply and value chain mapping, adapted from Cox (1999)

The focus of the supply chain is on upstream integration of supplier and buyer processes to improve the efficiency, emphasising the buyer-supplier relationship (Cox, 2001). The value chain focuses downstream on creating value. This shift in focus from supplier to customer may be lost in the language used in the business and research literature (Feller et al., 2006). "Supply chains and value chains are synonymous" (Lysons and Farrington, 2012, p. 98). In fact, the idea of 'adding value' is also applied in supply chain management which is defined by the Global Supply Chain Forum (Lambert et al., 1998, p.1) as "the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders"

Analysis of a supply chain generally uses the perspective of a focal company. The roles of the other entities in the supply chain can be roughly categorised into suppliers and customers. In this thesis, the focal company is the buyer in a buyer-supplier relationship. 'Customer' refers to the buyer of the buyer company. The structure of a supply chain network is illustrated in Figure 2-4. Lambert et al. (1998) identify three primary elements in the supply network: (1) the members of the supply chain, i.e., who are the suppliers and the customers, (2) the structural dimensions, i.e. the number of tiers across the supply chain, the number of members within each tier and the company's horizontal position, i.e. the distance to the source of supply or to the end customers, and (3) the different types of business process links between the participants in the supply chain.

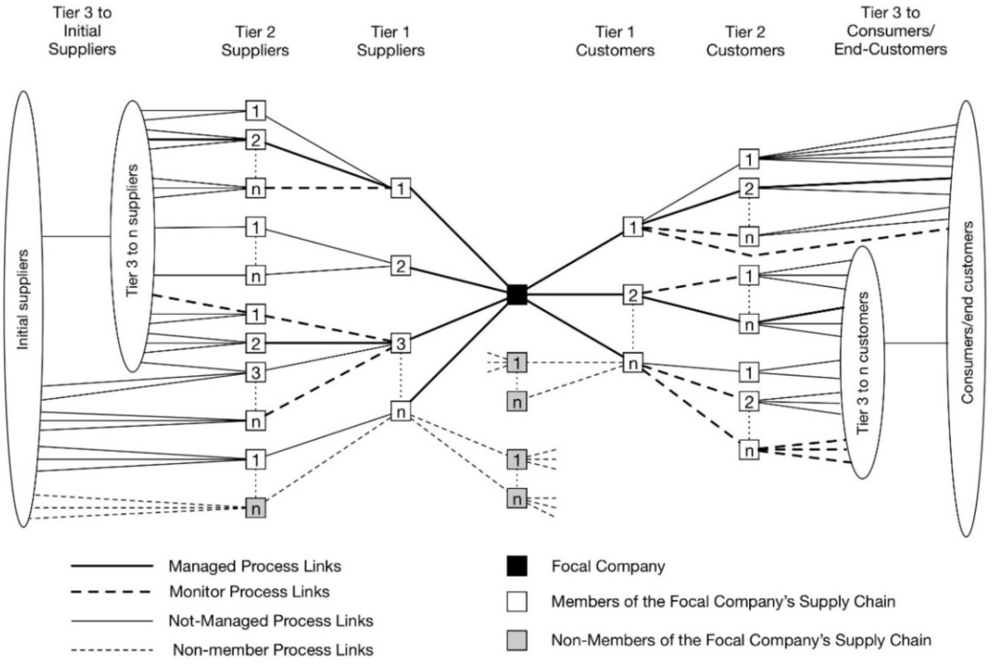


Figure 2-4 Supply chain structure with business process links (Lambert et al., 1998)

Tier 1 suppliers have direct interaction with the focal company and are evaluated and selected by the focal company in establishing the supply network. These Tier 1 suppliers provide various types of products, including proprietary parts (standard products developed by suppliers), black box parts (developed jointly between supplier and buyer) and detailed controlled parts (products where the supplier is responsible for much functional specification and detailed engineering) (Clark and Fujimoto, 1991). Kamath and Liker (1994) specified four supplier roles according to their responsibilities. Contractual suppliers provide standard parts and are used as an extension of a buyer's manufacturing capability. Child suppliers provide simple assembly and execute the design requirements from the buyers. Mature (full system) suppliers undertake complex assembly and from specifications develop the system and may suggest alternative solutions. Partner (full service) suppliers provide entire subsystems and participate in planning new models and designs even before the concept stage. These four types indicate a growth path of buyer-supplier relationship from contractual to a full partnership (Petroni and Panciroli, 2002). Suppliers of different types are evaluated differently using different evaluation criteria (Stremersch et al., 2001).

2.1.2 Supplier selection as a decision-making problem

Decision-making can be defined as intentional and reflective choice in response to the needs, which includes problem identification, determination of alternative possible solutions and their assessment (Kleindorfer et al., 1993). Several techniques support the decision-making process for assessment such as multiple criteria decision analysis methods, mathematical programming and artificial intelligence.

Supplier selection as the choice of competent suppliers (Weber et al., 1991) *is a decision-making problem* which follows the four phases (Figure 2-5) of the general decision process described by De Boer et al. (2001). The process consists of four phases: (1) *Problem definition* to identify the need for selecting or deselecting suppliers; (2) *Formulation of criteria* for assessing potential suppliers and evaluating exiting suppliers; (3) *Qualification* to identify the subset of suppliers which qualify against the criteria and (4) *Final Selection* of suppliers according to the assessment results and the ranking of their performance.

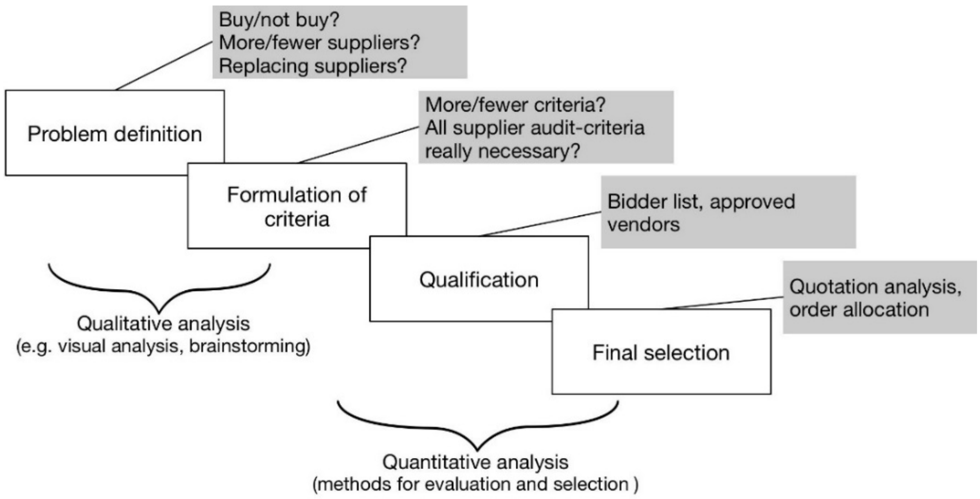


Figure 2-5 The supplier selection process adapt from De Boer et al. (2001)

To achieve the final selection, *supplier assessment is carried out by the buyer to assure that the prospective supplier can, reliably, meet the technical, financial and commercial requirements*

(Lysons and Farrington, 2012). Another similar term in the literature is supplier evaluation which takes place after the selection. *Supplier evaluation is the evaluation of purchasing performance after the buyer-supplier relationship has been established* (Lysons and Farrington, 2012). However, the two terms are often used interchangeable. The literature（e.g. Chan (2003), Noorul Haq and Kannan (2006b), Bevilacqua et al. (2006), Chen et al. (2006) ,Razmi et al. (2009), Sevkli (2010), Shemshadi et al. (2011), Pitchipoo et al. (2012), Lima Junior et al. (2014), and Azadnia et al. (2014)) use the term 'evaluation' when selecting the potential suppliers. Actually, the assessment of a potential supplier can involve any type of evaluation of their performance and the evaluation of existing suppliers is often down to assess whether they could do more. Lysons and Farrington (2012, p. 375) pointed out that "evaluation assists decision making regarding when a supplier is retained or removed from an approved list and assists in deciding with which suppliers a specific purchase order should be placed". By that distinction, the tool proposed in this research can support both supplier assessment and supplier evaluation. This research focuses on supplier selection and therefore uses the term 'assessment'.

Different purchasing situations can lead to different scenarios for selection. De Boer et al. (2001) argued that in a new task situation, there is usually a small initial set of suppliers where many criteria are involved and no historical records are available. In a rebuy of routine items (perhaps with some modification), a relatively large set of suppliers are available for comparison. If rebuying a strategic/bottleneck item, there is generally a small set of suppliers. When only few suppliers can be considered, a more realistic action is to deal with the suppliers through evaluation rather than selection. Two scenarios based on the size of suppliers set can be identified, as shown in Figure 2-6 where *Si* stands for the supplier and FC represents the buyer focal company.

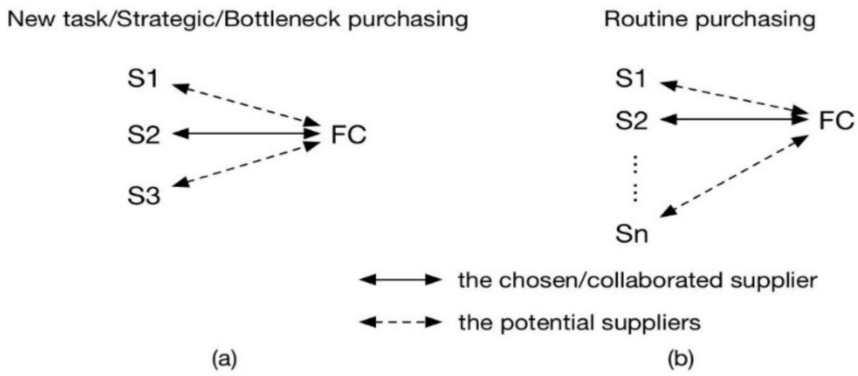


Figure 2-6 Suppliers election scenarios: (a) small set of suppliers; (b) large set of suppliers

In scenario (a) (Figure 2-6) of selecting amongst few suppliers, issues influencing the performance and the establishment of the buyer-supplier relationship should be considered when evaluating the suppliers. For example, the situation of few available suppliers could give a supplier more bargaining capability during negotiation (Cox, 2004; Caniëls and Gelderman, 2007; Porter, 2008). The importance of purchased items also increases a supplier's bargaining capability (Cool and Henderson, 1998; Porter, 2008). If a supplier has high levels of technological expertise, this might also increase the supplier's bargaining capability (Caniëls and Roeleveld, 2009; Sheu, 2014). A brand preferred by customers gives this supplier a certain bargaining capability (El-Ansary and Stern, 1972; Kähkönen and Virolainen, 2011). In scenario (b), pre-selection is used to reduce the supplier set, reducing decision maker effort on assessment and selection in the comparison of suppliers.

2.1.3 An overview of supplier assessment and selection research

Supplier selection has received considerable attention from both academic and industry researchers. From De Boer's phases, it can be seen that the criteria formulation and the methods for assessment and selection are two of the most important aspects in this decision problem. Criteria indicate what aspects of a supplier to evaluate. Gathering information without specific criteria can result in extraneous efforts. Methods based on the general decision making techniques produce the quantitative results on which the choice is based. Methods vary in the complexity of logic and the requirement on the gathered information.

To examine supplier assessment and selection, a literature search with key words 'supplier selection' and 'supplier evaluation' was carried out on the OU Electronic Library Service, focusing on the publications from 2004 to 2015 as well as highly cited papers published before 2004.

Articles of supplier selection are grouped according as they address criteria, methods or tools, as illustrated in Figure 2-7. This thesis defines criteria as *the standards by which the suppliers are judged*. However, the terms method and tool can be used with overlapping meanings in the research literature. For clarity, this thesis adopts the definitions from Gericke et al. (2017). A method is "a specification of how a specified result is to be achieved" while a tool is "an object, artefact or software that is used to perform some action" (Gericke et al., 2017). Thus, in this thesis, methods refer to calculation methods as *the specifications of how the performance or the power is calculated or quantified* such as AHP (Analytic Hierarchy Process), and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). Tools refer to *software tools that support or are based on the methods or approaches*.

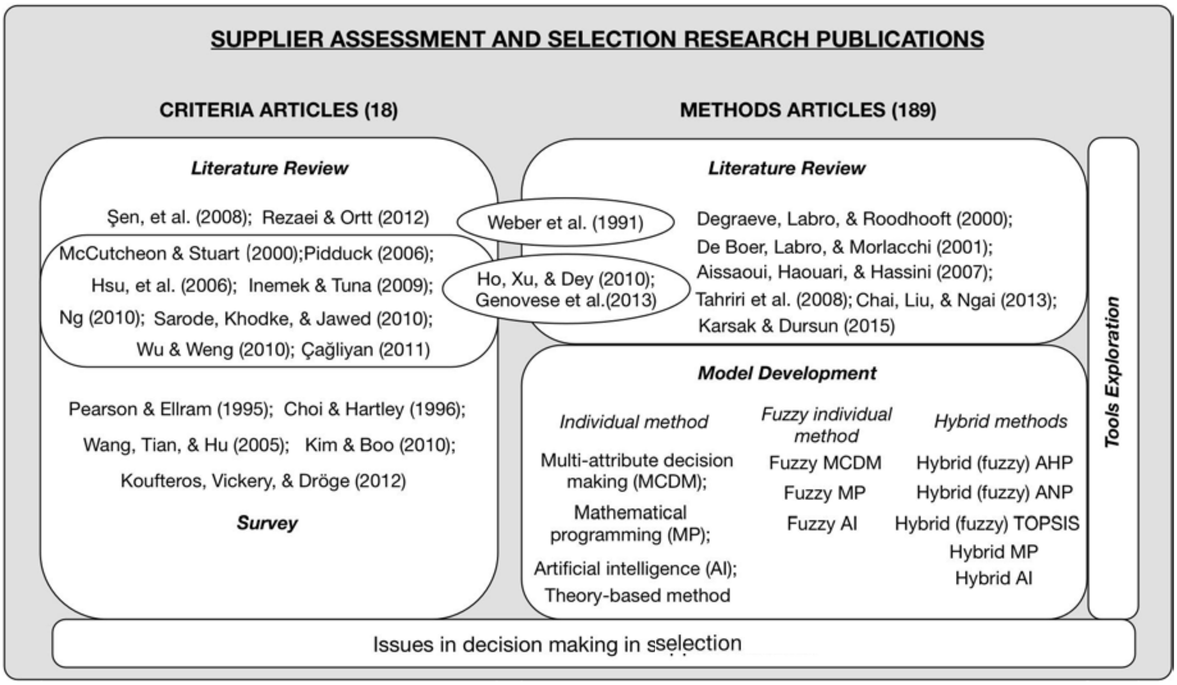


Figure 2-7 A framework to classify publications on supplier assessment and selection

(1) Articles that consider the ***criteria*** or pay certain attention to criteria formulation are mostly based on surveys on what criteria are available, their relative importance or connections. There are also articles reviewing criteria based on literature.

(2) Articles that focus on assessment ***methods*** for supplier selection. Based on the review articles on methods, this research adopts the following categorisations to organise these articles: an individual method that applies one decision making technique for assessment, fuzzy individual method that applies fuzzy set theory with one decision making techniques and hybrid methods based on multiple techniques. Some representative methods are discussed in section 2.4 and section 2.5.

(3) Along with reviewing these articles, the software ***tools*** supporting the corresponding methods are identified.

The literature review forms the theoretical foundation of this research on supplier analysis, as well as providing some empirical implications. The rest of this chapter will introduce the results of the literature review following the above classifications.

2.2 Criteria for supplier assessment and selection

The formulation of criteria is a fundamental phase during the supplier assessment and selection process. This section explores general criteria and considers how to identify those criteria most appropriate for a specific situation. This research focuses general criteria. However, the majority of the articles reviewed are concerned with manufacturing (e.g. Weber et al. (1991), McCutcheon and Stuart (2000), Şen et al. (2008), Sarode et al. (2010), Genovese et al. (2013), and Kumar et al. (2014)). A few articles were concerned with other industries such as agribusiness (Ng, 2010), covered a range of industries (Hsu et al., 2006), or did not specify a field (Rezaei and Ortt, 2012).

2.2.1 Criteria

The 23 criteria put forward by Dickson (1966) are used here as a benchmark for research on supplier selection, and have been employed as the primary basis of assessment by much of the later research. These 23 criteria as listed in Table 2-1 are ranked according to their importance based on a questionnaire sent to 273 purchasing agents and managers from the membership list of the National Association of Purchasing Managers.

No.	***Criteria***	***Explanation***	***Ranking***	
			Dickson	*Weber*
1	Quality	The ability of each vendor to meet quality specifications consistently.	1	3
2	Delivery	The ability of each vendor to meet specified delivery schedules.	2	2
3	Performance history	The performance history of each vendor.	3	10
4	Warranties and claim policies	The warranties and claims.	4	23
5	Production facilities and capacity	The production facilities and capacity	5	4
6	Price	Net price (including discounts and freight charges) offered by each vendor.	6	1
7	Technical capability	The technical capability (including research and development facilities) of each vendor.	7	6
8	Financial position	The financial position and credit rating.	8	10
9	Procedural compliance	Compliance or likelihood of compliance with your procedures (both bidding and operating).	9	16
10	Communication system	The communication system (with information on progress data of orders) of each vendor.	10	16
11	Reputation and position in industry	The position in the industry (including product leadership and reputation) of each vendor.	11	9
12	Desire for business	The desire for your business shown by each vendor.	12	21
13	Management and organization	The management and organization of each vendor.	13	8
14	Operating controls	The operational controls (including reporting, quality control, and inventory control systems).	14	14
15	Repair service	The repair service likely to be given by vendor.	15	10
16	Attitude	The attitude of vendor toward your organization.	16	13
17	Impression	The impression made by each vendor in personal contacts with you.	17	16
18	Packaging ability	The ability of each vendor to meet your packaging requirements for his product.	18	14
19	Labour relations	The labour relations record of each vendor.	19	16
20	Geographical location	The geographic location of each vendor.	20	5
21	Amount of past business	The amount of past business that has been done with each vendor.	21	21
22	Training aids	The availability of training aids and educational courses in the use of the product of each vendor.	22	16
23	Reciprocal arrangements	The future purchases each vendor will make from your firm.	23	16

Table 2-1 Dickson's 23 criteria with ranking, adapted from Weber et al. (1991)

They were further re-examined by Weber et al. (1991) who examined the changes in their importance in manufacturing, which is shown under the column ‘Weber’ in Table 2-1. This work was based on reviewing 74 journal articles that appeared since Dickson’s research was published.

The changes noted by Weber et al. (1991) are prompted by the emergence of Just-In-Time manufacturing and its growing emphasis during that period. The roles of suppliers have since diversified from physical component providers to technology providers or problem solvers (Helander and Möller, 2008; Petroni and Panciroli, 2002). Their activities have expanded from supplying products to involvement in product design and development (Helander and Möller, 2008; Laseter and Ramdas, 2002). The increasing importance of the suppliers might lead focal companies to evaluate and select more carefully with more requirements.

This research reviews (1) 18 articles that examine criteria and (2) 12 articles that develop supplier assessment methods with well-established criteria. Table 2-2 summarises the results, taking Dickson’s 23 criteria as the basis. No. 1 to 23 correspond to the criteria in Table 2-1; ‘N’ stands for new criteria added; ‘√’ means the article cites this criterion; ‘√√’ means the article expands this criterion. The correspondence of these criteria in these articles with Dickson’s criteria is based on the author’s judgement on their focus. For example, ‘the willingness of supplier to share information and expertise’ is treated as Dickson’s ‘desire for business’. More general term as *service* replaces Dickson’s ‘Repair service’. The criteria included in each article are presented in Appendix A.

Referring to Table 2-2, ‘technical capability’ (No. 7) is the top cited and most frequently expanded criterion followed by ‘quality’ (No. 1), ‘delivery’ (No. 2), ‘service’ (No. 15), ‘price’ (No. 6) and ‘production facilities and capacity’ (No. 5). The involvement of suppliers in new product development processes explains why these particular criteria, especially technical capability, are considered in detail. ‘Compatibility of buyer’s and supplier’s corporate culture’ and ‘match of management concepts’ are frequently added as criteria because they correspond to the evolution of the buyer-supplier relationship from arm’s length to strategic partners. Factors related to environment also arise during the assessment, because of the growing emphasis on sustainable and green supply chains. Meanwhile, the terms ‘power’, ‘commitment’, and ‘trust’ appear when evaluating and selecting long-term suppliers, for example (Inemek and Tuna, 2009), (Lee, 2009) and (Sarode et al., 2010). These attributes of a buyer-supplier relationship are treated as new criteria in addition to those in Dickson (1966) for assessment and selection.

	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***	***22***	***23***	***N***
(Pearson and Ellram, 1995)						√	√√	√					√							√				√
(Choi and Hartley, 1996)	√√	√√			√	√	√√	√√		√	√				√√									√
(McCutcheon and Stuart, 2000)			√				√√					√												√
(Wang et al., 2005)	√√	√			√	√√	√√					√			√					√				√
(Pidduck, 2006)							√√	√		√		√√					√							√
(Hsu et al., 2006)		√		√√		√	√√	√		√	√	√			√					√				√
(Şen et al., 2008)	√√	√√	√	√	√√	√√	√√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
(Inemek and Tuna, 2009)	√√	√√	√	√	√	√√	√√	√				√	√		√√					√				√
(Ng, 2010)	√√	√	√	√	√	√	√√	√			√	√√	√		√√					√				√
(Wu and Weng, 2010)	√√	√√	√			√√	√√	√√				√	√		√√				√√					√
(Kim and Boo, 2010)	√	√	√	√		√	√√		√		√				√√		√			√	√			
(Sarode et al., 2010)	√	√	√	√√	√	√	√√	√√		√	√√				√√	√		√						√
(Ho et al., 2010)	√√	√√				√√	√√	√			√		√		√									√
(Çağliyan, 2011)	√	√√			√√	√	√√																	
(Koufteros et al., 2012)	√√					√	√√																	
(Genovese et al., 2013)	√√	√√			√√	√√	√√			√√					√√								√	√

Table 2-2 Criteria examination based on selected articles

	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***	***22***	***23***	***N***
(Rezaei and Ortt, 2012)	√√	√	√	√	√√	√√	√√	√√	√	√√	√	√√	√√	√	√√	√√	√	√√	√	√	√	√	√	√
(Ordoobadi, 2009)	√√	√√				√	√√			√	√				√	√								√
(Lee, 2009)	√√	√√	√		√√	√√	√√	√		√					√									√
(Aydın Keskin et al., 2010)		√			√	√	√√	√										√	√	√				√
(Ravindran et al., 2010)	√	√√			√	√	√√	√							√									√
(Vinodh et al., 2011)	√	√		√	√			√			√	√	√		√									√
(Chen, 2011)	√√	√√				√√	√√								√√									√
(Vahdani et al., 2012)	√√				√√			√							√√			√		√				√
(Zouggari and Benyoucef, 2012)	√	√				√	√				√				√√					√				√
(Amin and Zhang, 2012)	√	√	√	√	√	√√	√√	√	√	√	√	√	√	√	√√	√	√	√	√	√	√	√	√	√
(Omurca, 2013)	√√	√				√√	√√						√											√
(Kasirian and Yusuff, 2013)	√√	√√			√√	√√	√√			√						√	√							√
(Kumar et al., 2014)	√	√	√			√				√	√									√				√
Note: 'N' stands for new criteria added; '√' means the article cites this criterion; '√√' means the article expands this criterion.																								

Table 2-2 (continued)

2.2.2 Selection of criteria

The literature shows that the number and range of criteria for assessment and selection are increasing. A practical question faced by the buyer is what criteria should be used in their specific situation. In the reviewed literature, the criteria selected depend on: supplier integration, collaboration duration, or a mix of both. In this research, *supplier integration refers to a state of synergy accomplished through a variety of practices that links externally performed work of the supplier with the internal work processes of an organization* (Bowersox et al., 1999; Das et al., 2006). Collaboration duration is a measure of how long the collaboration between company and supplier has been active.

For supplier integration various authors offer different ways to categorise criteria to assist supplier selection. Ghodsypour and O'Brien (1998) suggested categorising the criteria according to five levels of supplier integration. The first level assumes no integration between buyer and supplier, i.e. the buyer and the supplier are in a buy-offer relationship where price and quality are the most important criteria. The second level is the logistic integration where reliability and lead time are of great importance. The third level is the operational integration characterised by full implementation of JIT/TQM reflecting priorities for production and process capability. The fourth level identifies a deeper level integration where the process and products are integrated with the supplier. At this level, the supplier's human resources such as design involvement, management ability and culture, are integrated with those of the focal company. The fifth level corresponds to a business partnership between the buyer and the supplier who plays an important role in strategic decision-making for the business. At this level, the supplier's ability to align with the buyer's business direction becomes the focus.

Gunasekaran et al. (2004) suggested a framework that groups the criteria at operational, tactical and strategic levels. The operational level deals with the accurate operational data that represent the decisions against criteria such as delivery reliability and ability to avoid complaint. The tactical level focuses on the mid-level management decisions, such as the efficiency of purchase order cycle time, quality assurance methodology and capacity flexibility. At the strategic level, top-level management decisions influence long term plans and activities. However, this three-level framework for decisions does not include the situation where the buyer and the supplier are in a purely buyer-offer relationship.

Chen (2011) suggested classifying criteria in the selection of suppliers according to three levels of enterprise integration with suppliers. Target integration is to integrate with suppliers based on policies and strategic objectives. Related criteria include quality, cost, delivery, service, and organisation culture. Enterprise process/system integration requires the enterprise and its suppliers to work on process integration and application system integration. Criteria such as technical and production capability should be taken into account. Organisation integration focuses those criteria related to relationship management including technique cooperation and market cooperation. This framework also does not consider a purely buyer-offer relationship.

The research above classifies the criteria according to their contribution to integration with the supplier. Other research classifies the criteria by the time horizon of collaboration, for example McCutcheon and Stuart (2000). Short-term and long-term relationships are distinguished when developing the assessment models for supplier selection. Research such as Aydın Keskin et al. (2010), Guneri and Kuzu (2009), Dotoli and Falagario (2012), and Wu et al. (2013a) focuses on criteria for long-term relationships including quality, cost, delivery, service, production, technique, geography and organisation management.

A categorisation of criteria which takes into account both the integration with supplier and the time horizon of collaboration is proposed by Chan (2003), which classifies criteria according to five levels of the buyer-supplier interaction. At the level of temporary basic relationships, the value of interaction is very low and the buyer requests non-critical product from the suppliers. Only cost and quality are considered in this level. At the level of temporarily operational relationships, the interaction focuses on those aspects of the product where design capability is included. At the level of cyclically operational relationships, the interaction considers both product and process. Criteria reflecting the manufacturing, technical and technological capabilities are embraced. At the level of long lasting tactical relationships, there is a deeper consideration of product and process. The interaction focuses on the capability of human resources and the control of the product and its process within the firm. At the long lasting strategic relationship level, the buyer can fully interact or cooperate with the supplier. Criteria which influence the relationship such as willingness to share are included. Table 2-3 summarises the above categorisation of criteria for supplier selection and includes some additional literature on the classification of criteria.

Categorisation	***Publication***	***Categorisation detail***	***Type of study***	***Methodology***	***Sector***
Integration with supplier	(Ghodsypour and O'Brien, 1998)	Five levels of buyer-supplier integration	Conceptual with empirical illustrations	NA	JIT Manufacturing
	(Gunasekaran et al., 2004)	Strategic, tactical and operational decision levels	Empirical	Data collection	A range of industry settings
	(Şen et al., 2008)	Five levels of buyer-supplier integration	Empirical	Case study for demonstration	Manufacturing/ Electronics business
	(Chen, 2011)	Three levels of Enterprise integration	Empirical	Case study for demonstration	Product development/ Textile industry
	(Ertay et al., 2011)	Ordering and receiving, designing production process together, cooperating to design new products	Conceptual with real-life application	NA	Pharmaceutical industry
	(Rezaei and Davoodi, 2012)	Adversarial, Partnership, joint venture, vertically integrated	Conceptual	NA	NA
Duration of collaboration	(McCutcheon and Stuart, 2000)	contract-based arm's length relationship, long-term relationships	Empirical	Interviews	Manufacturing and service
Integration & duration of collaboration	(Masella and Rangone, 2000)	Short-term/long term logistic/strategic integration	Conceptual	NA	NA
	(Chan, 2003)	Five levels of buyer-supplier interactive relationships	Conceptual with empirical illustrations	NA	Manufacturing
	(Chang, 2013)	Long-term with median to high level management, short term with low level management	Empirical	Case study for demonstration	Manufacturing/ A Plastic material manufacturer
Other	(Smith, 2007)	Non-strategic products and Strategic partnerships	Conceptual	NA	Manufacturing
	(Chou and Chang, 2008)	Supply chain types: lean, agile, hybrid	Empirical	Case study for demonstration	Manufacturing/ Electronic products
	(Wu et al., 2013b)	The proficient supplier, the dependable supplier, arm's-length supplier, risky supplier	Empirical	Data collection	Manufacturing/ A range of settings

Table 2-3 Summary of research on criteria categorisation

Among these categorisations, the five levels of supplier integration (Ghodsypour and O'Brien, 1998) and the five levels of buyer-supplier interaction (Chan, 2003) are comparatively well-established taxonomies. Although Ghodsypour and O'Brien (1998) do not explicitly include the time horizon of a relationship into the taxonomy as Chan (2003) does, the two taxonomies are quite similar. At level 1 both refer to traditional buyer-supplier relationship where no integration or collaboration is present. At level 4, both focus on human resources to control the product and the process. Both emphasise strategic partnership at level 5.

The main differences exist at level 2. Chan (2003) focuses on the product aspects including the product design in order to satisfy the customer by the appearance and the cost of product under mass production, while Ghodsypour and O'Brien (1998) consider more the logistic performance. Both state operational considerations at level 3 including production time and process capability with Chan (2003) concentrates on the perspectives product and process while Ghodsypour and O'Brien (1998) emphasise the full implementation of JIT/TQM. Some levels of integration may reflect the duration of collaboration. For example, normally a buyer will maintain a long-term relationship with a strategic partner. However, a long-term relationship may also exist in basic or operational relationship levels.

2.2.3 Quantitative, qualitative criteria and objective, subjective data

The criteria for supplier assessment and selection can be distinguished as quantitative or qualitative. The data used for assessment can be categorised into objective and subjective. Figure 2-8 shows the categorisation. Quantitative criteria are those that can be measured by numbers, for example, price and delivery time. Objective data from facts that are turned into numerical values can be used for assessment and these values are objectively calculated. Qualitative criteria are those measured by expressions rather than numbers. For example, the criteria service and technical capability are generally expressed by linguistic terms like ‘high’, ‘medium’ or ‘low’. These linguistic expressions can be represented by numbers such as ‘5’ for ‘high’, ‘3’ for medium and ‘1’ for low. Those numbers are subjective data based on the experts’ judgements.

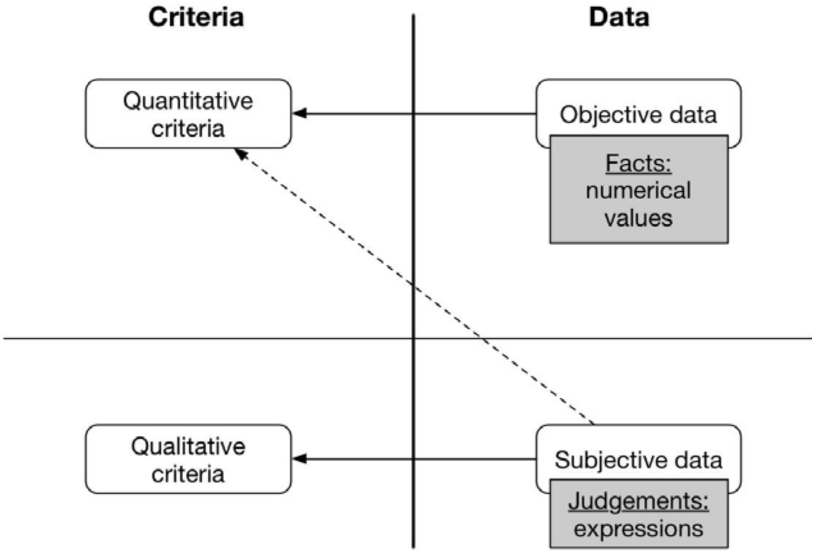


Figure 2-8 Categorisations of criteria and data

In some cases, it is hard to say whether a criterion is definitely quantitative or qualitative, as this depends on how the decision maker perceives it and what information is available. For example, if quality is defined by defect rate, then it is quantitative; if it is perceived as the conformance to design specification, then an element of this criterion is qualitative. Also, a theoretically quantitative criterion can be expressed through qualitative values based on judgement. Take delivery time for example. If a supplier only provides a duration in a range of 7 to 14 days, a decision maker may use linguistic expressions such as high, medium or low to describe the offered performance. Further the subjective data will be used for supplier assessment. This influences the choice of the assessment methods. The assessment methods also influence what kind of data can be used during the assessment and selection process.

2.3 Classification of methods for supplier assessment and selection

Criteria determine what to evaluate while methods determine how to evaluate. This section explores the decision methods that have been applied for supplier assessment and selection. Some representative methods are discussed in terms of data requirements and ease of use. This research defines data requirements as what data or information are needed by using the method and ease of use as how practically useful the method is especially the ease of application.

There is a wealth of literature detailing methods of supplier assessment and selection. 180 articles were reviewed according to two criteria – (1) published from 2004 to 2015 or highly cited if before 2004, and (2) focused on developing tools for assessment and selection. The articles are grouped according to how the methods are applied as shown in Figure 2-9. These articles are listed in Appendix B with their main contribution and how they apply the methods/techniques.

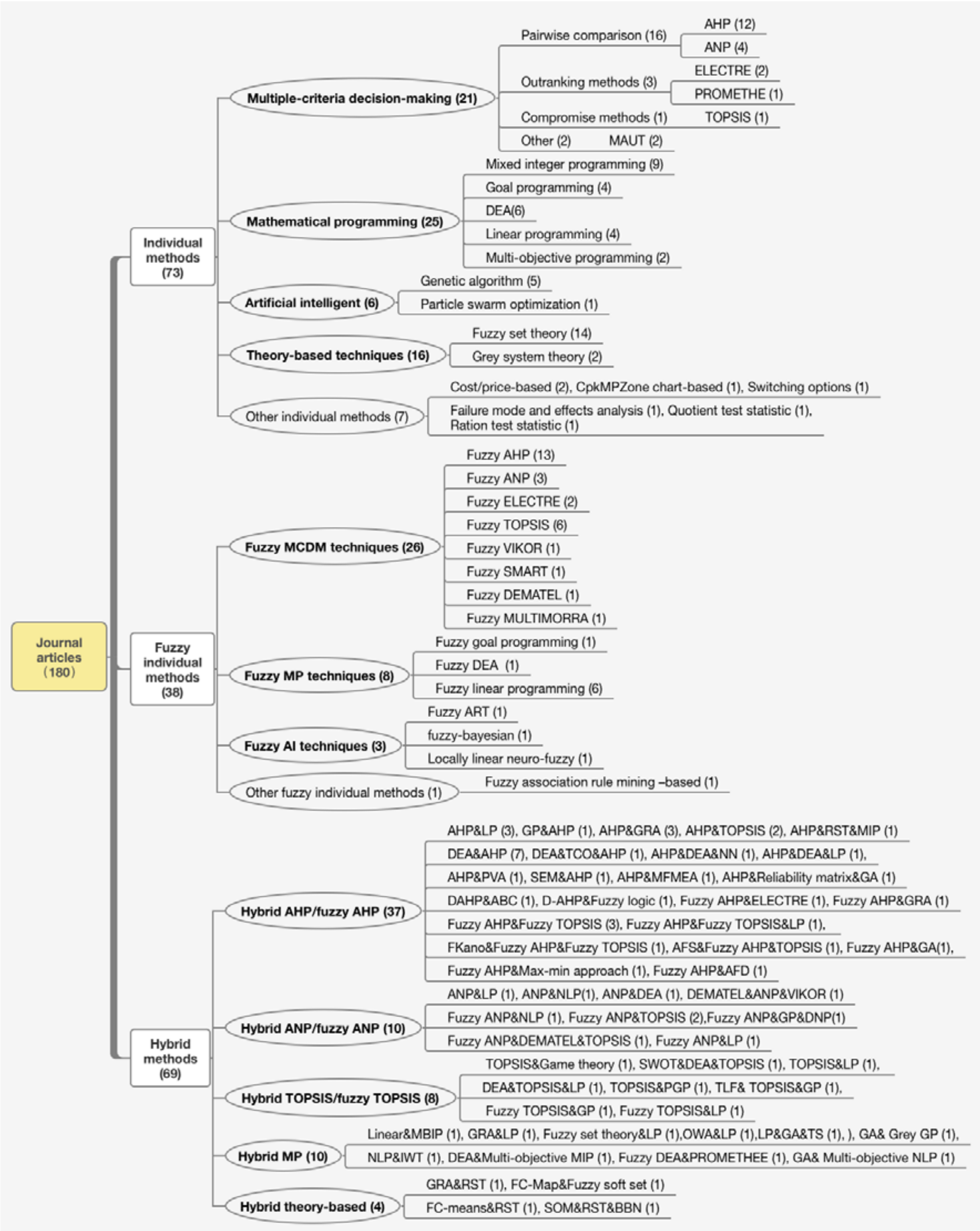


Figure 2-9 Classification of mathematical methods/techniques for supplier assessment and selection

Figure 2-9 summarises the methods according to three main groups: individual, fuzzy individual and hybrid methods. The number after each label indicates the number of articles in this group.

- ***Individual method***. The method for supplier assessment and selection is based on single decision-making technique.
- ***Fuzzy individual method***. The method is built up by integrating fuzzy set theory with a single decision-making technique.
- ***Hybrid methods***. Two or more methods are integrated for supplier assessment and selection.

In the individual method category, the articles are further distinguished by the decision making techniques used (Chai et al., 2013; Karsak and Dursun, 2016). These are multiple-criteria decision making (MCDM) or mathematical programming (MP) techniques which are not limited to supplier selection. Artificial intelligence (AI) mimics human cognition processes, computationally. The basic principle of the models based on different AI techniques for supplier selection is to train the system with historic data so that the choice can be deduced under similar situations. Theory-based techniques are from two theories – fuzzy set theory and grey system theory which both aim to deal with uncertainty, imprecision and fuzziness of information in a range of domains. There are 73 articles in this group, 12 of which apply the analytic hierarchy process (AHP). AHP seems the most popular MCDM method applied in supplier selection because it has been used by more articles (12 articles adopt AHP as a single solution and 50 articles integrate AHP with other technique as a solution), compared with other MCDM methods. Fuzzy set theory is more popular than grey system theory, both of which can resolve ambiguity in the decision. 14/73 articles employ the former while 2/73 articles use the latter.

Under fuzzy individual methods the most popular integration is fuzzy and AHP, with 13 out of 38 articles. Fuzzy Mathematical Programming (MP) methods and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) follow with 8 out of 38 and 6 out of 38 respectively.

The 69 articles in the hybrid methods group are classified according to the techniques in the previous two groups. 37/69 articles choose AHP as one of the techniques to build their models for supplier assessment and selection, while 10/69 articles combine ANP with other methods. Another two popular methods used to build hybrid supplier selection models are TOPSIS (8 articles, exclusive the 8 articles in the 'Hybrid AHP/fuzzy AHP' methods and the 3 articles in the 'Hybrid ANP/fuzzy ANP' methods) and MP (10 articles, excluding the 16 articles in the 'Hybrid AHP/fuzzy AHP' methods and the 6 articles in the 'Hybrid ANP/fuzzy ANP' methods).

From Figure 2-9, it can be seen that there are many methods for supplier assessment and selection. Some of them are easier to understand and apply, such as AHP. Some like MP may be more complex requiring the decision maker to establish objective function formulas for calculation. Some models may be simple to use but require considerable effort and knowledge to build before using them. For example, knowledge in computer science is required when using AI techniques to build supplier selection models. To understand the data requirements and the ease of use, some representative methods and combinations (mainly based on the number of referred articles) are summarised in Table 2-4 from full lists in Appendix B. These are discussed in the following sections. The individual methods are general methods applied for supplier selection. They are introduced in section 2.4, where the acronyms used in Table 2-4 and Figure 2-9 are explained. The fuzzy individual methods and hybrid methods are dedicated for supplier selection, introduced in section 2.5.

		Data requirement					Ease of use		
		Criteria accepted		Data used for calculation			Basic logic	Calculation complexity	Decision maker effort
		Quantitative	Qualitative	Objective	Subjective	Other			
Individual method/technique	AHP	√	√	-	√	Judgements	Pairwise comparison	Matrix calculation	Comparing relative importance
	ANP	√	√	-	√	Judgements	Pairwise comparison	Matrix calculation	Comparing relative importance, cluster the criteria
	ELECTRE I	√	√	-	-	Criteria weights	Outranking: "*a* as least as good as *b*	Basic arithmetic calculation	Deciding on discordance sets, threshold values of concordance index and discordance index
	TOPSIS	√	conditioned	√	quantified		Compromise: distance to ideal solutions	Vector normalisation	Judging the information under qualitative criteria
	General MP	√	conditioned	√	quantified		Mathematical formulating decision problem	Tools such as Excel are needed	Judging on the information under qualitative criteria, defining objective functions, knowing the use of tools like Excel solver
	Data Envelop Analysis (DEA)	√	conditioned	√	quantified		Mathematical formulating decision problem	Tools such as Excel are needed	Judging on the information under qualitative criteria, knowing the use of tools like Excel solver
	Genetic Algorithm (GA)	√	conditioned	√	quantified		Mimicking the mechanism of natural selection and natural genetics	Software implementation is needed	Judging on the information under qualitative criteria, programming
	Fuzzy inference system (FIS)	√	√	√	√	Values for expression	Inference: IF-THEN rules	Tools are needed such as Matlab	Defining the rules and solutions for a fuzzy inference system

Table 2-4 Summary of the methods/techniques applied in supplier selection

		Availability					*Usability*		
		Criteria accepted		***Data used for calculation***			***Basic logic***	***Calculation complexity***	***Decision maker effort***
		Quantitative	***Qualitative***	***objective***	***subjective***	***Other***			
Fuzzy individual method/technique	Fuzzy AHP	√	√	-	√	Judgements	Pairwise comparison, fuzzy sets replacing crisp judgement values	Matrix calculation, operations on fuzzy set	Comparing relative importance
	Fuzzy ELECTRE	√	√	-	-	Criteria weights	Outranking, fuzzy sets replacing crisp values	Operations on fuzzy set	Deciding on discordance sets, threshold values of concordance index and discordance index
	Fuzzy TOPSIS	√	√	-	√	Judgements	Compromise: distance to ideal solutions	Vector normalisation, aggregating and defuzzifying fuzzy sets	Judging the performance of each suppler with to each criterion
	Fuzzy MP	√	conditioned	√	quantified		formulating the goals and constraints with Fuzzy sets and their membership functions	Tools such as Excel are needed	Defining fuzzy membership functions, defining objective functions, knowing the use of tools like Excel solver
Hybrid methods	Fuzzy AHP & fuzzy TOPSIS	√	√	-	√	Judgements	Compromise: distance to ideal solutions	Vector normalisation, aggregating and defuzzifying fuzzy sets	Comparing relative importance of the criteria, judging the performance of each suppler with to each criterion
	AHP & MP	√	conditioned	√	quantified		Refer to AHP and MP	Refer to AHP and MP	Refer to AHP and MP
	DEA & TOPSIS	√	conditioned	√	quantified		Refer to DEA and TOPSIS	Refer to DEA and TOPSIS	Refer to DEA and TOPSIS

Table 2-4 (continued)

2.4 General methods

Supplier selection is a decision-making problem. The general decision making methods including those for multiple criteria decision analysis and mathematical programming can be applied for supplier assessment and selection. This section introduces the general methods identified through literature review and classifies them into four groups (summarised in Figure 2-9) – multiple criteria decision making, mathematical programming, artificial intelligent and theory based techniques. Each method is reviewed against its data requirements and ease of use.

2.4.1 Multiple criteria decision-making methods

Multiple criteria decision-making (MCDM) or multiple attribute decision making (MADM) aims to provide a recommendation from a finite set of alternatives (also known as actions, objects, solutions, or candidates) by evaluating them from multiple criteria (also known as attributes or features) (Chai et al., 2013). Three approaches are reviewed, i.e., pairwise comparison, outranking and compromise methods.

Pairwise comparison methods

AHP (Analytic Hierarchy Process) and ANP (Analytic Network Process) methods are proposed by Saaty (1980, 1990, 2005), where ANP is a generalisation form of AHP. The underlying principle is to compare the criteria and alternatives in pairs. The priorities of criteria and the preferences of alternatives are derived from the pairwise comparison.

Data requirements and ease of use of AHP

AHP incorporates both quantitative and qualitative criteria. However, it takes only judgements with respect to each criterion as the input when quantifying the suppliers. Even though objective values are available for quantitative criteria, they work as reference for the decision maker to judge which supplier is better and by how much rather than as direct input to the calculation. This allows the decision-making process to continue as long as the decision maker is able make the comparison (for example based on historic information) even if some actual data of some suppliers are missing. The disadvantage is that it introduces more uncertainty because the input is based on judgement, which greatly depends on the experience and knowledge of the decision makers. In addition, the pairwise comparison may lead to experts bias and make the comparison inconsistent (Chan and Kumar, 2007).

AHP is a popular decision making method, which is employed by 63 out of 180 articles in the collected literature. It has proved useful, practical, systematic and simple to use (Handfield et al., 2002; Tahriri et al., 2008; Chan and Chan, 2010). Its hierarchical structuring of the goal, the criteria and the alternatives presents the decision makers with an overview of what to do. There is a straightforward process for deriving the priorities of each criterion with respect to the goal, the preference of each alternative with respect to the criteria and the final preference of each alternative with respect to the goal through the pairwise comparison. The most important feature of AHP is that it calculates the weights of criteria, which most other decision making techniques do not. This is also the reason why many researchers choose AHP in combination with other methods to build their assessment models. However, one problem is that as the number of criteria and alternatives increases, the effort of pairwise comparison increases rapidly.

Data requirements and ease of use of ANP

The data requirement of ANP is the same as AHP in that it takes judgements as input for both quantitative and qualitative criteria. ANP considers the interrelationships among various criteria and alternatives, using a network of clusters and connections to structure the problem. However, this makes ANP more complex, because it requires the decision maker to define the interrelationship. Also the way to cluster the elements (criteria and alternatives) influences the subsequent assessment process, which is not as intuitive as the hierarchy of AHP. The consideration of interrelationships adds effort to calculation, especially when the number of interrelationships increases significantly. This might be the reason that ANP is less popular than AHP. 17 out of 180 articles employ ANP for supplier assessment and selection. Overall, the feasibility to use ANP falls in the middle of existing techniques for supplier selection. It does not require complex the mathematical calculations, but provides a robust solution (Sarkis and Talluri, 2002).

Outranking method

The basic principle of outranking methods is to determine an outranking relation between two alternatives *a* and *b*, i.e. *a* outranks *b* if sufficient justification exists to decide *a* at least as good as alternative *b* (Boer et al., 1998). ELECTRE (ELimination Et Choix Traduisant la REalité) and PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) are typical outranking methods. However, only 5/180 and 2/180 articles employ ELECTRE and PROMETHEE respectively.

Data requirements and ease of use of ELECTRE Ⅰ

ELECTRE Ⅰ (Roy, 1991) works with both quantitative and qualitative criteria. Objective values and judgements about these criteria are used for determining an outranking relation. The weights of criteria are the input for calculating the preference of suppliers. However, ELECTRE Ⅰ does not provide a way of calculating the weights.

The logic behind outranking is as follows. Alternative *a* outranks alternative *b* if: firstly, the concordance index "*a* as least as good as *b*" exceeds a predefined threshold value; secondly, a discordance index against the assertion is below a certain value. The decision maker needs to decide the values for these two types of thresholds. Different values will produce difference results for the same alternative set with the same data. How to decide a suitable threshold is not addressed in this method. The decision maker also needs to define the discordance sets which are the cases in which alternative *a* will be refused if *a* has a very bad score on a certain criterion relative to the score of *b* and irrespective of other criteria. In general, ELECTRE Ⅰ is more suitable to discard some alternatives rather than to rank the alternatives. However, other methods from the ELECTRE family such as ELECTRE Ⅲ can rank suppliers (Boer et al., 1998) but the complexity grows significantly.

Compromise method

The underlying principle of compromise methods is to choose a solution closest to the ideal (Zeleny and Cochrane, 1973; Yu, 1973). Two typical compromise methods are TOPSIS and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) chosen by 26/180 and 2/180 articles respectively.

Data requirements and ease of use of TOPSIS

TOPSIS (Hwang and Yoon, 1981) is not able to incorporate qualitative criteria unless subjective data for these criteria are provided, i.e. judgements under these criteria being translated to numeric values. For example, if the linguistic expression from ‘extremely poor’ to ‘extremely good’ with respect to criterion *service* can be represented by values from 0 to 8, then this qualitative criterion can be taken into account. With this premise, TOPSIS uses both objective and subjective data during the calculation process, which reduces the uncertainty brought by subjective judgements on all criteria and is the case with AHP and ANP.

TOPSIS is based on the concepts that the chosen alternative should have the minimum distance from the positive ideal solution and the maximum distance from the negative ideal solution. The decision maker does not need to set threshold as in the outranking methods. Further, TOPSIS does not provide the way of calculating the weights.

2.4.2 Mathematical programming methods

An alternative to the multiple criteria decision-making method is mathematical programming. The programming methods applied in supplier selection include DEA (Data Envelopment Analysis) (Kumar et al., 2014; Wu and Blackhurst, 2009), mixed integer programming (Mak et al., 2011), goal programming (Ravindran et al., 2010). These programming methods use iterative algorithms that search every possible value and gradually achieve an approximate solution to a prescribed accuracy (Luenberger and Ye, 2008).

Data requirements and ease of use of generic mathematical programming (MP)

MP incorporates quantitative criteria as well as qualitative criteria with the premise that the linguistic expressions are quantified into numeric values. Both objective data and those quantified values are the input of the calculation process. MP formulates the decision problem in terms of maximising (e.g. maximise profit) or minimising (e.g. minimise cost) a mathematical objective function (e.g. the amount of order from the suppliers) by varying the values of the variables in the function. The decision maker must explicitly state the objective function(s). MP models are often used to allocate the purchasing volume for each supplier rather than evaluating supplier performance.

Data requirements and ease of use of data envelopment analysis (DEA)

DEA is also based on a mathematical programming formulation. Unlike MP models DEA measures the performance of suppliers on the criteria important to the buyer, while the other MP methods optimise order quantity allocation (Weber, 1996). The data requirements of DEA are the same as general MP methods in that quantitative data is required.

DEA evaluates the alternatives by an efficiency measure which is defined as the ratio of the weighted sum of the inputs (performance on cost criteria) to the weighted sum of the outputs (performance on benefit criteria). For each supplier, DEA finds the most favourable set of weights, i.e. the set of weights that maximise the supplier's efficiency without making all suppliers' efficiency greater than 1. The alternatives can be ranked according to their efficiencies. However, this ranking could be misleading (Wu and Blackhurst, 2009), especially considering the fact that the suppliers are ranked under different sets of criteria weights.

2.4.3 Artificial intelligence methods

The underlying principle of artificial intelligence (AI) methods is to mimic the decision process of human beings with the aid of a computer. Some AI techniques include genetic algorithm (GA) (employed by 9/180 articles), particle swarm optimisation (1/180), Bayesian network (2/180) and adaptive resonance theory (1/180).

Data requirements and ease of use of GA

GA is a stochastic search algorithm inspired by the mechanism of natural selection (i.e. recombination and mutation) to identify approximate solutions (Ding et al., 2005). GA incorporates both quantitative and qualitative criteria. Objective data and subjective data (i.e. quantified values of judgements) are used in the assessment process.

GA starts with a set of alternatives (i.e. suppliers), called by analogy chromosomes. In each iteration (generation), these chromosomes are evaluated by fitness functions (similar to the objective function in MP methods). The fittest chromosomes are selected from this generation to produce offspring (next generation). The iteration exits when the stopping criteria are satisfied. GA requires: encoding of chromosomes (representation of the genetic composition), genetic operations to evolve and alter the composition, and fitness functions. A GA method must be implemented in a software programme before it can be applied.

2.4.4 Theory-based methods

Both fuzzy set theory and grey system theory aim to address the imprecision, uncertainty and vagueness of information. Fuzzy set theory is more popular in the supplier selection and assessment literature and there are 74/180 articles applying its relevant techniques. Fuzzy numbers, fuzzy relations and fuzzy inference systems are some of the techniques in fuzzy set theory employed in supplier assessment and selection. Fuzzy numbers and the fuzzy relations need to be combined with other decision making techniques while a fuzzy inference system (FIS) can itself address the supplier selection problem and is therefore is selected here for discussion of its data requirements and ease of use.

Data requirements and ease of use of FIS

FIS incorporates both quantitative and qualitative criteria. It uses objective data as well as subjective data for the supplier assessment process. The idea behind FIS is to map the input (supplier data with respect to each criteria) to the output (crisp value representing the overall performance) through a set of IF-THEN rules. For example, IF price is cheap AND service is good, THEN the performance is good. IF price is cheap AND service is bad THEN the performance is average. The mapping result (‘good’ or ‘average’ of performance) is then defuzzified to a crisp value for final ranking. The number of these rules goes up significantly as the number of criteria increase. Tools such as Matlab are needed to implement a FIS based assessment model.

2.5 Dedicated methods for supplier assessment and selection

Different decision making methods can be integrated to build an assessment method for supplier selection. In this section uncertainty in decision making is addressed by developing fuzzy versions of individual methods dedicated to supplier assessment and selection. This section also considers combining techniques in hybrid methods.

2.5.1 Fuzzy individual methods

To address the uncertainty in decision making, fuzzy set theory is combined with another technique. Some representative methods are fuzzy AHP, fuzzy ELECTRE, fuzzy TOPSIS and fuzzy MP methods which are employed by 13/38, 2/38, 6/38, and 8/38 articles respectively in this group. A common way of combining methods is to replace the crisp values for judgement, which are used in the methods discussed in Section 2.4, with fuzzy numbers.

Data requirements and ease of use of fuzzy AHP

Fuzzy AHP has the same feature as AHP in that it incorporates both quantitative and qualitative criteria while using subjective data for calculation. The advantage of Fuzzy AHP compared with AHP is that it deals with the uncertainty by using fuzzy sets rather than a discrete integer scale (Chan and Kumar, 2007). It is easier for the decision maker to give an interval judgement to deal with the vague data because of the fuzziness of the comparison process in AHP (Kahraman et al., 2003; Chan et al., 2008; Lee, 2009). However, this increases the calculation complexity, as it requires operations on fuzzy sets as well as defining fuzzy numbers to represent the preference scale.

Data requirements and ease of use of fuzzy ELECTRE

Fuzzy ELECTRE has the same features as ELECTRE, which can deal with both quantitative and qualitative criteria while using criteria weights for calculation, but uses the fuzzy triangular numbers to describe the weight of the criteria instead of crisp values (Sevkli, 2010). Fuzzy ELECTRE overcomes the shortcomings of crisp values while dealing with uncertainty and makes it easier to capture the subjective assessment of the criteria.

Data requirements and ease of use of fuzzy TOPSIS

Fuzzy TOPSIS can deal with both quantitative and qualitative criteria. Unlike TOPSIS which uses objective data for calculation, fuzzy TOPSIS takes subjective data for all criteria, i.e. judgements represented by fuzzy sets regarding the criteria (e.g., Chen et al. (2006), Boran et al. (2009) and Wu et al. (2013c)). Though the purpose of introducing fuzzy set theory into TOPSIS is to handle the uncertainty and fuzziness of information, disregarding the use of actual data might be counterproductive. In addition, techniques for aggregating and defuzzifying the fuzzy numbers play important roles in a fuzzy TOPSIS model.

Data requirements and ease of use of fuzzy MP

Fuzzy MP models incorporate fuzzy set theory to deal with the imprecise information and vague terms such as ‘‘very high in quality’’ or ‘‘low in price’’ (Kumar et al., 2004; Amid et al., 2006; Amid et al., 2009). They use fuzzy sets with membership functions to formulate the goals and constraints. Fuzzy MP models have the advantage of considering multiple objectives and can allocate order size. However, incorporating fuzzy sets increases the calculation complexity.

2.5.2 Hybrid methods

Some research combines several methods, employing one method to derive the weights of criteria and then other methods to quantify suppliers, for example, Ramanathan (2006), Vijayvagy (2012) and Viswanadham and Samvedi (2013). Some research applies one method to eliminate less qualified suppliers first and then evaluates the remaining relatively well qualified ones with other methods such as Chen (2011) and Dotoli and Falagario (2012). The data requirements and ease of use of models built on multiple methods depends on these component methods.

Data requirements and ease of use of fuzzy AHP & fuzzy TOPSIS

In this combination, fuzzy AHP calculates the weights of the criteria first and then fuzzy TOPSIS determines the most suitable alternative suppliers (e.g. Wang et al. (2009a) and Viswanadham and Samvedi (2013)). The data requirements are the same as fuzzy TOPSIS that deals with both quantitative and qualitative criteria but using subjective data for calculation. Compared with fuzzy AHP, this combination reduces the effort on pairwise comparison. Suppliers are not pairwise compared with respect to each criterion in order to obtain their preference. Instead, their preference is determined by the distance to the ideal solutions.

Data requirements and ease of use of AHP & General MP

Examples of this combination are Ghodsypour and O'Brien (1998) and Ting and Cho (2008). In this combination, AHP is used to obtain the weights of criteria and the preference of suppliers and to rank these suppliers according to the calculation results. Unless there are further constraints such as minimising the cost, a Linear Programming (LP) model is developed to find the optimal alternatives along with allocating the order quantities after AHP obtaining the final scores. The data requirement in the first stage is the same for AHP, i.e. incorporating both quantitative and qualitative criteria while using only subjective data as input. The data requirements in the second stage is the same as that of MP models that can deal with quantitative criteria as well as qualitative criteria with the premise that the linguistic expressions are quantified into numeric values.

Data requirements and ease of use of DEA & TOPSIS

This combination uses DEA first to delete the less qualified alternatives and then applies TOPSIS for precise assessment of the comparable alternatives and the final ranking, e.g. Chen (2011). This combination can deal with both quantitative criteria and qualitative criteria where subjective data is available for qualitative criteria, (i.e. judgements are quantified into numeric values). Both objective data and those quantified values are the input of the two calculation stages.

2.6 Tools to support and implement supplier assessment methods

All methods discussed in the previous sections require a certain amount of calculation and benefit from computer support. In some methods calculation could be done by hand, for example AHP, ANP, ELECTRE, and TOPSIS. However, when the number of criteria and alternatives rise, the calculation becomes cumbersome and can lead to mistakes. Some methods require computational tools for calculation such as MP and AI. This section explores what calculation tools exist for those methods, which fall into two categories: (1) **generic tools** that support a number of methods and applications (2) **dedicated tools** that are developed based on certain methods.

2.6.1 Generic tools

These tools have powerful calculation capabilities which can support several supplier assessment and selection methods. The user’s skill and expertise in using the tools determines their success.

Microsoft Excel

Microsoft Excel is a spreadsheet developed by Microsoft for Windows, Mac OS, and iOS. It has a large number of built-in functions, including math, trigonometric functions and statistics. Additional add-in programs, providing optional commands, functions, and features for Excel are available and users can write their own programs in Excel. Goal Seek function[2] in Excel can help to generate the preferences of elements being pairwise compared in AHP and ANP, which are

[2] Use Goal Seek to find a result by adjusting an input value, https://support.office.com/en-us/article/Use-Goal-Seek-to-find-a-result-by-adjusting-an-input-value-EF3495FE-9DDC-4249-89B4-0E24406B7FCB

obtained by calculating the comparison matrix's principal right eigenvector. Before applying the Goal Seek function, the formula for calculating the eigenvalue of a matrix, derived from equation $\det(A-\lambda I)=0$, needs to be defined by users in Excel. Once the values of the eigenvalues are calculated then the eigenvectors can be derived. Visual Basic Applications (VBA) in Excel (Chinowsky, 2009) can also carry out the same calculation, which allows user to code their own programmes and extend the existing functions in Excel for calculations. The success depends on the ability to code in Visual Basic and the relevant understanding of mathematical logic. Kulshrestha et al. (2007) mentioned using Excel for computing eigenvectors of a decision matrix of AHP when solving the supplier selection problem. Yang and Chen (2006) and Pitchipoo et al. (2012) wrote a program in Excel, automatically calculating the mathematical analysis in their proposed AHP-GRA (Grey Relational Analysis) model for supplier assessment. Gnanasekaran et al. (2008) also developed a program to aggregate the evaluators' judgements and calculate the weights using Excel, simplifying the calculation procedure in AHP and GRA.

Excel Solver[3], a Microsoft Excel add-in program, can solve mathematical programming methods. It is comparatively easy to operate as long as the users have clearly defined the formulas for objectives and identified the restrictions which are the requirements for applying mathematical programming methods. Applying Excel Solver for optimisation in the programming methods for supplier selection and quantity allocation problems is referred to in several articles (e.g. Ghodsypour and O'Brien (1998), Raut et al. (2010), Sevkli et al. (2007), Hadi-Vencheh (2011) and Ruiz-Torres et al. (2013)).

MATLAB

MATLAB, developed by MathWorks, is a high-level language and interactive environment, primarily intended for numerical computation. It allows matrix manipulations, plotting of functions and data, implementation of algorithms, and interfacing with programs written in other

[3] Define and solve a problem by using Solver, https://support.office.com/en-us/article/Define-and-solve-a-problem-by-using-Solver-5D1A388F-079D-43AC-A7EB-F63E45925040

programming languages. A range of applications in different fields like statistics and optimisation, signal processing and communications, control systems, test and measurement, computational finance, and computational biology are supported by MATLAB which provides various additional toolboxes.

MATLAB is able to do almost all the computing work of the mathematical methods in sections 2.4 and 2.5, provided the users can program in MATLAB. Aydın Keskin et al. (2010) coded their proposed fuzzy adaptive resonance theory (ART) supplier selection model in MATLAB. In addition, it is worth mentioning a toolbox in MATLAB, Fuzzy Logic Toolbox (Mathworks, 2014), because this toolbox facilitates the solutions that incorporate fuzzy logic, while providing graphical user interfaces to model fuzzy inference systems. For example, Amindoust et al. (2012) and Lima Junior et al. (2013) solved their fuzzy models for supplier selection in MATLAB.

2.6.2 Dedicated tools

Unlike generic tools, dedicated tools implement a particular method of supplier assessment and free the users from needing to understand the mathematical principles behind the methods. For supplier selection both commercial and academic tools exist.

Expert choice

Expert Choice[4] implements the whole process of AHP. Since the first version was created in 1983, it has become a sophisticated commercial software and been extended to a series of cross-platform and internet-based collaboration tools, with a large user community. With friendly user interfaces, it helps from the first step of structuring the problems to the last step of presenting the results of the compared alternatives. Rather than being required to figure out the way of calculating the comparison matrix’s principal right eigenvector, the user inputs the information of the pairwise comparison matrix and Expert Choice will automatically do the computing. Many researchers (e.g. Handfield et al. (2002), Chan (2003), Chan and Chan (2004), Chan and Chan (2010), Labib (2011)

[4] http://expertchoice.com/

and Ghodsypour and O'Brien (1998)) used Expert Choice to solve their AHP models for supplier assessment and selection.

Visual PROMETHEE

Visual PROMETHE implements the PROMETHEE/GAIA method, which is developed by VPSolutions under the supervision of Professor Bertrand Mareschal from the Solvay Brussels School of Economics and Management of the Université Libre de Bruxelles (VPSolutions, 2013). With a comprehensive spreadsheet interface for data, it provides visual representation of criteria weights, which enables users to have a view according to their priorities. An academic version for research purposes is available with full functions.

Mathematical programming solvers

There are many tools available to solve mathematical programming models. LINGO and LINDO are two software packages from the same company.

LINGO[5] provides an integrated package that includes a language for expressing optimisation models, an environment for building and editing problems, and a set of built-in solvers. It can deal with both linear and non-linear optimisation problems, supporting general and binary integer restrictions in its non-linear solvers. Hadi-Vencheh (2011) mentioned using LINGO software package. LINDO[6] is able to solve various programming models, including stochastic, linear, non-linear, quadratic, quadratically constrained, second order cone and integer optimization. Chaudhry (1993) and Ramanathan (2007) used LINDO in their research. Narasimhan and Talluri (2006) mentioned two other solvers CPLEX and XPRESS. Both aim to solve linear programming, mixed integer programming, and quadratic programming problems.

[5] http://www.lindo.com/index.php?option=com_content&view=article&id=2&Itemid=10
[6] http://www.lindo.com/index.php?option=com_content&view=article&id=1&Itemid=9

2.7 Power and supply chains

The previous sections showed that the literature puts considerable effort into developing methods to evaluate and select suppliers where more and more criteria are taken into account and power is treated as a single criterion. However, 'power' is a complex concept determined by multiple aspects (French et al., 1959; Porter, 1979, 2008; Ireland and Webb, 2007). This section and the followings explore the literature on power.

Power has been studied for a long time in many different fields, especially in social science. Early in 17th century Thomas Hobbes, the English philosopher, defined power as "a man's present means, to obtain some future apparent good" (Hobbes, 1651). Porter (1979) introduced power into supply chain research, where the market is considered as a battlefield and power is used as a competition force to gain profits. This section explores the concepts of power and the influence of power on buyer-supplier behaviour.

2.7.1 What is power

Reviewing the literature, there is no agreement on a unique definition of power even if there are some largely agreed aspects in different fields. In social science, power of A over B in a system is defined as the maximum potential ability of A to influence B in the system (French et al., 1959). In psychology, power is mostly referred as the ability to change things such as behaviours, decisions and strategies (Blau, 1964). Applied to the political field, power is considered as the ability of one individual or group to push another unit to do something that it would be reluctant to do (Dahl, 1957) or a capacity that A has to influence the behaviour of B so that B acts in accordance with A's wishes (Robbins and Barnwell, 2006). In marketing and supply chain power has a similar definition as capacity to influence the decisions and behaviours of others (Ratnasingam, 2000; Yeung et al., 2009). Power is also viewed as the ability one member has to control or change the decision variables in the marketing strategy of another member (Hunt and Nevin, 1974; El-Ansary and Stern, 1972). Ireland and Webb (2007, p. 485) stated that "Power is a multi-dimensional construct encompassing an influence that can be used to evoke desired actions from partners".

Power is a property of a relation rather than an attribute of an individual. "To say that *X* has power is vacant, unless we specify over whom" (Emerson, 1962, p. 32). The asymmetric distribution of power in the relationship is reflected in the behaviour of suppliers/ buyers in the operation of the supply chain. The stronger party may use its power to achieve its own goals and outcomes by coercing others to do what they would otherwise be reluctant to do (Brown et al., 1996), or at least to influence the behaviour of others. For the purpose of this research, we define *power as the ability of leverage of one party over another.*

An illustration of power in a supply chain is the relationship between big UK supermarkets and their vegetables suppliers, as discussed by Hugh Fearnley-Whittingstall in a BBC documentary on food waste[7]. To improve sales, the supermarkets prescribe the appearance of vegetables. Carrots or parsnips that are too large, too small, or not straight enough will be not accepted. As a result, the suppliers have to carefully select and pack their harvested vegetables, and throw away those that do not look good, but would be just as good to eat. The suppliers cannot pass their losses on to the supermarkets, because the supermarkets have power over the suppliers due to their size, market centrality, brand effect and low supplier switching cost. By contrast many of the suppliers are family businesses relying on a single large supermarket. The power of the supermarkets over the suppliers guarantees the good performance of suppliers.

2.7.2 How power influences the performance of buyers or suppliers

The asymmetric distribution of power enables the stronger party, either supplier or buyer, to behave or make decisions according to their own interests during the course of the supply chain operation. Power influences multiple aspects of the relationship, although a party has a choice whether they enact their power.

[7] Source: Hugh's war on waste, http://www.bbc.co.uk/programmes/b06nzl5q

Influence on cost control and pricing strategy

The asymmetric power distribution could create obstacles for cost savings for the weaker party and enable the stronger party to assure price or quantity discount (Munson et al., 1999). When studying the cost control strategy in direct-mail publishing field Watson (1999) found out that the domination of the postal service by only one company, the Post Office, left publishers no way to negotiate costs. Another example from Wei et al. (2013) is manufacturers, who cannot dominate their retailers, have to make their price decisions based on the retail prices of the products. Therefore, research has addressed the question that how one party can respond to the greater power of the other. For example, Kwak et al. (2006) suggested that when a supplier has the power to determine the order size, the buyer can minimise the cost by choosing a suitable contract length and order points, however when the buyer has the power, the supplier has to accept the buyer's conditions.

Influence on Just-in-time (JIT) and inventory strategy

JIT manufacturing pioneered by Toyota has been widely put into practice since the early 1970s. When investigating the factors for applying JIT successfully, Cox (1999) pointed out that Toyota could create an assembly-based, demand-pull and JIT system because it had a dominant power relationship with its suppliers, which allowed it to force through the innovations it desired from supply chain supplicants. The dominant power of Toyota over its suppliers comes from the dependence of suppliers on them and a highly competitive market of suppliers. Bichescu and Fry (2009) found that the power relationship can significantly influence the performance of vendor-managed inventory (VMI). The greatest system benefits from VMI arise from asymmetric power distribution.

Influence on knowledge sharing and information exchange

Knowledge sharing between buyer and supplier is a key aspect to be competitive in the market. An investigation by Cai et al. (2013) showed that power of a supplier is positively correlated with the degree of technical exchange and technology transfer between the buyer and the supplier. Power is also a force that pushes supplier/buyer to adopt better communication systems. Munson et al. (1999) mentioned a survey reporting that 55 percent of respondents started to use electronic data interchange under the requirement from their principal buyers/suppliers. Another survey by Ke et al. (2009) suggested that the supplier/buyer's adoption of electronic supply chain management systems is related with its perceived pressures from the dominant member.

Influence on operations control

A powerful buyer or supplier can impose operational practices on its suppliers or buyers. Strong manufacturers like Toyota placed strict requirement, which lead to improved quality and adopting higher quality standard by suppliers (Munson et al., 1999). Many suppliers had to pass expensive and time consuming ISO 9000 certification in order to gain the opportunity to supply these manufacturers. Strong retailers can have a similar influence on their suppliers, as the example of UK supermarkets and their vegetable suppliers illustrates.

Influence on the quality of relationship

Power influences the quality of buyer-supplier relationship through the impact it has on trust, conflict or commitment. Figure 2-10 illustrates the relationship between these factors based on the findings mainly from surveys, reported in the literature. Surveys by Maloni and Benton (2000) and Benton and Maloni (2005) concluded that power from reward, expertise and reference has a positive effect on commitment, trust, and conflict resolution. This benefits the performance throughout the chain, while power from coercion and legitimation leads to a negative effect. Brown et al. (1996) examined power with two types of commitment. Instrumental commitment is one's compliance driven by rewards or punishments and normative commitment is one's identification with another. They identified that higher use of power from reward, coercion and legal legitimate by the supplier is associated with higher instrumental commitment to the relationship by the retailer. This leads to lower performance level of the retailer. Higher use of power from expertise, referent and traditional legitimate by the supplier is associated with higher normative commitment by the retailer, which is further related to a higher performance level of the retailer.

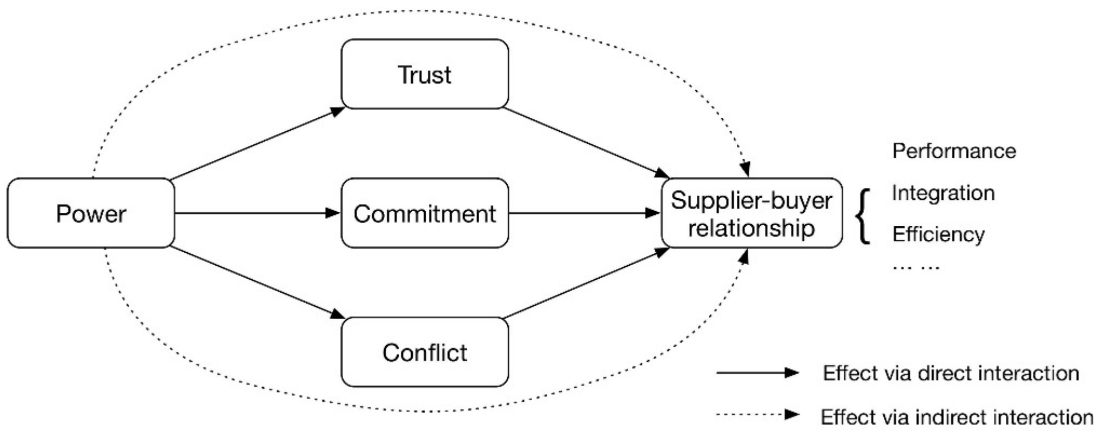


Figure 2-10 An abstracted process of analysing power effects on buyer-supplier relationship

Zhao et al. (2008) did a similar survey on customer power and suppler commitment. hey found that a supplier's normative commitment is positively related to its perception of the expert, referent power of its customer and negatively related to the coercive power. A supplier's instrumental commitment is positively related to its perception of the reward and coercive power of its customer. They pointed out that legitimate power seems not related to the commitment and that the increased normative commitment encourages supplier-customer integration, which is different from the survey by Brown et al. (1996). Liu et al. (2015) found from their survey that referent, expertise and information power of the dominant firm has positive influence on the trust of the target firm including contractual trust (the expectation of the target firm on the ability of the dominant firm), competence trust (the willingness of the target firm to rely on the competence of the dominant firm), and goodwill trust (the faith of the target firm in the profitability of the dominant firm). Coercion and legal legitimate power has a negative influence on both competence and goodwill trust. Increasing competence and goodwill trust increases the intention of the target firm to adopt supply chain integration.

2.7.3 Power consideration in supplier selection

Relatively little work has been published that explicitly takes power into account when assessing and selecting suppliers. Cox's research (Cox, 1999, 2001; Cox et al., 2001; Cox, 2004) contributes most. He suggested three aspects to be considered for an effective sourcing decision: a specification of the sourcing strategy (supplier selection, supply chain outsourcing, supplier development or supply chain management), an understanding of the power and the leverage environment, and an understanding of the basic relationship management styles. Four circumstances for power are identified based on the buyer power and the supplier power as illustrated in Figure 2-11.

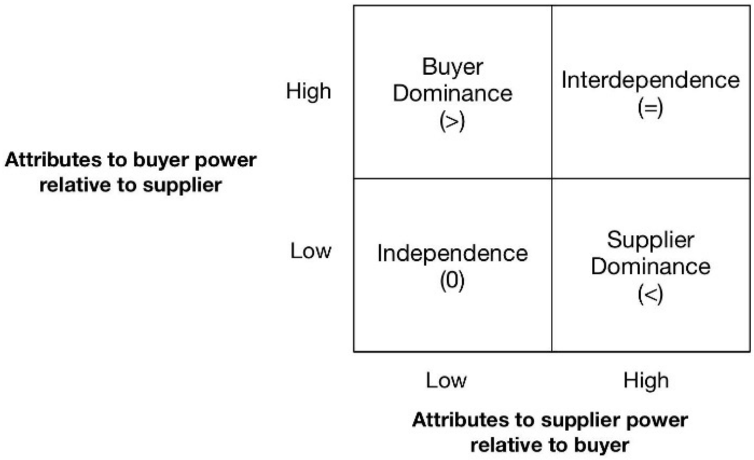


Figure 2-11 Four power circumstances, adapted from Cox (2004)

Four relationship management styles are distinguished by (Cox, 2004):

- Adversarial arm's-length: each partner seeks to maximise their value share and regularly uses short-term market testing.
- Non-adversarial arm's-length: each partner pays the current market price without resorting to aggressive bargaining but tests the market actively.
- Adversarial collaboration: each partner provides extensive operational linkages and relationship-specific adaptions, but seeks to maximise the appropriation of value.
- Non-adversarial collaboration: each partner operates in a transparent operational manner with a long-term commitment and shares any resulting commercial value equally.

Table 2-5 shows the alignment of sourcing approaches, power circumstances and management styles. With regard to supplier selection, if the buyer dominates the supplier, the appropriate relationship management style is either buyer adversarial arm's-length or supplier non-adversarial arm's-length. If the supplier dominates the buyer, the management style is then opposite.

Sourcing approach	**Power and leverage circumstance**	**Appropriate relationship management style**
Supplier selection	Buyer dominance (>)	Buyer adversarial arm's-length/supplier non-adversarial arm's-length
	Independence (0)	Buyer and supplier adversarial arm's-length
	Interdependence (=)	Buyer and supplier non-adversarial arm's-length
	Supplier dominance (<)	Supplier adversarial arm's-length/buyer non-adversarial arm's-length
Supply chain outsourcing	Buyer dominance (>)	Buyer adversarial arm's-length /supplier non-adversarial arm's-length
	Independence (0)	Buyer and supplier adversarial arm's-length
	Interdependence (=)	Buyer and supplier non-adversarial arm's-length
	Supplier dominance (<)	Supplier adversarial arm's-length /buyer non-adversarial arm's-length
Supplier development	Buyer dominance (>)	Buyer adversarial collaboration/supplier non-adversarial collaboration
	Independence (0)	Not applicable
	Interdependence (=)	Buyer and supplier non-adversarial arm's-length
	Supplier dominance (<)	Buyer non-adversarial collaboration/supplier adversarial collaboration
Supply chain management	Buyer dominance (>)	Buyer adversarial collaboration/supplier non-adversarial collaboration
	Independence (0)	Not applicable
	Interdependence (=)	Buyer and supplier non-adversarial arm's-length
	Supplier dominance (<)	Buyer non-adversarial collaboration/supplier adversarial collaboration

Table 2-5 Appropriateness in sourcing strategies, power circumstances and relationship management (Cox, 2004)

It can be seen from the table that no collaborative relationship is suggested for supplier selection, which is at variance with the other literature on supplier selection. Section 2.2 argues that buyers seeking long-term relationships with suppliers leads to increasing consideration on how to select qualified suppliers. It might be better to consider power as a means to assure a continued relationship rather than to choose a type of relationship. Though Cox's research tried to link sourcing strategy, power circumstance and relationship management styles, how an individual sourcing approach is linked with power circumstance seems missing. Questions remain as to how power works in the selection of suppliers.

Zolghadri et al. (2011b) attempted to fill this gap by estimating power while evaluating the suppliers' performance. By comparing the power situations and the performance results they argue that the most comfortable collaboration situation is to choose a relatively less powerful supplier with relatively high performance. However, this research considers that both power and performance are determined under the same criteria like price, quality, delivery and etc., and does not address what constitutes power.

Kähkönen and Virolainen (2011) argued that an awareness of the sources of power enables the supply managers to select efficient alternatives. This research contributes to the factors that determine power, but does not address the question how power can be used for better supplier selection.

2.8 Three dominant research streams on power

While power is recognised as an important factor in supplier selection, little research exists on how power should be conceptualised. This section explores three dominant research streams on power for a deeper understanding and the possibility of modelling it. **Power-dependence relation theory** (Emerson, 1962), pointing out the origins of power, is the prevailing school of thought not only in the supply chain field but also in other fields like social science and politics. **Porter's five forces model** (Porter, 1979, 2008) explicitly proposes the factors that determine buyer's and supplier's power. It provides a framework for companies to analyse the competition within an industry and thus the underlying sources of power in the supply chain. **The five bases of power** (French et al., 1959) characterise power and are also widely used.

2.8.1 Power-dependence relation theory

The power-dependence relation theory (Emerson, 1962) states that power resides implicitly in another's dependence. *The dependence of party A upon party B, D_{AB} is* (Emerson, 1962):

(1) "directly proportional to A's motivational investment in goals mediated by B", and

(2) "*inversely proportional to the data requirements of those goals to A outside of the A-B relation*".

The power of *B* over *A* denoted as P_{BA} is based upon the dependence of *A* on *B*. In a relationship D_{AB} and D_{BA} will generally have different values which give rise to the concepts of relative dependence (Anderson and Narus, 1990) or interdependence asymmetry (Kumar et al., 1995). ***Power advantage*** (Emerson, 1962) is considered as the result of this difference. *If A depends upon B more than B depends upon A, then B has power advantage over A* (Pfeffer and Salancik, 2003).

In a supply chain, dependence exists when one company needs something from another, which could be a product, a resource, a certain distribution channel etc. For example, the supermarket is dependent on the vegetable supplier to provide carrots and parsnips, which gives the supplier some power. Meanwhile the supplier depends on the supermarket to sell their vegetables, which gives power to the supermarket. But the dependence between them is asymmetrical. The vegetable supplier is dependent on the supermarket more than vice versa, because the supermarket can easily switch one supplier to another and survive without a specific supplier while the vegetable supplier may not. This asymmetrical dependence generates the power advantage of the supermarket over the vegetable suppliers.

This dependence idea is further specified by Pfeffer and Salancik (2003) in their resource-dependence theory. The basis of the theory is that the need for resources, including financial and physical resources as well as information, obtained from the environment, made the organisation potentially dependent on the external sources of these resources (Pfeffer and Salancik, 2003). The dependence is determined by the importance of the resources to the organisation and the concentration of the control of discretion over resources**.** The importance of the resources depends on the relative magnitude of the exchange which is measurable and the criticality of the input or output to the organisation, which is more difficult to measure. Concentration of the control can arise from a monopoly position of an organisation; or a collective organisation acting as a cartel.

The power-dependence relation theory points out that power originates from dependence. The resource-dependence theory further reveals the constructs of dependence. They together indicate how to determine the power.

2.8.2 Porter's five forces model

Another piece of key research on power is Michael Porter's five forces model (Porter, 1979, 2008) as illustrated in Figure 2-12. This model describes five forces that shape industry competition. Porter focuses on the relative power a company has with an industry sector rather than the power relationship between a buyer and a supplier.

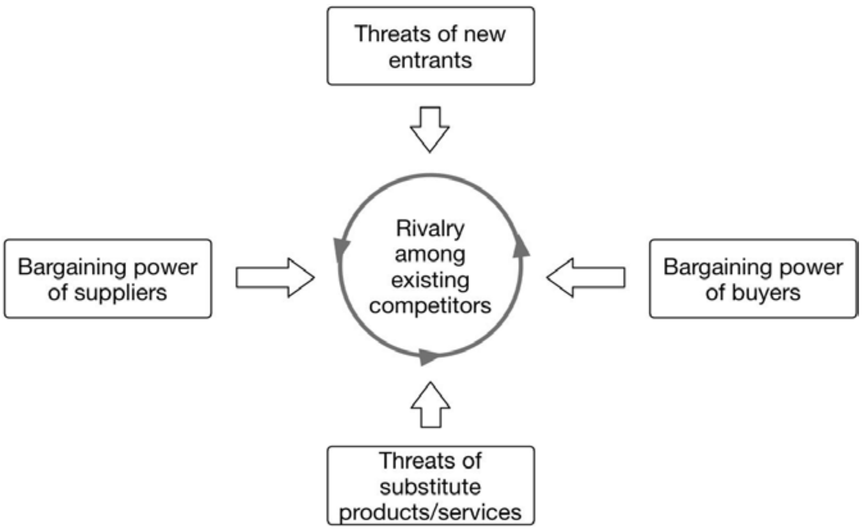


Figure 2-12 Michael Porter's Five Forces Model (Porter, 2008)

This model points out that bargaining power of supplier and that of buyer are two competitive forces to gain profits. These five forces with their determinants (Porter, 1979, 2008) are:

- ***Threats of new entrants***, which decrease profitability by bringing new capabilities, capacities, the desire to gain market share and substantial resources.

- ***Bargaining power of suppliers*** can be determined by

  (1) Supplier concentration: This could be the market share or control a supplier takes up in the industry. The suppliers will be powerful if they are more concentrated than the industry it sells to.

  (2) Importance of volume to supplier: The supplier who does not depend heavily on the industry for its revenues is powerful.

  (3) Switching cost: When switching costs are high, industry participants find it hard to play suppliers off against one another.

  (4) Differentiation of the products: The supplier has power if its product is unique or at least differentiated.

  (5) Available substitutes: The less substitutes for what the supplier provides, the more power inhabited in supplier.

  (6) Threat of integrating forward into the industry's business: this provides a check against the industry's ability to improve the terms on which it purchases.

- ***Bargaining power of buyers*** can be determined by:

  (1) Purchase volume, because a large volume relative to the size of supplier makes buyers powerful.

  (2) Differentiation of the products from available alternative suppliers, because the buyer has power over a single supplier if they can easily find an equivalent product.

  (3) Switching cost, where less cost gives the buyer more power.

  (4) Price sensitivity, which contains several aspects, such as the fraction of buyer’s budget spent with the supplier, how much the quality of buyer’s products or services is affected by the purchased product.

  (5) Backward integration, where the buyer gains power through the threat of integrating backward to make the industry's product.

- ***Threat of the substitutes***, which perform the same or a similar function as an industry's product by a different means. Substitutes place a threat to an industry if they offer attractive trade-off and low switching cost.
- ***Competitive rivalry within an industry***, which is affected by factors such as the number of competitors, the rate of industry growth, switching cost, product differentiation, fixed cost, exit barriers, and diversified rival strategies.

2.8.3 Five bases of power

Another widely cited theory is the five bases of power by French et al. (1959), which was first applied in social science and later extended to other fields. This theory points out power depends on one party's recognition of an ability of another, which would motivate a compromise. The following five bases categorise the source of power:

- ***Reward power*** has its basis in the ability to reward. The strength of reward power depends on the magnitude of the perceived rewards, one party's ability to increase positive impact while decreasing negative impact, and the probability of exercising the reward. A supermarket's promise to increase the order volume from the vegetable suppliers, if they can strictly meet the vegetable appearance requirements, is an example of reward power.
- ***Coercive power*** stems from the expectation on the part of one party that they will be punished by the other if they resist an attempt to influence them. To withdraw certain orders, or switch to another supplier is coercive power.
- ***Legitimate power*** comes from one party's perception that the other has a legitimate right to prescribe behaviour for them and they have an obligation to accept this influence. A contract clause is an example of legitimate power.
- ***Referent power*** has the basis in the identification of one party with another. For example, if the company admires the way its partner runs the business, its partner has referent power.
- ***Expert power*** stems from a difference in the knowledge level between two parties in a given area. Expertise, advanced technology and special training are examples.

2.9 Power determinants and measurement

Section 2.7 has argued that the existence of power imbalance between the buyer and the supplier influences the supplier's performance as well as the quality of the relationship. This raises the question of how a buyer or a supplier could recognise and assess this power imbalance. The three main theories, especially Porter's five forces model, indicate the possibility of measuring the power relationship. This section examines the power determinants in the literature and explores how to measure the power with the three theories.

2.9.1 What determines the power in supply chain

Porter's five force model and French's five bases of power both point to the source of power but from different perspectives. The former addressed the supplier's and buyer's power determinants from the point of view of market environment, most of which are quantifiable. In this thesis *power determinants are defined as the factors that determine the power of one party (buyer or supplier) over the other*. While the both parties might not be aware of all relevant determinants, the power arising from those determinants exists and should be factored in when constructing a measure of power. French's five bases of power are qualitative categories of power more from social relation view point, rather than measurable variables. They point out some determinants but do not consider other factors outside a relation such as available alternatives or market share. By comparison Porter's five force model is more suitable for quantifying supplier/buyer's power.

This section explores the power determinants specified in supply chains. Among the comparatively limited research on power determinants in supply chains, ten highly cited articles were selected for Table 2-6 to show the type of study with their methodology. The last two columns highlight whether the article focuses on supplier power or buyer power.

Publication	***Type of study***	***Methodology***	***Buyer***	***Supplier***
El-Ansary and Stern (1972)	Empirical	Survey and interview among wholesaling companies and dealers.	√	√
Cho and Chu (1994)	Conceptual with empirical illustrations	NA	√	√
Cool and Henderson (1998)	Empirical	Survey among 178 companies in different industries	√	√
Cox (2004)	Conceptual	NA	√	√
Caniëls and Gelderman (2007)	Empirical	Survey among purchasing professionals with 21.5% response rate (248/1153)	√	√
Caniëls and Roeleveld (2009)	Empirical	Qualitative research on four dyadic cases	√	√
Pai and Yeh (2010)	Empirical	Survey with 63.26% response rate in 196 informants in semiconductor industry	√	√
Kähkönen and Virolainen (2011)	Empirical	Case study comprising 29 individual semi-structured interview	√	√
Chaurasia (2014)	Empirical	Survey among 128 unites of apparel manufacturers if India	√	
Sheu (2014)	Empirical	Interview and survey among retailers of consumer electronics products	√	√

Table 2-6 Literature on power determinants

As listed in Table 2-7, power determinants applicable for assessing power are extracted from the articles in Table 2-6. Whether the determinants are used in measuring buyers or suppliers is indicated. The correspondence of the determinants mentioned in these articles is based on the author’s judgement on their focus. For example, El-Ansary and Stern (1972) use ‘customer preference’ on supplier and Kähkönen and Virolainen (2011) use supplier ‘brands’, where the two terms are considered the same. “Its brand and reputation in the eyes of the end-customers are significant factors in determining its power position” (Kähkönen and Virolainen, 2011). Brand is considered as a power determinant when the customers recognise and prefer it. Therefore, ‘customer preference’ on supplier and supplier ‘brands’ are termed as ‘customer preference on supplier (Determinant 15)’.

No	Determinants	Supplier	Buyer	Reference
1	Available alternative buyers		√	(Porter, 1979, 2008), (Cho and Chu, 1994), (Cool and Henderson, 1998), (Cox, 2004), (Caniëls and Gelderman, 2007), (Caniëls and Roeleveld, 2009), (Chaurasia, 2014), (Sheu, 2014)
2	Available alternative suppliers	√		(Porter, 1979, 2008), (Cho and Chu, 1994), (Cool and Henderson, 1998), (Caniëls and Gelderman, 2007), (Kähkönen and Virolainen, 2011), (Sheu, 2014)
3	Buyer's switching cost (on supplier)	√		(Porter, 1979, 2008), (Cho and Chu, 1994), (Cool and Henderson, 1998), (Cox, 2004), (Caniëls and Gelderman, 2007), (Caniëls and Roeleveld, 2009), (Pai and Yeh, 2010), (Kähkönen and Virolainen, 2011), (Sheu, 2014)
4	Purchased volume relative to supplier's sales		√	(El-Ansary and Stern, 1972), (Porter, 1979, 2008), (Cho and Chu, 1994), (Cool and Henderson, 1998), (Cox, 2004), (Caniëls and Gelderman, 2007), (Caniëls and Roeleveld, 2009), (Pai and Yeh, 2010), (Kähkönen and Virolainen, 2011), (Chaurasia, 2014)
5	Impact on buyer 's product differentiation	√		(Cool and Henderson, 1998)
6	Differentiation of the product of supplier			(Porter, 1979, 2008), (Cho and Chu, 1994), (Cox, 2004), (Pai and Yeh, 2010), (Kähkönen and Virolainen, 2011)
7	Importance to the quality of buyer's products or services	√		(Porter, 1979, 2008)
8	Supplier's threat of integrating forward to the business	√		(Porter, 1979, 2008), (Cho and Chu, 1994), (Cool and Henderson, 1998)
9	Buyer's threat of integrating backward		√	(Porter, 1979, 2008), (Cho and Chu, 1994), (Cool and Henderson, 1998)
10	Impact on buyer's cost structure	√		(Cool and Henderson, 1998)
11	Supplier's expertise and knowledge	√		(El-Ansary and Stern, 1972), (Cho and Chu, 1994),(Caniëls and Gelderman, 2007), (Caniëls and Roeleveld, 2009), (Pai and Yeh, 2010), (Kähkönen and Virolainen, 2011), (Sheu, 2014)
12	Buyer's expertise and knowledge		√	(El-Ansary and Stern, 1972), (Caniëls and Gelderman, 2007), (Caniëls and Roeleveld, 2009), (Pai and Yeh, 2010), (Kähkönen and Virolainen, 2011)
13	Supplier's reliable delivery	√		(El-Ansary and Stern, 1972), (Pai and Yeh, 2010), (Kähkönen and Virolainen, 2011)
14	Customer recognition on buyer		√	(El-Ansary and Stern, 1972), (Kähkönen and Virolainen, 2011), (Chaurasia, 2014)
15	Customer preference on supplier	√		(El-Ansary and Stern, 1972), (Kähkönen and Virolainen, 2011), (Sheu, 2014)
16	Anticipated profits for supplier brought by buyer		√	(Chaurasia, 2014)
17	New business opportunity for supplier brought by buyer		√	(Chaurasia, 2014)

Table 2-7 Power determinants of supplier and buyer

There are determinants mentioned in the reviewed articles but not listed in Table 2-7 for one of the two reasons: (1) it is not a suitable determinant for power; (2) it is too specific and can be included in another determinant. For example, 'role of price' is considered as a power determinant by Cool and Henderson (1998). However, whether the supplier can offer a low price or high price does not add or decrease its power over the buyer. An example for reason 2 is 'financial and business advice' in El-Ansary and Stern (1972), which is included in 'buyer's expertise and knowledge (Determinant 12)'.

Among the determinants identified from the literature two types can be distinguished:

- Independent determinants, which arise from the capability of the buyer or supplier. For example, customer preference on supplier (Determinant 15) adds to power, but it does not mean the buyer depends on it. Supplier's threat of integrating forward (Determinant 8) and Buyer's threat of integrating backwards (Determinant 9) are two other examples.
- Dependent determinants, which arise from a dependence of the buyer on the supplier or vice versa such as available alternative suppliers (Determinant 2). A small number of available suppliers lead to great dependence of the buyer on the supplier, which adds to the power of a selected supplier. On the contrary, if the number is large, the buyer is less dependent and the power of the selected supplier is less. Purchased volume relative to supplier's sales (Determinant 4) is another example. The more a buyer purchases, the more dependent the supplier is on this buyer for selling its product, and as a result the more power the buyer has. Some determinants such as buyer's switching cost (on supplier) (Determinant 3) implicitly show the dependence. When the switching cost of a supplier is high, it indicates the buyer has invested highly in this supplier, which increases the dependence of the buyer on this supplier and as a result gives power to the supplier. Some determinants can be treated as power determinants only when either buyer or supplier claims a dependence. If the buyer depends on supplier's reliable delivery (Determinant 13)

to develop or manufacture its own product, then it becomes a power determinant that enhances the power of the supplier over the buyer.

The majority of these power determinants are qualitative factors such as importance to the quality of buyer’s products or services (Determinant 7), supplier’s threat of integrating forward to the business (Determinant 8), supplier’s expertise and knowledge (Determinant 11), and new business opportunity for supplier brought by buyer (Determinant 17). Only few are quantitative factors including available alternative suppliers or buyers (Determinants 1 and 2), buyer’s switching costs (on supplier) (Determinant 3), purchased volume relative to supplier’s sales (Determinant 4). However, it can be difficult for a buyer or a supplier to obtain a numeric value for these quantitative factors, such as purchased volume relative to supplier’s sales. A buyer knows its own purchase volume but might not know a concrete number of the supplier’s other sales.

Unlike the general supplier assessment which compares a group of suppliers, power measurement is between one supplier and one buyer. A judgement is required on how much influence a particular determinant has. For example, an estimation of ‘high’, ‘medium’ or ‘low’ value of available alternatives makes more sense than a numeric value. Because a small supplier set for a standard product, e.g. five available suppliers, might be considered as a relatively large supplier set for a strategic product. Therefore, subjective judgement is critical for all the power determinants in Table 2-7.

2.9.2 Power measurement

When the determinants of power have been identified, the next step is to measure power according to these determinants. The literature shows three streams of research: conceptual models for power evaluation based on the power-dependence relation theory; evaluation of power according to different power determinants; and analyses of how buyers exert power based on the five bases of power.

Conceptual models based on power-dependence theory

Extending the power-dependence model in section 2.8.1, El-Ansary and Stern (1972) proposed a conceptual model considering power as a function of both dependence and sources of power as independent variables as equation 2-1:

$$P_{ab} = \alpha D_{ab} + \beta S_{ab} \tag{2-1}$$

Where:

P_{ab} = power of *A* over *B*.

D_{ab} = dependence of *A* on *B*.

α = direction coefficient of dependence: if $D_{ab} > 0$, α = -1; if $D_{ab} < 0$, α = +1; D_{ab} = 0, no relationship exists.

S_{ab} = sources of power held by *A* relative to *B*.

β = direction coefficient of power sources: if $S_{ab} > 0$, β = +1; if $S_{ab} < 0$, α = -1.

However, the power-dependence theory as discussed in Section 2.8.1 recognises that power of *A* over *B* is equal to and based upon the dependence of *B* upon *A*. Equation 2-1 ignores the dependence of *B* on *A* constituting the power of *A* over *B*. Instead, it only considers that the power of *A* over *B* should subtract the dependence of *A* on *B*. This model does not explain under what circumstance the dependence of *A* on *B* could be negative ($D_{ab} < 0$). It would make more sense if D_{ab} represents the relative dependence between *A* and *B*, considering D_{ab} can be negative in the equation.

Power can also be resisted. For example, a supplier B might have power to resist the buyer A’s demands. This is called countervailing power, i.e. the power that allows B to resist A’s attempts to control. Etgar (1976) proposed a model with a concept of countervailing power, which generates power from the sources of power and the sources of countervailing power. Equation 2-2 shows this model:

$$P_{ab} = f(V_{ab}, C_{ba}) \quad 2\text{-}2$$

where:

f = a function for conceptualising power

P_{ab} = power of A over B.

V_{ab} = a vector of sources of power that allows A to control B.

C_{ba} = a vector of sources of countervailing power that allows B to resist A's attempts to control.

However, this model is based on a different understanding of power. If the power of *A* over *B*, P_{ab}, is determined as equation 2-2, then the power of *B* over *A* should be calculated in the same way. In this case, how to calculate the countervailing power of *A* on *B* remains a problem. It would be more sensible to consider P_{ab} as **power advantage** as mentioned in power-dependency theory ((Emerson, 1962) and (Pfeffer and Salancik, 2003)), which is the result of difference between the mutual dependencies (power). For the purpose of this research two concepts are distinguished:

- ***Power of X over Y, denoted as P(X/Y)***: the power *X* has to influence *Y*, which comes from all the determinants that allow *X* to influence *Y*.
- ***Power advantage of X over Y, donated as PA(X/Y)***: the difference between *P(X/Y)* and *P(Y/X)*, the result of which indicated three types of power relationship, i.e.
    - *X* dominates *Y* when $PA(X/Y)>0$;
    - *X* and *Y* are balanced when $PA(X/Y)=0$;
    - *Y* dominates *X* when $PA(X/Y)<0$.

Measurement by power determinants

The conceptual models provide guidelines for measuring power. There is limited research addressing power quantification in practice, which needs to sum all measurable determinants. The following introduces the research on measuring power by various power determinants. Cho and Chu (1994) proposed a way of calculating power according to eight suggested power determinants.

A number between 1 to 9 is assigned to each determinant, where 1 stands for the lowest value and 9 is the highest. This number is multiplied by the weight of the corresponding determinant to give the power value for that determinant. The power of *A* over *B* is the sum of all power values of these determinants, shown as Figure 2-13 from Cho and Chu (1994).

Distribution of Intrinsic Bargaining Power between Nike and HS after the Separation in 1985

Intrinsic Bargaining Power of Nike			Intrinsic Bargaining Power of HS		
Determinants of Power	Importance Weight	Evaluation	Evaluation	Importance Weight	Determinants of Power
Determinant 1	0.15	3	7	0.15	Determinant 1
Determinant 2	0.15	4	6	0.15	Determinant 2
Determinant 3	0.15	4	6	0.15	Determinant 3
Determinant 4	0.10	5	5	0.10	Determinant 4
Determinant 5	0.10	5	5	0.10	Determinant 5
Determinant 6	0.15	6	4	0.15	Determinant 6
Determinant 7	0.10	5	5	0.10	Determinant 7
Determinant 8	0.10	5	5	0.10	Determinant 8
Weighted Average		**4.55**	**5.45**		Weighted Average

Nike's Propensity to Exert Power			HS's Propensity to Exert Power		
Factors Infuencing Propensity	Importance Weight	Evaluation	Evaluation	Importance Weight	Factors Influencing Propensity
Factor 1	0.25	5	5	0.25	Factor 1
Factor 2	0.25	5	5	0.25	Factor 2
Factor 3	0.25	5	5	0.25	Factor 3
Factor 4	0.25	5	5	0.25	Factor 4
Weighted Average		**5**	**5**		Weighted Average

Nike's Bargaining Power: $4.55 \times 5 = \mathbf{22.75}$ HS's Bargaining Power: $5.45 \times 5 = \mathbf{27.25}$

Figure 2-13 Distribution of power between Nike and HS (Cho and Chu, 1994)

This method assumes that the power of two parties in a relationship stems from the same determinants and when one gets a lower value on one determinant, the other will get a higher value. Therefore, the authors set a constant sum scale summing to 10 for each of the determinants. For example, in Figure 2-13, when Nike got a value of 3 on determinant 1, the value for HS is 7 on the same determinant. This research considers the exertion of power when deciding the final power. The power from the determinants is considered as intrinsic power and the final power will come only when one party exerts it. In this case, the propensity to exert power is also calculated in a similar way to assign a number to each factor and summing them by multiplying the corresponding weights. Then the final power is the result of intrinsic power multiplied by the propensity to exert power. By comparing the power values of the supplier and the buyer, who has more power can be established. However, power measurement involves many subjective judgements. This method does not take the imprecision of judgement into account. It is not able to tell by how much power one party has over the other, i.e. strong dominance, dominance, subordinate or strong subordinate.

Cox (2001, 2004) proposed a power matrix as seen in Figure 2-14, which generates the power scenarios by qualifying the power determinants rather than quantifying them. For example, there is ‘buyer dominance’ when the buyer power is high and the supplier power is low. The attributes leading to this scenario are listed in the top left quadrant of Figure 2-14 and include: few buyers/many suppliers, buyer has high % share of total market for the supplier, supplier is highly dependent on buyer for revenue with few alternatives, supplier’s switching costs are high, buyer’s switching costs are low, buyer’s account is attractive to supplier, supplier’s offering is a standardised commodity, buyer’s search costs are low, supplier has no information asymmetry advantages over buyer.

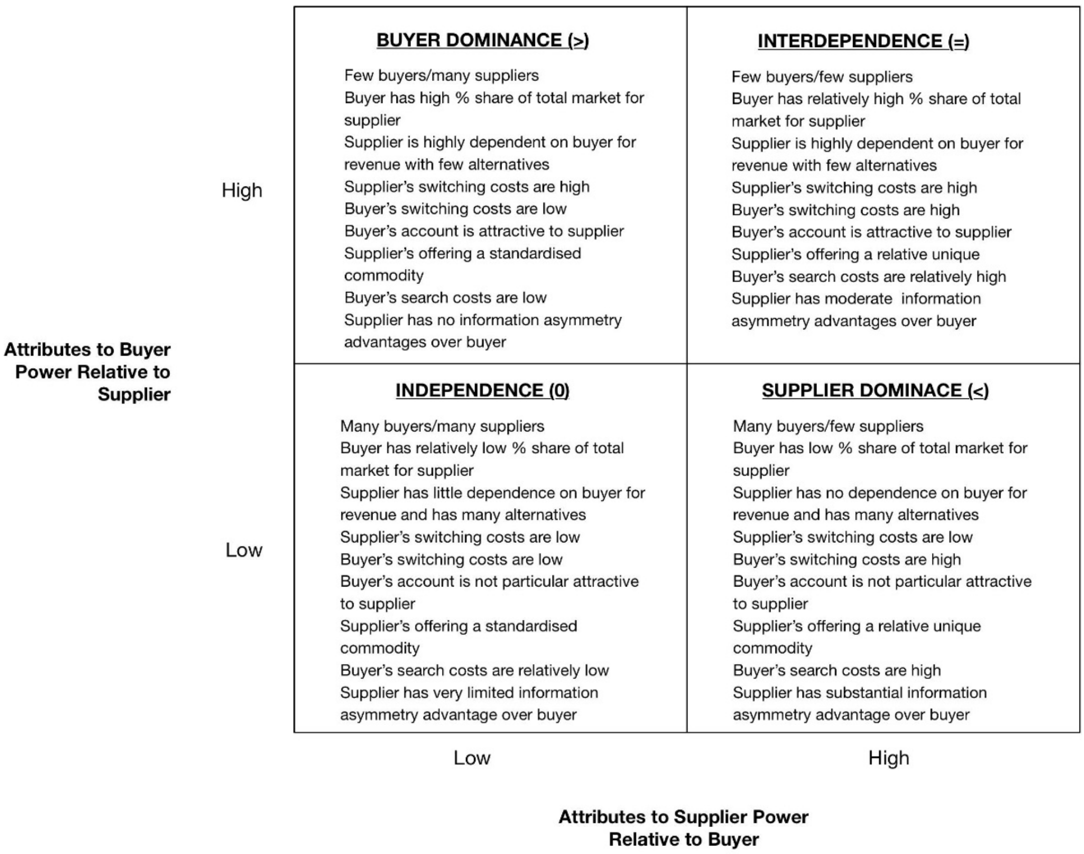


Figure 2-14 The power matrix: the attributes of buyer and supplier (Cox, 2001, 2014)

This matrix provides a picture of the power relationship with the power determinants listed in each quadrant, but leaves many questions unanswered. Should all these determinants with the qualified values (‘few’, ‘many’, ‘low’, ‘high’, etc.) be considered, or how can a power relationship be determined when only part of the determinants are available or a mixture of determinants from different quadrants are available? For example, how is a buyer/supplier positioned if there are few buyers/many suppliers while the buyer has low % share of the total market for the supplier? The flexibility of this measurement is also limited, because it does not explain how to deal with extra determinants not listed in the matrix. From the previous section, it is clear that some power determinants are missing from Figure 2-14, for example, supplier's threat of integrating forward to the business and buyer's treat of integrating forward (Determinants 8 and 9 in Table 2-7).

Zolghadri et al. (2011b) proposed a threshold method to determine the power situation based on performance criteria. The assumption of this method is that if the supplier performs badly on a criterion, then the buyer has power over the supplier regarding this criterion. Otherwise, the buyer will be dominated by the supplier. A set of thresholds consisting of four values are pre-set by the buyers. These reflect power scenarios: strong domination, domination, equilibrium, subordination and strong subordination, as shown in Table 2-8. *T1*, *T2*, *T3* and *T4* denote the four values of thresholds that *T1<T2<T3<T4*. 'Bigger is better' means the buyer looks for a big value for a criterion such as the order fulfilment rate. 'Smaller is better' means the opposite. For each determinant, a threshold range determines which scenario the supplier falls in.

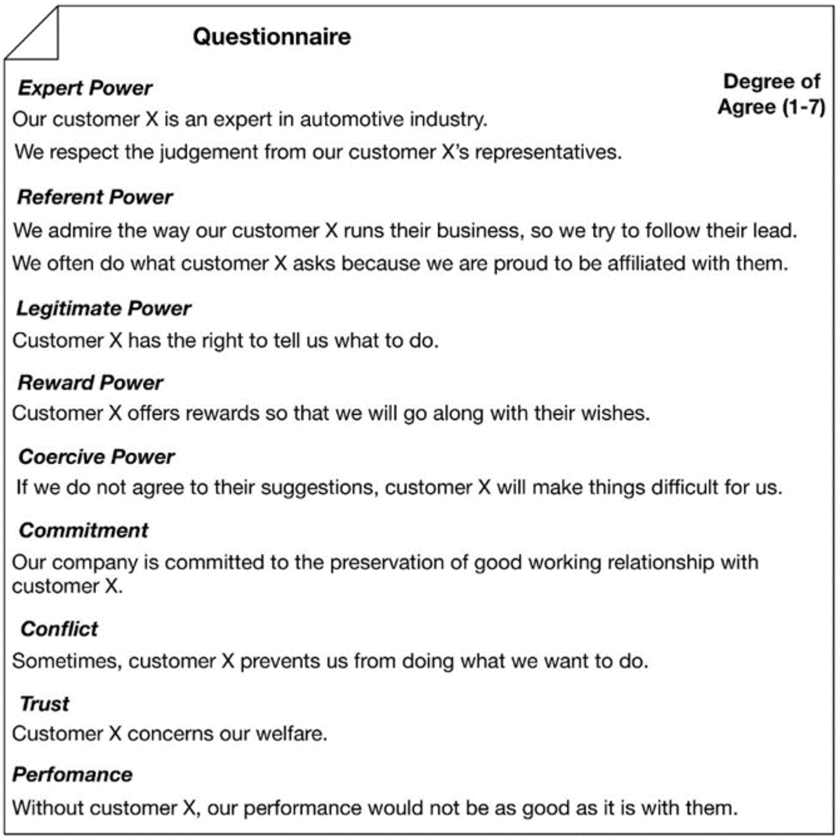
Smaller is better	**Bigger is better**
If $v \in [\min, T1]$ then buyer is strongly dominated by supplier (Strong subordination)	If $v \in [\min, T1]$ then buyer strongly dominates supplier (Strong domination)
If $v \in [T1, T2]$ then buyer is dominated by supplier (Subordination)	If $v \in [T1, T2]$ then buyer dominates supplier (domination)
If $v \in [T2, T3]$ then buyer and supplier are balanced (equilibrium)	If $v \in [T2, T3]$ then buyer and supplier are balanced (equilibrium)
If $v \in [T3, T4]$ then buyer dominates supplier (domination)	If $v \in [T3, T4]$ then buyer is dominated by supplier (Subordination)
If $v \in [T4, \max]$ then buyer strongly dominates supplier (Strong domination)	If $v \in [T4, \max]$ then buyer is strongly dominated by supplier (Strong subordination)

Table 2-8 Threshold rules for transformation of measured or assessed values v into power factors, adapted from Zolghadri et al. (2011b)

The advantage of this method is that the five power scenarios are clear and intuitive. However, this paper built the method merely on performance criteria rather than the power determinants in Table 2-7. The principles ('bigger is better' and 'smaller is better') and the thresholds in Table 2-8 are only for performance criteria. They do not work for most power determinants. Consider the determinant 'available alternative suppliers' for example. The buyer possesses power over a supplier if there many alternative suppliers. However, according to Zolghadri's principles, the buyer looks for 'bigger is better' because more suppliers means more options with more bargain spaces. With Table 2-8, a great number of available suppliers would indicate that buyer will be dominated by supplier, which is clearly contradicted in practice.

Measurement by five bases of power

Questionnaire studies have investigated the effect of power on supplier performance through the linkages between power and trust, commitment and conflict and from them to the performance (see Figure 2-15 as an example).


Questionnaire

Degree of Agree (1-7)

Expert Power
Our customer X is an expert in automotive industry.
We respect the judgement from our customer X's representatives.

Referent Power
We admire the way our customer X runs their business, so we try to follow their lead.
We often do what customer X asks because we are proud to be affiliated with them.

Legitimate Power
Customer X has the right to tell us what to do.

Reward Power
Customer X offers rewards so that we will go along with their wishes.

Coercive Power
If we do not agree to their suggestions, customer X will make things difficult for us.

Commitment
Our company is committed to the preservation of good working relationship with customer X.

Conflict
Sometimes, customer X prevents us from doing what we want to do.

Trust
Customer X concerns our welfare.

Perfomance
Without customer X, our performance would not be as good as it is with them.

Figure 2-15 Sample survey questions, adapted from Maloni and Benton (2000)

Some studies (e.g. Zhao et al. (2008), Nyaga et al. (2013), Liu et al. (2015), Maloni and Benton (2000) and Benton and Maloni (2005)) consider all the five bases of power while others such as Yeung et al. (2009) analyse fewer. Statements concerning each power base introduced in section 2.8.3 as well as others about Commitment, Conflict, Trust and Performance, in the questionnaire are rated on a seven point Likert scale (Likert, 1932) where '1' indicates 'strongly disagree' and '7' indicates 'strongly agree'.

These questionnaires provide an indication whether and how the buyer uses its power, rather than evaluating how much power a buyer possesses. It focuses on the behaviours of the buyer or the supplier, rather than the mutual effects. Lastly, a Likert scale is used to get an overall measurement of sentiment about the influence of power and to collect specific data from a large group of companies. The results show the general trends rather than analysing a specific power relationship between two collaborators in a supply chain

2.10 Refining the research questions

The literature review on supplier selection and power contributes to an answer to the first preliminary research question in Chapter 1: *How are suppliers assessed and selected effectively?* Supplier selection contains two major aspects, criteria and assessment methods. Formulation of criteria is the fundamental phase. Section 2.2 collects the criteria used by the literature and explores how to determine which criteria are relevant with a growing number and range of criteria. The assessment of the suppliers is a core phase. Sections 2.3, 2.4 and 2.5 introduce various assessment methods for supplier selection. Power as an aspect influencing the selection is discussed in terms of its definition, determination and measurement in sections 2.7, 2.8 and 2.9.

Through the literature review, the research gaps are identified. Further, the research questions are refined to fill these gaps.

2.10.1 Research gaps

Supplier selection has received considerable attention from academia. Some research addresses supplier selection criteria, which identifies criteria and their contribution in assessing potential suppliers. The criteria reflect the concerns of a buyer company about its potential suppliers. As examined in Section 2.2, ccriteria related to relationship such as power also appear, for example McCutcheon and Stuart (2000) and Lee (2009). However, few researchers mentioned power in supplier selection, which treated it as an additional criterion. This neglects the complexity of defining the power relationship and does not address how to assess the consequences of power in the supply chain. Other researchers tried to handle the complexity of power, however they miss the link between power relationship and supplier selection (e.g. Cox (2001, 2004)). Based on the literature review presented in detail in section 2.2.1 and section 2.7.3, we identify the preliminary research gap.

Research gap 1 (G1): Limited work has been published that explicitly takes power into account when assessing and selecting suppliers.

The majority of research in the literature focuses on building an assessment method for supplier selection using general decision making techniques. Some techniques such as AHP use subjective data for assessment, which comes from the judgements of decision makers. Some techniques like TOPSIS use objective data in the assessment process but are not able to take qualitative criteria into account unless subjective data for those criteria are provided. Incorporating fuzzy set theory is a popular solution to deal with the imprecision by subjective data during the assessment and allow the methods to incorporate qualitative criteria. About 1/3 of the reviewed articles have applied fuzzy set theory in their models, for example fuzzy TOPSIS methods (Chen et al. (2006) , Boran et al. (2009) and Wu et al. (2013c)). However, in some cases this fuzzification leads to objective data being abandoned in the assessment methods (see Table 2-4 which summarises the techniques/ methods for supplier selection). Through this literature review on the existing assessment methods, a second research gap is identified.

Research gap 2 (G2): There is a need for a decision method, which can deal with the multiple criteria, multiple judgements, as well as both objective and subjective data.

There are three main schools of thought on power: the power-dependence theory (Emerson, 1962); Porter's five force model (Porter, 1979, 2008); and French's five bases of power (French et al., 1959). Each describes the origins and sources of power in a buyer supplier relationship. There is research on the influence of power in supply chain, including pricing strategy and cost control (Munson et al., 1999; Wei et al., 2013; Kwak et al., 2006), inventory strategy (Bichescu and Fry, 2009), information exchange (Cai et al., 2013), operations control (Munson et al., 1999), the quality of relationship (Benton and Maloni, 2005; Zhao et al., 2008; Liu et al., 2015). However, little literature exists on the quantification of power besides the work of Cho and Chu (1994), Cox (2001, 2004), and Zolghadri et al. (2011b). Limitations in these methods of quantifying power are further discussed in Section 2.9.2 Power measurement. A third research gap is identified.

Research gap 3 (G3): An effective quantitative assessment is missing for power in the (potential) buyer-supplier relationship.

When reviewing these articles on supplier selection, the software tools supporting the corresponding methods were also identified (see Section 2.6 on Tools to support and implement the methods). Existing tools fall into two categories. The first is supporting the decision maker in calculations. These require a mathematics background and knowledge of the tool. The second is implementing a single decision-making method, which cannot deal with imprecise data or multiple judgements. A fourth research gap is identified.

Research gap 4 (G4): There is a lack of software tools dedicated for supplier assessment and selection.

2.10.2 Research questions

To fill the research gaps, the research questions are refined. The first research question bridges supplier selection and the understanding of power relationship, the answer to which addresses Research gap 1. Selection based on best performance does not necessarily result in a suitable supplier to work with. Insight into performance, power and their interaction will support the solution of the selection problem. An approach that takes into account power and performance can help select a suitable supplier.

Research question 1 (Q1): How can supplier selection be enhanced by including the considerations of power relationship?

The second research question concerns building an appropriate method for supplier assessment to address Research gap 2. An exploration of existing methods and models is undertaken during the literature review.

Research question 2 (Q2): How can qualitative and quantitative criteria and both subjective and objective data be integrated into a robust supplier assessment method?

The third research question concerns the quantitative assessment of power in a supply relationship to address Research gap 3. By examining the factors that determine power it should be possible to quantify power and assess its impact on supplier assessment and selection in terms of the determinants of supplier power and buyer power.

Research question 3 (Q3): how can the power distribution between the buyer and the supplier be assessed?

The fourth research question turns to the support of a software tool for supplier selection, the answer of which addresses Research gap 4. Based on the answers to the previous questions a software tool is developed, which supports the proposed approach to supplier selection.

Research question 4 (Q4): how can a software tool supporting supplier selection be developed?

The overall objective of this research is to provide an alternative perspective on decision making for supplier selection which includes consideration of the power relationship as well as supplier performance. The results of the research can also be applied during on-going collaboration for supplier evaluation, monitoring and development.

2.11 Chapter conclusion

The challenge of supplier selection is not only to pick a supplier with best performance but also one who is collaborative. Cox (1999) suggested companies also consider power relationships when developing the supply chain. “Only by understanding the power regime that exists can buyers and suppliers fully understand what is the appropriate way for them to manage relationships”(Cox, 2004). The ideal position for the buyer is a relationship where no supplier has the power to pressurise them into unfavorable conditions. Even if it is not possible to achieve this kind of position, the company should be aware of its current position.

This chapter explored the literature on supplier selection and power, which answered the first preliminary research questions, identified the research gaps and further refined the research questions. This research aims to fill the four research gaps by answering the four proposed questions. The next chapter will introduce the research methodology designed to achieve these aims.

Chapter 3 Methodology

A research methodology provides a framework for systematic research. It allows results to be compared across different studies and enables other researchers to replicate the study. This chapter describes the overall research methodology for this thesis, followed by an explanation of research methods applied within the methodology.

3.1 Overall research methodology

This research aims to design an approach and a software tool to aid a company in selecting suppliers. This work adapts the spiral research methodological framework proposed by Eckert et al. (2003), which assists researchers to achieve the threefold goals (understanding a phenomenon, improving a particular aspects and producing tools and techniques for industry), and to integrate research from different domains. The spiral model assumes that a large-scale research effort, such as a multi-person research project or a research group, has multiple stages starting with empirical studies, theory development, tools development and tool introduction. Each of the stages draw on the methodology of different fields, e.g. empirical studies follow social science methods, and tool development follows computer science. Each phase of the research leads to insights that can necessitate research in other steps. For example, theory building can show that more empirical research is required or an existing tool can meet the needs identified in an empirical study. However, individual researcher projects like a PhD only carry out some of the steps while building on the findings of others.

In the case of this PhD, the research was built on and motivated by the empirical research in the CONVERGE project mentioned in Chapter 1. The research started with theory and tool development and carried out empirical studies to validate the research questions and the results. It did not follow the more linear sequence of research advocated in the Design Research

Methodology (DRM) proposed by Blessing and Chakrabarti (2009), which suggests an descriptive study, followed by tool or method development and followed by a further empirical study to evaluate the tool or method.

3.1.1 Methodological framework

Eckert et al. (2003) base their methodological framework on the interaction of empirical studies of design behaviour, the development of theory, the development of tools and procedures, and the introduction of tools and procedures. It emphasises an evaluation after each of the steps. Rather than being a linear process it links different processes through insight. This linking requires revisiting previous states and skipping stages. Figure 3-1 illustrates this framework. Although it emphasises the application to design process research, its scope covers applied research in general. The application here is to the process for assessing and selecting suppliers.

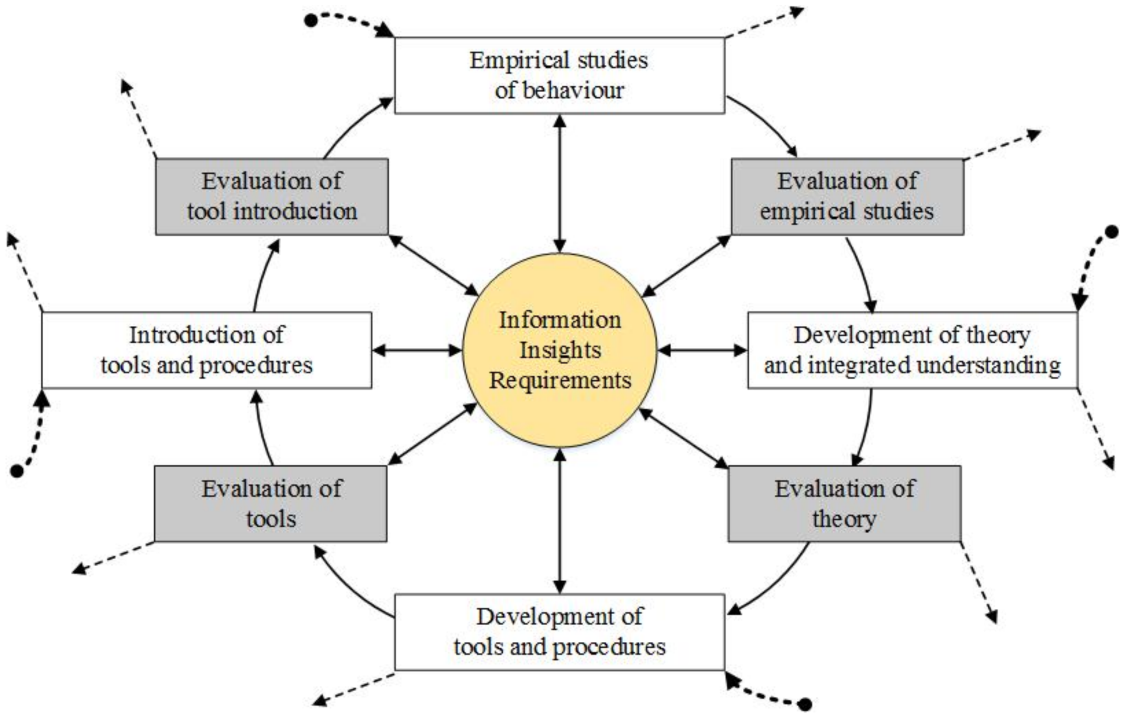


Figure 3-1 The spiral of applied research, adapted from Eckert et al. (2004)

- ***Empirical studies of behaviour***. These can include case studies, a range of analytical approaches, cross-process comparisons and experimental studies of individual activities.

- ***Evaluation of empirical studies***. This includes assessing the validity of the research results with respect to the results generalisation and the relation with other studies or theories.
- ***Development of theory***. Empirical studies should lead to the development of understanding of practice in the form of theories or models.
- ***Evaluation of theory***. The theoretical results are assessed in terms of their philosophical and methodological assumptions as well as their grounding in more general theoretical frameworks.
- ***Development of tools and procedures***. These are activities that depend on the developers' objectives. Software tools grounded in an understanding of the theories and practices should be developed with the aims of encouraging and supporting the application of the theoretical results in practice.
- ***Evaluation of tools and procedures***. Software tools and procedures are evaluated in terms of whether they fulfil requirements.
- ***Introduction of tools and procedures***. Tools and procedures must be sufficiently robust to be used independently by a company.
- ***Evaluation of dissemination***. The introduction of the tool is evaluated for validity in a practical context. In particular, this will cover partial use of the tool.

The information and insights generated in one of these activities can be used to guide any other step. The eight steps are presented as a cycle. In practice, the design research is often iterative, with several phases occurring in parallel or in smaller iterative cycles. Also the research could enter at any point marked by the black dotted lines in Figure 3-1. While this research framework targets the research performed in large research groups, all the eight steps usually cannot be completed by individual researcher during the course of a PhD thesis. However, it is important for researcher to be aware of the bigger picture of research and be clear of how the thesis fits into a boarder context.

3.1.2 Research roadmap using the framework

This research builds on the empirical studies carried out in the CONVERGE project, when the author was working at Lab IMS-CNRS. The aim of the CONVERGE project was to build a communication and information sharing platform for members of a non-hierarchical supply chain. A non-hierarchical supply chain emphasises an equal relationship of all the members without one member imposing overwhelming managerial decisions. However in practice this was rarely the case, because some members are still more 'important' than others due to their roles in the network, their activities during product development and manufacturing as well as the criticality of their performance (Liu and Zolghadri, 2011).

Figure 3-2 illustrates the roadmap adopted for this research. The research started with a detailed literature review, which was revisited periodically throughout the thesis as new issues come to prominence. Theory and understanding was developed based on the literature, then evaluated and refined through empirical studies. During this phase, several interviews were conducted to justify the research questions, identify and understand the problems, and improve the theory. This led to the development of a software tool, which was evaluated through a research collaboration addressing the comparison of sustainable suppliers.

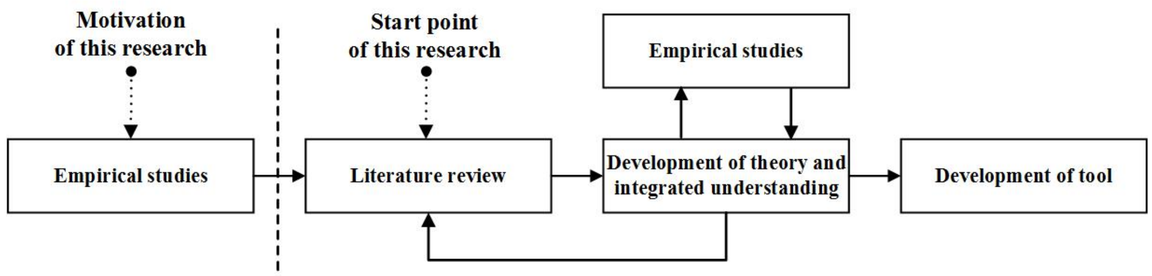


Figure 3-2 Research Roadmap

Table 3-1 shows the timeline of the research by academic terms.

Time	***Activity***	***Study mode***
05/2011 – 09/2011	Study the cases from CONVERGE project while working in the project; collect and read literature	Part-time
10/2011 – 03/2012	Review literature and set up the research questions; work in CONVERGE project	
04/2012 – 09/2012	Prepare probation report; review literature (focus on power); start to build the theory (mainly on power assessment); work	
10/2012 – 03/2013	Review literature (focus on power); do the interview with the company M&M (see section 4.1.1); build the theory (mainly on power assessment)	
04/2013 – 08/2013	Review literature (focus on supplier selection)	
09/2013 – 02/2014	Maternity leave	Suspension
03/2014 – 09/2014	Review literature (focus on supplier assessment and selection); change to work in a university in China; do the interview with Fospix Technology Inc. (see section 4.1.2)	Part-time
10/2014 – 03/2015	Review literature (focus power and supplier selection); do the interview with the company W&H (see section 4.1.3); build the supplier assessment model	
04/2015 – 09/2015	Review literature; build the supplier assessment model; start to build the whole relative positioning approach (integrating power analysis into supplier selection); design and start to implement the tool	
10/2015 – 03/2016	Build the whole relative positioning approach; do interviews with the engine company (see section 4.2 to 4.6); revise and improve the approach; implement the software tool; write the thesis	Full-time
04/2016 – 10/2016	Finalise the approach; Implement the software tool; evaluate the research by one case, finish the thesis	

Table 3-1 Research timeline

3.1.3 Linking thesis structure to the framework

This PhD research enters the spiral of applied research (see Figure 3-1) at ‘Development of theory’ by reviewing literature, goes back to ‘Empirical studies’ and carries on until ‘Evaluation of tools’, covering six steps. These steps are covered in different chapters of this thesis, as shown in Figure 3-3 where the chapter numbers are indicated in blue circles.

- ***Empirical studies of behaviour***. This is the topic of Chapter 4 which addresses the importance of supplier assessment as well as power considerations. From this the requirements for a tool in practice are derived.

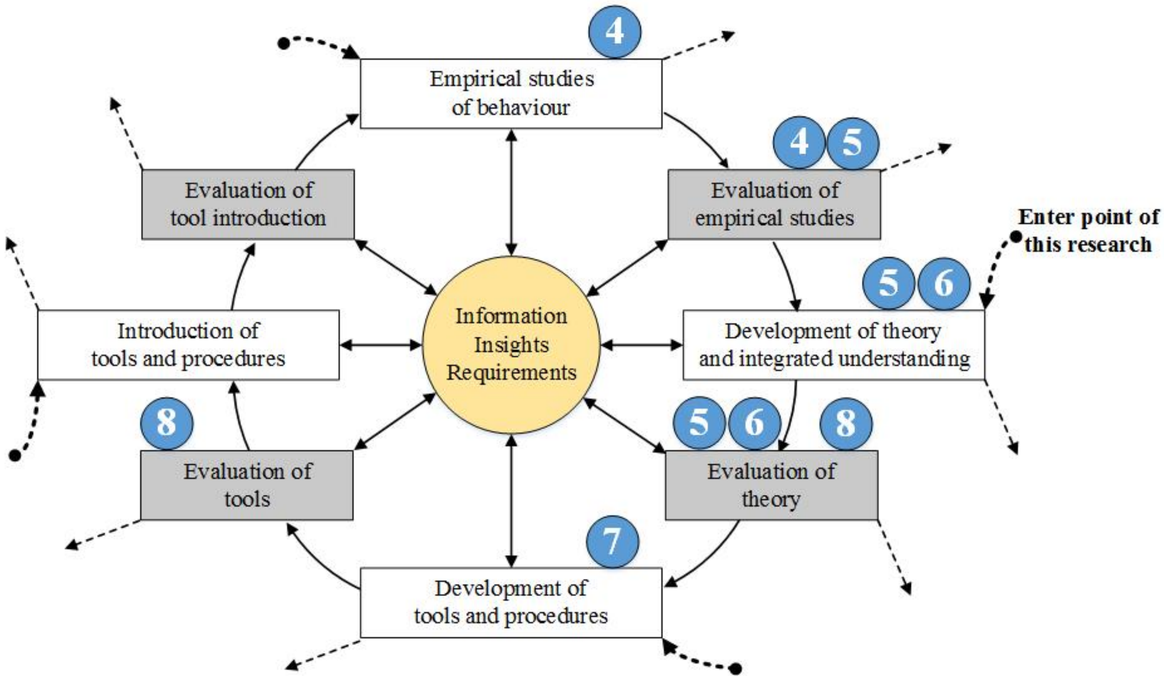


Figure 3-3 The link between thesis structure with the research methodology

- ***Evaluation of empirical studies***. The evaluation process focuses on what has been learnt and how this learning can be generalised, which is presented as a conclusion in Chapter 4 and an introduction to the elements which build up the analysis in Chapter 5.
- ***Development of theory***. This is the topic of Chapters 5 and 6, which develop the theoretical approach for supplier selection taking performance and power into account. Further, the assessment methods are developed to quantify performance and power. These methods are based on theoretical and practical implications from the literature review and the empirical studies.
- ***Evaluation of theory***. The approach and the methods are evaluated during their development in Chapters 5 and 6 by using evidence from the empirical studies and the literature. An evaluation case is also presented in Chapter 8.
- ***Development of software tool***. This is the topic of Chapter 7, which describes how the approach and the methods are implemented in a software tool.

- ***Evaluation of software tool***. The software tool is verified in terms of whether it implements the approach and methods for supplier assessment and selection correctly in the last section of Chapter 7. The user experience is evaluated in Chapter 8.

Though performing all the steps of the spiral research methodology is beyond the scope of an individual research activity (Eckert et al., 2004), this research covers many stages while remaining strongly grounded in the results from the literature.

3.2 Research methods

The spiral research methodology argues that the individual stages of the research draw on the methodology of different fields depending on the context and opportunities of the research.

3.2.1 Interviews and evaluation case

The literature review identified a gap in current research. This gap focussed on integrating power understanding into supplier selection. To address this gap the thesis aims to develop a decision tool for supplier selection that takes both power and performance into account. Though this research is mainly based on theoretical study of supplier selection criteria, power determinants and mathematical methods, it is important to investigate the relevance of the issues in practice. Several interviews were conducted to gain evidence to justify the research questions and support the development of theory. For the interviews the research turned to companies, to which relations existed through the EU CONVERGE project or the supervisors existing network of companies.

First stage interviews

The first stage interviews were done during the initial theory development when the author was getting a better understanding of the topic and completing the literature review. As Chapter 2 discusses, the literature indicates that power should be considered during the selection process but limited research has been done. Therefore, initial questions for the interviews centred around the following topics:

(1) whether supplier assessment/evaluation is an important activity;

(2) what the selection process is;

(3) whether power is an important issue in the buyer-supplier relationship;

(4) how power is perceived;

(5) whether power is considered during supplier selection and evaluation.

The interviews were semi-structured allowing the opportunity to probe for details. The list of topics was set down beforehand. The interviews started with the same list but did not require the interviewers to stick on the specific questions or the sequence of questions.

There were two semi-formal interviews and one informal interview with interviewees from different companies, as shown in Table 3-2.

Role	***Company***	***Sector***	***Time***	***Note***
Consultant	M&M (name changed for confidentiality)	Automobile	Feb 2013	The interviewee had good knowledge on supplier selection. But as the CONVERGE project finished and the author changed jobs, no further interviews could be conducted.
Chairman	Fospix Technologies Inc.	Electronics	Aug 2014	The interviewee was eager to provide information, but as a newly started company had little experience on the supplier selection process. A very interesting case on establishing collaboration with a supplier was provided. This case presented an interaction between power and performance.
Sales manager	W&H (name changed for confidentiality)	Information Technology	Jan 2015	Due to strict confidentiality from the interviewee's company and the work content of the interviewee, only general information on supplier selection was provided.

Table 3-2 Initial interviews for justifying the research questions and developing the theory

All companies focus on manufacturing of high technology. The names of the companies are changed to assure anonymity:

- M&M is a large automobile supplier in France. It was selected, because it participated in the CONVERGE project. The interviewee was a consultant with a good knowledge of supplier selection.

- Fospix is a small and newly founded company in China. The company was chosen, because of the great willingness of the chairman to share his experience. This company had just established a collaboration with a manufacturer to produce their product and could therefore provide useful information on how they chose this manufacturer.
- W&H is a big company in the information technology sector in China. It was chosen because the interviewee is an acquaintance of the author and, as a sales manager, he could provide a sales and market perspective on supplier selection.

Second stage interviews

The research questions were refined and the theory was developed alongside further interviews. The main aim is to find out how power relationships are understood from a practical perspective. In addition to the initial questions from the first stage, further topics were addressed:

(1) how suppliers are evaluated and selected;

(2) how power is understood and considered;

(3) how and when power influences supplier selection;

(4) what expectations companies have towards the approach (or the tool) that assists in supplier selection.

The interviews were carried out at a European engine company. The company is one of the world’s leading providers of engines for off-highway vehicles. They supply engines to their parent company who amongst other activities is a large OEM (original equipment manufacturer) for construction equipment, and to many other OEMs. They also sell generators under their own label. One reason to interview this company is a long standing connection through previous PhD studies (e.g. Jarratt (2004), Flanagan (2006) and Tahera (2014)). The interviewee is very knowledgeable and has experience supporting PhD students with empirical study. Considerable useful information was provided within a limited time. Table 3-3 lists the interviews carried out at this company.

Role	***Time***	***Activity***
Technical manager	Feb 2016	Explored the practice on supplier selection with power consideration
Technical manager	Apr 2016	Answered the questions raised from the first interview

Table 3-3 Interviews for revising and improving the theory

Both interviews were semi-structured. Questions were provided ahead of the interview. The interviewee prepared slides with explanations in answer to the questions. Subsequently outstanding points were clarified by Emails. The interviews were recorded and transcribed. The first interview was fully transcribed whereas the second was transcribed with key parts. Useful information was picked out according to the topics defined in the questions and additional points were identified. The analysis of the first interview raised several questions, which led to the second interview. Recordings of both interviews were listened to several times to avoid overlooking important information.

Evaluation case

In addition to interview, data from a French research project was analysed to evaluate the research. Supplier data is an essential requirement to evaluate the proposed approach and methods. However, this information is often confidential. Professor Gwenola Yannou-Le Bris, a research partner of Professor Claudia Eckert, provided data from an on-going project carried out by her research student Gaelle Petit, on establishing a sustainable supply chain in the agricultural sector. She obtained permission from their industry partners. Due to the limitations of this project's scope, the quantification and analysis of power relationships could not be directly evaluated in this case study. However, the case study did indicate some interesting implications for power relationships. The study was carried out in two phases of working with the research team, as shown in Table 3-4.

Phase	***Time***	***Objective***
Phase 1	Mar 2016	To understand the scope of the project, the participants (organisations) of the 'Sustainable agriculture' value chain and their relationship, and what supplier data could be retrieved for this research
Phase 2	Jun 2016	To evaluate the methods with the software tool by applying the data

Table 3-4 Two phases of case study for evaluation

3.2.2 Development of the theory

Theory development includes improving existing explanations of what is readily observable as well as the generation of new hypotheses (Whetten, 2002), based on findings from empirical studies. Whetten (2002) suggests six conceptual building blocks to develop a theory:

- "***What***" constructs (variables or elements) make up the theory? The constructs are assessed in terms of their complementarity or compatibility.
- "***How***" are constructs related? The basic "*how*" questions must be addressed in all theoretical frameworks; however, the level will vary depending on the intention of making a "*what*" versus a "*how*" theoretical contribution.
- "***Why***" are specific variables and elements chosen? This shifts the focus from the composition of a model to the context of the model and its conceptual assumptions. The answers to the 'why' questions explain the relevance of those variables to the study and the theoretical basis and rules for 'how'.
- "***When***" is the study valid? This is a contextual assumption which defines the boundary of the theory and refers to whether the study is valid only for a specific time period.
- "***Where***" are the phenomena studied? This is another contextual assumption which defines the boundary of the theory, and refers to whether the phenomena are studied in a specific geographical setting.
- "***Who***" does the theory relate to? This is also contextual assumption and is the third building block that defines the boundary. It focuses on whether the theory concerns a specific organisation or industry.

This research follows these building blocks and develops a theory to analyse the relative positioning and influence of buyers and suppliers. The theory includes (1) an overall approach to supplier selection which integrates performance and power relationship, and (2) methods to assess the performance and the power relationship. The assessment methods can be applied independently. Table 3-5 shows the building blocks of the analysis approach and the methods.

	The analysis approach	***The methods***	
		Performance evaluation	Power assessment
What	(1) performance, (2) power relationship	(1) criteria, (2) evaluation methods and techniques	(1) determinants, (2) evaluation methods and techniques
How	The influence of power on performance and their interaction	The general evaluation procedures	The general evaluation procedures and comparing principles
Why	The influence understanding from both empirical study and reviewed literature	The understanding from both empirical study and reviewed literature	
When/ where/who	The approach aims for supplier selection but can also be used later for supplier evaluation. This is a general approach where no specific industry section is emphasised.	This is a general model for supplier assessment without highlighting any industry sectors. Criteria are selected for specific sectors	The model is in the supply chain field and does not emphasise a specific industry sector. However, this model is most suitable when there is a need for negotiation.

Table 3-5 Building blocks of the analysis approach and models

3.2.3 Development of a tool

The software tool, which implements the analysis approach and the assessment methods, is an important contribution of this research due to the complexity of computation in the assessment methods. The analysis also needed a tool to visualise the results of the calculations. During the development of the methods, MATLAB R2013a (Licence no. 614513) was used for the calculations and displays of the distribution plots.

To limit the programming effort for the research prototype version, a waterfall development approach was followed broadly as it provides guidelines for the requirements definition, system design and implementation. Figure 3-4 illustrates the tool development approach.

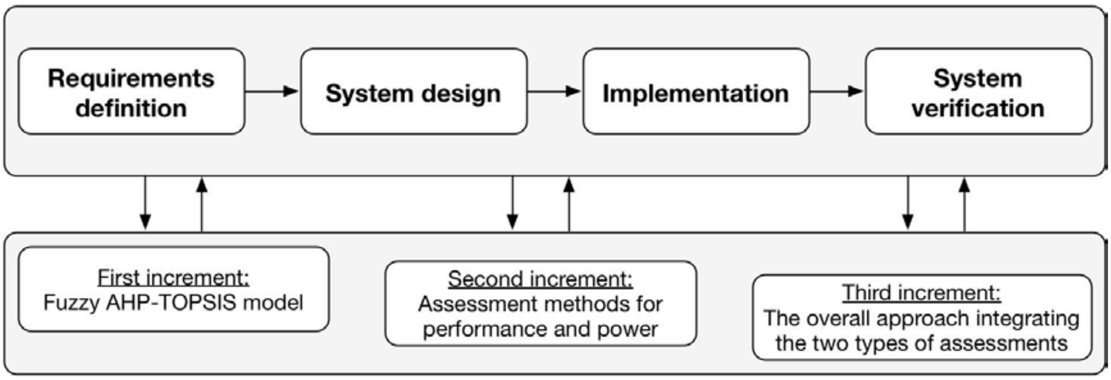


Figure 3-4 The approach for the tool development in this research

- ***Requirements definition*** generates the specifications of the software tool. The requirements arose from the development of the approach and the methods. Only the main functionality has been considered in this version of the software. System attributes such as robustness, security, and maintainability were out of the scope of this research.
- ***System design*** translates the requirements into the program structure. It includes high level design of the system architecture and low level design of the components and algorithms. The logic of integrating the functions and the display solutions is also included.
- ***Implementation*** is the programming process that implements the design in Java.
- ***System verification***, often called testing, ensures the software meets the requirements, and reports its quality and associated risk of failure. Verification is the preferred term in this research because the software was checked as to whether it implements the approach and the methods correctly rather than a full test.

Mainly there were three increments in the software development as set out in Figure 3-4: (1) the Fuzzy AHP-TOPSIS method, (2) assessment methods for performance and power relationship based on the Fuzzy AHP-TOPSIS method, (3) the overall approach that positions a supplier by integrating the results from the two types of assessments.

3.3 Chapter conclusion

The applied spiral research approach is the methodological foundation for the thesis. The themes of its steps form the backdrop of the remaining chapters. The iterations among the steps improve the robustness of the research. Specific research methods have been applied. Interviews were conducted to justify the practical importance and to address the research gaps, as well as to aid the development and improvement of the theory; Whetten's six conceptual building blocks (What, How, Why, When, Where, and Who) guided the development of theory; a waterfall process guided the development of the software tool. In the following chapters, these three aspects – empirical studies, theory development and tool implementation are introduced in sequence. They constitute the main research contribution of this thesis.

Chapter 4 Industry practice in supplier analysis including a consideration of power

The literature review shows a gap in integrating power analysis into supplier selection and a lack of method for assessing power. The empirical research was set up to find out whether this gap exists in practice and the importance of filling the gap.

As introduced in section 3.2.1, semi-structured interviews were conducted for the empirical research, which involved two stages. The first stage were initial interviews to justify the research questions and to develop the theory. The second stage was carried out in a European engine company and aimed at obtaining a more complete picture of supplier selection and power. The empirical studies contributed to development, revision and improvement of theory.

4.1 First stage interviews

Three interviews were carried out at three separate companies, i.e. M&M, Fospix and W&H. The main aims of theses interviews were to find out (1) whether supplier assessment is an important activity, (2) whether power plays a role in the buyer-supplier relationship, and (3) whether power is considered during the supplier selection. The full list of the prepared questions is presented in Appendix C (C1 Questionnaire for the first stage interviews).

4.1.1 An interview with a consultant for an electronics company in the automobile industry

This interview was carried at M&M, a project partner in the CONVERGE project. M&M designs and produces electronic systems including infotainment systems and dashboards for the automobile industry. The relationship with their suppliers varies. In the Human-Machine Interaction part of the infotainment platform, the relationships with the suppliers were mainly co-development relationships. Two suppliers participated in the design and development, one in charge of the definition of the Interface Windows and the other providing the Display Manager. For the dashboards the relationship was a contract-based arm's length relationship with the supplier of a purchasing component.

The interviewee was the representative of M&M, who had worked as a consultant for OEM companies and has extensive experience with product development and supply chains in manufacturing industries. The interview focused on how suppliers are evaluated and issues of power are addressed.

Supplier categories

M&M classified suppliers into (1) strategic suppliers who share risk, are involved in co-design, and provide strategic input; and (2) procurement suppliers who provide standard components. The 80–20 rule helps to decide who are the strategic partners. When developing the new product, after defining the BOM (bill of material), M&M typically finds that 20% components taking 80% cost. Those 20% are critical components and their suppliers are strategic suppliers. Normally the selection of strategic suppliers is based on technological needs. Supplier selection in M&M follows four steps, which are mapped in Figure 4-1 onto the generic steps (Figure 2-5) proposed by De Boer et al. (2001).

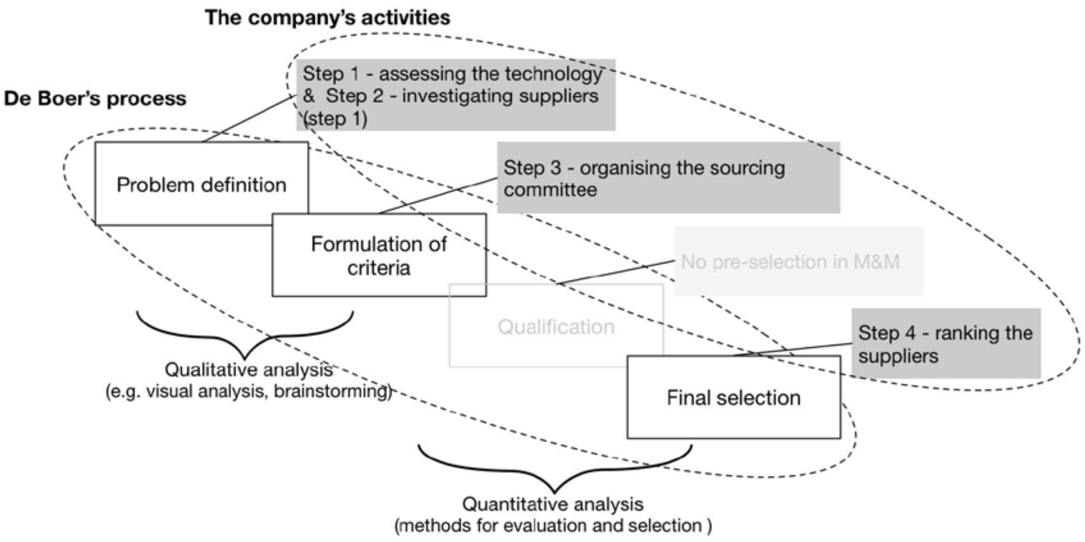


Figure 4-1 Selection process of strategic supplier in the company M &M

Step 1: Assessing the technology offered by potential suppliers and selection of the preferred technology.

Step 2: Investigating the suppliers in terms of their organisation, improvement policy, reactivity, flexibility and capacity to be a partner.

Step 3: Organising the sourcing committee. The committee decides the selection criteria (these criteria are agreed on by all the members). The committee could be composed of the buyers, people from quality assurance, engineering department and program management.

Step 4: Ranking the suppliers by the sourcing committee (normally 3 or 4 suppliers).

The discussion focussed on strategic purchasing, where few alternatives exist and there is no need to do pre-selection. It also shows that the decision process involves multiple experts, which indicates an assessment method should be able to deal with multiple judgements.

Power consideration

M&M equates power with the size of the company. While collaborating M&M does not conceptualise the interaction as power relationship unless a crisis occurs, such as a delay in delivery, a shortage or quality issues. Power comes in when the crisis happens. The company tries to shift the loss brought by the crisis to its suppliers or customers. How much of the loss its suppliers or customers will afford depends on who has more power in the relationship. Strong players can refuse to take any responsibility. However, during the crisis, all the parties want to maintain a balance and focus on resolving the problem together. Sometimes they find an agreement. Sometimes M&M takes control over part of the production phase, which might be considered as help by the supplier, as they have shown themselves unable to solve this problem.

This indicates a contradiction in how supply chain members see and treat power. On one hand, they do not always admit there is a power relationship. On the other hand, when a crisis comes, they try to make use of the power they have. In addition, though power is understood by M&M as the size of a company, the ability to solve problem seems a complementary view of power. This points to the necessity to understand power relationships, but does not provide details.

4.1.2 An interview with the Chairman of small producer of photosensitive chips

This interview was carried out with the Chairman of Fospix Technologies Inc. (Fospix hereafter). Fospix is a small company in China, founded in 2012. They design and develop photosensitive chips that can be used in cameras, web cameras, security monitors, mobiles cameras, etc. They need a supplier for semiconductors as well as manufacturer for their chips, which is normally the same company. Fospix selects the supplier (manufacturer) at the very beginning of the design process or even before design begins. Each manufacturer has a set of rules that influence the design because the manufacturers vary in their equipment and their techniques. Though the manufacturer is not involved in the product design process, it influences the design and the quality of the product. Therefore, Fospix maintains a close relationship with their manufacturer.

The most interesting issue in the interview was how Fospix achieved its collaboration with a much larger company. As a new and small company, Fospix does not have a formal process for selecting suppliers. They obtain the information about suppliers on the web. There were a small number of big companies that can manufacture the required kind of chip, one in mainland China, three in Taiwan, one in Israel, one in Japan, one in Korea. They ranked the suppliers only by their technical ability, but did not contact them based on the ranking results. They contacted the smaller ones first (not real small companies), because they expected these would be more interested in producing their product. As a matter of fact, this turned out not to be true.

The process from contacting the suppliers to establishing collaboration was quite difficult and long. Some potential suppliers showed no interest at all. Others showed interest at first and later declined. For example, a Korean company at first agreed to produce, but later refused because their CEO had changed, and the new CEO did not want to accept new customers. This led to a 6 months’ delay.

After failing to reach an agreement with a smaller company, the company contacted the largest potential supplier. To their surprise, they succeeded in interesting them in collaboration. Fospix showed their background, products to be manufactured, finance ability, human resource, strategic plan, customers and market. The manufacturer was willing to collaborate, because chips for security control were exactly the field the manufacturer wanted to be involved in and the background of Fospix gave the manufacturer confidence.

During the whole collaboration process, Fospix presented their new design from time to time in order to show that they have good design ability and a promising market. The purpose was to make the manufacturer confident in Fospix and interest them in a longer collaboration relationship as well as to gain more bargaining space. "*I consider power as the ability of leverage. We don't have any power at the beginning of the negotiation or even the collaboration opportunity, but their need to enter the market gives us advantage. Though I still don't think we have power currently, but by showing them our design ability helps us find a position in the relationship. And once our products are widely accepted and ordered, we will have the capability for arguing more during the negotiation.*" – Quotation from the interview record (throughout this chapter, the quoted interview records are in *Italics* with double quotation marks.)

Fospix also equated size with power and contacted the potential suppliers in an ascending order of the power. In practice the largest potential supplier was the one who was most interested. This again indicated that the size of company is not the only aspect giving a company power. Factors such the opportunity to enter a new market and the capability development could also be considered.

4.1.3 An informal interview with a sales manager of an information and communication technology company

W&H, a large Chinese enterprise in information and communication technology, produces a broad range of products including intelligent terminals such as mobiles and computers as well as providing enterprise business solutions. The relationship with its suppliers varies, depending on the supplied product and the suppliers’ involvement. W&H categorises its partners into three levels. The first level is “certificated partners”, who are able to provide independent software or hardware products and have passed the certification process by W&H. The second level is “advanced partners”. These partners possess a recognised position in their sectors and are able to co-design competitive solutions with W&H. The top level is “established partners”, who have a leading position in their sectors and are able to design advanced solutions with W&H. This interview mainly focused on establishing buyer-supplier collaboration from a supplier’s perspective. However, due to business confidentiality only general information was provided.

Supplier selection

The enterprise has a supplier database for selection and an online platform where potential suppliers can register their product or service information for potential future collaboration. The enterprise has a strict and formal supplier selection process. Suppliers are selected in terms of technology, quality, response, delivery performance, cost, environmental protection, social responsibility and cyber security. The enterprise has relatively fixed suppliers in different regions and countries. Those suppliers are certified by the procurement committee of this enterprise, which includes, but is not limited to, representatives from R&D, market analysis, global technical service, manufacturing, supply chain management, marketing, finance, and administration.

Making decisions on working with a customer

A supplier-buyer relationship with a customer of the enterprise can be initiated in two ways. Customers who have good pre-existing relationships approach the enterprise directly for business negotiation. The more general way is that potential customers call for tenders and the enterprise takes part in the bidding. There are many factors to consider before going to the bidding process, including the maturity level of their solution, competition, market share, future development opportunities, the difficulty level in delivering the solutions, profits and risk. The ranking given to these factors depends on the stage of the development of the enterprise in the local market. The company divides its development into two stages:

- ***Breakthrough stage***: the enterprise prioritises entering a new market. Therefore, profits are much less important than business opportunities.
- ***Stock market stage***: the enterprise already has a share of the market. The more important issues are to gain profits and control risk.

The enterprise also defines four stages of collaboration with their customers:

- ***Acquaintance stage***: an initial stage where the enterprise and its potential customers get in touch with each other. At this stage, the customers care most about whether the enterprise is able to provide a solution at a reasonable price. What the enterprise cares about is if the customer can bring profits or opportunity to enter the market.
- ***Trust stage***: a stage where the enterprise and its customers have prior collaboration. At this stage customers usually do not have much doubt about the enterprise's capability to provide the solution. The enterprise has an idea about the customers' requirement. The collaboration is easier to establish than in the acquaintance stage.
- ***Partner stage***: a stage where the enterprise and the customers have a stable collaboration relationship.
- ***Strategic partner stage***: a stage where the enterprise and the customers develop and collaborate for long-term goals.

The description above reveals two important points. As a supplier, before establishing the collaboration, the company also considers such issues as the maturity of their solution, competition, market share, future development, etc. which might influence their position in the relationship. Secondly, the company categorises its relationship with customers and treats its partners differently according to the relationship category.

4.1.4 Lessons learned

Supplier assessment and selection is a critical business activity. The interviewed companies manage their suppliers by classifying them. M&M has strategic and procurement suppliers. W&H groups suppliers by their design capabilities and defines itself as a supplier with four stages of collaboration with their customers. Though Fospix did not mention explicitly its categorisation, it eliminated smaller suppliers when considering collaboration. This corresponds to the findings in the literature that suppliers vary in their roles (see section 2.1.1) and are kept in different buyer-supplier relationships (see section 2.2.2). For example Kamath and Liker (1994) classify suppliers as standard parts providers, simple products assemblers, complex products assemblers and partners. As argued by Stremersch et al. (2001), suppliers of different types should be evaluated differently in relation to purchasing criteria.

Power affects the buyer-supplier relationship and a company's decision on selecting suppliers. When a crisis occurs, M&M tries to shift the loss to its suppliers or customers while strong partners could refuse any responsibility. Fospix contacted the potential suppliers in an ascending order of the power because it considered powerful suppliers having less interest in collaboration. To gain more bargaining space, Fospix tries to improve and present its design capability to its supplier during the collaboration. As discussed in the literature review (see section 2.7.2), power has effects on performance including cost control, pricing strategy, inventory strategy and information exchange.

"Only by understanding the power regime that exists can buyers and suppliers fully understand what is the appropriate way for them to manage relationships" (Cox, 2004). The interviewed companies equated the size of company with power, but implied other factors in defining its power such as design capability and need to enter a new market, as seen in the case of Fospix. Section 2.9.1 described how power can be determined by various factors like available alternatives, purchased volume relative to supplier's sales or switching cost. However, neither the practice nor the literature has addressed the question of how to determine the power relationship by taking these factors into account.

4.2 The engine company and its supply network

This section and the following ones present the results from the interviews at a leading European engine company. The interviews focussed on (1) how company assesses and selects their suppliers, (2) whether a power relationship exists in their supplier-buyer relationship, and (3) how the company understands and analyses power. Appendix C lists the prepared questions and the follow-up questions (C2 Questionnaire for the engine company and C3 Follow-up questions at the engine company). The quotations from the interviews are highlighted with italic style and double quotation marks.

4.2.1 Introduction to the company

This engine company has facilities operating around the globe including North and South America, India, China and the United Kingdom, but develops its products in the UK. The company has the capacity to produce up to about 800,000 units a year. The company has distributors in 180 countries and 3,500 outlets, with a reliable delivery network for products and services. Figure 4-2 is a simplified supply network of the company, showing the main roles of its network members.

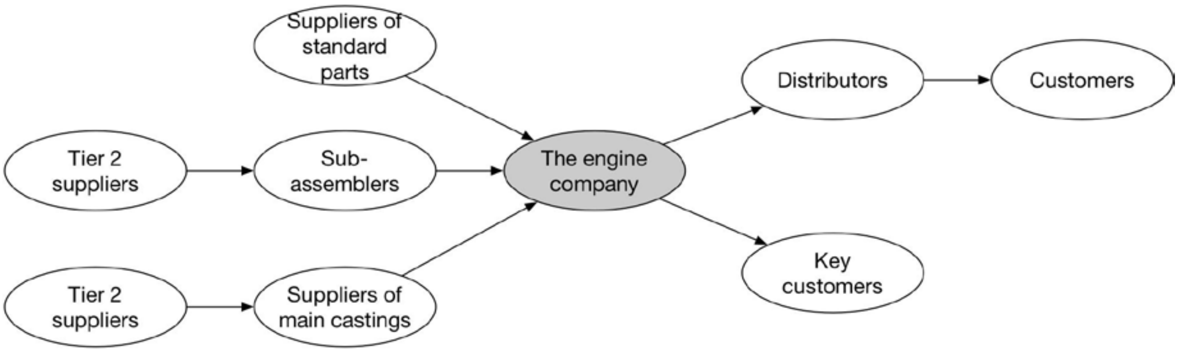


Figure 4-2 Simplified supply network

4.2.2 Suppliers, customers and distributors

The company uses ***category management*** instead of ***supplier management***, because they manage their suppliers according to categories of the provided products or services. An engine many have thousands of parts which are divided into standard parts and long lead time components such as major castings and control software. The company is mainly concerned with supplier relationships in the latter category. These are components which include their intellectual property or are part of their product differentiation.

The suppliers are classified further. *"What we do is that we classify suppliers as A, B, C, D or E. A means there is a core piece of the architecture. Therefore, we mitigate risk of a supply chain with those first. B might mean that getting the part may be right quick but validating performance could take longer time. C comes down to system integration where it's not an individual part. So there is more risk of design propagation. When coming down to like E, it is the part we won't bother. Because we know we can make it and buy from second tier suppliers."* Sub-assemblers are a special group of suppliers who buy parts from component suppliers and assemble for the company. The company sometimes also manages these tier 2 suppliers who supply materials to assemblies or important suppliers, depending on the products criticality. *"So we will just do our market research to say this is the supplier we want to work with, because historically he's done a good job of managing his suppliers and the quality of his product is good."*

The company has a wide range of customers from big brand global businesses to small privately owned companies. The majority of the customers are served by the company's distributors who offer parts and service support. The distributers also configure engines to offer standard and customised engines. If large customers have specific needs, these are handled from the UK headquarters. Sometimes, the company allow the customers to buy from suppliers directly if the purchase adds value. For example, if a customer *"wants the engine on day 1 but he doesn't want the after treatment after day 30. We just want the after treatment sitting around for 30 days.*

Though we could supply that, but we are not adding any value. So what we do is we sell the engine and allow this customer to buy after treatment directly from supplier."

4.2.3 The importance of supplier relationship

The company buys 70-80% of its components (Jarratt, 2004), therefore on-time delivery and reliable quality is essential. The innovation and technology capacity of suppliers influence the design process of a new product. The company gives greatest consideration to selecting strategic suppliers who are aligned with the company development strategy, collaborate with the company to identify optimal design solutions and share information with the company. "*Whereas with a strategic partner we would share with them forecast, the bad news and good news…. We've given out those capabilities back to our suppliers because they're the ones that can optimise that rather than telling them we want this feature."* Long-term collaboration does not imply strategic collaboration. "*When I say long term, we are bound by a long term agreement. But it doesn't necessarily mean strategic. I would like to think all our long-term partners are strategic but sadly, it's not always the case.*" To fund suppliers to improve its quality is one way the company develops strategic partnership. "*We often get into that dilemma. And because the strategy is that and it was a little bit of reluctant to change once we made a strategic decision even if products coming up badly*."

4.3 Seven steps of supplier management

The supplier management strategy, called category management, involves seven steps, as illustrated in Figure 4-3, from planning to execution. The company monitors supplier's strategic fit quarterly. They have a variety of templates with instructions for each step.

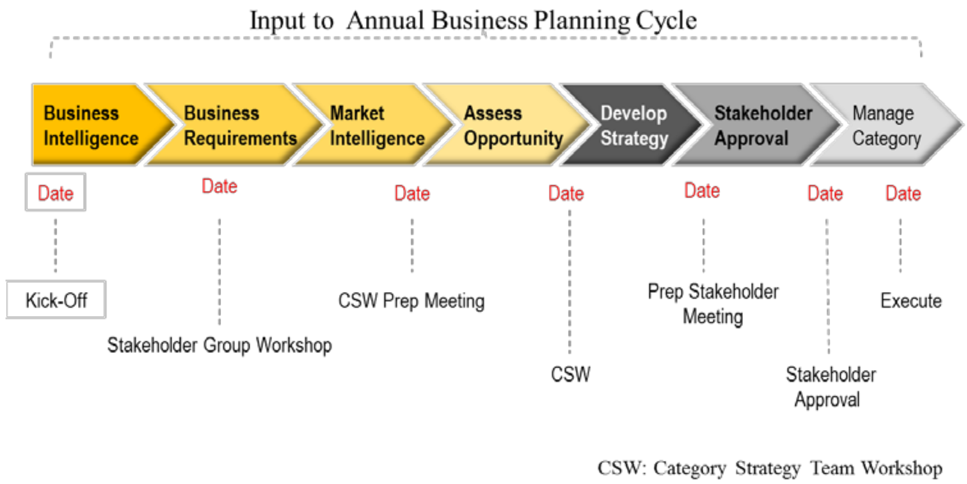


Figure 4-3 Seven-step category management, from the provided material (company material)

The category management process starts with **Business Intelligence** that generates visions, processes, methodologies and tools for the Global Supply Network Division (GSND) to enable accurate cost management and product sourcing decisions. There is a Feature Based Business Intelligence (FBBI) Team who acquires, aggregates, analyses, and visualizes data about part features and integrate it with other data. *"Business intelligence, you can't do it without any data"*. The following activities will be completed during this step: Category profile, Spend and Cost Analysis, Supplier Preference Analysis, Supplier Segmentation & Availability Analysis, Relationship & Performance KPI (key performance indicators) Baseline and Capacity Analysis.

Business Requirements collects and analyses the data based on a long-term strategy from the stakeholders. This data reflects their requirements, interests, priority and alignment in terms of cost, relationship, performance, risk and supplier network. *"Within business requirement we got the voice of regulator, all the regulation and legal issues."* The following activities are carried out: 3+ Year Product Strategy, Gather Stakeholder Requirements, Prioritise and Align Stakeholder Requirement to Category KPIs.

Market Intelligence collects supply market data and analyses it in terms of social, technological, economic, environmental and political aspects (STEEP). The STEEP Analysis, created by Harvard professor Francis Aguilar (Aguilar, 1967), analyses the impact of external factors on the organization and predicts what might happen in the future. It is used worldwide under different names as PEST, PESTEL, PESTLE, STEPJE, STEP, STEEPLED, and LEPEST. Porter's Five Forces model (see section 2.8.2) is also applied to understand the market situation. *"Supply market intelligence is what we want to do, what the strategy is and the market is telling us what product we shall sell…… It's really understanding what's happening out there with suppliers, technologies."* The followings activities are carried out: Supply Market Intelligence Plan, Gather Supply Market Insights, and Supplier Investigation & Evaluation (eSourcing).

Assess Opportunities identifies gaps, brainstorms options and develops action plans. One of the tasks is to understand the future state in terms of the category vision, including cost management strategy, category performance improvement strategy and supplier relationship management. *"What vision we got, what opportunity we got and how we develop suppliers."* The following activities will be done: Category Vision, Gap Assessment & Option Generation, and Strategic Actions.

Develop Strategy covers Cost Management Strategy, Supplier Performance Strategy, Supplier Relationship Management Strategy, Enterprise & Supplier Risk Management Strategy, and Global Supplier Network Strategy.

Stakeholder Approval and **Strategy Management** are the last two steps. The team commitment and stakeholder approval finalise category approval. Strategy management maintains stakeholder engagement and ensures strategy execution. During this step, category strategy performance is monitored and managed, strategy KPIs are incorporated into annual goals, and the communication plan is executed.

Figure 4-4 shows the process of getting the suppliers plan into practice. The cycle can be shortened if rich information is presented to the stakeholders. *"It's bit like a gateway. The stakeholders sign off to proceed. If you come in there with poor information, they will tell you to go away."*

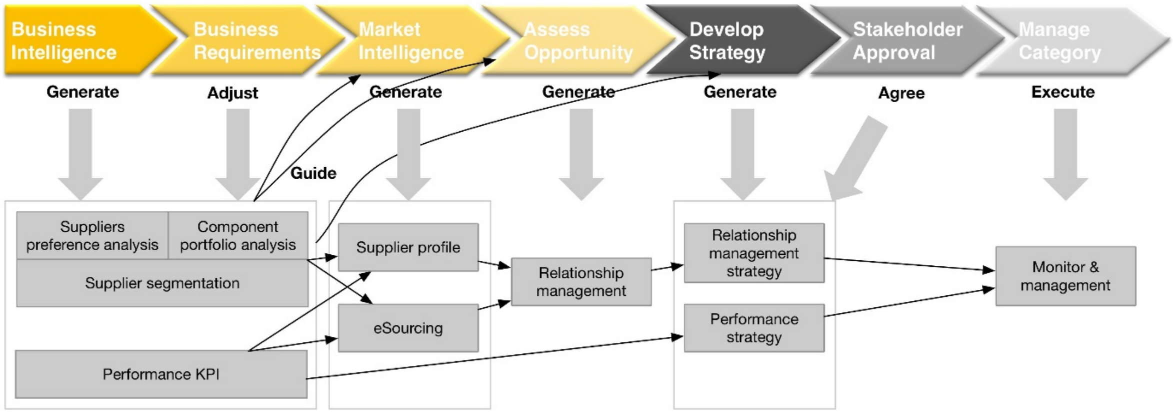


Figure 4-4 Activities during supplier management (based on company material)

4.4 Supplier evaluation and selection in the company

Business strategy guides the supplier selection process. It starts with business strategy vision and comes down through marketing strategy to product strategy to manufacturing strategy and down to component strategy before looking at the supplier strategy.

4.4.1 Selection of new partners

"There are not a lot of opportunities to change suppliers because we don't want to keep changing suppliers……. The biggest opportunity to change them is when we introduce new product."

Supplier selection during New Product Introduction

Supplier selection mainly takes place during the New Product Introduction (NPI) process. NPI is the process the company uses to develop, build and delivery quality products to customers. It starts with identifying key technologies which add value in the market. The company can then evaluate whether a category supplier of a particular technology has the capacity and ability to deliver the new technology based on quality, logistics, cost, development and management, and understands the risk associated with it. The company values and encourages customers and suppliers to be involved throughout the NPI process. For each new product, the company has the opportunity to ask: *"where are we targeting this engine to the world? Where do we want our supplier to be based? Do we have the correct suppliers today or shall we change them?"*

Other opportunities to change suppliers

In addition to the quarterly strategic assessment, suppliers are evaluated weekly in terms of key performance indicators like quality and on time delivery and responsiveness. Strategic partners cannot be changed easily, even if they are not performing well. Therefore, power could come into play by pushing the suppliers to improve their performance. The company is reluctant to change a strategic partner, because of issues such as switching cost and available alternatives. These factors give some power to strategic partners. This points to the need to estimate the power relationship.

4.4.2 Supplier analysis method

The company carries out three analyses of their suppliers using classification grids. *"If we are looking for a long term partner, if they don't sit in one of the opportunity pots, we probably wouldn't consider them or we have to develop them."* It is important to the company that the supplier's own perspective is taken into account in these analyses.

Supplier preference analysis

Supplier preference analysis, as shown in Figure 4-5, is used to position suppliers according to the extent to which the category products fit to the supplier's business and how much value the category brings to them. They use the following categories (from company material):

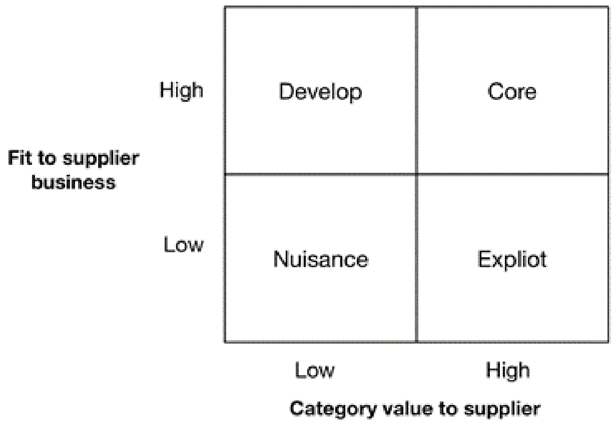


Figure 4-5 Supplier preference analysis (company material)

- ***Nuisance***: The supplier doesn't consider the business offered by this product category significant to them as it doesn't offer significant value and is not aligned to their long-term strategy and success.
- ***Exploit***: The supplier considers the business offered by this category significant to their current success as it offers significant value, however it is not aligned to their long-term strategy and success.
- ***Develop***: The supplier considers the business offered by this category as a good fit to their business and is motivated to work with the company to grow it.
- ***Core***: The supplier considers the business offered by this category as critical to their business and is very motivated to work with the company to share in profitability and gains in competitive advantage.

Component portfolio analysis

Component portfolio analysis, as shown in Figure 4-6, is used to categorise the components according to how challenging it is to procure the components and how much value they bring to the enterprise.

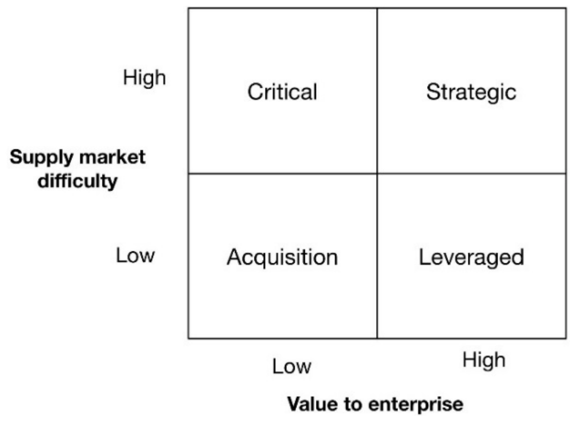


Figure 4-6 Component portfolio analysis (company material)

- ***Acquisition***: components of low value to the company and low supply risk.
- ***Leveraged***: components of high value to the company and low supply risk.
- ***Critical***: components of low value to the company and high supply risk.

- ***Strategic***: components of high value to the company and high supply risk.

Supplier segmentation

Supplier segmentation (Figure 4-7) points out the types of relationship between the supplier and the company based on supplier preference (Figure 4-5) and component portfolio analysis (Figure 4-6). This segmentation indicates how much impact the supplier has on the company profitability.

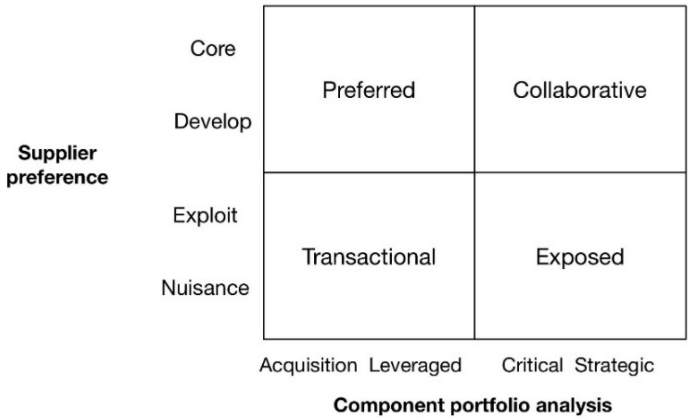


Figure 4-7 Supplier segmentation (company material)

- ***Transactional*** when supplier preference is either exploit or nuisance while the component is either acquisition or leveraged. They require minimal commercial involvement and have minimal impact on profitability.
- ***Exposed*** when their preference is either exploit or nuisance while the component is either critical or strategic. They expose the company to risk and can have a negative impact on profitability.
- ***Preferred*** when supplier preference is either develop or core while the component is either acquisition or leveraged. Because they could contribute significantly to sustain company profitability through maximising the purchases and commercial involvement.
- ***Collaborative*** when supplier preference is either develop or core while the component is either critical or strategic. Because they could contribute significantly to sustain the company profitability and competitive advantage through technical and the commercial collaboration.

4.5 Understanding of power in the company

Power is an important aspect in resolving potential problems for a company with its suppliers.

4.5.1 Definition of power

The company defines power by the purchased volume relative to supplier's sales (Determinant 4 in Table 2-7). *"There's a market out there for a billion units. If a supplier is serving a half billion of those, then you know he is the most powerful supplier, and your volume proportion of that is the way we look at it, as how much power we have. So if we're on servicing in a few hundred thousand units, we are not important to that supplier at all. Therefore, there is no reason why he should do anything rather than giving us a price that suits him for the inconvenience of doing this small volume."* For example, Zeta (names changes for confidentiality) is a global supplier of electronic control components and supplies up to 400,000 electronic control modules to the company a year. This is a high volume for the company as an off-highway engine manufacturer, but small compared to order volumes for platform product in the automotive industry. This volume is a very small proportion of Zeta's whole market size. The company does not have a powerful position in this relationship.

In some situations the company only has few alternatives (Determinant 2 in Table 2-7), which can lead to a highly dependent relationship. *"When we came to emission technology, we have to use certain technologies and devices that only a few companies have. So you don't have lot of choice rather than go to those companies. Therefore, you are very dependent on some of those companies."*

Switching cost also affects power (Determinant 3 in Table 2-7), for example when working with a casting supplier. *"We also look at this cost of switching…… So that casting supplier got power over us, knowing if we switch, they got three years before we are going to switch. Because we are not going to switch just like that, especially if they've got IP from tooling and we don't. Power is available to our supplier depending on how long it takes us to develop a new supplier"*

Brand is found as a kind of leverage between the company and its parent company, with whom it has a subsidiary-parent and supplier-buyer relationship. Though the company's power is limited as a subsidiary but as a brand, it is better known than its parent company for example in India. Therefore, "- *You got some power, some control back to your parent company. -Yes, because of brand."* This brand effect is the customer preference (Determinant 15 in Table 2-7).

4.5.2 Estimating the power relationship

The interviewee pointed out that power is a matter of perception. The power comes into effect only when it is perceived. For example, power is tested by recording if suppliers respond to the company request or not. The company might think they have power over a supplier, but if supplier does not respond, they might reconsider. *"So we know all our perception of having power is wrong." "Power is a perception and our power definition doesn't encompass everything power should."* Therefore, the mutual perception of the power also gives the company potential actions. *"We look at where that supplier is and they look where we are. Each will take a stand and know what game to play."*

Power comes down to how important the company is to the supplier and vice versa. *"Either the supplier has a need of your business, or you have a need on your supplier. Power comes down to a need."* Therefore, when a supplier does not perceive power in the same way, the company makes them aware of this. *"Supplier may think they don't have a need on you but you need to convince them. You must work with us, look what we bring."*

In this case, power becomes subject to negotiation. For a new product, a lot of considerations are given to suppliers, for example, suppliers' financial stability or global footprint. In estimating power, the company asks questions like "*Are they bigger than us? Are they smaller than us? Will they listen to what we say or not?*" The company will *"try to negotiate in the real world by implying that we have much more power."* They try to convince the suppliers by showing the company's strength, even when the company wants to develop a partnership with a strong supplier. For example, there is only one supplier who can provide a special customised sensor. Both know this situation. Therefore, it is a tough situation for the company to establish collaboration. To convince that supplier to be a partner of the company, the company could negotiate based on who they are "*We are developing business; we have got highest pins of any off highway engines producer. The developing world is relying on diesel engines, going to forward, going to be expanding. We are quite willing to work with you.*"

4.6 Responding to power imbalance

As argued in section 2.7.2, the power imbalance could lead to various impacts. This section introduces the impacts on the company and how it analyses power relationships.

4.6.1 The impacts of power imbalance

The direct result of power imbalance is that the supplier could refuse a request by the company. Sometimes this imbalance situation also drives communication, negotiation and even the type of contract. The following examples were mentioned in the interview:

- ***Shift in volume***: When there is a shift in the engine manufacturing volume, for example a doubling volume in the following month. The company goes back to their suppliers and asks if they could increase their schedule in the next month. Zeta, as a powerful supplier, probably will say *"sorry, we've an agreement. If you are not smart enough to tell us 6 months ahead, that's what you're getting."* But if the supplier is dependent on the company's business, the company can request the supplier to run on additional shifts to produce more components.
- ***Excess cost***: The company calculates what the cost actually should be. If a supplier is selling the parts 10% above that, the company will require open book accounting to understand why the supplier charges so much money. If it is the result of an inefficient process, the company will try to work with the supplier to improve their process to reduce the cost. However, the company could not do this with Zeta.

- ***Quality issues***: The company monitors the performance of the suppliers. When they notice Zeta not performing as well as previously the company can notify them but Zeta might do nothing. But if it is a supplier dependent on the company, the supplier usually responses very quickly to sort the problem out. *"Power is important on the communication side"*
- ***Component phased out***: The company received notice from Zeta that they are thinking of replacing the provided type of ECM (electronic control modules), because there is no other demand for this type of ECM. The typical way to solve the problem is to negotiate to maintain production at a certain level. But Zeta left the company two choices, either moving to a higher volume product at the same cost or to pay twenty percent more. *"That is the way they negotiate because they have the power to do that."* This could lead to the problems on the customer side. *"If we've got a very powerful supplier insisting change something. It's a real problem with our customers."*
- ***Contractual arrangements***: With each supplier there is a supply agreement which clarifies who is responsible for quality defects. Because the volume exchanged between the company and customer is high (50,000 a year is quite usual), this involve large sums. Therefore, *"the power of supplier also determines the type of contracts, expectations on cost recovery, on quality and so on."*
- ***New regional suppliers***: When opening new manufacturing facilities in a new region, the company seeks new strategic partnership. Though Zeta has already some manufacturing capabilities, the company might still prefer to develop a supplier rather than to work with Zeta. The reason is because *"they can knock us around and tell us they are not manufacturing these and we have a sudden down turn of volume that will charge fortune and penalties."*
- ***Component development cost***s: The company is going to bring out a new product in 2019. Customised ECMs will be purchased, which will require high investment. If a large customer requires a new ECM, Zeta will absorb this development cost. But with the company, Zeta will charge the development cost.

Influence can also arise from specific knowledge. In the days of fully mechanical engines the company used to design everything in the engine and knew the technologies and the way they performed in detail. When buying fully mechanical parts, like the cylinder, the company can correct their suppliers. *"We can tell our head supplier: 'hey, you are making that cylinder too thin and it won't work'. They have to believe us because we know how they are going to work together. If they do casting, modulating and machining, we again can tell them 'you are not casting properly'."*

Power balance also affects the purchasing volumes. The company does long term volume forecasts of 2-5 years, which drive their business strategy. Small suppliers rely on contracts to plan recruitment, investment in machines, procuring raw materials and setting up logistics. These types of fixed volume contracts may require the company to pay the same, even if the order volumes are lower. Big companies like Zeta can be more flexible, because they produce millions of parts so that increasing the purchase volume from 40,000 to 50,000 does not cause a problem.

4.6.2 Porter's five forces model to analyse the market environment

The company uses Porter's five forces model as discussed in section 2.8.2 is applied to each of the five core segments served by the company supply base. Figure 4-8 shows how the model is applied in the company.

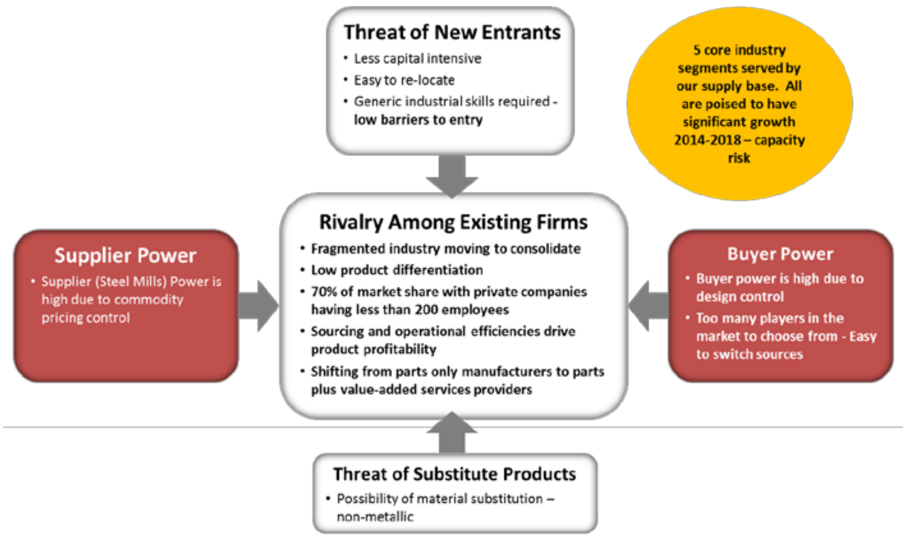


Figure 4-8 Porter's five model analysis (company material)

The power of a supplier, such as a steel mill, is high because commodity pricing is controlled by the supplier. The buyer's power comes in very differently. When the buyer has the design control and many alternatives sources in the market, the buyer power is high. Not much theoretical work on power has been done in the company. There is no tool to assess who has power over whom and to understand power at a strategy level. *"I don't believe we use power academically. Our power definition doesn't encompass everything power should. Power is looked out infrequently."* Though the company tried to use Porter's five force model, it is still difficult for them to have a whole view of the power relationship. *"We do look at the factors. But I don't know if we use that well."*

4.7 Chapter conclusion

The case studies corroborate Gap 1 and Gap 3 identified in the literature that power analysis is not included in supplier selection and it is hard to quantify. The interviewed companies understand that power has an influence on relationships, but how to select suitable suppliers by incorporating power relationship remains a question. The companies are lacking methods and tools to asses power for supplier selection.

As discussed in chapter 3, the information collected addressed the following aspects:

(1) Whether supplier assessment/evaluation is an important activity.

The various ways of managing suppliers at the interviewed companies indicate that supplier assessment/evaluation is important, especially strategic supplier assessment/evaluation.

(2) What the selection process is.

The interviews showed that as a small company, Fospix does not have a selection process. While big companies as M&M, W&H and the engine company have strict selection processes. The interview at M&M indicated that the selection follows broadly the De Boer process as shown in Figure 4-1.

(3) How suppliers are evaluated and selected.

The interviews revealed the companies analysed suppliers by categorising them. For example, W&H grouped suppliers by their importance or collaboration stages. In the engine company, suppliers are assessed according to the product category. This implies that the requirements on different suppliers are different and to group suppliers facilitates the decision process. Various examples highlighted the importance of understanding suppliers and having an appropriate assessment method for suppliers.

(4) Whether power exists in the buyer-supplier relationship.

Power does exist in the buyer-supplier relationship. However, it might not be admitted or exercised explicitly. For example, M&M would not like to admit there is a power relationship. However, in a crisis they would try to make use of the power they have

(5) How power is perceived.

All companies had a narrow understanding of power. M&M and Fospix viewed power by the size of company. In the engine company, power is considered as the ratio of purchase and sales. However, ‘available alternatives’, ‘switching cost’, ‘brand’ and ‘pricing control’ also appear in discussions. This indicates that power comes from various aspects. While the engine company used Porter’s five forces to analyse what aspects affect supplier power and buyer power, there is no way of getting a big picture of power by considering all these aspects together. We also noticed that the terms **power** and **dependence** always come together. Power of the company comes down to the importance of the company to that supplier or the supplier to the company.

(6) How and when power has an influence.

Unbalanced power distribution affects the buyer-supplier relationship. The interviews at the engine company clearly showed the impacts of unbalanced power. Understanding power is critical generally and in particular during negotiation, especially if clear strength and weakness can be identified.

(7) Whether power is considered during the supplier selection phase.

All interviewed companies perceived power and its influence, but how to integrate power consideration into supplier selection remains a problem.

(8) What are the expectations from a supplier assessment and selection method (and associated tools).

The interviews at the engine company revealed two requirements for a support tool:

- Tools are indicators and guidelines. The users need to understand the logic behind the tool. *"It is dangerous to blindly use a tool"*.
- Simplicity is another requirement. The company has in the past stopped using many tools because of their complexity. *"We have created many complex tools which is extremely useful. But the business hasn't necessarily adopted them. Because it is academically too complex for them."*

These arguments corroborate the practical importance of developing a tool for supplier selection that considers both performance and power. Aspect (3) is picked up in the four level criteria taxonomy of buyer-supplier relationship proposed in Chapter 5. Aspect (5) acknowledges that power comes from various elements such as purchased volume, available alternatives and switching cost. It points to the need for a method to quantify the power relationship, which is addressed by the power analysis methods proposed in Chapter 5 and Chapter 6. The interviews at the engine company show that power is a matter of perception. Knowing how suppliers could perceive power sometimes can be more revealing than how the company perceives the power relationship. Power 'perceptions' is included in the assessment approach in section 5.3.2 and section 6.4.3. Aspect (8) guides this research to choose a straightforward but practical technique to build the assessment methods in Chapter 6.

Chapter 5 Development of an approach to analyse the relative positioning of suppliers

The literature review and the case studies have both shown that there is a gap in integrating power analysis into supplier selection. The majority of current research proposes to construct supplier selection models based on 'hard' criteria that reflect the potential performance of a supplier. This chapter proposes an approach for supplier selection based on analysing (1) the relative position of a supplier's potential performance among all alternatives according to a comprehensive set of criteria, and (2) the relative position between a supplier and a buyer in the power relationship according to a set of 'soft' factors. The results of the two types of relative positioning further categorise a supplier through six different scenarios that indicate the extent to which a supplier is **suitable** for collaboration.

5.1 Building up the approach

The information collected from interviews supports that performance is generally the indicator to assess and select supplier. Power acts as a means to negotiate with suppliers and poses influences on the buyer-supplier relationship, although it is not considered explicitly for supplier selection. Especially, the interviews at the engine company and Fospix the producer of the photosensitive chips point to the possible interactions between performance and power. Based on this information, an approach that integrates both performance and power is proposed. This section further discusses the two concepts, performance and power, and generates a conceptual model of their interactions. Methodologically, this approach is built with Whetten's method for theory development (introduced in section 3.2.2), which considers six building blocks. The first is 'What' to establish relevant constructs. Performance and power are two important constructs in this thesis. Performance is concerned with the question whether the supplier will meet the buyer's requirements and expectations. Power concerns the ability of a company to influence the quality of the relationship and the collaboration with a supplier. The second is 'How' to establish relations between the constructs. Performance and power influence the decisions regarding supplier selection. They are related. A supplier of high performance is usually preferred, but an imbalance in power distribution might affect whether the supplier will provide high performance. The interviews described in Chapter 4 helped to analyse the interaction between the two constructs and to inform the third building block of 'Why' the constructs of performance and power were chosen for supplier selection. The research aims for supplier selection in general with no specific industry section being emphasised. This indicates the broad boundaries of the theory in terms of the 'When/Where/Who' building blocks.

5.1.1 A distinction between performance and capability

Most research on supplier selection and evaluation uses the term of performance, but some distinguish between **performance** and **capability**. For example, Sarkar and Mohapatra (2006) define the two terms according to how a buyer's goals are met, where criteria for short-term goals include price, delivery and quality are performance criteria. For long-term goals criteria relating to technology and quality systems are examples of capability criteria. For the purpose of the thesis the following distinction is drawn:

- ***Performance***: What a supplier will do or does.
- ***Capability***: What a supplier is able to do.

The empirical study at the engine company included examples where the actual performance was lower than the potential performance. For example, when the engine company selected from three suppliers for a product released in 2019, the cost of supplier Zeta was the highest, because Zeta included development cost. Zeta could offer a cheaper price if they chose to carry the development cost. This is a difference between what a supplier is able to do and what a supplier is willing to do. This difference indicates the space of manoeuvre for a buyer, where they can choose to use their power, as shown in Figure 5-1. The value axis indicates the data about capability and performance against each criterion. The space for bargaining space varies from criterion to criterion, which depends on what a supplier offers and what a supplier can provide regarding each criterion.

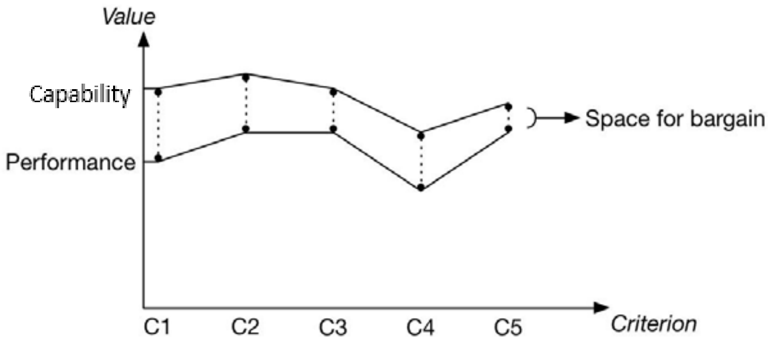


Figure 5-1 Space for bargain as the difference between performance and capability

For some criteria which refer to properties of the business, such as financial stability, quality system certification and process flexibility, the performance and the capability are equal. These criteria are connected, so that providing a better performance in one criteria might lower the performance in others. For example, a supplier offers £100 per item and 2 weeks' delivery. If the price is reduced to £90, the supplier offers a delivery time to 3 weeks. In this case, £90 can be regarded as the capability on price and 2 weeks the capability regarding delivery. The buyer can use its power to seek the trade-off between price and delivery .

5.1.2 The notion of dependence in the definition of power

As discussed in section 2.7, there is no single definition of power. Power is defined as the ability to influence (Yeung et al., 2009), the ability to control (Hunt and Nevin, 1974; El-Ansary and Stern, 1972), or the ability to induce a desired change in the behaviours and decisions of others (Ganesan, 1994). The terms used in the definitions are problematic. 'Control' might be too aggressive to apply to the collaboration between buyers and suppliers. 'Influence' and 'induce the change' are less aggressive, but are expressions of the purpose of power rather than power itself. Consider the way the engine company uses power. In many senses, the company is a powerful buyer. They do not use power directly to force their suppliers to meet their requirements. Instead, power is treated as a means to negotiate with suppliers and influence them towards a better performance. The Chairman of Fospix appropriately describes power, i.e. "*power is the ability to leverage*".

These definitions do not reflect that power is determined by multiple aspects or indicate that power might be measurable. The definition adopted in this thesis is one by Ireland and Webb (2007), who state that "Power is a multi-dimensional construct encompassing an influence that can be used to evoke desired actions from partners".

The determinants of power reflect a dependence of the buyer on the supplier or vice versa. For example, the engine company defines power as "*the purchased volume relative to supplier's sales*". The supplier relies on the purchase for revenue. The larger the proportion of purchase is, the more dependent the supplier is on the company. As discussed in section 2.8, theories exist that consider power arising from dependence. Emerson's power-dependence relation theory (Emerson, 1962) states that the power of A over B is based on the dependence of B on A, where dependence is defined as (1) "directly proportional to A's motivational investment in goals mediated by B", and (2) "inversely proportional to the availability of those goals to A outside of the A-B relation". In this definition dependence is generalised. Pfeffer and Salancik (2003) argue that dependence is determined by a combination of the control over resources and the importance of the resources to the organisation. In this case resources refer to financial and physical resources as well as information.

Dependence on resources leads to a power relationship between two organisations. For example, consider the determinants 'available alternative buyers' or 'available alternative suppliers'. When the engine company is planning to develop a new product, there are only a small number of qualified suppliers. This creates relatively high dependency The company does not have much choice, which means that the company is relatively dependent on the chosen supplier and gives power to the supplier. However, dependence is not all of power. The determinant 'brand effect' gives the engine company a certain power over its parent company, who is also a buyer of the engine company. Though brand effect does not create a dependence between company and parent, it provides leverage in the relationship. The determinants collected from the reviewed literature also indicate that while dependence constitutes a major part of power, there are other independent elements contributing to power, such as the determinant ‘backward integration’ (i.e. buyer’s ability or threat to integrate backwards). These independent determinants do not reveal dependence between the buyer and the supplier, but pose a threat to the supplier and add to the power of the buyer.

5.1.3 Interactions between performance and power

As discussed in section 5.1.1, the difference between supplier performance and supplier capability leaves the buyer space to bargain. Power is the means by which the buyer can bargain. However, the buyer’s demands should not exceed the supplier’s capability. For example, when a supplier offers a price 10% above the calculated cost, the engine company can use its power to ask the supplier for open book accounting to understand the reason. If the high cost results from an inefficient manufacturing process, the engine company could work with the supplier to improve the process. In this case, a price of 10% above expectation is the performance while the reduced price is the capability. Power pushes the performance towards to the capability, i.e. from the original price to the reduced price. Both the company and the supplier can benefit from this process.

This case also shows that power could have an indirect influence on supplier capability. Meanwhile, the capability also has a reverse effect on power. Suppose the reduced price makes the supplier cheaper than the potential alternatives. It gives this supplier a kind of leverage for future negotiation with the engine company. The company’s effort to improve its suppliers is a cost to itself, which also raises its dependence on this supplier. Sometimes, dependence itself influences the capability, regardless of the power relationship as in the case of Fospix. The desire of the manufacturer to enter a particular market led to the collaboration and a certain dependence on Fospix to quickly put the products into the market. This dependence encouraged the manufacturer to provide an opportunity for Fospix to test and improve its design.

Figure 5-2 summarises the above discussion: (1) the difference between supplier performance and supplier capability generates a bargaining space; (2) one party's dependence on the other contributes a major part of the other party's power; (3) a power advantage of the buyer over the supplier may lead to a better supplier performance if the powerful buyer use its power to push the supplier; (4) capability is a reference for the buyer to require a better performance since it reflects what the supplier can do; (5) power of the buyer over the supplier has an indirect influence on capability when the buyer uses its power to help the supplier; (6) an outstanding capability of the supplier can contribute to its own power when the buyer relies on its capability for business; (7) a dependence of the buyer on the supplier may result in an improvement of supplier capability because of the investment and support from the buyer; (8) an improved supplier capability may also make the buyer more dependent on the supplier.

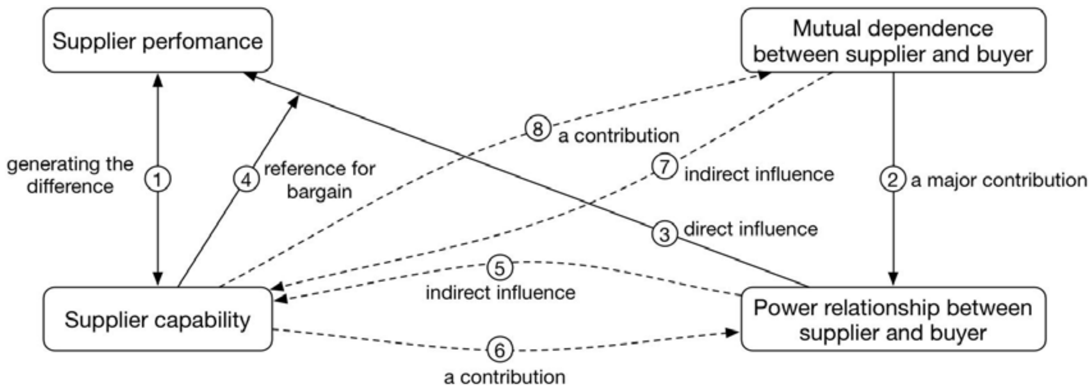


Figure 5-2 Interaction between power, dependence, performance and capability

The interactions between performance, capability, power and dependence vary in different situations. Figure 5-3 (a) shows the interaction in the case of the engine company. The power of the company helps to increase the capability of the supplier, which further provides a better supplier performance. An improved capability to offer a competitive price and better product contributes to the supplier's power, which counteracts the company's power. An improved capability in the supplier's manufacturing process increases the company's dependence, because of its time investment in the supplier. Figure 5-3 (b) shows the interaction in the Fospix case. A dependence of the manufacturer on Fospix gives Fospix an opportunity to improve its capability.

This improving capability gradually strengthens the dependence of the manufacturer, which increases the power of Fospix.

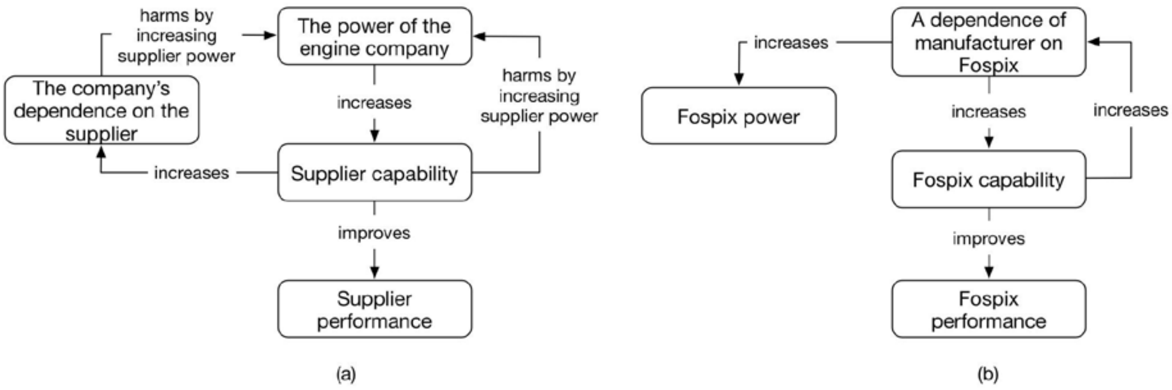


Figure 5-3 Interaction between power, dependence, performance and capability in (a) the engine company case and (b) the Fospix case

5.1.4 An approach to relative positioning analysis

Performance and power together with their interactions provide the basis for the approach proposed in this thesis. This is termed 'relative positioning analysis' (or position analysis for short) as illustrated diagrammatically in Figure 5-4. The approach to relative positioning analysis for supplier assessment contains three main steps: (1) performance analysis, (2) power relationship analysis, and (3) integration of the two analyses.

Performance analysis measures supplier performance according to various criteria and then profiles the strength and weakness of the supplier. There are four steps as follows.

1a: Determine the assessment scenario in terms of the number of the suppliers, which is introduced in section 5.2.1. This section also discusses the different requirements of the assessment scenarios.

1b: Analyse performance criteria for assessment. Section 5.2.2 proposed a criteria taxonomy and section 6.3.1 groups the criteria collected from literature into the taxonomy.

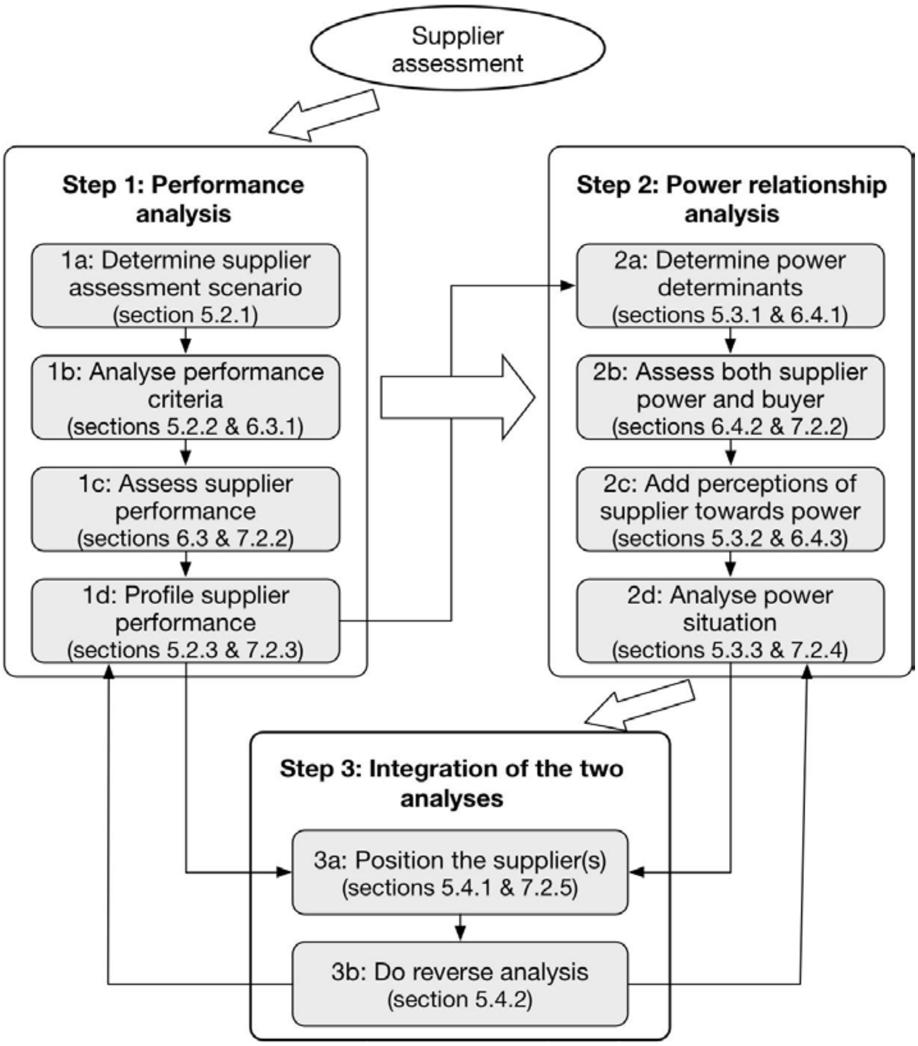


Figure 5-4 The approach to relative positioning analysis

1c: Assess supplier performance against the selected criteria where the mathematical methods are needed. This research splits the introduction to the approach and the assessment methods for performance and power into two chapters because the methods involve in lots of mathematical explanations. Their implementation into the tool is introduced in Chapter 7. Section 6.3 presents the methods for performance assessment under different assessment scenarios. Section 7.2.2 discusses the representations of the assessment results in the tool.

1d: Profile supplier performance in terms of their strengths and weakness, based on the assessment results, which is introduced in section 5.2.3. Section 7.2.3 describes its visualisation in the tool.

Power relationship analysis is carried on after performance analysis, which has four steps.

2a: Determine power determinants. Section 5.3.1 proposes a model for determinants identification and section 6.4.1 introduces the model to analyse them for assessment.

2b: Assess both the supplier power and buyer power against the determinants. Section 6.4.2 proposes the model for power quantification. Section 7.2.2 discusses the representations of the results in the tool.

2c: Add perceptions of supplier toward power. Section 5.3.2 analyses how a supplier might perceive the power relationship, which is called 'perceptions of supplier'. Adding these perceptions can establish the power relationship from the perspective of the supplier. Section 6.4.3 introduces how to include them during the assessment.

2d: Analyse the power situation. Power relationship is appraised by comparing the numerical results from assessing the supplier and the buyer power. Section 5.3.3 concludes the power situations for the relationship, whilst section 7.2.4 presents their visualisation.

The last step is the integration of the two types of analysis.

3a: Position the supplier with the assessment results of the performance of supplier(s) and its (/their) power relationship with the buyer, which indicates which supplier(s) is (/are) 'suitable' to work with. Section 5.4.1 introduces the positioning model and section 7.2.5 discusses its visulisation problem.

3b: Do reverse analysis when more than two suppliers seems 'suitable'. Section 5.4.2 suggests looking back to the details of performance and power relationship to compare the suppliers.

Performance analysis can assess a set of suppliers in a single calculation. Power relationship analysis is only for one supplier and the buyer. When there are more than one suppliers, Step 2 is repeated for each supplier. It is noted that the sequence of performance analysis and power analysis is exchangeable. This approach prefers the presented sequence because performance analysis can eliminate the unqualified suppliers and reduce the number of suppliers for power relationship analysis. Section 5.2.1 and Section 6.3.2 introduces when and how to pre-select suppliers respectively.

5.2 Supplier performance analysis

Performance analysis begins by identifying the **assessment scenario** (single, group or multi-group suppliers) which determines the method for calculation (section 6. 3 introduces these methods). The criteria for assessment are then formulated with a **four-level criteria taxonomy** proposed by this research and the performance of potential suppliers are assessed and ranked. Based on the assessment results, a **supplier performance profile** is proposed to estimate the weakness and strengthens of each supplier.

5.2.1 Assessment scenarios

In practice, two relatively straightforward scenarios exist. The first is that there is only one supplier for assessment. The engine company interviewee said *"We even got some suppliers, let's say Diesel exhaust fluid sensor. They may be the only supplier in the world for those types of sensors. We know it, they know it…"*. In this case the company monitors the supplier. There is an alternative scenario where the company assesses a set of suppliers who might be already suppliers in different supply chains. *"If it is a brand new supplier, there is huge risk. We would not take a brand new supplier into critical component."* For example, when the company considers a strategic partnership to open a new manufacturing facility, they prefer to use a supplier with whom they have worked successfully in the past.

As discussed in section 2.1.2, De Boer et al. (2001) distinguishes between the two scenarios: single supplier and multiple potential suppliers. In addition, the study at the engine company points to a third scenario, where suppliers are selected form a pool of existing supplier on other product lines. Figure 5-5 shows the three assessment scenarios.

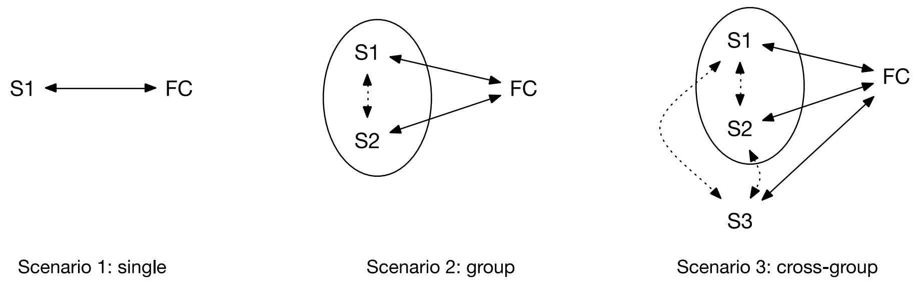


Figure 5-5 Supplier assessment scenarios

Different scenarios present different requirements for the assessment method:

- ***Single supplier***: this could happen when selecting a strategic partner or when assessing a particular supplier's performance. A linguistic expression of the result such as 'poor', 'acceptable' and 'excellent' is more suitable than a numeric value for assessment.
- ***A group of alternative suppliers*** who provide the same product. This is the most common scenario for supplier selection. All the decision-making methods in the literature review chapter can be used. Numeric values of the results can show clearly the differences between suppliers. When there is a large group of suppliers, it reduces the decision makers' efforts by **pre-selection** to eliminate the unqualified suppliers.
- ***A set of cross-group suppliers***: this could happen when selecting a supplier from the current supplier base. Because these suppliers might be part of different supply chains, the reference points to judge their performance will not be the same and subjective judgement is suitable for comparing these two suppliers.

To understand the bargaining space (i.e. the difference between performance and capability) it not only necessary to assess performance of a supplier but also to understand their capability. This can be difficult to establish. In some cases the best historic data can be taken as the capability.

5.2.2 A four-level criteria taxonomy

As discussed in section 2.2, it is necessary to categorise the criteria based on the types of suppliers. Big companies have their own supplier categorisation. For example, the engine company classifies suppliers by how they could contribute the company's business. The company M&M classifies suppliers into strategic suppliers and procurement suppliers. In this research supplier integration is chosen to group suppliers as it reflects the degree of involvement of suppliers in buyer's business.

A Four-level criteria taxonomy is extracted from the literature review (see section 2.2.2), mainly based on the work of Ghodsypour and O'Brien (1998) and Chan (2003). The latter also considers buyer-supplier interaction. Table 5-1 shows the two taxonomies and summarises their differences.

Level	***Ghodsypour and O'Brien (1998)***	***Chan (2003)***	***Difference***
1	No integration	Temporarily basic relationship	No difference. Both emphasise a simple buy-offer transaction.
2	Logistical integration	Temporarily operational relationship	The former focuses on logistical performance only. The latter focuses on product only in terms of appearance, cost and quality improvement.
3	Operational integration	Cyclically operational relationship	Both focus the process capability. The former emphasises on the full implementation of JIT/TQM, e.g. the production line. The latter emphasises on product design and manufacturing process, e.g. production methods.
4	A deeper integration than level 3	Long lasting tactical relationship	Both emphasise human resources to control the product and process.
5	Business partnership	Long lasting strategic relationship	Both emphasise a strategic partnership.

Table 5-1 The five levels of supplier integration versus the five levels of buyer-supplier interaction

Though the two taxonomies are well-established, neither was used directly in this thesis, as both temporal and logistical aspects needed to be considered together. The Ghodsypour & O'Brien taxonomy treats logistical integration as a separate level, which is better considered as an integration aspect (Bennett and Klug, 2012). Though Chan's taxonomy fits well to the different levels of decision, it does not take the logistics aspect into account at any level. These two taxonomies are combined into a four level taxonomy.

- ***Level 1 – no relationship***: neither the buyer nor the supplier is concerned with the long term benefit of other party. The buyer requests nothing special or critical from the suppliers. Price and quality are the key considerations.

- ***Level 2 – operational relationship***: the supplier plays an important role in the firm's daily operations. Great importance is given to a supplier's ability to maintain pre-agreed delivery schedules to assure in-time delivery of the products. Therefore, besides the elements of the operational logistical performance such as lead time, set up time and stable supplies, the capabilities to ensure a consistent delivery are also considered such as production capacity and transportation infrastructures.
- ***Level 3 – tactical relationship***: the buyer and the supplier work together for mid-term goals including collaborative planning, problem solving and continuous improvement. Product and process capability as well as the supplier's organisational culture and financial situation are considered. The buyer and the supplier cooperate to increase savings and make future improvements. A certain degree of commitment and trust is required.
- ***Level 4 – strategic relationship***: the buyer and the supplier can fully cooperate in the long run. In addition to the aspects considered in Level 3, the supplier's potential for future development such as future technology development and future manufacturing capability are included. In addition, the market situation including market research, market share and annual sales growth are considered. Since this level of relationship involves close collaboration and interaction, good communication is critical. The supplier needs to adhere to polices and standards.

5.2.3 Establishing a strengths and weakness profile for performance

Profiles are constructed to compare different suppliers. This research applies the SWOT matrix analysis showing strength, weakness, opportunity and threat (SWOT). A SWOT matrix analysis is a planning method to analyse these four aspects at an organisation or business level by identifying the internal and external factors that influence the achievement of a business objective (Pickton and Wright, 1998). Here the concept is applied purely to the supplier performance. The two dimensions of the matrix are the weight of criteria, i.e. the importance the buyer gives to the criterion and the score of the supplier for these criteria, i.e. the performance of the suppliers, as seen in Figure 5-6. All criteria are plotted into the four quadrants:

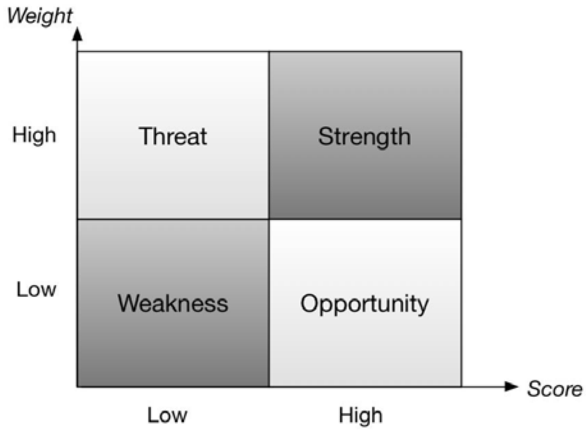


Figure 5-6 SWOT matrix for supplier's performance

- ***Strength***: A criterion is important and the performance score is high. A supplier with more criteria in this quadrant is preferred.
- ***Weakness***: a criterion is not very important and the score is low. This captures a vulnerability for the supplier, but is of no particular importance to the buyer.
- ***Threat***: A criterion is important and the score is low. To work with a supplier having several criteria in this quadrant puts the buyer at increased risk.
- ***Opportunity***: The criterion is not particularly important, but the score is high. The criteria falling into this quadrant imply a potential advantage if the buyer changes the priorities.

The overall performance of a supplier is the weight multiplied by the score regarding each criterion. If the majority of criteria lies in the strength quadrant this can lead to an 'excellent' overall performance, however a majority of criteria in Weakness quadrant could lead to "poor" overall performance. Threat and Opportunity keep the performance in an 'acceptable' level because a low value in either weight or score gives an 'average' value to the overall performance. Figure 5-7 indicates the mapping between the SWOT matrix and the overall performance level.

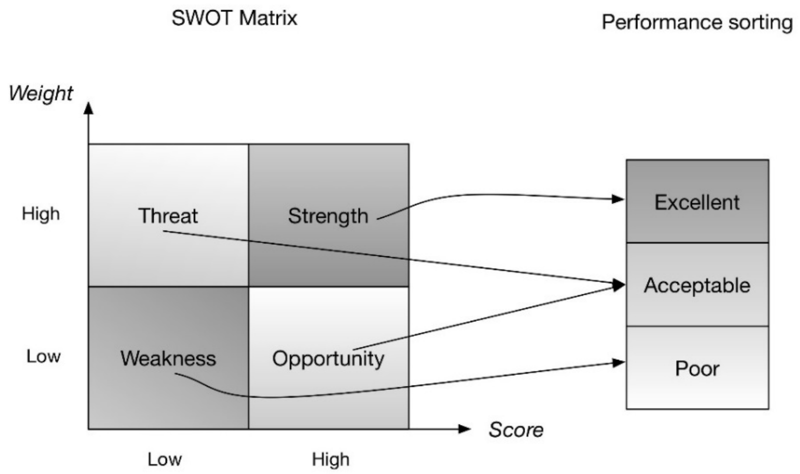


Figure 5-7 Mapping SWOT to sorting

Dynamics of strength, weakness, opportunity and threat

To monitor a supplier the SWOT analysis is extended to analyse the transition of a criterion from one quadrant to another. Transition happens when the buyer changes the priorities or the supplier changes their performance. Figure 5-8 (a) shows the **vertical transition** where the buyer changes its priorities on the criteria. Threat will become the weakness and the strength will become opportunities when the criteria become less important. On the contrary, the weakness goes towards threats and opportunity towards strength if the weight increases. Solely considering this transition, a supplier with more criteria in the strength and opportunity quadrants is preferred. Suppliers with similar numbers of criteria in these two quadrants could swap. The suppliers with more criteria in strength could be the first choice and the one with more in opportunity could be used as a back-up.

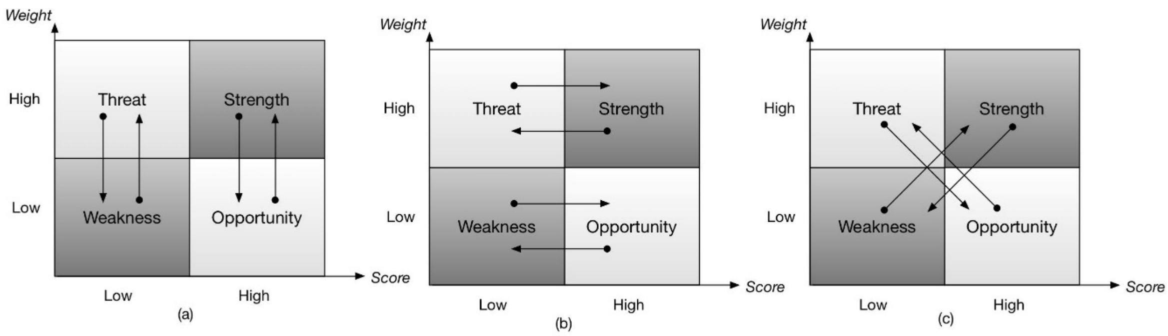


Figure 5-8 (a) Vertical transition; (b) Horizontal transition; (c) Diagonal transition

Figure 5-8 (b) shows the **horizontal transition** where the supplier changes its performance. Threat move towards strength and weakness moves towards opportunity if the performance is improved. Vice versa strength moves to threat and opportunity to weakness. It indicates that to get a better overall performance from a supplier, the buyer assists the supplier to improve performance in the criteria in the threat and weakness quadrants. Figure 5-8 (c) shows the diagonal transition where the buyer changes its priorities on the criteria and the supplier changes its performance.

These transitions help to understand why a supplier's performance is improved or decreased. Table 5-2 shows a simple example of a supplier *S1* with two criteria *C1* (delivery time) and *C2* (technology capability). At the beginning the overall performance of this supplier is acceptable with a value of 4.6. At this point, *C1* is an opportunity and *C2* is in threat quadrant. After three months at Period1, *S1*'s overall performance increases to an excellent level with a score 5.8. Six months after the beginning, marked as Period2, *S1*'s overall performance still excellent, but the score and criteria have gone through transition.

<table>
<tr><th colspan="3"></th><th>Beginning</th><th>Period1</th><th>Period2</th></tr>
<tr><td rowspan="5">C1
(delivery time)</td><td rowspan="2">Weight</td><td>Value</td><td>0.4</td><td>0.7</td><td>0.4</td></tr>
<tr><td>High/low</td><td>low</td><td>High</td><td>Low</td></tr>
<tr><td rowspan="2">Performance Score</td><td>Value</td><td>7</td><td>7</td><td>7</td></tr>
<tr><td>High/low</td><td>High</td><td>High</td><td>High</td></tr>
<tr><td colspan="2">SWOT</td><td>Opportunity</td><td>Strength</td><td>Opportunity</td></tr>
<tr><td rowspan="5">C2
(technology capability)</td><td rowspan="2">Weight</td><td>Value</td><td>0.6</td><td>0.3</td><td>0.6</td></tr>
<tr><td>High/low</td><td>High</td><td>Low</td><td>High</td></tr>
<tr><td rowspan="2">Performance Score</td><td>Value</td><td>3</td><td>3</td><td>5</td></tr>
<tr><td>High/low</td><td>Low</td><td>Low</td><td>High</td></tr>
<tr><td colspan="2">SWOT</td><td>Threat</td><td>Weakness</td><td>Strength</td></tr>
<tr><td rowspan="2">Overall Performance</td><td colspan="2">Score</td><td>4.6</td><td>5.8</td><td>5.8</td></tr>
<tr><td colspan="2">Sorting</td><td>Acceptable</td><td>Excellent</td><td>Excellent</td></tr>
</table>

Table 5-2 Example for transition illustration

The buyer receives a better performance from *S1* during Period1 is because of vertical transition. The priorities of the two criteria are changed but actually the performance of *S1* regarding *C1* and *C2* stays at the same level compared as at beginning. In Period2 better performance is achieved because of the horizontal transition. The priorities of *C1* and *C2* are the same as at Beginning, but the performance in *C2* is improved. Both Period1 and Period2 have better overall performance than at Beginning, but an ‘actual’ improvement of performance occurs in Period2.

5.3 Power relationship analysis

As discussed in section 2.9, there is limited research addressing power assessment. To the best of our knowledge no research addresses how a company can identify power determinants. The power relationship analysis starts by identifying the power determinates with **a power determinant identification model** proposed by this research. With these determinants, both supplier power and buyer power are quantified (the assessment method is introduced in section 6.4). The **perception of power** is added during the assessment, which helps to understand the power relationship from the perspective of a supplier. The quantification results are then applied by a **power situation analysis** which identifies the characteristics of the power relationship.

5.3.1 A model to identify power determinants

By analysing factors determining the power, collected from the literature and the empirical study, some factors arise from an internal environment relating to the buyer-supplier relationship such as the importance to the buyer’s business, impact on buyer’s cost structure, and importance to buyer product function. The first two factors indicate the supplier power through an influence on the buyer’s business. The third factor comes from the product level. Other factors relate to the external environment and do not relate to a specific relationship, such as available suppliers and available buyers. Based on this analysis, this research suggests a model in Figure 5-9 to identify the power determinants.

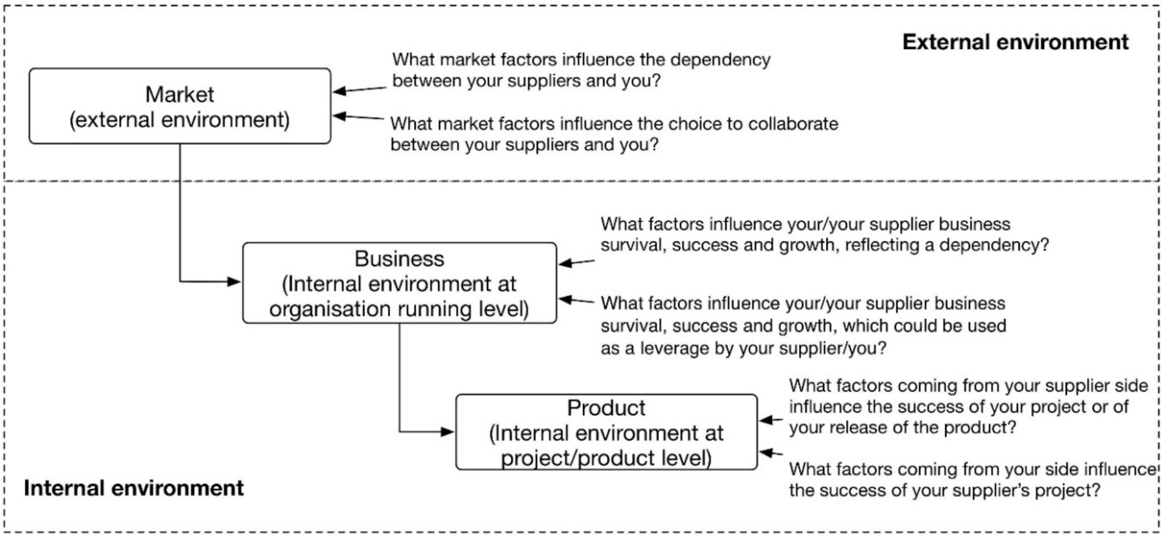


Figure 5-9 Power determinant identification model

The buyer must look at three aspects to identify its own power determinants and those of a potential supplier.

- ***Market*** is the external environment. Two questions help identify the determinants: (1) what market factors create or influence the dependence between the company and the supplier. Examples are available alternative buyers, available alternative suppliers. (2) what market factors create or influence the choice of collaboration partner. An example is the customer's brand preference. The external environment is also influenced by other aspects such as social regulation, but this research only considers market aspect.
- ***Business*** considers the influences on business survival, success and growth. Four questions help identify the determinants: (1) what factors reflect a company's dependence on a supplier in terms of business, e.g. buyer's switching cost? (2) what factors give the supplier leverage, such as threat of integrating forward to the business? (3) what factors determine the supplier's dependence, e.g. purchased volume relative to supplier's sales? (4) what factors influence the company leverage such as threat of integrating back to supplier's business.
- **Product** reflects criteria regarding product level. Two questions help identify the determinants: (1) what factors coming from the supplier side affect the project or the

market release of the product, e.g. dependence on supplier's reliable delivery (2) what factors coming from the company influence the timely delivery by the supplier such as dependence on buyer's technology and expertise.

5.3.2 Perceptions on power

Power can be determined relatively objectively by various factors. However, it only becomes power when it is perceived as power. As the technical manager in the engine company said, *"I think power is something that we deal with very flippantly. The power is a perception rather than a fact."* For example, Fospix did not even initially consider collaborating with its supplier, because they thought they would be too insignificant as a customer for the large suppliers. However, Fospix had not recognised the supplier's need to enter the market, which actually gave Fospix an advantage. Although overall, the supplier was still much more powerful than Fospix, a perception of this advantage narrowed the gap.

As a power relationship involves two parties – the supplier and the buyer, they could perceive it differently. If these perceptions are not aligned, the way that the relationship will work becomes unpredictable for the buyer. There are three possible perceptions of power:

- ***Objective perception***, which is shared by both parties. The supplier and the buyer know each other's advantages and disadvantages. *"We even got some suppliers, let's say Diesel exhaust fluid sensor. They may be the only supplier in the world for those types of sensors. We know it, they know it. So you don't have a lot of choices unless go with what they are asking. They know they hold all the cards."* (the engine company)
- ***Optimistic perception***: when one party underestimates the other's power, and needs to be educated about the other party's power. *"They might come in, thinking they got no need of your business, what you are going to do is to change that perception. 'Yes, you do. Look at all this value we bring to your business.'"* (the engine company)

- ***Pessimistic perception***: when one party underestimates its own power. A pessimistic perception by the supplier on the power relationship tends to lead to a buyer-dominant relationship in a supplier's view.

5.3.3 Power situation analysis

The power relationship is determined by a comparison of the buyer power and the supplier power. Three power relationship situations are concluded with the comparison results as illustrated in Figure 5-10.

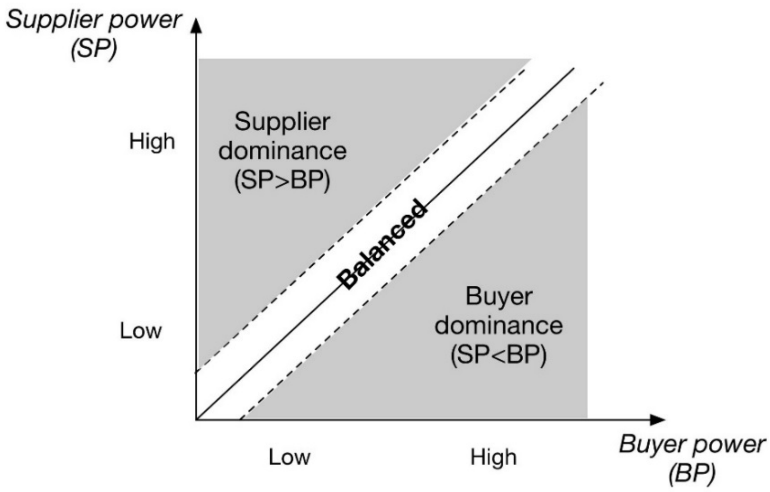


Figure 5-10 Power relationship situations

- ***Supplier dominance***: when supplier power is greater than buyer power (*SP*>*BP*).
- ***Buyer dominance***: when supplier power is less than buyer power (*SP*<*BP*).
- ***Balanced***: when supplier power and buyer power are approximately equal (*SP*=*BP*).

A major part of power comes from dependence, which to some extent reflects the need for collaboration. In comparing the dependence the supplier and the buyer have on each other, four different attitudes can be presumed, shown in Figure 5-11. When the supplier has a high dependence on the buyer, the supplier is likely to more active in developing the relationship with the buyer. The buyer is more active when it has a high dependence on the supplier. When there is low mutual dependence between the supplier and the buyer, neither partly might be very active, however when both see a benefit in the collaboration, both might become active.

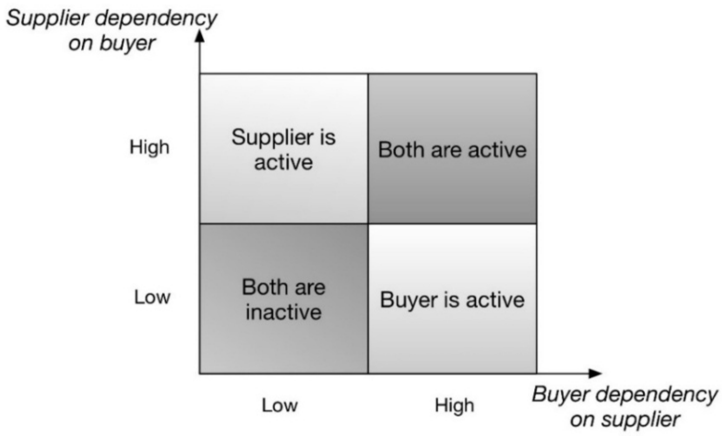


Figure 5-11 Supplier/buyer dependence with their attitude towards collaboration

Dynamics of the power situation

The power relationship could change due to differences in perception, which can again be seen as a form of horizontal and vertical transition. As shown in Figure 5-12 (a), horizontal transition occurs when a supplier's optimistic perception moves towards an objective perception. For example, supplier *A* is the only available supplier to buyer *B*. Buyer *B* is not the only buyer to supplier *A*. However, *B*'s purchases 60 percent of *A*'s sale and provides critical business opportunities. In the objective perception, this can be seen as a balanced situation as represented by the open circle in the Figure 5-12.

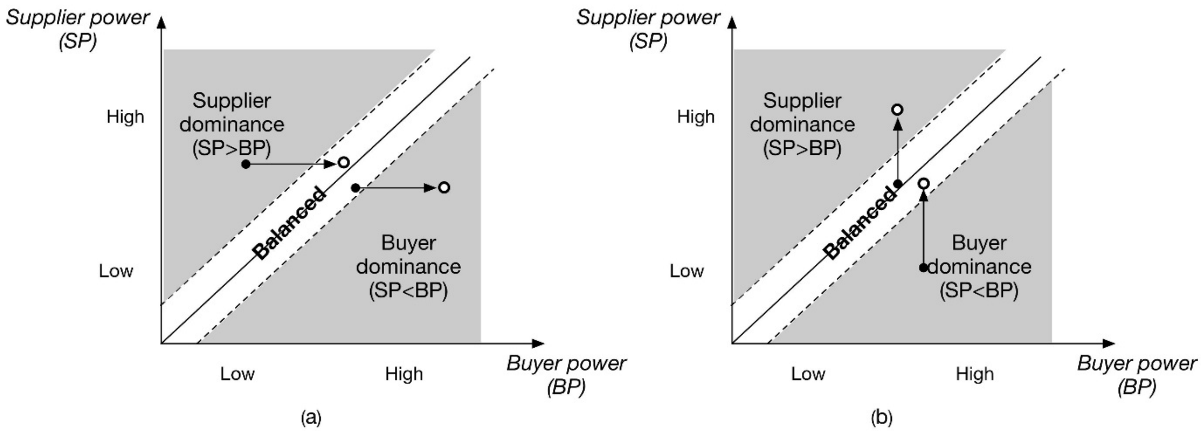


Figure 5-12 (a) Horizontal transitions of power relationship; (b) Vertical transitions of power relationship

By not being aware of the new opportunities, *A* underestimates *B*'s power and perceives a supplier dominant relationship, represented by the filled circle in the figure. Once *A* realises the opportunity provided by *B*, the power relationship shifts from supplier dominant to balanced. To benefit the buyer horizontal transition is encouraged. The buyer should put effort into making the supplier fully aware of its power.

Vertical transition happens when a supplier’s pessimistic perception moves towards an objective perception, as shown in Figure 5-12 (b). For example, if the supplier has little idea of the buyer’s switching cost and therefore its importance to the buyer’s business, then the supplier could underestimate its own power. If the supplier increases its awareness vertical transition might occur. This transition will not be welcomed by the buyer. From the buyer’s perspective it is better to keep the supplier with a pessimistic perception.

5.4 Integration of supplier performance analysis and power relationship analysis

The last part of the approach is the integrating the assessment results on performance and power. It gives guidance for supplier selection by identifying the extent to which a supplier is in a position that benefits the buyer.

5.4.1 The positioning analysis

The results from the two analyses on performance and power relationship together determine relative positioning. Six positioning scenarios are considered as illustrated in Figure 5-13. These scenarios are analysed from the perspective of the buyer.

- ***Ideal*** is a buyer who is dominant relationship over a supplier with excellent performance. The buyer receives excellent performance without investing in supplier improvements. As the buyer dominates the relationship they can assure that they keep receiving a good performance.

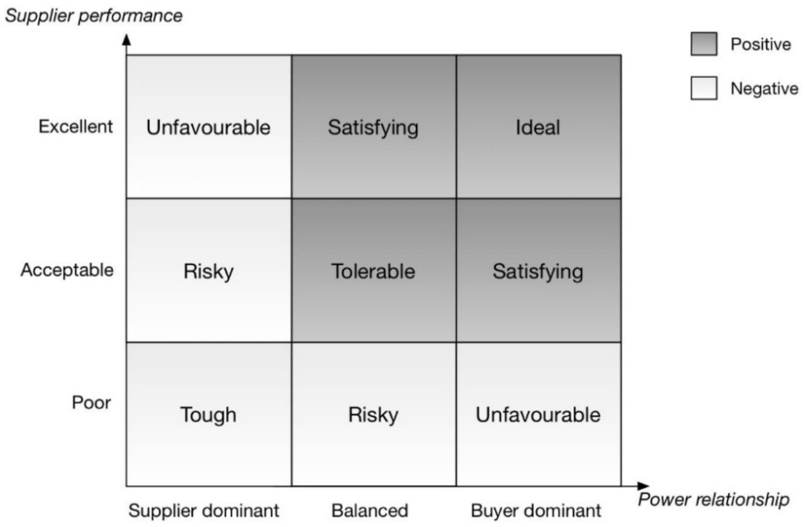


Figure 5-13 Model for positioning suppliers

- ***Satisfying***: Two cases arise. (1) when it is a buyer dominant relationship and supplier performance is acceptable then the buyer can push the supplier for a better performance if required. (2) when it is a balanced power relationship and supplier performance is excellent then there is no leverage to push for supplier improvements that may be required.
- ***Tolerable*** is a balanced power relationship with acceptable supplier performance. Even though the buyer does not have an advantage to require more from the supplier, the buyer still receives an acceptable performance from the supplier.
- ***Unfavourable***: There are two cases. (1) when it is a buyer dominant relationship and supplier performance is poor then, although the buyer can push the supplier, it takes efforts to negotiate and time to achieve an acceptable supplier performance. (2) when it is a supplier dominant relationship and supplier performance is excellent then the buyer runs a high risk that the supplier lowers its performance or asks for more favourable conditions.
- ***Risky***: There are two cases. (1) when it is a balanced power relationship and supplier performance is poor, then the buyer cannot push for improvements. (2) when it is a supplier dominant relationship and supplier performance is acceptable then the buyer runs a risk that the supplier might lower its performance or ask for more favourable conditions.

- ***Tough***: when it is a supplier dominant relationship and supplier performance is poor then there is no leverage for the buyer to obtain improvement in a supplier's performance. There is a high risk of the supplier pushing for better conditions.

Ideal, satisfying and tolerable can be seen as positive scenarios. Suppliers in these three scenarios are suitable and the collaboration should be relatively easy to establish or maintain. Unfavourable, risky and tough are negative scenarios, where the suppliers are not suitable either because they do not perform or carry a high risk.

Dynamics of the positioning

A balanced power relationship is stable, because neither the supplier nor the buyer has the advantage over the other. A buyer dominant relationship could lead to a transition from one scenario to another as illustrated by the vertical straight lines in Figure 5-14 (a).

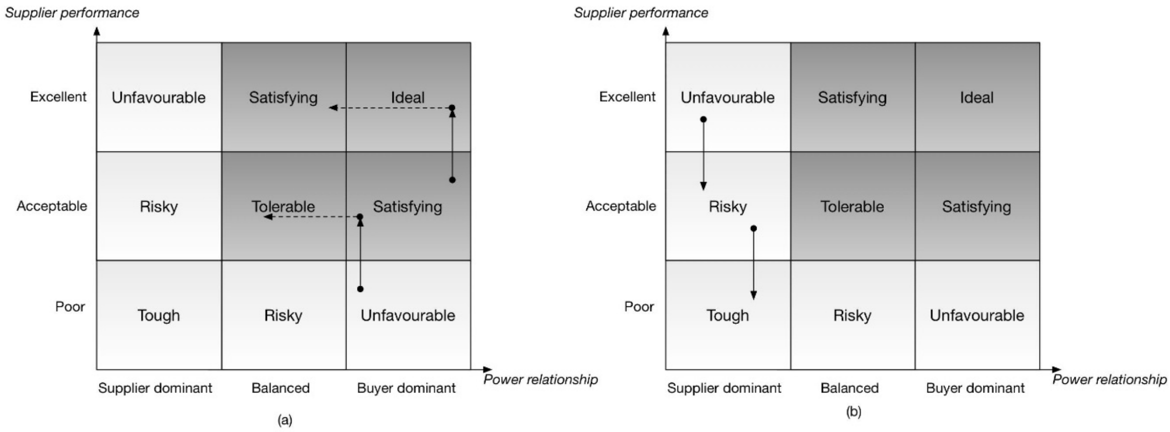


Figure 5-14 (a) Transitions under buyer dominant relationship; (b) Transitions under supplier dominant relationship

A transition from unfavourable to satisfying or from satisfying to ideal could occur, because of improvements in supplier performance required by the buyers. The transition in the opposite direction is less likely because the buyer could exert its power once it notices a downward trend in the supplier performance. However, the buyer sometimes develops the supplier, which means the buyer invests to improve supplier capability in terms of financial support, technical support or information support. This increases the switching cost for the buyer, resulting in an increase in supplier power. A transition from a buyer-dominant relationship to a balanced relationship is possible, as denoted by the horizontal dashed lines in Figure 5-14 (a).

The supplier dominant relationship could also lead to transitions, as shown the vertical straight lines in Figure 5-14 (b). A transition from an unfavourable scenario for the buyer to a risky one or from risky to tough takes place when the supplier exerts its power to lower its own performance. An upwards transition is less likely because the supplier does not have the pressure from the buyer, although it could occur at the supplier's convenience. An example might be offering improved quality, because it has bought a more effective machine which produces better quality.

5.4.2 A reverse analysis

The relative positioning analysis groups the suppliers according to different scenarios of their suitability for the buyer. If more than one supplier falls into the same group the buyer could look back into the performance profiles and the power situations and carry out a 'reverse analysis'. Figure 5-15 shows two suppliers A and B are in an ideal scenario. But which one is better and with which is it easier to establish a relationship? The SWOT matrix shown in the left upper corner of Figure 5-15, clearly profiles the suppliers' advantages and disadvantages. Five criteria *C1* to *C5* are used to rank supplier performance. The priorities of these criteria are *C2* > *C3* > *C1* > *C4* > *C5*. Most of supplier A's criteria concentrate in the Strength quadrant and one in Opportunity. Supplier B has a dispersed distribution with two criteria C2 and C3 in Strength with very high scores, one in Opportunity, but two in Threat. Though both score as 'ideal', supplier A is more stable than supplier B. Looking back to the dependence matrix in the power situation analysis, both suppliers have high dependence on the buyer, while the buyer has a high dependence on Supplier A and low dependence on supplier B. This indicates that collaboration should be easier to establish between the buyer and supplier A.

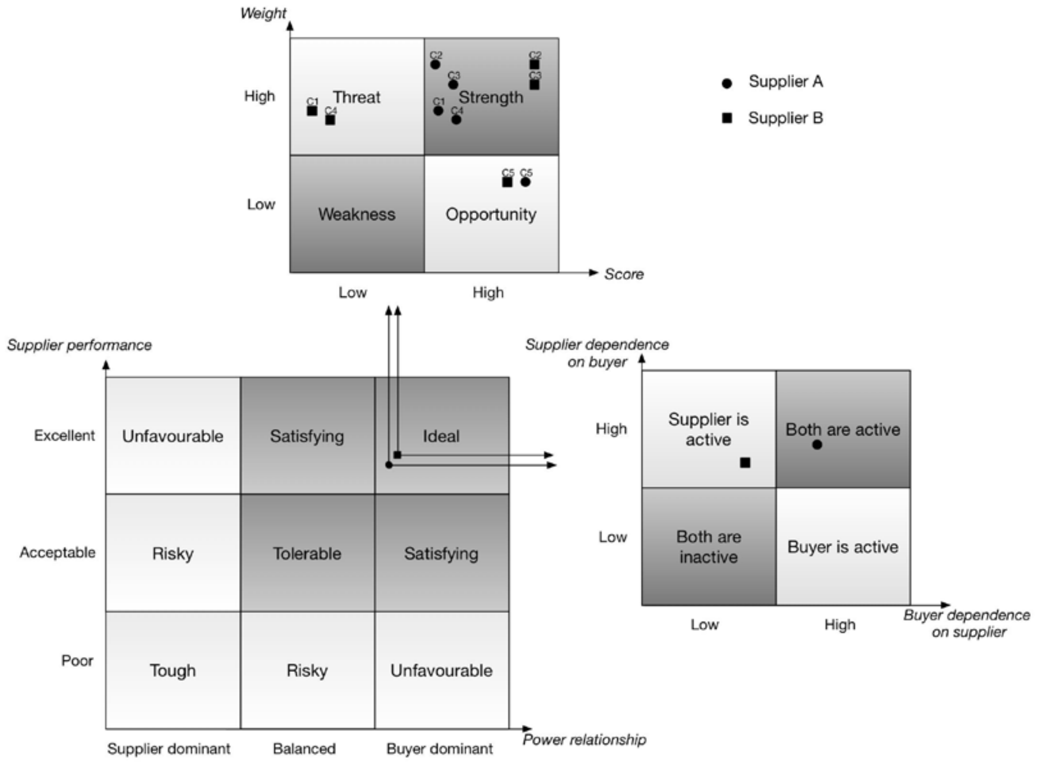


Figure 5-15 Reverse analysis

5.4.3 Model for performance adjustment by power

As discussed in section 5.1.3, supplier performance can be influenced by the power relationship. There are two ways that the power influences supplier performance as shown in Figure 5-16. This sub-section proposes a way to adjust the overall supplier performance through the power relationship.

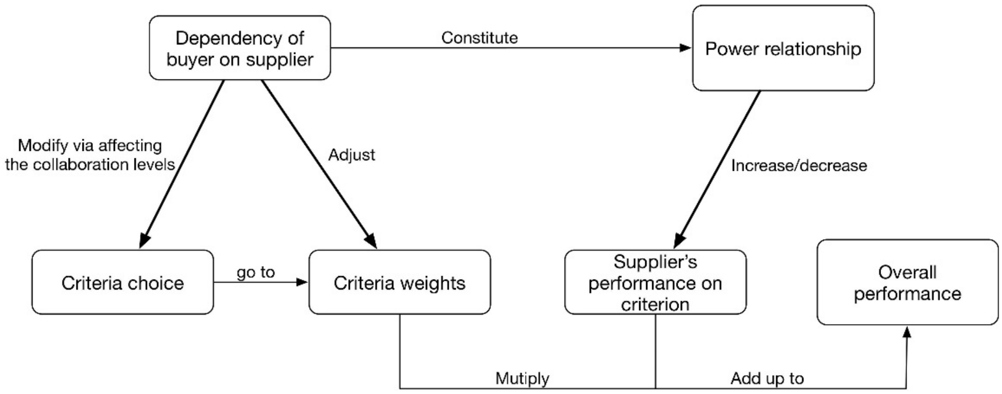


Figure 5-16 Model of performance adjustment by power

Firstly, the buyer’s dependence on the supplier could have an impact on the performance criteria chosen or the weights assigned to them. For example, buyer B classifies supplier A as an operational level partner, because A is involved in B’s short term goals such as scheduling the products according to consumer demands and a quick response to consumers’ feedback. However, the power situation analysis shows that B has a high dependence on A’s delivery reliability, and on A’s technology to customise the product in order to meet its consumers varied needs. Meanwhile few alternative suppliers are available. In this case, B should aim for a deeper collaboration with A maybe turning A into a strategic partner.

The degree of dependence on different power determinants could influence the priorities/weights assigned to the performance criteria if the power determinants relate to these criteria. Continuing with the example of buyer B and supplier A, during the performance assessment, suppose that buyer B considers delivery as more important than technology, because the market competition is fierce and earlier delivery enables B to enter the market earlier. However, the power situation analysis shows that B depends more on A’s technology than on the reliability of delivery because of the need to customise the product. In this case, the priority of delivery over ability should be lowered maybe to equal importance. The effect of the priority adjustment between delivery and technology will spread to all the criteria. For example, previously, delivery was considered as more important than technology and much more important than cost, while the technology was more importance than cost. After the adjustment, the priorities of both delivery and technology are higher than cost.

The second way that power influences performance is directly from the power relationship to the performance against a criterion. For example, buyer dominance increases possibility that the buyer will receive better performance. For example, during the performance evaluation, supplier A provides a 2-week delivery and £145 per unit for buyer B. Suppose B is much powerful than A, because B purchases 80% of A’s sales and there are many more available suppliers. After assessing the performance from supplier A, B requires a 10-day delivery and a lower price of £135.

A is likely to agree and try to satisfy at least the delivery requirement. On the other hand, if this was a supplier-dominant relationship and supplier A had an urgent order from another important buyer, supplier A may specify a 3-week delivery time to B or ask for a higher price to make up the possible loss if A cannot deliver one or both of the orders on time.

The influence of dependence comes into effect quickly. Because the choice of criteria and their priorities only reside with the buyer. As soon as the buyer realises the difference from the power analysis, the buyer can adjust its judgement on the criteria priorities. However, it takes time to create a change in performance, because the power relationship involves both supplier's and buyer's perceptions. If they do not have the same perception, the buyer has to push the supplier towards a more beneficial perception. However, not all aspects of performance can be influenced by power. When supplier performance reflects their capability, i.e. no difference between performance and capability, then the power buyer has no effect on changing performance – there is no space for bargaining. For example financial *stability* is a performance criterion, which also reflects a kind of capability of the supplier. If the financial status of the supplier is not stable, even a powerful buyer cannot require more. However, a powerful buyer can require a closer look into the accounts of a supplier business in order to help them or consider the potential for acquiring them.

5.5 Chapter conclusion

Performance is the basis against which to judge if a supplier is qualified or not. The power relationship indicates if the supplier or buyer possesses an advantage in the collaboration. These two aspects together can help to identify if a supplier is suitable. The approach proposed in this chapter achieves this by providing procedures to analyse the supplier performance and the power relationship. The functions of the approach can be summarised as follows.

- ***Supplier performance assessment***: This part of the approach presents the identified assessment scenarios and how they influence the choice of calculation techniques

Performance criteria are the foundation of the supplier assessment procedure. The proposed criteria taxonomy helps to identify suitable performance criteria.

- ***Power relationship assessment***: Both literature and industry cases show a gap in identifying what factors can be used as power determinants. Existing research proposes determinants but does not calculate values for them. The case studies show that although the companies have a clear idea of power, they do not have a clear picture what exactly gives them power. The power relationship assessment procedure suggests a model to identify power determinants.
- ***Integrative analysis***: This part outlines who are the suitable suppliers and who are not, based on the results from assessments of supplier performance their power relationship. This can indicate possible adjustments to the performance due to the power situation.

The positioning approach which analyses the strength and weakness of both parties in a supplier-buyer relationship and enables better supplier assessment through integrating analysis of their performance and their power relationship. Although the approach explains the general procedure for the assessment of performance and power, it remains to calculate values for performance and power. The next chapter will introduce our proposed methods for assessing performance in different scenarios according to a taxonomy of criteria and for assessing power distributions after identifying the power determinants.

Chapter 6 Assessing performance and power

The positioning approach takes the performance and power relationship to categorise a supplier through six different scenarios that indicate the extent to which a supplier is suitable for collaboration. Significant questions remain: how to assess supplier performance, how to assess the power relationship and how to consider both power and performance in an integrated assessment of a supplier. This chapter addresses these questions about assessment and proposes a solution.

This chapter begins with the introduction of the three methods used to build the proposed solution and explains the reasons for choosing them. A Fuzzy AHP-TOPSIS method is proposed as the core assessment method, which aims to prioritise elements (performance criteria and power determinants) and to compare alternative suppliers against the prioritised criteria and determinants. This method is adapted to quantify supplier performance according to different assessment scenarios as discussed in section 5.2.1 and to quantify power of the supplier and the buyer, which are introduced in section 6.3 and 6.4 respectively.

6.1 An introduction to the modelling method

The considerations for choosing the techniques which make up the main method come from three aspects. First, as discussed in section 2.2 and section 2.9, the criteria as well as the power determinants can be quantitative or qualitative. Second, the different assessment scenarios and the characteristics of the power relationship described in Chapter 5 require the flexibility to deal with entirely numeric data, entirely subjective judgements, or a mix of numeric objective data and subjective judgements. Third, from the conclusion of the studies in Chapter 4, a straightforward but practical method is preferred.

Based on these considerations, the modelling method uses three techniques: (1) AHP, which is widely applied to prioritise elements; (2) TOPSIS, a technique comparing the alternatives against the best and the worst situations; and (3) triangular fuzzy numbers (TFNs), which are used to capture the vague expressions. Table 6-1 lists their data requirements from chapter 2 and where they are applied in the proposed method for supplier assessment. Actual data refers to the objective numeric data representing a supplier's performance with respect to each criterion.

	Criteria accepted		**Data for calculation**		**Application in this research**
	Quantitative	***Qualitative***	***Objective***	***Subjective***	
AHP	√	√	-	√	Derive the weights
TOPSIS	√	Conditioned	√	√	Compare alternatives
TFNs	√	√	-	√	Deal with the subjective judgement

Table 6-1 Summary of the three basic techniques for the core assessment model

6.1.1 A prioritising method for decision making – AHP

As discussed in section 2.4, the analytic hierarchy process (AHP) is a widely used method in decision making, because of its ease of use and nice mathematical properties. It provides a way for decision makers to organise the problem in a hierarchy which is efficient both structurally, for representing a system, and functionally, for controlling and passing information down the system (Saaty, 1980). Establishing the hierarchy is the first step in using AHP. Figure 6-1 takes performance assessment as an example to describe how AHP decomposes a problem.

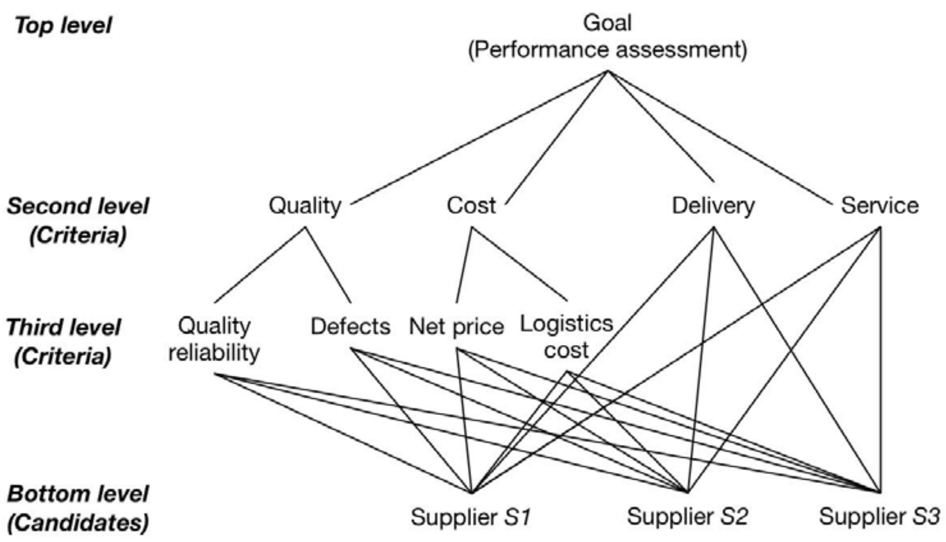


Figure 6-1 An example of supply hierarchy

For simplicity, to explain AHP, four criteria are taken from Dickson's 23 criteria in Table 2-1 where price is replaced by cost (as in this case cost to the buyer can be regarded as a price) and repair service is replaced by the more general term service. Examining the content of the criteria (introduced in section 2.2.1), some criteria were expanded by the later literature. For example, quality contains two sub-criteria, i.e. quality reliability and defects. Cost also contains two sub-criteria, net price from supplier and logistics cost.

The top level in Figure 6-1 is the overall goal of 'performance assessment'. In the second level, there are the four criteria which contribute to the goal. The third level is sub-criteria which contribute to their parent criteria. For example, quality reliability and defects are used to examine quality. The bottom level is the candidate suppliers. The hierarchy shows what is the problem (goal), what are the standards to choose the solution (criteria and sub-criteria), and what are the possible solutions (candidate suppliers).

The second step is the elicitation of pairwise comparison judgements of the criteria in the second level. In order to do this, the criteria are arranged into a matrix and judgements are elicited from the decision maker about the relative importance of one criterion over another with respect to the goal. The scale used in making the judgement is given in Table 6-2.

Importance	***Definition***
9	Extreme importance
7	Very strong importance
5	Strong importance
3	Moderate importance
1	Equal importance
2,4,6,8	Intermediate values

Table 6-2 Scale for relative importance, from Saaty (1990)

If the relative importance of a criterion *i* over another *j* is a_{ij}, the relative importance a_{ji} of *j* over *i* is equal to $1/a_{ij}$. The matrix of pairwise comparison for the example in Figure 6-1 is illustrated in Table 6-3.

Goal	*Quality*	*Cost*	*Delivery*	*Service*
Quality	1	3	5	6
Cost	1/3	1	3	3
Delivery	1/5	1/3	1	2
Service	1/6	1/3	1/2	1

Table 6-3 Example matrix of pairwise comparisons

The weights (the importance) of the criteria are generated by calculating the principal right eigenvector of the pairwise comparison matrix. The weights of the criteria in Table 6-3 are given in Table 6-4.

Criteria	***Weights***
Quality	0.568
Cost	0.245
Delivery	0.112
Service	0.075

Table 6-4 Weights of the criteria in the second level

The third step is to calculate the weights for the sub-criteria (the criteria in the third level). The way to obtain the weights is the same as the previous step: pairwise compare the sub-criteria with respect to their parent criterion, establish the comparison matrix and calculate the principal right eigenvector. This weight is called the local weight, which when multiplied by the weight of their parent criterion gives the global weight. Table 6-5 gives the weights of the sub-criteria of quality and cost.

Quality (0.568)	*Quality reliability*	*Defects*	*Local weight*	*Global weight*
Quality reliability	1	3	0.75	0.426 (0.75×0.568)
Defects	1/3	1	0.25	0.142 (0.25×0.568)
Cost (0.245)	*Net price*	*Logistics cost*	*Local weight*	*Global weight*
Net price	1	5	0.833	0.204
Logistics cost	1/5	1	0.167	0.041

Table 6-5 Weights of sub-criteria of quality and cost

The last step is to compare the alternatives with respect to each sub-criterion (if there is no sub-criterion, then take the criterion). In the example, the three candidate suppliers *S1, S2* and *S3* are pairwise compared on who has better performance in terms of quality reliability, defects, net price, logistics cost, delivery and service. The weights of the alternatives regarding these sub-criteria (and criteria) are derived from each comparison matrix, as shown in Table 6-6.

The overall preference of alternative suppliers is calculated by equation 6-1. The results of the example are given in Table 6-7.

$$P(S_j) = \sum_{i=1}^{n} w_i \times w^i(S_j) \qquad \text{6-1}$$

Where:

$P(S_j)$ = the overall score of supplier j

w_i = the global weight of the sub-criterion i (or the criterion if it does not have sub-criteria)

$w^i(S_j)$ = the weight of supplier j regarding sub-criterion i (or criterion i)

Quality reliability	*S1*	*S2*	*S3*	*Weight*	***Defects***	*S1*	*S2*	*S3*	*Weight*
S1	1	3	1/2	0.309	*S1*	1	3	1	0.429
S2	1/5	1	1/5	0.109	*S2*	1/3	1	1/3	0.143
S3	2	5	1	0.582	*S3*	1	3	1	0.429
Net price	*S1*	*S2*	*S3*	*Weight*	***Logistics cost***	*S1*	*S2*	*S3*	*Weight*
S1	1	1/4	2	0.182	*S1*	1	1	1/3	0.2
S2	4	1	8	0.727	*S2*	1	1	1/3	0.2
S3	1/2	1/8	1	0.091	*S3*	3	3	1	0.6
Delivery	*S1*	*S2*	*S3*	*Weight*	***Service***	*S1*	*S2*	*S3*	*Weight*
S1	1	½	½	0.2	*S1*	1	1/7	1/3	0.072
S2	2	1	1	0.4	*S2*	7	1	3	0.650
S3	2	1	1	0.4	*S3*	5	1/3	1	0.278

Table 6-6 Preference of suppliers S1, S2 and S3 with respect to each criterion

	Quality reliability (0.426)	***Defects (0.142)***	***Net price (0.204)***	***Logistics Cost (0.041)***	***Delivery (0.112)***	***Service (0.075)***	***Final preference score***	***Rank***
S1	0.309	0.429	0.182	0.2	0.2	0.072	0.266	3
S2	0.109	0.143	0.727	0.2	0.4	0.650	0.317	2
S3	0.582	0.429	0.091	0.6	0.4	0.278	0.418	1

Table 6-7 Comparison results of the three candidate suppliers

One advantage of AHP is that its pairwise comparison is also able to derive the weights of the criteria. Almost all the other techniques cannot do this and assume the weights are known. This is why AHP is chosen over other techniques. However, the pairwise comparison also brings a drawback that greatly increases the computational complexity. Suppose there are *m* criteria and *n* candidates. Regardless of the comparisons between criteria, there are in total $m \times n \times (n-1)/2$ comparisons between the candidates with respect to the criteria.

Another drawback of AHP is that it is not able to take objective data into the calculation process directly. With respect to those unquantifiable criteria such as service, technology and packaging capability, it needs a decision maker to give a judgement to express candidates' performance. For quantifiable criteria, there are objective data to describe the performance. For example, when comparing the performance, the delivery of supplier *S1* and supplier *S1* are 10 days and 11 days respectively. If the decision maker considers the performance of *S1* and *S2* as equal, the subtle difference of 1 day will not be distinguished. The rank of the two suppliers will be the same although *S1* is better than *S2*. Though fractional values are suggested to describe how many times one element (criterion or alternative) is larger (or better) than the other (Saaty, 2012b), it requires the decision maker to estimate this fraction, which increases the calculation efforts. Therefore, AHP is chosen to prioritise the performance criteria and the power determinants, and another method, TOPSIS, is used to compare the suppliers, which is introduced in the next subsection 6.1.2. Before doing that the issue of possible inconsistencies among the pairwise comparisons is considered and the technique used in AHP to detect these inconsistencies is described.

Inconsistency of judgement

Inconsistency exists in the pairwise comparison matrix. One reason lies in the imprecision of subjective judgement. For example, suppose that quality is considered moderately more important that cost. This may be because although the cost of the parts provided by the supplier influences the total profits, especially when the buyer purchases a large amount, the parts are critical to the whole product. If the parts do not function, the whole product will fail. Meanwhile, quality is considered strongly more important than delivery time because the buyer has a time buffer. The delivery is allowed to be delayed but a decrease of quality is not acceptable. Since quality is moderately more important than cost, and strongly more important than delivery, logically, cost should be moderately more important than delivery. However, when only comparing cost and delivery, cost could be considered as strongly important. Because the cost of the purchased part directly influences the cost of the whole product whilst there is buffer for delivery. The customer may care much more on the price than the delivery. The customer will refuse an increase of the price but can accept a certain delay in delivering the product. As a result, an inconsistency appears between the logical deduction of relative importance from comparing quality with cost and delivery, and the pairwise comparison of cost over delivery by the decision makers.

Inconsistency also comes from the mathematical property of comparison, i.e. the transitivity. Transitivity is an important property regarding the relations: if element a is related to element b and b is in turn related to element c, then a is also related to c. Let A = [a_{ij}] be an $n \times n$ pairwise comparison matrix. n is the number of elements to be compared and a_{ij} is the judgement of relative importance of element i over j, denoted as $Pref(i,j)=a_{ij}$. Then $Pref(j,t)=a_{jt}$, $Pref(i,t)=a_{it}$. According to the transitivity, $Pref(i,j)* Pref(j,t)= Pref(i,t)$, i.e. $a_{ij}*a_{jt}=a_{it}$. But this is not always the case. Back to the previous example where quality is moderately more important than cost and strongly more important than delivery, suppose the judgement of pairwise comparing between cost and delivery is consistent with the logical deduction. In this case, cost is moderately more important than delivery. The comparison matrix is given in Table 6-8. The relative importance of quality over cost is a_{12} = 3 and that of quality over delivery is a_{13} = 5. If the transitivity is met, the relative importance of cost over delivery should be 5/3. However, in the matrix a_{23} is 3 rather than 5/3.

		a_1	a_2	a_3
quality	a_1	1	3	5
cost	a_2	1/3	1	3
delivery	a_3	1/5	1/3	1

Table 6-8 Comparison matrix of quality, cost and delivery

A certain level of inconsistency should be tolerated because the judgements cannot be perfectly precise. Saaty (2012a) proposed equations to measure the consistency of the decision matrix, which allow for a modicum of inconsistency. The consistency ratio (*CR*) is used to judge the consistency of the comparison matrix. He has discussed that a matrix with a *CR* less than 0.1 is considered as adequately consistent.

$$CR = CI / RI \tag{6-2}$$

$$CI = (\lambda_{\max} - n) / (n - 1) \tag{6-3}$$

Where:

CI = consistency index, calculated by equation 6-3

λ_{max} = the max eigenvalue of the comparison matrix A

RI = the random index whose value depends on the size of the matrix A which is the number of the elements compared. Table 6-9 provides a look up.

Number	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54

Table 6-9 Random index from Saaty (2008)

When *CR* is larger than 0.1, it indicates a lack of consistent understanding of the problem, which could lead to a wrong decision. In this case, the judgements need to be adjusted.

Though a *CR* helps to assess if the judgements are consistent or not, a better solution is to reduce the possible inconsistency during the assessment. For example, this could be done by a method that better captures subjective judgement. This is the reason for using triangular fuzzy numbers for the judgement scales rather than absolute values in the model. Triangular fuzzy numbers for judgements will be introduced in subsection 6.1.3.

6.1.2 A compromise decision making method – TOPSIS

AHP is not able to take the objective data into the calculation. Further given the computational complexity of pairwise comparisons to the decision makers, another method, TOPSIS, is chosen to calculate the supplier performance whist AHP is used to calculate the weights of the criteria. TOPSIS, short for The Technique for Order of Preference by Similarity to Ideal Solution is a compromise decision making technique, originally developed by Hwang and Yoon (1981). Compromise means an agreement established by mutual concessions. The compromise solution is a solution closest to the ideal, which was introduced by Zeleny and Cochrane (1973) and Yu (1973). We choose TOPSIS for the following reasons: (1) It can easily be understood by the decision makers. TOPSIS is based on the concepts that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). (2) The results are reliable and robust. The ranking of the alternatives stays the same when adding or removing an alternative unless the PIS and NIS are changed. (3) It is able to calculate data from different scales, which makes it possible to use the objective data. For example, if the unit of delivery is day/week/month, and the unit of cost is £, then the values of the alternatives with respect to the two criteria can be directly input into the assessment process, rather than used as the basis for a relative importance judgement of one alternative over another.

The first step in TOPSIS is to establish an $m \times n$ decision matrix T = $[x_{ij}]$ consisting of *m* candidates and *n* criteria. The entry x_{ij}, is the performance value of alternative *i* with respect to criterion *j*. A decision matrix is given in Table 6-10 using the same example as in the previous subsection but with actual data as input rather than judgements.

	C1: Quality reliability % (0.426)	*C2: Defects %* (0.142)	*C3: Net price £/unit* (0.204)	*C4: Logistics Cost £/unit* (0.041)	*C5: Delivery days* (0.112)	*C6: Service 1-9* (0.075)
S1	84	5	180	20	14	4
S2	80	10	120	20	12	9
S3	90	5	190	16	12	7

Table 6-10 An example of decision matrix

The second step is to normalise the decision matrix by using the vector normalisation in equation 6-4. This process is to transform the various attributes/criteria into dimensionless quantities r_{ij}.

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=}^{m} x_{ij}^2} \qquad \text{6-4}$$

The next step is to construct the weighted normalised decision matrix V = [v_{ij}]. The weights of the criteria $w = (w_1, w_2, \ldots w_j, \ldots w_n)$ are accommodated to the normalised decision matrix in the previous step using $v_{ij} = w_j \times r_{ij}$. In the example referred to in Table 6-4 and Table 6-5, w = (0.426, 0.142, 0.204, 0.041, 0.112, 0.075). The weighted normalised decision matrix is given in Table 6-11.

	C1: Quality reliability % (0.426)	*C2: Defects %* (0.142)	*C3: Net price £/unit* (0.204)	*C4: Logistics Cost £/unit* (0.041)	*C5: Delivery days* (0.112)	*C6: Service 1-9* (0.075)
S1	0.244 (0.426×0.572)	0.058 (0.142×0.408)	0.128 (0.204×0.625)	0.025 (0.041×0.615)	0.071 (0.112×0.636)	0.025 (0.075×0.331)
S2	0.232 (0.426×0.545)	0.116 (0.142×0.817)	0.085 (0.204×0.417)	0.025 (0.041×0.615)	0.061 (0.112×0.545)	0.056 (0.075×0.745)
S3	0.261 (0.426×0.613)	0.058 (0.142×0.408)	0.135 (0.204×0.66)	0.02 (0.041×0.492)	0.061 (0.112×0.545)	0.043 (0.075×0.579)

Table 6-11 Normalised decision matrix

The fourth step is to determine the positive ideal (PIS) and negative ideal (NIS) solutions. They are derived by equations 6-5 and 6-6. PIS contains the largest value in each column of the matrix if it is associated with the benefit criteria and the smallest value if associated with cost criteria. NIS is the opposite.

$$PIS = A^* = \{v_j^* \mid \max_i v_{ij} \text{ if } j \text{ in } J_1, \min_i v_{ij} \text{ if } j \text{ in } J_2, i = 1,2,\ldots,m\} \qquad \text{6-5}$$

$$NIS = A^- = \{v_j^- \mid \min_i v_{ij} \text{ if } j \text{ in } J_1, \max_i v_{ij} \text{ if } j \text{ in } J_2, i = 1,2,\ldots,m\} \qquad \text{6-6}$$

where:

$J_1 = \{j = 1,2,\ldots,n \mid j$ associated with benefit criteria$\}$

J_2 = {j = 1,2,…,n| j associated with cost criteria}

Benefit criteria are those of the greater preference on larger outcomes while cost criteria are those of the less preference on larger outcomes. The PIS and NIS of the example are:

$$A^* = (\max_i v_{i1}, \min_i v_{i2}, \min_i v_{i3}, \min_i v_{i4}, \min_i v_{i5}, \max_i v_{i6}) = (0.261, 0.058, 0.085, 0.02, 0.061, 0.056)$$

$$A^- = (\min_i v_{i1}, \max_i v_{i2}, \max_i v_{i3}, \max_i v_{i4}, \max_i v_{i5}, \min_i v_{i6}) = (0.232, 0.116, 0.135, 0.025, 0.071, 0.025)$$

The fifth step calculates the separation of each alternative, which is measured by the n-dimensional Euclidean distance. The separation of each alternative from PIS and NIS is given by equation 6-7 and equation 6-8 respectively. The separations of S1, S2 and S3 from PIS and NIS are: D_1^* = 0.057, D_2^* = 0.065, D_3^* = 0.051, D_1^- = 0.06, D_2^- = 0.06, D_3^- = 0.068.

$$D_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \quad i = 1, 2, .., m \qquad 6\text{-}7$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \quad i = 1, 2, .., m \qquad 6\text{-}8$$

The last step is to calculate the similarities of the alternatives to the PIS concerning the distances to both NIS and PIS. The relative similarity C_i^* is calculated as:

$$C_i^* = D_i^- \big/ (D_i^* + D_i^-), \quad i = 1, 2, ..m \qquad 6\text{-}9$$

The similarities of S1, S2 and S3 to A^* are: C_1^* = 0.513, C_2^* = 0.48, C_3^* = 0.571. The ranking is S3>S1>S2.

TOPSIS provides an aggregation of all criteria, their relative weights, and a balance between distances from the positive and the negative ideal points. The two distances are obtained from D_i^* and D_i^- in equations 6-7 and 6-8, which represent a balance between total (all criteria) and individual (single criterion) satisfaction by using n-dimensional Euclidean distance. This principle of balancing between the best and worst fits the consideration that the decision should be close to the benefit and distant from the risk. A quotation in Lai et al. (1994) may be pertinent: "Do humans strive to be as close as possible to the ideal or as far away as possible from the anti-ideal? Our answer - both."

A discussion on the normalisation in TOPSIS

TOPSIS uses vector normalisation during the calculation procedure (refer to equation 6-4). Tzeng and Huang (2011) presented in their book a linear normalisation as equation 6-10 when introducing TOPSIS.

$$r_i = (x_i - x_i^-) / (x_i^* - x_i^-), \text{where } x_i^- = \min x_i, x_i^* = \max x_i \qquad 6\text{-}10$$

Compared with vector normalisation, linear normalisation is unit independent, i.e. the normalised value does not depend on the evaluation unit of a criterion (Opricovic and Tzeng, 2004). Suppose, as an example, that either a number scale or a score set as Table 6-12 is used to describe *satisfaction* on the provided service from the supplier. The transformation formula from a score to a number scale: $y = 10x\text{-}1$, where y is the scale and $y \in [1,9]$, x is the score and $x \in [0.2,1]$.

Scales		***Satisfaction***
Number (y)	score(x)	
9	1	Extremely satisfied
7	0.8	Satisfied
5	0.6	Fairly satisfied
3	0.4	Unsatisfied
1	0.2	Extremely unsatisfied
2,4,6,8 and 0.3, 0.5,0.7, 0.9 are mediate values		

Table 6-12 Two different scales to judge satisfaction

Suppose the decision maker uses a number scale to describe how satisfied the buyer is with the service from the suppliers. In this example they are 'fairly satisfied' with the service provided by supplier A, 'extremely unsatisfied' with supplier B, and 'extremely satisfied' with supplier C. Suppliers A, B and C are marked with values 5, 1 and 9 respectively. If the decision maker uses a score scale, suppliers A, B and C are marked with values 0.6, 0.2 and 1 respectively. Because the two scales are describing the same thing, after normalisation, the corresponding values should be the same. However, vector normalisation cannot meet this condition, as seen in Table 6-13.

	Judgement		Linear normalisation		Vector normalisation	
	Number	Score	Number	Score	Number	Score
Supplier A	5	0.6	0.5	0.5	0.483	0.507
Supplier B	1	0.2	0	0	0.097	0.169
Supplier C	9	1	1	1	0.87	0.845

Table 6-13 Comparison of two normalisation results.

Because of the issue of unit independence, this research chose linear normalisation instead of vector normalisation during the calculation process of TOPSIS.

6.1.3 Representing subjective judgement in decision making with Triangular Fuzzy Numbers

When decision makers are asked to compare the relative importance between two criteria, linguistic terms such as equally important, moderately more important, and strongly more important better express their judgements. To use absolute values to represent these linguistic expressions neglects the ambiguity and imprecision in subjective judgement. Fuzzy set theory introduced by Zadeh (1965) is capable of representing these kinds of vague data.

A fuzzy set (Klir and Yuan, 1995) consists two components, a set and a membership function associated with it. The membership function embodies the mathematical representation of membership of an element in a set, which assigns to each element a value ranging between 0 and 1. A triangular fuzzy number (TFN), $\tilde{A}$, is a special class of fuzzy sets, which is expressed as a triple (l, m, h) where $l \le m \le h$. In general the 'tilde' in the notation refers to a TFN while symbols without such 'tilde' represent ordinary sets or crisp values. The membership function $\mu(x)$ is defined as following and illustrated in Figure 6-2.

$$\mu(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m \\ (h-x)/(h-l), & \mathrm{m} \le x \le h \end{cases}$$

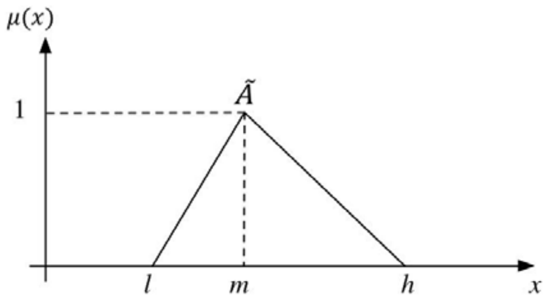


Figure 6-2 Triangular fuzzy number

The α-cut or α-level of a fuzzy set $\tilde{A}$, denoted as A_α, is a crisp value set that contains all the elements of the set $I = [l, h]$ from which values are drawn, whose membership grades are greater than or equal to the specified value of α:

$$A_\alpha = \{x \in I : \mu(x) \geq \alpha\}$$

Then the α-cut of a TFN $\tilde{A} = (l, m, h)$, $A_\alpha = [l+(m-l)\alpha,\ h-(h-m)\alpha]$ as shown in Figure 6-3. This concept will be used to derive the corresponding crisp value from the TFN, which will be introduced in section 6.2.1.

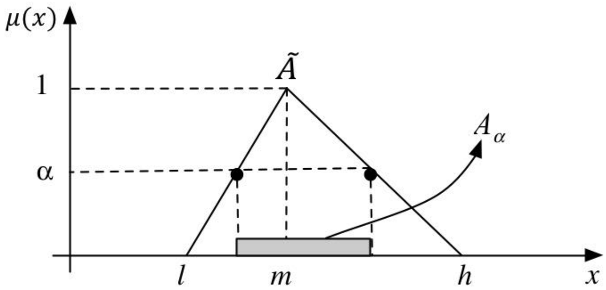


Figure 6-3 α-cut of a TFN, A_α

Algebraic operations on TFNs are defined as follows.

Addition: $\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, h_1) \oplus (l_2, m_2, h_2) = (l_1 + l_2, m_1 + m_2, h_1 + h_2)$

Multiplication: $\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, h_1) \otimes (l_2, m_2, h_2) = (l_1 l_2, m_1 m_2, h_1 h_2)$

$$\lambda \otimes \tilde{A}_1 = \lambda \otimes (l_1, m_1, h_1) = (\lambda, \lambda, \lambda) \otimes (l_1, m_1, h_1) = (\lambda l_1, \lambda m_1, \lambda h_1), \text{where } \lambda \text{ is a constant}$$

Reciprocal: $\tilde{A}_1^{-1} = (l_1, m_1, h_1)^{-1} = (1/h_1, 1/m_1, 1/l_1)$

Using TFNs to express linguistic judgements

In the assessment models, there are two types of linguistic judgements. First, there are those that express the relative importance of one criterion over another and the relative importance of one power determinant over another. Table 6-14 shows the TFNs that replace the crisp values in AHP to represent different levels of importance in AHP.

Crisp value in AHP	***TFN for importance***	***Definition***
9	(8,9,9)	Extreme importance
7	(6,7,8)	Very strong importance
5	(4,5,6)	Strong importance
3	(2,3,4)	Moderate importance
1	(1,1,1)	Equal importance
2,4,6,8	(1,2,3), (3,4,5), (5,6,7), (7,8,9)	Intermediate values

Table 6-14 TFNs for relative importance

(1,1,1) that is a crisp value 1 is used to express equal importance rather than a TFN (1,1,2) because the judgement on whether two criteria are of equal important is objective.

The other type of linguistic judgement is to describe how a supplier performs with respect to the qualitative criteria during performance evaluation and how high (or low) a value is with respect to the power determinants. Table 6-15 lists the TFNs for the judgements.

Linguistic expression	***Scale for benefit criteria/ power determinant***	***Scale for cost criteria/ power determinant***
Extremely good/high	(7,8,8)	(0,0,1)
Very good/high	(6,7,8)	(0,1,2)
Good/high	(5,6,7)	(1,2,3)
Medium good/high	(4,5,6)	(2,3,4)
Fair/Medium	(3,4,5)	(3,4,5)
Medium poor/low	(2,3,4)	(4,5,6)
Poor/low	(1,2,3)	(5,6,7)
Very poor/low	(0,1,2)	(6,7,8)
Extremely Poor/low	(0,0,1)	(7,8,8)

Table 6-15 Judgement scales for performance/power

6.2 Building the fuzzy methods

The previous section introduced the three methods for building a decision model. AHP prioritises the performance criteria and power determinants. TOPSIS compares the alternatives. TFNs capture the linguistic expressions. There is research which has already considered this combination in supplier selection such as Wang et al. (2009a), Viswanadham and Samvedi (2013) and Lima Junior and Carpinetti (2016). However, the problem is that they only take subjective judgement for evaluation as concluded in the literature review (refer to section 2.3 and section 2.5). Three issues present themselves in this combination, i.e. aggregating TFNs, defuzzifying TFNs, and checking the consistency of fuzzy judgement. To our best knowledge, there is no research addressing all these issues together. Moreover, it is noted that a method called Extent Analysis Method (EAM) has been widely used in research to aggregate TFNs and defuzzify TFN. However, this method presents significant shortcomings.

This section first introduces how this research addresses the three issues and then presents an analysis of why EAM does not produce correct results. Based on a solution of the issues, a modified Fuzzy AHP-TOPSIS method is proposed that takes both objective and subjective data to assess suppliers.

6.2.1 Using TFNs in AHP and TOPSIS

As discussed in section 6.1.3, TFNs better describe the linguistic expressions. Therefore, TFNs are used to capture the relative importance between two criteria in AHP and the judgements on performance with respect to qualitative criteria in TOPSIS.

Calculating the weights of criteria in Fuzzy AHP

The absolute number scale in AHP is replaced by a TFN scale as set out in Table 6-14. The comparison matrix of Table 6-3 in section 6.1.1 is then transformed to a fuzzy comparison matrix as Table 6-16.

Goal	*Quality*	*Cost*	*Delivery*	*Service*
Quality	(1,1,1)	(2,3,4)	(4,5,6)	(5,6,7)
Cost	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(2,3,4)
Delivery	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)
Service	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)

Table 6-16 Example of fuzzy comparison matrix

One issue arises about how to calculate these TFNs and to generate the associated weights. Most research in supplier selection using fuzzy methods makes use of the arithmetic mean of the TFNs in calculating weights. However, using geometric mean might be a better choice. Aczel and Saaty (1983) have proved that when a reciprocal is used, the geometric mean is a better way to combine the judgements. The geometric mean has also been used by many researchers to derive the weights from the pairwise comparison matrix. For example, Barzilai (1997) and Dong et al. (2010) discuss the advantage of using the geometric mean to replace the right eigenvector method in AHP for calculating the weights. Suppose the $n \times n$ fuzzy comparison matrix F = $[\tilde{A}_{ij}]$, where n is the number of the criteria, $\tilde{A}_{ij}$ is a TFN representing the relative importance of criterion i over another j and $\tilde{A}_{ij} = (l_{ij}, m_{ij}, h_{ij})$, then the weight of criterion i using the geometric mean is:

$$w_i = ((\prod_{j=1}^{n} l_{ij})^{\frac{1}{n}}, (\prod_{j=1}^{n} m_{ij})^{\frac{1}{n}}, (\prod_{j=1}^{n} h_{ij})^{\frac{1}{n}}) \quad \text{6-11}$$

In the model, equation 6-11 is also used to synchronise the judgements of multiple experts by calculating an aggregated judgement.

Defuzzifying TFNs in fuzzy TOPSIS

There are two places in the model that require defuzzifying a TFN. The first place is to translate the fuzzy weights of criteria (or power determinants) to a crisp value before the weights are accommodated into the performance quantification (or power quantification). The second place is to translate the aggregated TFN of multiple experts judgements into a crisp value before the normalization of the decision matrix (refer section 6.1.2, the second step in TOPSIS). There is some research on using TFNs in the decision matrix and then normalising these TFNs. However, in general normalising fuzzy numbers is a quite disputable issue. Wang and Elhag (2006) proved that the existing normalization methods based on interval arithmetic and fuzzy arithmetic are flawed and proposed a 'correct' method. Later, Li et al. (2009) argued this proposed method is also flawed by showing an example.

Yager's approach (Yager, 1981) is adopted to defuzzify the TFN. This approach analyses the mean of the elements within an interval. Assume $\tilde{A}$ is a fuzzy set of universal set I with maximum membership grade α_{max}. Its α-cut sets $A_\alpha = \{x \in I : \mu(x) \geq \alpha\}$ (refer to section 6.1.3) and the function $F(\tilde{A})$ calculates the crisp value associated with the fuzzy set $\tilde{A}$ is as equation 6-12:

$$F(\tilde{A}) = \int_0^{\alpha_{\max}} Ave(A_\alpha) d\alpha \tag{6-12}$$

For a TFN $\tilde{A} = (l, m, h)$ with its α-cut set A_α=[l+$(m$-$l)\alpha$, h-$(h$-$m)\alpha$], the function $F(\tilde{A})$:

$$\begin{aligned} F(\tilde{A}) &= \int_0^{\alpha_{\max}} Ave(A_\alpha) d\alpha = \int_0^1 ((l+(m-l)\alpha + h-(h-m)\alpha)/2) d\alpha \\ &= (l+h)/2 + \int_0^1 ((2m-l-h)\alpha/2) d\alpha \\ &= (l+2m+h)/4 \end{aligned} \tag{6-13}$$

It is proved by Facchinetti et al. (1998) that this way of obtaining a crisp value for a TFN takes into consideration both the worst and best results arising from a fuzzy number.

Consistency of judgements in fuzzy comparison matrix

Though a TFN gives a certain tolerance on inconsistent judgement, a consistency examination is still necessary because a big inconsistency can indicate a lack of understanding of the problem. According to Buckley (1985), the fuzzy comparison matrix F =$[\tilde{A}_{ij}]$ is consistent if and only if:

$$\tilde{A}_{ik} \otimes \tilde{A}_{kj} \approx \tilde{A}_{ij} \tag{6-14}$$

The approximate equal $\approx$ between two fuzzy numbers $\tilde{A}_1$ and $\tilde{A}_2$ with membership functions $\mu_{A1}(x)$ and $\mu_{A2}(x)$ respectively is defined as:

$$\min(v(\tilde{A}_1 \geq \tilde{A}_2), v(\tilde{A}_2 \geq \tilde{A}_1)) \geq \theta$$

Where $v(\tilde{A}_1 \geq \tilde{A}_2) = \sup_{x \geq y}(\min(\mu_{A1}(x), \mu_{A2}(y)))$ and θ is some fixed positive fraction less than or equal to 1. Literally speaking, $\tilde{A}_1$ and $\tilde{A}_2$ are approximately equal if $\tilde{A}_1$ is not greater than $\tilde{A}_2$ and $\tilde{A}_2$ is not greater than $\tilde{A}_1$.

Based on equation 6-14, Arbel (1989) further proved that a fuzzy comparison matrix can be considered as consistent when the ratio of the weight w_i of criterion c_i and the weight w_j of criterion C_j is between the upper and lower bounds of the correspondent TFN $\tilde{A}_{ij}$, as shown in equation 6-15.

$$l_{ij} \leq w_i / w_j \leq h_{ij} \qquad 6\text{-}15$$

6.2.2 The Extent Analysis Method (EAM) for defuzzifying

The Extent Analysis Method (EAM) proposed by Chang (1996) aims to solve the problem of both calculating the weights and translating the TFNs into crisp values. A large proportion of articles apply this method when combining TFN and AHP in their fuzzy solution (refer to Appendix B where the research applying EAM has been identified), some of which are widely cited, for example Lee (2009). This subsection discusses why EAM is not used in the method proposed in this thesis.

EAM is introduced and then the problems with the method are discussed. Suppose a $n \times n$ fuzzy pairwise comparison matrix F = $[\tilde{A}_{ij}]$. $\tilde{A}_{ij}$ is the relative importance of criterion i over j or the preference of alternative i over j with respect to a criterion. The fuzzy weight of criterion i, $\tilde{w}_i$ is calculated as equation 6-16:

$$\tilde{w}_i = \sum_{j=1}^{n} \tilde{A}_{ij} \otimes [\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{A}_{ij}]^{-1} \qquad 6\text{-}16$$

The crisp value for the weight of *i* is determined as the minimal degree of possibility of its fuzzy weight $\tilde{w}_i$ being greater than the fuzzy weights of the others. The degree of possibility of *V* of $\tilde{w}_1 \geq \tilde{w}_2$ as shown in Figure 6-4 is defined by equation 6-17.

$$\begin{aligned} &V(\tilde{w}_1 \geq \tilde{w}_2) = 1 \text{ iff } m_1 \geq m_2 \\ &V(\tilde{w}_2 \geq \tilde{w}_1) = \text{hgt}(\tilde{w}_1 \cap \tilde{w}_2) = (l_1 - h_2)/((m_2 - h_2) - (m_1 - l_1)) \end{aligned} \qquad 6\text{-}17$$

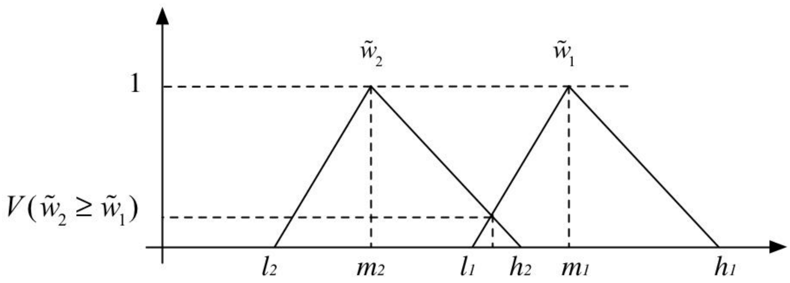


Figure 6-4 Definition of the degree of possibility

The crisp weight of *i*, w_i is obtained by the equation 6-18.

$$w_i = \min V(\tilde{w}_i \geq \tilde{w}_k),\ i,k = 1,2,3,...,n; k \neq i \qquad 6\text{-}18$$

Incorrect results when no intersection between two TFNs

The definition of the degree of possibility of $\tilde{w}_1 \geq \tilde{w}_2$ only considers the scenario where the two fuzzy numbers intersect each other. This method cannot deal with the comparison if there is no intersection. The scenario of no intersection exists in the example of Chang (1996). However, due to mistakes during generating the aggregated comparison matrices (Table 3b' and Table 3c' in that paper), the scenario of no intersection was missed.

Zhu et al. (1999) noticed this no intersection problem when running the EAM model on computer which produced an error message. The way they solved this problem was to give a value of 0 in case of no intersection. The modified definition on degree of possibility of $\tilde{w}_1 \geq \tilde{w}_2$ is defined as:

$$\begin{aligned} &V(\tilde{w}_1 \geq \tilde{w}_2) = 1 \text{ iff } m_1 \geq m_2 \\ &V(\tilde{w}_2 \geq \tilde{w}_1) = \begin{cases} (l_1 - h_2)/((m_2 - h_2) - (m_1 - l_1)), \text{ if } l_1 \leq h_2 \\ 0, \text{ otherwise} \end{cases} \end{aligned} \qquad 6\text{-}19$$

This solution sorts out the problem that EAM is unable to attain the weights if there is no intersection. However, this makes EAM unable to derive the right weights by introducing a 'zero weight' which leads to some criteria or alternatives being ignored in the analysis and potentially results in a wrong decision (Wang et al., 2008). An example extracted from Wang et al. (2008) is used to show this problem. Figure 6-5 presents the hierarchy of a catering firm selection problem. Three criteria *H* (hygiene), *QM* (quality of meal) and *QS* (quality of service) with their weights are obtained by EAM. Table 6-17 shows the comparisons of the criteria and their weights by EAM with the compensation of the case without intersection.

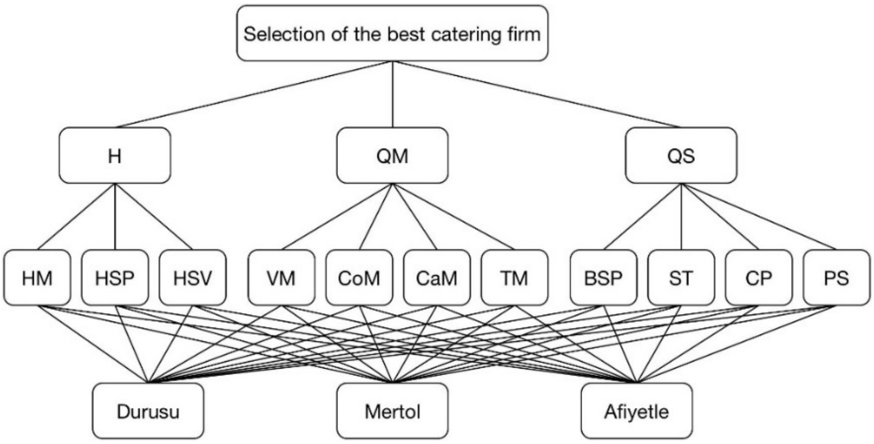


Figure 6-5 Hierarchy of catering firm selection problem (Wang et al., 2008)

Criteria	*H*	*QM*	*QS*	Weights
H	(1, 1, 1)	(2/3, 1, 3/2)	(2/7, 1/3, 2/5)	0
QM	(2/3, 1, 3/2)	(1, 1, 1)	(2/5, 1/2, 2/3)	0
QS	(5/2, 3, 7/2)	(3/2, 2, 5/2)	(1, 1, 1)	1

Table 6-17 Fuzzy comparison and weight by EAM of the criteria H, QM and QS

Both criteria *H* and *QM* have a weight of 0, which results in their removal from the further decision analysis as well as their sub-criteria. A decision made based on this lacks reasonable inference and is likely to be wrong.

Inconsistent results from EAM

No intersection and associated zero weight makes the EAM method unable to derive the proper weights of criteria and the alternatives. Does this mean that if every two fuzzy numbers have an intersection, then this method is appropriate to attain their relative importance? The answer is no. An example is considered. Given two TFNs $\tilde{A}_1 = (l_1, m_1, h_1)$ and $\tilde{A}_2 = (l_2, m_2, h_2)$ according to equation 6-19, when $m_1 = m_2$, $V(\tilde{A}_1 \geq \tilde{A}_2) = V(\tilde{A}_2 \geq \tilde{A}_1) = 1$. However, if $m_1 = m_2$ but $l_2 < l_1$ and $h_2 < h_2$, as seen Figure 6-6 (a), $\tilde{A}_1$ should have a priority above $\tilde{A}_2$ rather than the same priority. Consider another example as seen in Figure 6-6 (b). Here $m_2 = m_1 + \varepsilon$ where ε is a very small positive number close to 0, $h_2 = m_2 + \varepsilon$, $l_1 = m_1 - \varepsilon$, $l_2 = m_2 + \alpha$, $h_1 = m_1 + \alpha$, where α is a large number. According to equation 6-19, $V(\tilde{A}_2 \geq \tilde{A}_1) = 1 > V(\tilde{A}_1 \geq \tilde{A}_2)$ which indicates $\tilde{A}_2$ has a higher priority. However, it is apparent that $\tilde{A}_1$ should be preferred over $\tilde{A}_2$.

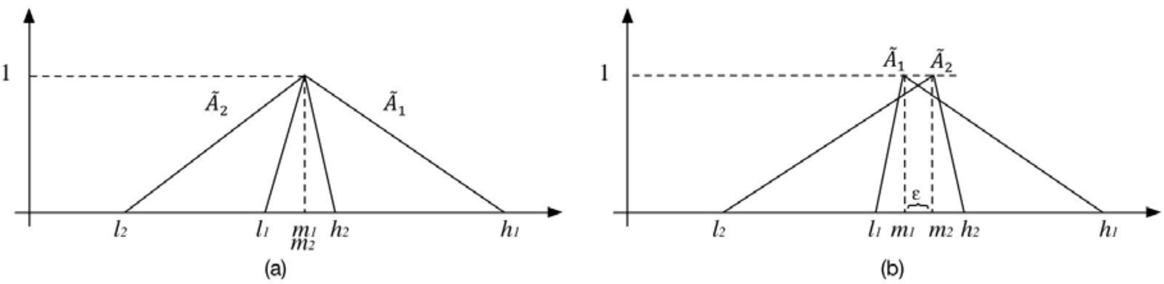


Figure 6-6 (a) Case of m_1=m_2; (b) case of m2 -m1≤ε, m_1-l_1<ε, but h_1 >> l_2

Returning to equation 6-19, the ordinate of the highest intersection cannot represent the degree of possibility of $\tilde{A}_2 \geq \tilde{A}_1$ or their relative weights, because it only depends on the two lines defined by m_2, h_2 and l_1, m_1 respectively. Values l_2 and h_1 should also play a role to determine the relative importance, and neglecting them could lead to improper weights. Further it leads to an inconsistency that does not come from the judgements and can cause a confusion to decision makers. This point can be explained by an example from Chang (1996). Table 6-18 shows the pairwise comparison matrix of the criteria C_1 to C_4. Table 6-19 shows their aggregated judgement and the associated weights resulting from the EAM method.

	C_1	C_2	C_3	C_4
C_1	(1, 1, 1)	(2/3, 1, 3/2) (2/5, 1/2, 2/3) (3/2, 2, 5/2)	(2/3, 1, 3/2)	(2/7, 1/3, 2/5) (2/7, 1/3, 2/5) (2/5, 1/2, 2/3)
C_2	(2/3, 1, 3/2) (3/2, 2, 5/2) (2/5, 1/2, 2/3)	(1, 1, 1)	(5/2, 3, 7/2) (5/2, 3, 7/2)	(2/3, 1, 3/2) (2/3, 1, 3/2) (3/2, 2, 5/2)
C_3	(2/3, 1, 3/2)	(2/7, 1/3, 2/5) (2/7, 1/3, 2/5)	(1, 1, 1)	(2/5, 1/2, 2/3)
C_4	(5/2, 3, 7/2) (5/2, 3, 7/2) (3/2, 2, 5/2)	(2/3, 1, 3/2) (2/3, 1, 3/2) (2/5, 1/2, 2/3)	(3/2, 2, 5/2)	(1, 1, 1)

Table 6-18 Pairwise comparison matrix of performance criteria, table 1 in Chang (1996)

	C1	*C2*	*C3*	*C4*	$\tilde{S}_i$	$w(C_i)$
C1	(1, 1, 1)	(0.86,1.17,1.56)	(0.67,1,1.5)	(0.33,0.39,0.49)	(0.21,0.19,0.29)	0.13
C2	(0.64,0.85,1.16)	(1, 1, 1)	(2.5,3,3.5)	(0.95,1.33,1.83)	(0.22,0.32,0.48)	0.41
C3	(0.87,1,1.49)	(0.29,0.33,0.4)	(1, 1, 1)	(0.4,0.5,0.67)	(0.11,0.15,0.23)	0.03
C4	(2.04,2.56,3.03)	(0.55,0.75,1.05)	(1.49,2,2.5)	(1, 1, 1)	(0.21,0.33,0.49)	0.43

Table 6-19 Aggregation, synthetic Results and weights

Proper weights, reflecting the relative importance among the criteria, should be consistent with the original judgement. Examining the weights derived by EAM, the relative importance of C_2 over C_1, $w(C_2)$ / $w(C_1)$ is 0.41/0.13, i.e. 3.15, which means C_2 is about 3 times more important than C_1. However, returning to the pairwise comparison between C_2 and C_1 in Table 6-18, the upper boundary of the judgement is 5/2. A greater inconsistency exists when comparing C_4 and C_3. The pairwise judgement indicates the relative importance of C_4 over C_3 should probably fall between 3/2 and 5/2, while the weights derived by EAM show that $w(C_2)/w(C_1)$ is 0.43/0.03, about 14 times more important of C_4 over C_3. The result is not consistent, and this inconsistency is not because of an inconsistent judgement from the decision maker.

6.2.3 Fuzzy AHP-TOPSIS method

The previous subsections discussed how to incorporate TFNs in AHP and TOPSIS and the related issues of aggregation, defuzzification and consistency. Based on the results, this subsection describes the core model for assessment. This Fuzzy AHP-TOPSIS method includes two parts, one for deriving the weights of performance criteria (and power determinants), the other for the general supplier assessment problem (i.e. comparing a group of alternatives). The steps are described in Figure 6-7. The equations are sequentially numbers for readers to follow even if some are repeated.

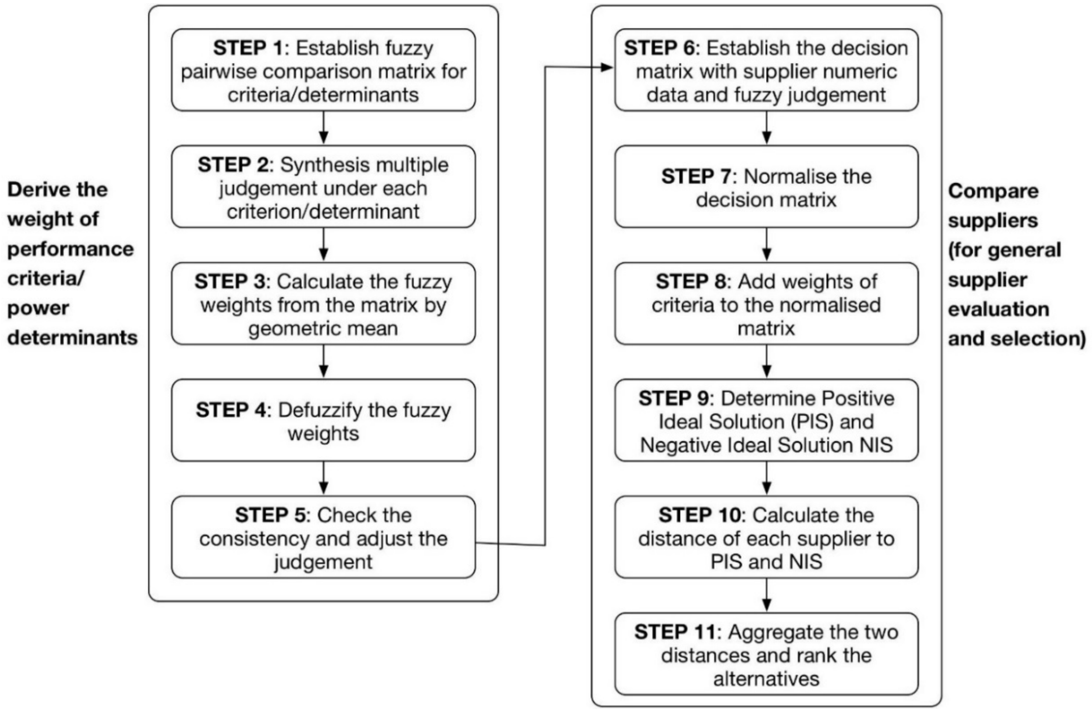


Figure 6-7 Fuzzy AHP-TOPSIS method

Step 1: establish the $n \times n$ fuzzy pairwise comparison matrix F=$[\tilde{c}_{ij}]$ for the n assessment criteria (or determinants). $\tilde{c}_{ij} = (l_{ij}, m_{ij}, h_{ij})$ is a TFN representing the relative importance of criterion i over another j by capturing the linguistic judgement.

Step 2: synthesise the judgements of multiple decision makers. If this is a group decision, each decision maker gives a judgement on the comparison. $\tilde{c}_{ij}^t = (l_{ij}^t, m_{ij}^t, h_{ij}^t)$ is the relative importance of criterion (or determinant) i over j judged by decision maker t. The judgements are synthesised by equation 6-20 (refer to equation 6-11 in section 6.2.1) and the synthesised result of the relative importance of i over j is as follows, where q is the number of the decision makers.

$$\tilde{c}_{ij} = (l_{ij}, m_{ij}, h_{ij}) = ((\prod_{t=1}^{q} l_{ij}^t)^{\frac{1}{q}}, (\prod_{t=1}^{q} m_{ij}^t)^{\frac{1}{q}}, (\prod_{t=1}^{q} h_{ij}^t)^{\frac{1}{q}}) \qquad 6\text{-}20$$

Step 3: calculate the fuzzy weights of the criteria (or determinants) from the synthesised judgements by equation 6-21. The fuzzy weight $\tilde{w}_i$ of criterion i is:

$$\tilde{w}_i = (l_i, m_i, h_i) = ((\prod_{j=1}^{n} l_{ij})^{\frac{1}{n}}, (\prod_{j=1}^{n} m_{ij})^{\frac{1}{n}}, (\prod_{j=1}^{n} h_{ij})^{\frac{1}{n}}) \qquad 6\text{-}21$$

Step 4: derive the crisp values of the criteria (or determinants) weights using equation 6-13. The weight of criterion (or determinant) i, w_i is as equation 6-22. If there are sub-criteria, repeat step 1 to 3. That is to establish the fuzzy pairwise comparison matrix with respect to each corresponding criterion, and then calculate their fuzzy local weights. By multiplying the crisp weight of their parent criterion, their fuzzy global weights are derived. For the convenience in describing the model, $\tilde{w}_i$ is used to denote the fuzzy global weight, w_i for crisp global weight and term 'criterion/criteria' is used to denote the sub-criteria and criteria without sub-criteria, which are input into further calculation.

$$\begin{aligned} F(\tilde{w}_i) &= (l_i + 2m_i + h_i)/4 \\ w_i &= F(\tilde{w}_i) \Big/ \sum_{j=1}^{n} F(\tilde{w}_j) \end{aligned} \qquad 6\text{-}22$$

Step 5: check the consistency by equation 6-23 (refer to equation 6-15). If there is a ratio of w_i/w_j out of the boundary [l_{ij}, h_{ij}], the decision makers have to adjust their judgements on criteria (or determinants) i and j. This is because this indicates an inconsistent judgement on the relative importance.

$$l_{ij} \le w_i / w_j \le h_{ij} \qquad 6\text{-}23$$

Step 6: establish an $m\times n$ decision matrix T = [x_{ij}] consisting of m candidate suppliers and n criteria (or determinants). For quantitative criteria, x_{ij} is the actual data of the performance of alternative i with respect to criterion j. For qualitative criteria, x_{ij} is the judgement of the performance from decision makers, which is firstly synthesised from fuzzy judgements of multiple decision makers and then translated to crisp value. The scale for the judgement refers to Table 6-15.

Step 7: normalise the decision matrix by linear normalisation by equation 6-24 (refer to equation 6-10), where $x_j^* = \max_i x_{ij}$, $x_j^- = \min_i x_{ij}$, or set x_j^* as the aspired/desired level and x_j^- the worst level. r_{ij} is the normalised value of the entry x_{ij} in the decision matrix T.

$$r_{ij} = (x_{ij} - x_j^-) / (x_j^* - x_j^-) \tag{6-24}$$

Step 8: construct the weighted normalised decision matrix V = [v_{ij}]. The weights of the criteria w = (w_1, w_2, …, w_j, … w_n) from step 4 are accommodated to the normalised decision matrix in the previous step. $v_{ij} = w_j \times r_{ij}$.

Step 9: determine the PIS A^* and NIS A^- by equation 6-25 and 6-26 respectively (refer to equations 6-5 and 6-6), where J_1 represents benefit criteria set and J_2 is cost criteria.

$$PIS = A^* = \{v_j^* \mid \max_i v_{ij} \text{ if } j \text{ in } J_1, \min_i v_{ij} \text{ if } j \text{ in } J_2, i = 1, 2, ..., m\} \tag{6-25}$$

$$NIS = A^- = \{v_j^- \mid \min_i v_{ij} \text{ if } j \text{ in } J_1, \max_i v_{ij} \text{ if } j \text{ in } J_2, i = 1, 2, ..., m\} \tag{6-26}$$

Step 10: calculate the distance of each supplier from A^* and A^- by equation 6-27 (refer to equations 6-7 and 6-8, which is denoted as D^* and D^- respectively (also shown below).

$$\begin{aligned} D_i^* &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \\ D_i^- &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \end{aligned} \tag{6-27}$$

Step 11: calculate the relative similarity C_i^* of each supplier with respect to the ideal solution by equation 6-28 (refer to equation 6-9), and rank the preference order, sorting by the C_i^* in decreasing order. The best is the one who has the maximum value.

$$C_i^* = D_i^- \big/ (D_i^* + D_i^-) \tag{6-28}$$

6.3 Assessment method for performance

The previous section proposed the Fuzzy AHP-TOPSIS method. This section introduces how to adapt this model into the three different assessment scenarios proposed in section 5.2, i.e. single supplier, a group of suppliers and cross-group of suppliers.

6.3.1 The criteria analysis

A common point among the three assessment scenarios is to conduct a criteria analysis at the initial stage, which includes formulating the criteria and calculating the weights. To formulate the criteria means identifying what criteria are used. In section 5.2.2, a four-level criteria taxonomy is proposed based on the collaboration closeness between suppliers and buyers. This taxonomy provides a guideline to decide the criteria for different types of suppliers. This research collects the criteria from the reviewed literature, groups them and maps them into the taxonomy.

The collected criteria are mainly from the articles on criteria review and comparatively highly cited articles on supplier assessment and selection methods in recent years. These criteria are grouped into 22 categories according to their target assessment aspect. Figure 6-8 shows these categories mapping with the four-level criteria taxonomy. The fraction [*a*/*b*] under each category indicates how many criteria there are in this category (a) and how many are used in this level (b).

The higher level contains all the categories of its lower level with new ones added. Meanwhile, the criteria set in the categories from lower level could be expanded in the higher level. Take the level 2 ‘operational relationship’ for example. The three categories, product quality, delivery & transportation, and cost are from level 1. The number of criteria in delivery & transportation used for assessment increases from 1 to 6. Another six categories are added, as shown on the right side in the box labelled ‘level 2’ in Figure 6-8. A full list of criteria in each category mapping to the four levels is given in Appendix D with their attributes analysis (quantitative or qualitative).

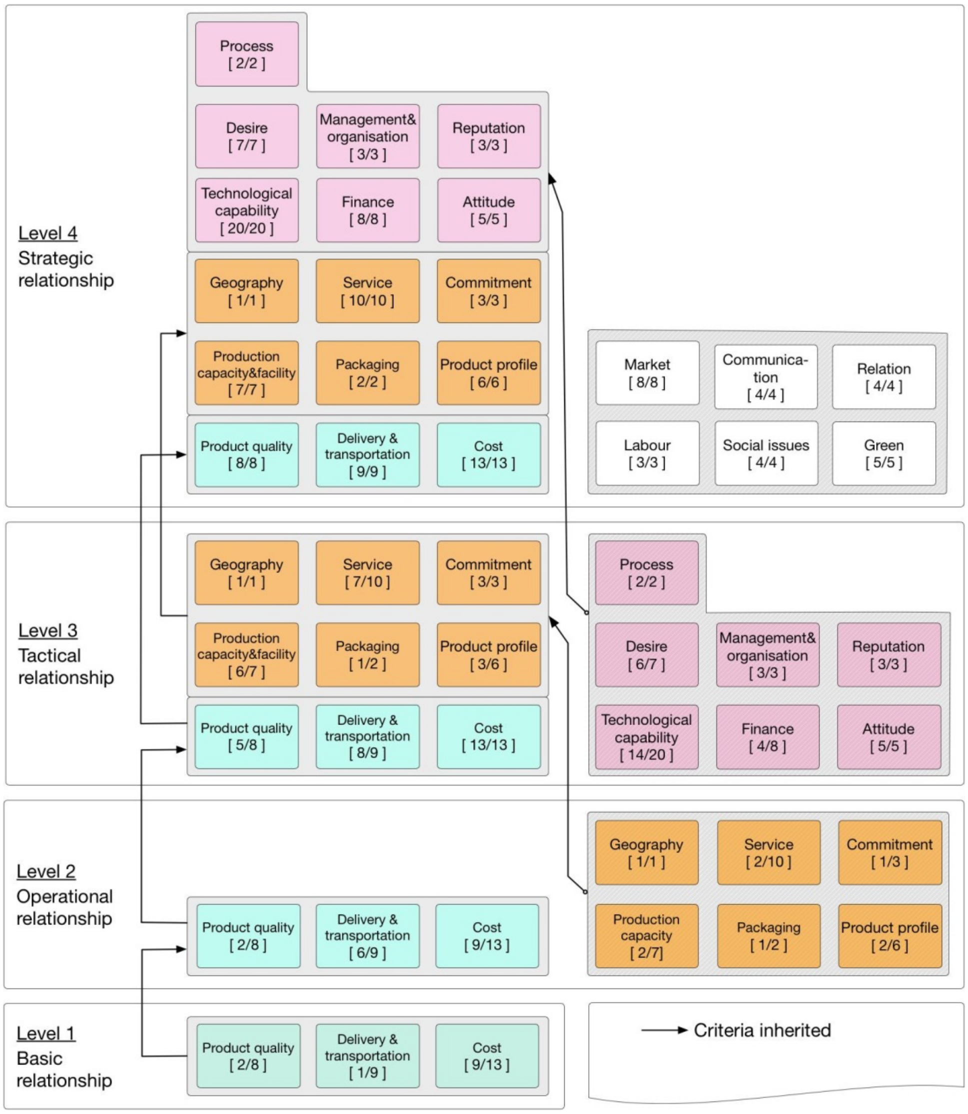


Figure 6-8 Mapping criteria to the four level taxonomy

6.3.2 Single assessment and history performance

Single assessment is used to evaluate a single supplier. There are two situations. The first is without history, which means a supplier can only be measured according to its current performance. A conclusion using a linguistic expression for the final result is more meaningful than a numeric value because there is no reference and no comparison. Step 6 and subsequent steps in the Fuzzy AHP-TOPSIS method that compare alternatives are replaced by evaluating a single alternative as shown in Figure 6-9.

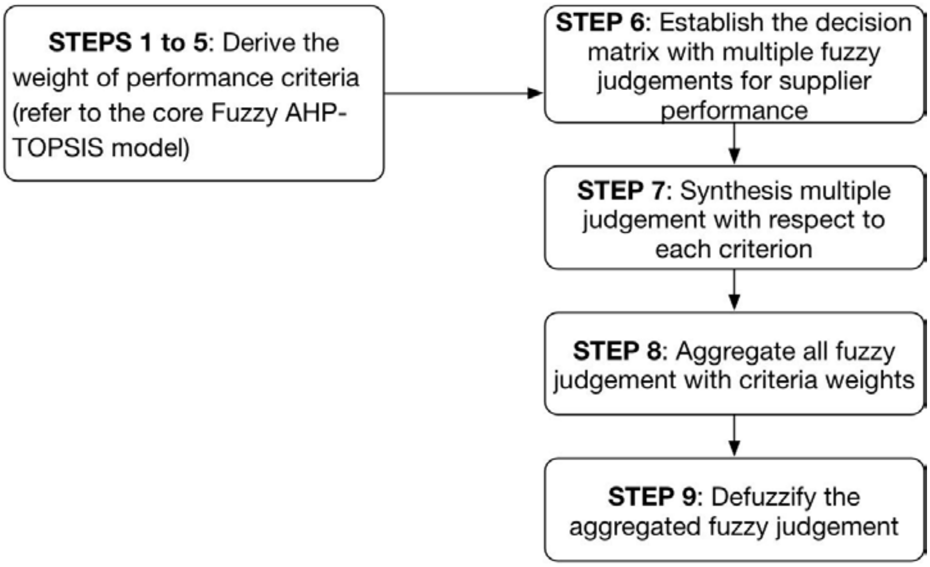


Figure 6-9 Single assessment method

Step 6: establish an $m \times n$ decision matrix T = $[\tilde{x}_{ij}]$ consisting of m decision makers and n criteria. The TFN $\tilde{x}_{ij} = (l_{ij}, m_{ij}, h_{ij})$ represents the linguistic judgement of decision maker i on the supplier with respect to criterion j.

Step 7: synthesise the judgements of multiple decision makers by following equation. $\tilde{r}_j$ is the synthesised result with respect to criterion j.

$$\tilde{r}_j = (l_j, m_j, h_j) = ((\prod_{i=1}^{m} l_{ij})^{\frac{1}{m}}, (\prod_{i=1}^{m} m_{ij})^{\frac{1}{m}}, (\prod_{i=1}^{m} h_{ij})^{\frac{1}{m}}) \quad 6\text{-}29$$

Step 8: aggregate the judgement with respects to each criterion by taking the criterion weight, as equation 6-30. $\tilde{A} = (l, m, h)$ is the aggregated fuzzy result and w_j is the weight of criterion j.

$$\tilde{A} = (l, m, h) = (\sum_{j=1}^{n} w_j \times l_j, \sum_{j=1}^{n} w_j \times m_j, \sum_{j=1}^{n} w_j \times h_j) \quad 6\text{-}30$$

Step 9: defuzzify the result by equation 6-31 (refer to equation 6-13).

$$A = (l + 2m + h) / 4 \quad 6\text{-}31$$

The defuzzified result can be mapped back to the judgement scale as shown in Figure 6-10. Which performance set the result belongs to depends on the comparison of the memberships. For example, a defuzzified result of 5.7 belongs to 'medium good' with a membership of 0.3 while to 'good' with a membership of 0.7. In this example, supplier's performance is measured as 'good'.

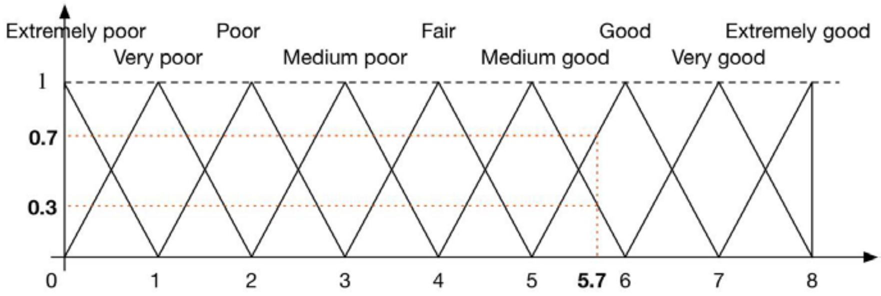


Figure 6-10 Fuzzy scales and their memership functions for performance

The second situation in evaluating a single supplier is based on performance with history, where the whole Fuzzy AHP-TOPSIS method is applied. The $m \times n$ decision matrix in step 6, T = $[\tilde{x}_{ij}]$, consists of m periods and n criteria. The entry $\tilde{x}_{ij}$ is the performance of the supplier at period i with respect to criterion j. An advantage is that the model is able to point out the best possible performance of this supplier. This is because the positive ideal solution is constituted by the best performance among different periods of this supplier with respect to each criterion.

6.3.3 Group assessment and pre-selection

Group assessment compares the alternative suppliers who provide the same product. This is the most common scenario for supplier selection. The Fuzzy AHP-TOPSIS method is applied in this scenario.

De Boer et al. (2001) pointed out that the size of the suppliers set will be different according to which items are purchased, which was introduced in Chapter 2. There is a smaller set when purchasing strategic or bottleneck items or when setting up a new task. A larger set occurs when purchasing routine items. To reduce the computation effort, a pre-selection will be helpful for a large set of suppliers. A simple threshold technique is used to remove the suppliers who perform poorly from the set.

After step 6 for establishing the decision matrix in the model, two steps are added as Figure 6-11.

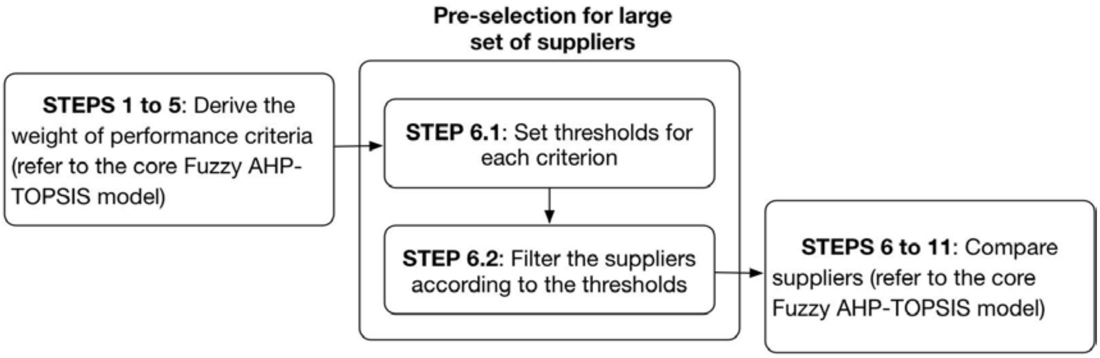


Figure 6-11 Group suppliers assessment method with pre-selection

Step 6.1: set a boundary for each criteria [Min_j, Max_j]. Min_j is the minimum value that will be accepted and Max_j is the maximum value. Min_j and Max_j can be numeric values or linguistic expressions using the same scale in Table 6-15. They can also be left empty if there is no upper or lower boundary. For example, if the buyer considers a supplier offering *delivery* that exceeds 15 days unqualified, then a threshold for delivery is set as [0, 15].

Step 6.2: eliminate the suppliers who have values outside the thresholds. For qualitative criteria, the threshold expressions are firstly translated into the corresponding TFNs. The threshold of criterion *j* is expressed as $[(l^j_{\min}, m^j_{\min}, h^j_{\min}), (l^j_{\max}, m^j_{\max}, h^j_{\max})]$. Then compare the boundary with $x_{ij,}$ the performance of supplier *i* with respect to criterion *j*, which is a crisp value of synthesised judgements of decision makers of from step 5. Supplier *i* will be removed from the supplier set if any of following conditions is met.

$$(1) x_{ij} < l^j_{\min};$$
$$(2) x_{ij} > h^j_{\max};$$
$$(3) x_{ij} \in (l^j_{\min}, m^j_{\min}, h^j_{\min}) \text{ or } (l^j_{\max}, m^j_{\max}, h^j_{\max}) \text{with a membership } \mu(x_{ij}) \geq 0.5$$

6.3.4 Cross-groups assessment

Cross-groups assessment compares suppliers who are from different groups. Actual numeric data could not be used directly in the calculation process because these data are not comparable. For example, a delivery time of 10 days might be considered ‘good’ for a standard component, but a period of 90 days might be also considered ‘good’ for a part with new technology. 10 days and 90 days cannot be compared to decide which is better. The whole Fuzzy AHP-TOPSIS method is then slightly modified in step 6 to evaluate suppliers in this scenario.

Modified Step 6: establish an $m \times n$ decision matrix T = [x_{ij}] consisting of m candidate suppliers and n criteria. Regardless the attribute of the criteria (quantitative or qualitative), x_{ij} is the judgement of the performance from decision makers, which is firstly synthesised from fuzzy judgements of multiple decision makers and then translated to a crisp value.

6.4 Assessment method for power relationship

The previous section discussed how the suppliers under the three scenarios are assessed by the Fuzzy AHP-TOPSIS method. This section introduces how the power relationship is assessed.

6.4.1 A dependence-power table to analyse the determinants

The interviews and reviewed literature shows that power comes from both the dependent factors which reflect the need or willingness of the supplier or the buyer towards the collaboration, as discussed in section 5.3.3. The independent factors give a leverage ability to the supplier or the buyer. The power determinants are analysed in terms of whether they indicate dependence and in terms of which party, supplier or buyer, the determinant will add power to.

- ***Dependence***: whether a determinant reflects either a dependence of supplier on the buyer or a dependence of the buyer on the supplier. A high dependence increases the power of the other party. For example, the determinant ‘available alternative buyers’ reveals supplier dependence on the buyer company. A small number of available buyers lead to high dependence of the supplier on the buyer.
- **Power**: whose power this determinant adds to – the supplier or the buyer. A high dependence of the supplier on the buyer leads to high power to the buyer. For those independent factors, it is necessary to analyse whether a high value in this determinant leads to higher or lower power. For example, ‘high customer recognition on supplier’s brand’ gives high power to the supplier.

Based on these two levels, a dependence-power table is suggested to analyse the determinants for further assessment. Table 6-20 is an example table. *V* is for value of the determinants. *SD* is for supplier dependence on buyer. *BD* is for buyer dependence on supplier. *SP* is for supplier power and *BP* for buyer power. *H* means a high value and *L* means a low value of the determinant, dependence or power. Take the first row, Determinant 1 for example. High value of a determinant *A* leads to low dependence of supplier on buyer and as a result a lower buyer power.

Determinant	***V***	***SD***	***BD***	***SP***	***BP***	***Definition***	***Explanation***
Determinant1	H	L	-		L	*A* is ……	It reflects supplier dependence on buyer, further gives power to buyer. High value leads to low dependence and low buyer power.
Determinant2	H	H	-		H		
Determinant3	H	-	L		L		
Determinant4	H		H		H		
Determinant5	H	-	-	H			High value leads to high supplier power.
Determinant6	H	-	-		H		
V: value, SD: supplier dependence on buyer, BD: buyer dependence on supplier, SP: supplier power, BP: buyer power							

Table 6-20 Dependence-power analysis table

According to the power determinant identification model proposed in section 5.3.1, the power determinants in Table 2-7 in chapter 2 are grouped into market, business and product aspects and analysed by the dependence-power table, as shown in Table 6-21 to Table 6-23. The 'No.' in these tables refer to the determinant number in Table 2-7. Note that in Table 6-22 for Determinant 5, 'importance to buyer's business' replaces 'impact on buyer's product differentiation' in Table 2-7 for generality. In Table 6-23 for Determinant 6, 'importance to buyer product function' replaced 'differentiation of the product of supplier', because the latter is considered to restrict the number of appropriate suppliers (Cho and Chu, 1994; Porter, 2008), which to some extent overlaps with Determinant 1. Different types of products from the suppliers play different roles in the buyer's product. An engine is more critical than window glasses in the vehicle. Thus, 'importance to buyer product function' is used. For Determinants 11, 12 and 13, 'Dependence' is added into the terms because those determinants contribute to power only when buyer or supplier claims a dependence.

No	**Determinant**	**V**	**SD**	**BD**	**SP**	**BP**	**Definition**	**Explanation**
1	Available alternative buyers	H	L	-		L	The number of available alternative buyers	It reflects supplier dependence on buyer, further gives power to buyer. A high number leads to low dependence and low buyer power.
2	Available alternative suppliers	H	-	L	L		The number of available alternative suppliers	It reflects buyer dependence on supplier, further gives power to supplier. A high number leads to low dependence and low supplier power
14	Customer recognition on buyer	H	-	-		H	Customer recognition on buyer brand	High customer's recognition on buyer brand adds up buyer power
15	Customer preference on supplier	H	-	-	H		Customer preference on supplier brand	High customer's preference on supplier brand adds up supplier power

Table 6-21 Dependence-power analysis table for market aspect

No	**Determinant**	**V**	**SD**	**BD**	**SP**	**BP**	**Definition**	**Explanation**
3	Buyer's switching cost (on supplier)	H	-	H	H		Fixed cost in changing suppliers, arising from investment on suppliers, learning how to operate a supplier's equipment, and etc.	High switching cost on a supplier leads to high dependence of buyer on the supplier. High cost lead to high supplier power.
4	Purchased volume relative to supplier's sales	H	H	-		H	A portion of supplier's volume or profits relying on buyer's purchase	High proportion means high dependence of supplier on buyer for revenues, further leads to high buyer power.
5	Importance to buyer's business	H	-	H	H		The importance to the buyer's business in terms of product differentiation.	It reflects buyer dependence on supplier. High importance leads to high dependence and high supplier power.
8	Supplier's threat of integrating forward to the business	H	-	-	H		Supplier's ability to come into buyer's business industry	High supplier's ability to come into buyer's business industry adds up supplier power.
9	Buyer's threat of integrating backward	H	-	-		H	Buyer's ability to come into supplier's business industry	High buyer's ability to manufacture themselves adds up buyer power.
17	New business opportunity for supplier brought by buyer	H	H	-		H	New business opportunity for supplier brought by buyer	More opportunities leads to more dependence of supplier on buyer, which give more power to buyer.

Table 6-22 Dependence-power analysis table for business aspect

No	***Determinant***	***V***	***SD***	***BD***	***SP***	***BP***	***Definition***	***Explanation***
6	Importance to buyer product function	H	-	H	H		The importance of the purchased product to buyer product function	High importance indicates a high buyer dependence on supplier and leads to high supplier power.
7	Importance to the quality of buyer's products or services	H	-	H	H		How much the quality of buyer's products or services will be affected by the purchased product	High effect leads to a high buyer dependence on supplier and leads to high supplier power.
11	Dependence on supplier expertise & knowledge	H	-	H	H		Buyer dependence on supplier expertise and knowledge during its involvement in NPI	High dependence leads to high supplier power.
12	Dependence on buyer expertise & knowledge	H	H	-		H	Supplier dependence on buyer knowledge and expertise to manufacture or assemble the product.	High dependence leads to high buyer power.
13	Dependence on supplier reliable delivery	H	-	H	H		The criticality of supplier reliable delivery (activity) to buyer product development, manufacture, or delivery to customer	High dependence leads to high supplier power.

Table 6-23 Dependence-power analysis table for product aspect

Based on the above analysis, the power determinants are grouped according as they constitutes supplier power or buyer power as well as reflecting a dependence, as shown in Table 6-24.

		Supplier dependence & buyer power	***Buyer dependence & supplier power***		
Dependence	1	Available alternative buyers	Available alternative suppliers	2	Dependence
	4	Purchased volume relative to supplier's sales	Buyer's switching cost (on supplier)	3	
	12	Dependence on buyer expertise & knowledge	Importance to buyer's business	5	
	16	Anticipated profits of supplier brought by buyer	Importance to buyer product function	6	
	17	New business opportunity for supplier brought by buyer	Importance to the quality of buyer's products or services	7	
	9	Buyer's threat of integrating backward	Impact on buyer's cost structure	10	
	14	Customer recognition on buyer	Dependence on supplier expertise & knowledge	11	
			Dependence on supplier reliable delivery	13	
			Supplier's threat of integrating forward to the business	8	
			Customer preference on supplier	15	

Table 6-24 Dependence and power of supplier and buyer

6.4.2 The model of power quantification

After formulating the power determinants, the buyer power and the supplier power will be calculated separately by the Fuzzy AHP-TOPSIS method with a modification on the pairwise comparison when prioritising the determinants and a replacement for Step 6 and subsequent steps when aggregating power from the different determinants.

Modification during the pairwise comparison

For Step 1 in Fuzzy AHP-TOPSIS method, there are two modifications. The first one is in the scales used for pairwise comparison. Determinants do not contribute equally to supplier power or buyer power. The following questions are used for pairwise comparison.

- When considering buyer power: ***which determinant contributes more to your company's leverage capacity, and by how much?***
- When considering supplier power: ***which determinant contributes more to your supplier's leverage capacity, and by how much?***

By answering these questions, the decision maker should give linguistic judgements such as "determinant A contributes moderate more/strongly more/etc. than determinant B". The expected answers are used to judge how much more one determinant contributes to power than the other. They will be further translated into numeric values by the scales in Table 6-25. Multiple decision makers are allowed because our proposed assessment method can synchronise multiple judgements. To carry on the assessment, at least one decision maker is needed.

Linguistic judgement	***Scale***	***Linguistic judgement***	***Scale***	***Linguistic judgement***	***Scale***
Equally (E)	(1,1,1)	Weakly more (W)	(1,2,3)	Moderate more (M)	(2,3,4)
Moderate plus more (M+)	(3,4,5)	Strongly more (S)	(4,5,6)	Strongly plus more (S+)	(5,6,7)
Very strongly more (VS)	(6,7,8)	Very very strongly more (VVS)	(7,8,9)	Extremely strongly more (ES)	(8,9,9)

Table 6-25 Scale for power determinants comparison

The other modification is that the perception of the supplier towards the power relationship as discussed in section 5.3.2 is added. The determinants, against which these perceptions are added, are identified by the buyer company. The theoretical situation is that supplier has the same perspective as the buyer company and uses the same power determinants. However, in practice there is a possibility that the supplier is not aware of some determinants. For example, the supplier may not know the buyer could provide new business opportunity unless the buyer tells them. A probability between 0 and 1 is added to indicate *the possibility the supplier perceives determinant i* to the diagonal of the pairwise comparison, denoted as p_i, which is used in the aggregation of power. Figure 6-12 shows the matrix for pairwise comparison incorporating the perception along the diagonal.

Dependence area

Supplier dependence & buyer power		A	B	C	D	E	F	G
A	Available alternative buyers	1				E	S	S
B	Purchased volume relative to supplier's sales	M+	1	W	M	M+	VS	VS
C	Anticipated profits of supplier brought by buyer	M		0.4	W	M	S+	S+
D	New business opportunity for supplier brought by buyer	W			0.4	M	S	S
E	Dependence on buyer expertise, knowledge					1	S	S
F	Buyer's threat of integrating backward						0.8	E
G	Customer recognition on buyer							0.6

Perception possibility

Figure 6-12 Comparison and perception analysis matrix

Aggregating power

The following steps in Figure 6-13 replace the step 6 to step 11 in the Fuzzy AHP-TOPSIS method (after prioritising the determinants) to quantify the power. For the ease of explaining the model, *X* is used to denote either supplier or buyer and *Y* as the other.

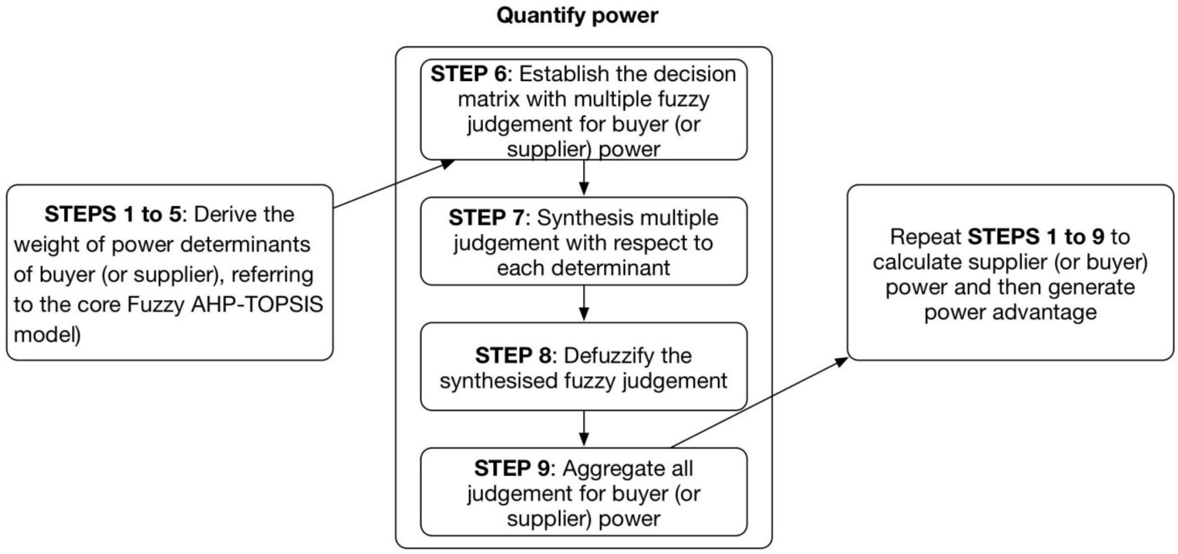


Figure 6-13 Power quantification method

Step 6: establish an *m*×*n* decision matrix T = $[\tilde{x}_{ij}, \tilde{x}_{ik} \mid i=1,..m;\ j=1,...t; k=t+1,...n]$ consisting of *m* decision makers and *n* power determinants of *X* where there are *t* determinants reflecting a dependence. The difference to the previous step 6 in the Fuzzy AHP-TOPSIS method is that this decision matrix contains the views of all decision makers on each power determinants, which are all subjective data. The t dependent determinants and the n-t independent ones are distinguished. A TFN $\tilde{x}_{ij} = (l_{ij}, m_{ij}, h_{ij})$ or $\tilde{x}_{ik} = (l_{ik}, m_{ik}, h_{ik})$ represents linguistic judgement of decision maker *i* on the value with respects to determinant *j* or *k*. The scale refers to Table 6-15. A benefit determinant means that a high value leads to a high power of *X* (also indicating a high dependence of *Y* on *X*). A cost determinant means that a high value leads to a low power of *X* (also indicating a low dependence of *Y* on *X*).

Step 7: synthesise the judgements of multiple decision makers by equation 6-32 (refer to equation 6-11). $\tilde{r}_j$ is the synthesised result with respects to determinant *j* which reflects dependence. $\tilde{r}_k$ is the synthesised result with respects to determinant *k* which is dependence irrelevant.

$$\tilde{r}_j = (l_j, m_j, h_j) = ((\prod_{i=1}^{m} l_{ij})^{\frac{1}{m}}, (\prod_{i=1}^{m} m_{ij})^{\frac{1}{m}}, (\prod_{i=1}^{m} h_{ij})^{\frac{1}{m}}) \qquad 6\text{-}32$$

Step 8: defuzzify the synthesised judgement by equation 6-33 (refer to equation 6-13).

$$r_j = (l_j + 2m_j + h_j)/4 \tag{6-33}$$

Step 9: calculate the power of *X* over *Y* by equation 6-34. Where *D(Y/X)* is *Y*'s dependence on *X*, *U(X)* is the dependence irrelevant power of *X*, p_j and p_k are the perceiving possibility of determinant *j* and *k* respectively. w_j and w_k are the weights of determinant *j* and *k* respectively.

$$P(X/Y) = D(Y/X) + U(X/Y) = \sum_{j=1}^{t} p_j \times w_j \times r_j + \sum_{k=t+1}^{n} p_k \times w_k \times r_k \tag{6-34}$$

The power of *Y* over *X*, *P(Y/X)*, is calculated in the same way. Then the power advantage of *X* over *Y*, *PA(X/Y)* is obtained by comparing *P(X/Y)* and *P(Y/X)*, as equation 6-35.

$$PA(X/Y) = P(X/Y) - P(Y/X) \tag{6-35}$$

The reason that the dependence is highlighted from the beginning of the analysis of the power quantification is because dependence itself indicates the need for collaboration from each side. By understanding how much dependence of *X* on *Y*, and *Y* on *X*, the buyer could have different decision. This aspect was discussed in section 5.4.

6.4.3 Estimation based on perception scenarios

In Chapter 5, when analysing the power situations, there are three types of possible perceptions by a supplier of the power relationship, namely, objective, optimistic and pessimistic perception. Based on this, four types of estimation are considered where the perception possibility is applied.

Objective estimation

Objective estimation is that *X* has the same perception as *Y*, i.e. the supplier and the buyer both have a full understanding of each other's power. In this case, the perceiving possibility is set as 1 for each determinant. Equation 6-34 becomes to the following equation:

$$P_{full}(X/Y) = D_{full}(Y/X) + U_{full}(X/Y) = \sum_{j=1}^{t} w_j \times r_j + \sum_{k=t+1}^{n} w_k \times r_k \qquad \text{6-36}$$

$P_{full}(X/Y)$ is used to denote a full estimation of the power of *X* over *Y*, $D_{full}(Y/X)$ denotes the full estimation of *Y*'s dependence on *X* and $U_{full}(X)$ denotes the full estimation of dependence irrelevant power of *X* over *Y*. In this case, the power advantage of *X* over *Y*, $PA_{full}(X/Y)$ is:

$$PA_{full}(X/Y) = P_{full}(X/Y) - P_{full}(Y/X) \qquad \text{6-37}$$

In a full estimation situation, *Y* (the buyer) is not able to manipulate *X* (the supplier) through access to information, because *X* is fully aware of its own strength and weakness as well as *Y*'s.

Possibility estimation

Possibility estimation means *X* does not have a full understanding of the power of either itself or the power of *Y*. In other words, *X* underestimates both the power of itself and *Y*. In this case, the perception possibility of all the determinants on both sides (supplier and buyer) are taken into account. The calculation equations are exactly the same as equation 6-34 and 6-35, with $P_{poss}(X/Y)$ and $PA_{poss}(X/Y)$ used instead of *P(X/Y)* and *PA(X/Y)* to distinguish from full estimation.

In a possibility estimation, *X* is neither fully aware its own strength and weakness or *Y*'s. Therefore, what *Y* should do is to keep *X* continuing with this awareness on *X*'s power while making *X* aware that *Y* is more powerful than *X*'s understanding. For example, *Y* can remind and emphasise the importance of the *new business opportunity* it will bring to *X*.

Optimistic estimation

Optimistic estimation is that X underestimates its own power while fully understanding *Y*'s power. *X*'s pessimistic perception leads to an optimistic estimation of the power relationship to *Y*. In this case, perception possibility is added to *X*'s power but not to *Y*'s power. The power advantage of *X* over *Y* is:

$$PA(X/Y) = P_{poss}(X/Y) - P_{full}(Y/X) \qquad 6\text{-}38$$

This is a beneficial situation for *Y*, because *X* has a full awareness of *Y*'s power but a partial understanding of its own. It would be easy for *Y* to communicate, bargain and negotiate with *X*. However, *Y* should be aware of the extent to which X realises it underestimates its power.

Pessimistic estimation

Pessimistic estimation occurs when *X* underestimates *Y*'s power while fully understanding its own power. *X*'s optimistic perception leads to a pessimistic estimation of the power relationship to *Y*. In this case, the perception possibility is added to *Y*'s power but not to *X*'s power. The power advantage of *X* over *Y* is:

$$PA(X/Y) = P_{full}(X/Y) - P_{poss}(Y/X) \qquad 6\text{-}39$$

This is a tough situation for *Y*, because *X* has a full awareness of its own power but a partial understanding of *Y*'s. Therefore, it is not easy for *Y* to communicate, bargain and negotiate. What *Y* should do is to make *X* aware that *Y* is more powerful than *X*'s understanding.

6.5 Chapter conclusion

Performance assessment and power quantification are the premise for any further analysis of suppliers. This section discussed why and how the Fuzzy AHP-TOPSIS method has been built. This core assessment model is adapted to solve the performance assessment problem in different scenarios and to assess the power relationship. Although the model is straightforward, its application involves significant computational effort. Therefore, a software tool is developed to implement the assessment methods and display the positioning approach proposed in Chapter 5, which is introduced in the next chapter.

Chapter 7 Implementation of a tool to assess relative positioning of suppliers

The previous two chapters introduced the approach to assess relative positioning in supplier selection as well as the assessment methods for performance and power relationships. A software tool reduces the computational effort and the likelihood of mistakes from manual calculation. Graphical user interfaces allow users ways to interact with the tool. The literature reviewed in Chapter 2 revealed that there is no tool using a hybrid model specifically for supplier assessment. A dedicated software tool for supplier selection called PEPA (Performance Evaluation and Power Assessment) is described in this chapter. It implements the approach proposed in chapters 5 and 6. The five main graphical displays in the software are discussed first before showing how the tool supports supplier selection.

7.1 Software tool implementation

This section focuses on the implementation of the software in terms of its design principles, system architecture, system logic and data entities. Java was selected as the programming language because the author was most familiar with it. However, Java has other advantages, as it is platform independent, able to run in Windows, Mac OS and Linux'. Also, as a widely used object-oriented language it is suitable for future development of the tool. The layout of the functions in the tool with Java classes is also discussed.

7.1.1 System design principles

A software tool should be extendable to accommodate new research directions and refinements in user requirements. This version of PEPA has been implemented so that the functions can easily be rewritten and new functions can be added as new modules. Individual functions are implemented so that they are extendable. Take 'processing the supplier information' as an example. The current value format is either single values (e.g. 1, 2, 3…) or triple values (i.e. fuzzy triangular numbers). These values are processed first by the program through synthesising the multiple values (judgements) with respect to each criterion (Step 6 in the Fuzzy AHP-TOPSIS method in section 6.2.3). Then the values are input into the quantifying phase. If the ‘processing’ and ‘quantifying’ stages are implemented in one function, then changing to a new value format (for example to a real interval, i.e. [*a*, *b*] where *a* and *b* are real numbers,) would mean that the whole function would have to be re-written. However, if they are implemented as two separate functions, only the ‘processing’ function will require rewriting.

The software is set up to allow new modules to be added. For example, a new algorithm to quantify suppliers could be added, which also needs to pre-process the information on suppliers. This extension is made easier by a separate function for pre-processing information.

To give extendibility, the PEPA software is designed with as little overlap in functions as possible. In the implementation three design principles for ‘classes’ in object-oriented programming, proposed by Martin (2012), were followed. A class is an extensible program code template, which abstracts objects of the same kind. Martin’s three design principles are:

- ***Single-responsibility principle***: “a class should have one, and only one, reason to change”. A responsibility is considered to be a reason to change in this context. It means one class handles one responsibility with all the behaviours serving this purpose. A class with two or more responsibilities leads to difficulties in reading, reusing, and changing.
- ***Open-closed principle***: “software entities (classes, modules, methods) should be open for extension but closed for modification”.
- ***Dependency inversion principle***: “Abstractions should not depend on details. Details should depend on abstractions. High level modules should not depend on low level modules.” Each layer of the system does not need to know the details of how the other layers work. If two classes are linked together and dependent on each other, they are

considered as tightly coupled so that any change in one will lead to the change propagating to the other.

7.1.2 System architecture

Following Martin's (2012) design principles, a Model-View-Control (MVC) architecture is selected, because MVC separates the logic, the representation, and the interpretation of user input (Bevis, 2012).

- ***Model*** manages data and the rules that govern the access to and updates the data. It responds to the instructions from the controller and pushes the requested data to the view.
- ***View*** displays information. It specifies how the model data is represented. If the model changes, the view will update its presentations.
- ***Controller*** translates the user's interactions with the view into actions that the model will perform.

MVC is an architectural pattern but the software systems designed on this pattern vary due to their own functions and features. The system architecture of our tool PEPA is designed as Figure 7-1. **Controller** connects **Model** and **View**. It receives the request from View, invokes the corresponding modules in Model and returns the data for View to display.

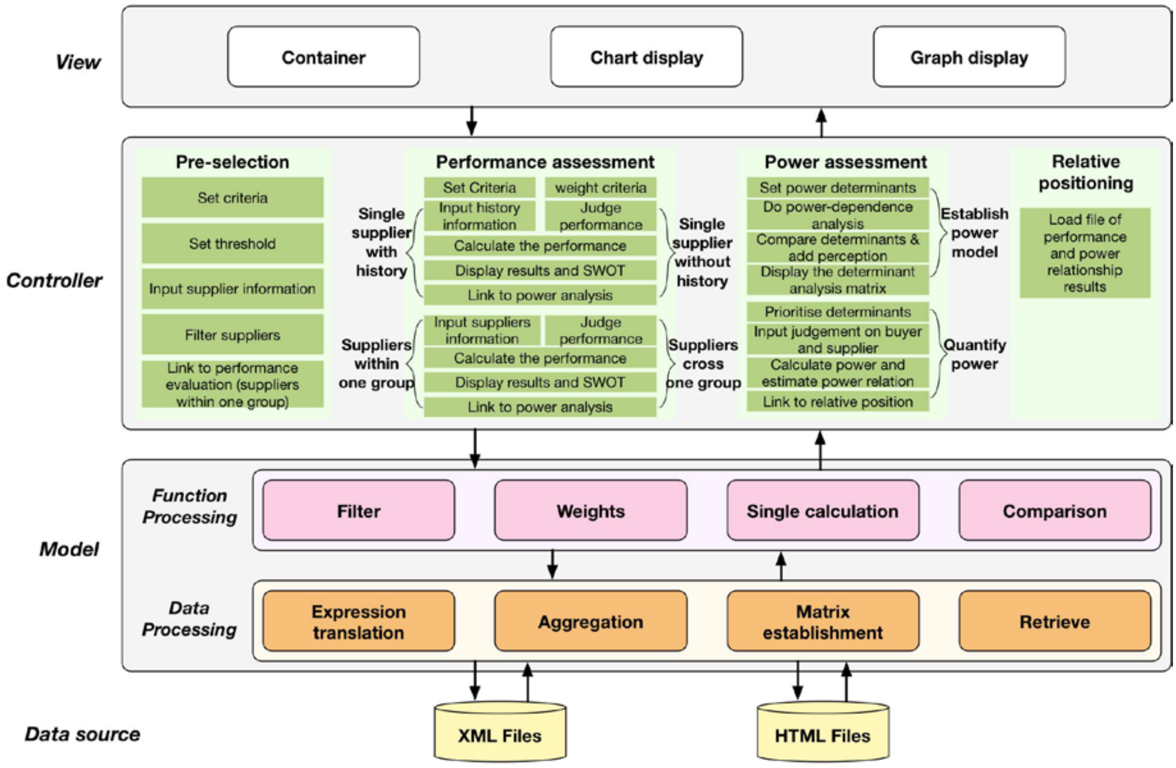


Figure 7-1 System architecture of PEPA

Model is in charge of the calculation-related tasks. It contains the two layers: a function processing layer and a data processing layer. The function processing layer is responsible for calculation and includes four modules.

- *Filter*: removes the unqualified suppliers according to the thresholds (see Section 6.3.3).
- *Weights*: implements the Fuzzy AHP algorithm in the Fuzzy AHP-TOPSIS method to derive the weights for suppliers after pairwise comparison (see Section 6.2.3).
- *Single calculation*: calculates the result when there is only one alternative. It is used for both the scenario of ‘single supplier without history’ and the supplier/buyer power calculation (see Section 6.3.2 and 6.4.2).
- *Comparison*: implements the TOPSIS algorithm in the Fuzzy AHP-TOPSIS method and applies it to the scenarios of single supplier with history, group assessment and cross group assessment (see Section 6.3.2, Section 6.3.3 and Section 6.3.4).

The data processing layer in Model parses the data and includes four modules.

- *Expression translation*: translates linguistic expressions to triangular fuzzy numbers. Both pairwise comparison and performance/power judgement need the translations, but at different scales.
- *Aggregation*: aggregates multiple triangular fuzzy numbers for pairwise comparison and in performance/power judgements when there are multiple experts.
- *Matrix establishment*: establishes the matrix for comparison or calculation.
- *Retrieve module*: is used to prepare data for SWOT analysis, power situation determination and display of relative positioning.

Controller bridges the modules Model and View. On the one hand, it has all functions registered, which will call the corresponding modules in the Model. On the other, it notifies the corresponding modules in View what functions need to be displayed.

There is one layer in **View** containing three modules, which provides the graphical user interface and displays the results.

- *Container*: creates the basic panels as containers to display the user interfaces.
- *Chart display*: creates two types of charts – line chart and bar chart.
- *Graph display*: provides the customised graphical representations in the proposed approach for SWOT analysis (Section 5.2.3), power situation quadrants (Section 5.3.3) and relative positioning (Section 5.4.1).

The bottom layer in Figure 7-1 is data sources where XML files are used to store inputs such as criteria, power determinants, supplier information, and expert information. HTML files are used to store intermediate and final results throughout the execution of the tool.

7.1.3 System logic

The previous subsection shows the system architecture with modules in charge of different functions. This subsection goes into the details of the system logic of PEPA as illustrated in Figure 7-2. Each step in the figure will call corresponding modules in Figure 7-1.

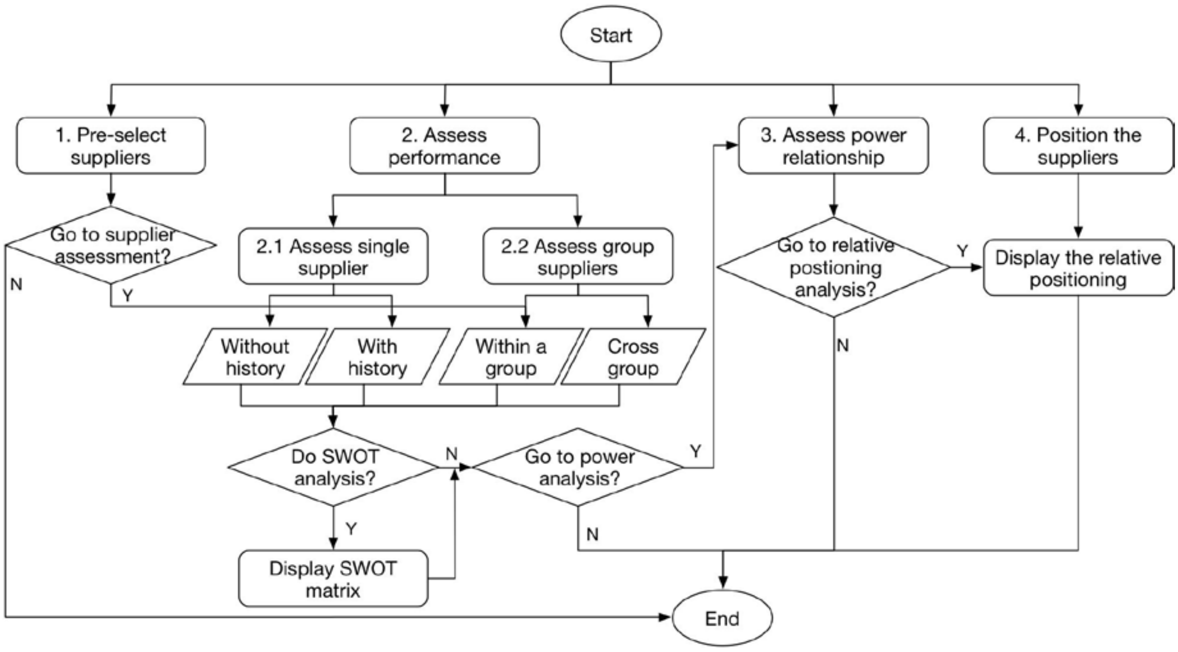


Figure 7-2 System logic of PEPA

The tool starts with four functions for the user to choose: **Pre-select suppliers**, **Assess performance**, **Assess power relationship** and **Position the suppliers**. The Container module in View in Figure 7-1 is in charge of displaying the graphical user interfaces of these functions. The chosen function and its follow-up actions are converted to Model by Controller. The return results from Model are then converted to View to show by Controller.

When there is a large set of suppliers (see Section 5.2.1 and Section 6.3.3), the user can begin with **Pre-select suppliers**, The Filter module in the function processing layer in Figure 7-1 is used to eliminate unqualified suppliers. As discussed in section 5.2.1, this usually happens in the scenario where a group of suppliers can provide the same standard product. After pre-selection, the tool directs the user to assess suppliers within one group.

The user can directly go to the function **Assess performance** which supports the four types of performance assessment in section 6.3, namely single supplier without history, single supplier with history, suppliers within a group, and suppliers of cross-groups. Modules in the function processing layer, apart from Filter, in Figure 7-1 are called for Assess performance. The numeric calculations results are displayed in a line chart and a bar chart by calling the Chart display module in View. The internal logic of this function will be introduced later. With the numeric results, the user can choose to carry on the SWOT analysis (Section 5.2.3). The Retrieve module is used to get the data and the Graph display module draws the SWOT matrix. The tool also directs the user to power assessment which can be executed independently.

The function **Assess power relationship** implements the power analysis and assessment in section 5.3 and section 6.4. The Expression translation module in the Data processing layer in Figure 7-1 translates the user's subjective judgement into fuzzy triangular numbers. The Matrix establishment module establishes the comparison matrix of the determinants with the fuzzy triangular numbers. The Weight module calculates weights for the determinants. The Single calculation module calculates the power of a supplier. During the calculation process, the Aggregation module synchronises the multiple judgements from multiple decision makers. The tool also directs the user to the function Position the suppliers, if the performance evaluation results are available.

Position the suppliers implements the relative position analysis integrating the assessment results of performance and the power relationship (refer to Section 5.4.1). Retrieve module prepares the data for the Graph display module which draws the six supplier-buyer scenarios in the nine squares (refer to Figure 5-13) in the tool.

The process 'Assess performance'

The Fuzzy AHP-TOPSIS method in section 6.2.3 is used to assess supplier performance. This method is adapted for performance assessment in the different scenarios of single, group and cross group (refer to Sections 6.3.2, 6.3.3 and 6.3.4). Figure 7-3 describes the process that the tool uses to guide the user towards these different scenarios and calculate the results in the chosen scenario. The three scenarios lead to four types of assessment (single supplier without history, single supplier with history, suppliers within a group, and suppliers of cross-groups). The four level criteria taxonomy (no relationship, operational, tactical, strategic relationships) developed in section 5.2.2 provides the user with pre-defined criteria, listed in Appendix D. The user is also able to define new criteria.

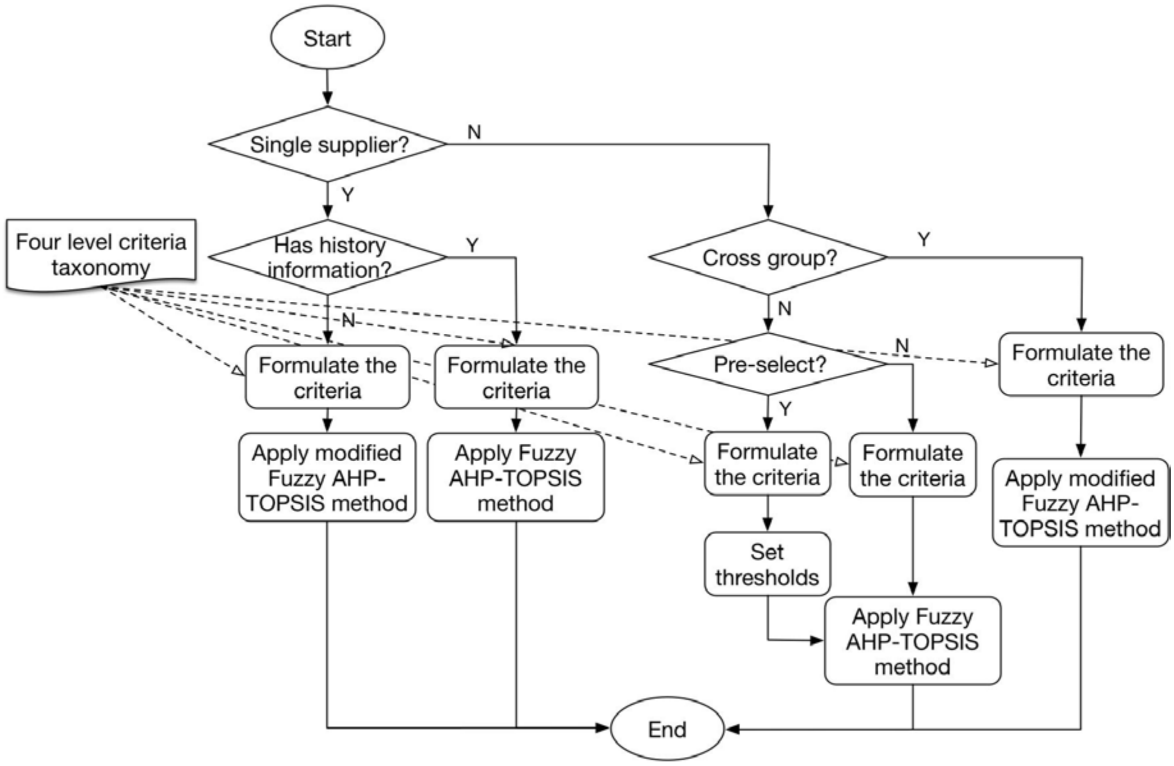


Figure 7-3 Process of performance assessment

The process 'Assess power relationship'

Power relationship assessment is based on the results of the power quantification for both the supplier and the buyer (refer to Section 6.4). Figure 7-4 describes the process of power relationship assessment applied in the tool. The power determinant identification model in Figure 5-9 is applied by the user to identify their determinants. The dependence-power table in section 6.4.1 is used to analyse whether a determinant contributes to supplier power or buyer power. The power determinants from the literature in Table 6-21, Table 6-22 and Table 6-23 are provided by the tool for the user to select the determinants. The modified Fuzzy AHP-TOPSIS method is applied to assess both supplier power and buyer power. The calculation results are compared to conclude the power situation, namely supplier dominance, buyer dominance or balanced, (section 5.3.3). As a power relationship involves two parties – the supplier and the buyer, each party could perceive it differently. Section 5.3.2 calls this the perception of power. Three perception scenarios exist, namely, objective, optimistic and pessimistic. The estimate of the supplier's perception of power helps the buyer understand the implications of the power relationship (refer to Section 6.4.3). If the supplier's perception of power is added, the tool continues by making four estimates of the power relationship: objective, possibility, optimistic and pessimistic described in section 6.4.3.

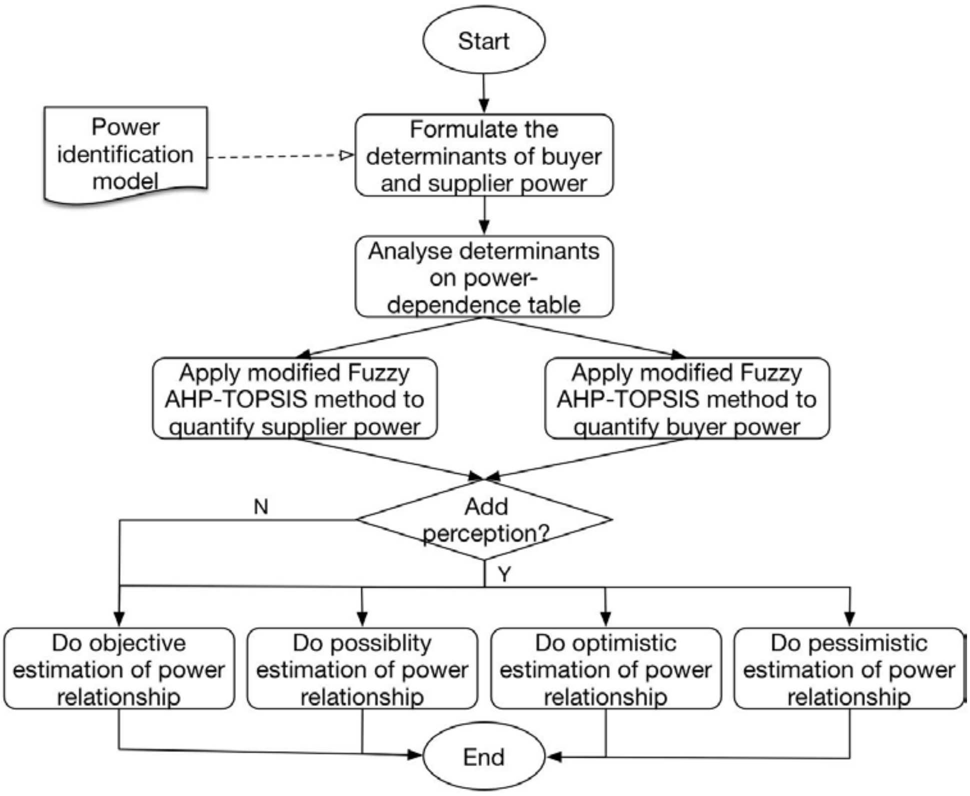


Figure 7-4 Process of power relationship assessment

7.1.4 Data entity model

Data is transferred according to the system logic summarised in Figure 7-2. This subsection introduces the data entities and how they are organised in the tool. Four groups of data entities are distinguished by the way they are used in the calculations for power and performance assessment: **judgement data**, **power data**, **performance data** and **result representation**, as shown in Figure 7-5.

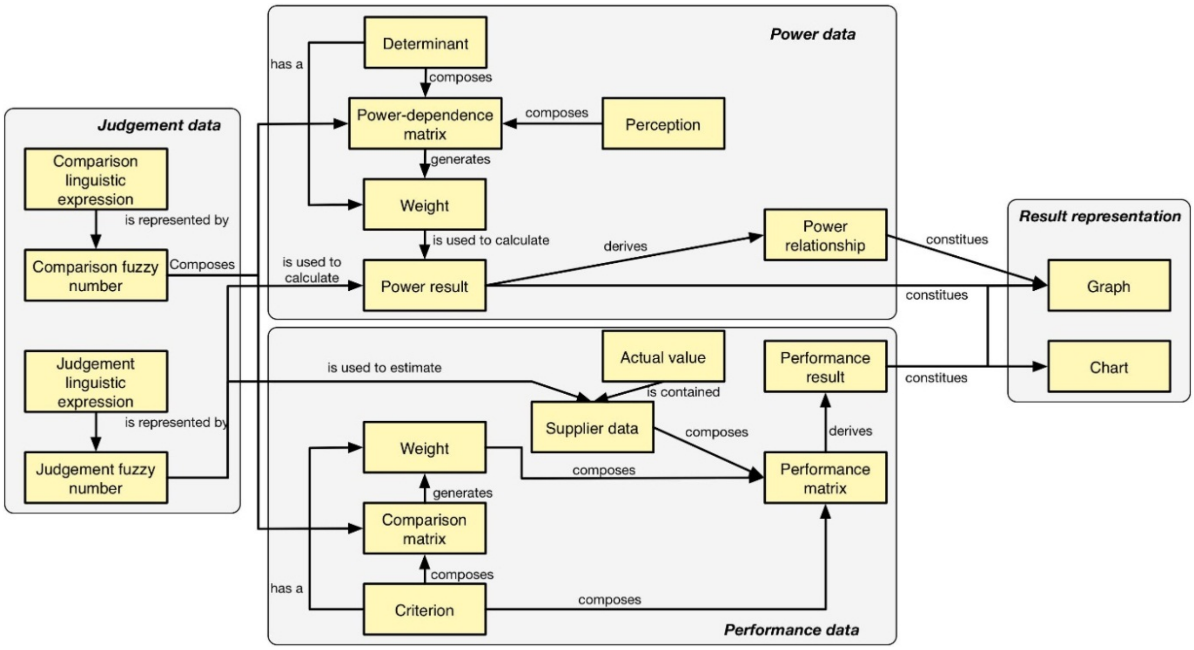


Figure 7-5 Data entity model

As discussed in section 6.1.3, there are two types of judgements. One is to express the relative importance of one criterion or determinant over another during pairwise comparison. The other is to describe how a supplier performs with respect to the criteria or how high (or low) a value is with respect to the power determinants. These jugdements are gathered in the **Judgement data** group. *Comparison linguistic expression* is the linguistic expression of the first type of judgements, such as 'equal importance', 'moderate importance' and 'strong importance' (see Section 6.1.3). Each comparison linguistic expression is linked to a corresponding *Comparison fuzzy number* for calculation (see Table 6-14). *Judgement linguistic expression* is the second type of judgements such as 'poor', 'fair' and 'good' (see Section 6.1.3), which is also linked to a fuzzy number, the *Judgement fuzzy number* (see Table 6-15).

The **Power data** group contains the data related to power assessment. *Determinant* labels power determinants according to (1) whether they reveal dependence or not and (2) whether they are associated with supplier power or buyer power (see Section 6.4.1). *Perception* is a numeric value within [0,1] that presents how a supplier perceives a power determinant (see Section 6.4.2). The *Power-dependence matrix* is composed from Determinant, Perception, and Comparison fuzzy number. The latter are from the Judgement data group representing the relative importance of one determinant over another. *Weight*s represent the numeric values of the weights of power determinants, which are generated from the *Power-dependence matrix* (see Section 6.4.2). *Power result* is the power value of buyer or supplier, calculated with the model proposed in section 6.4.2 based on Weights and Judgement fuzzy numbers. *Power relationship* records the power situation (supplier dominance, buyer dominance or balanced) using the difference in value between a supplier Power result and a buyer Power result.

The **Performance data** group consists of the data related to performance assessment. *Criterion* labels a performance criterion. *Comparison matrix* is the matrix for pairwise comparison of the criteria with Comparison fuzzy numbers. *Weight* is a numeric value as the weight of a criterion, generated form the Comparison matrix. *Supplier data* contains supplier performance data that is either Judgement fuzzy number or *Actual value* or a mix. *Performance matrix* is the decision matrix for performance comparison (see Sections 6.3.2, 6.3.3 and 6.3.4). *Performance result* records the calculation results of the suppliers from the Performance matrix.

The ***Result representation*** contains two data entities namely, *Chart* and *Graph*. *Chart* includes the data to display in bar chat and line chart. *Graph* includes the data to display in the customised graphical representations for SWOT analysis, power situation quadrants and relative positioning. These data are constituted from the data entities *Power result*, *Power relationship* and *Performance result*

7.1.5 Layout of components of the tool

The system has many functions and intermediate steps to display to the users. The display of windows and the layout of the components such as buttons and panels needs to be decided before coding. Generally when one function is selected or an intermediate step is generated for illustration, a new tab appears rather than a new window. This presents a neater display on the screen. Figure 7-6 presents how the components are organised by using Java classes in the software tool.

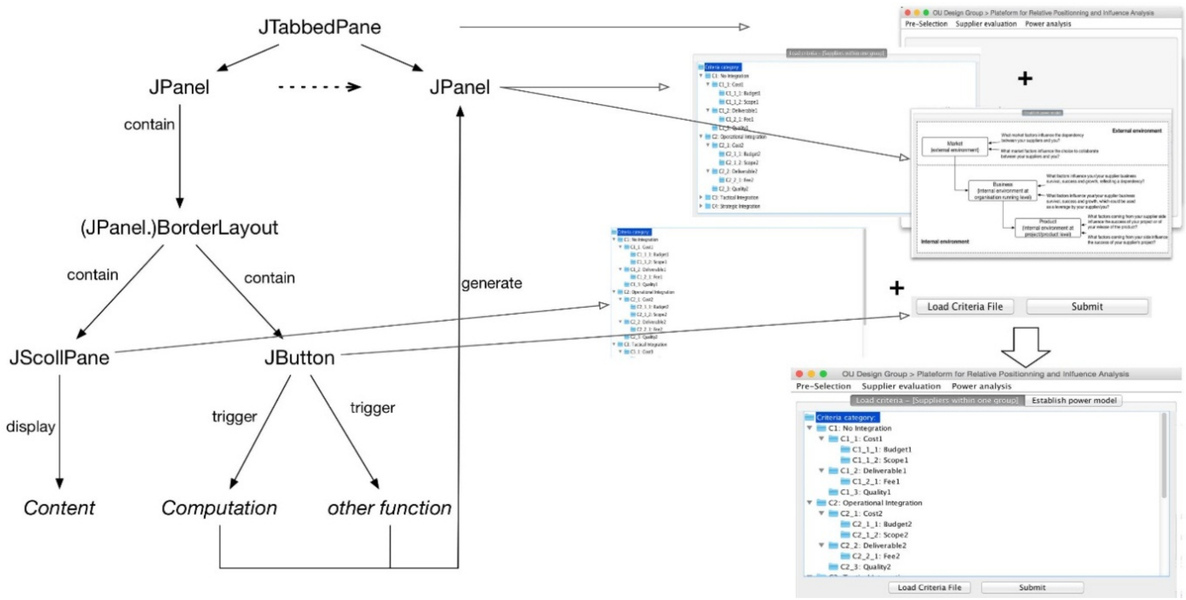


Figure 7-6 Implementation mechanism of PEPA

JTabbedPane, *JPanel*, *BorderLayout*, *JscrollPane* and *JButton* are all Java class names. *JTabbedPane* works like a top-level container, allowing several components such as panels to share the same space. *JPanel* is also a kind of container to hold the contents in one panel. *JPanel* objects are added to the *JTabbedPane* object as tabs to display different information in one window. To manage the positions of the contained components, a *BorderLayout* object is specified for a *JPanel* object, which assigns the components to five areas as north, south, east, west and centre. *JScrollPane*, is a low-level container, providing a scrollable view of the content. The *JScrollPane* object is added to a *JPanel* object, where the data is displayed. *JButton* objects are also contained in a *JPanel* object. They generate buttons to click to trigger specific actions. A *JButton* object in this system either triggers a computation action for example calculating the pairwise comparison matrix, or another function such as switching to power analysis after performance assessment, which might generate a new *JPanel* object as a tab.

7.2 Results visualisation

The ways that the results are displayed influences the ease of use of the tool. This section discusses the five main visualisations used to display results.

7.2.1 Display of pairwise comparison

Pairwise comparison prioritises the performance criteria and the power determinants in the assessment. A user can easily miss the links when filling in large matrixes, PEPA provides a list of questions comparing the criteria, shown in Figure 7-7 and establishes the pairwise comparison matrix based on the answers provided to the user. The tool constructs the comparison matrix from the input from answers by the users. Table 7-1 provides an illustration. For example, if quality is more important than cost, the input should be at the cell in the first column and second row. If quality is less important than cost, the judgement should appear at the cell in the second column and first row.

Goal	*Quality*	*Cost*	*Delivery*	*Service*
Quality	Equal	*Here for quality is more important than cost*		
Cost	*Here for cost is more important than quality*	Equal		
Delivery			Equal	
Service				Equal

Table 7-1 One way of representing pairwise comparison

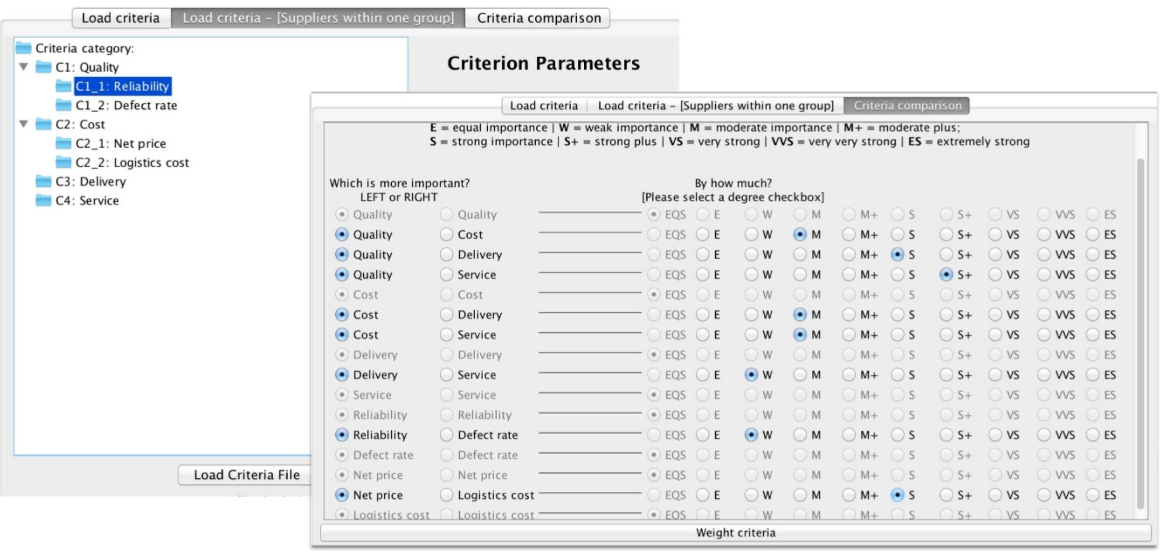
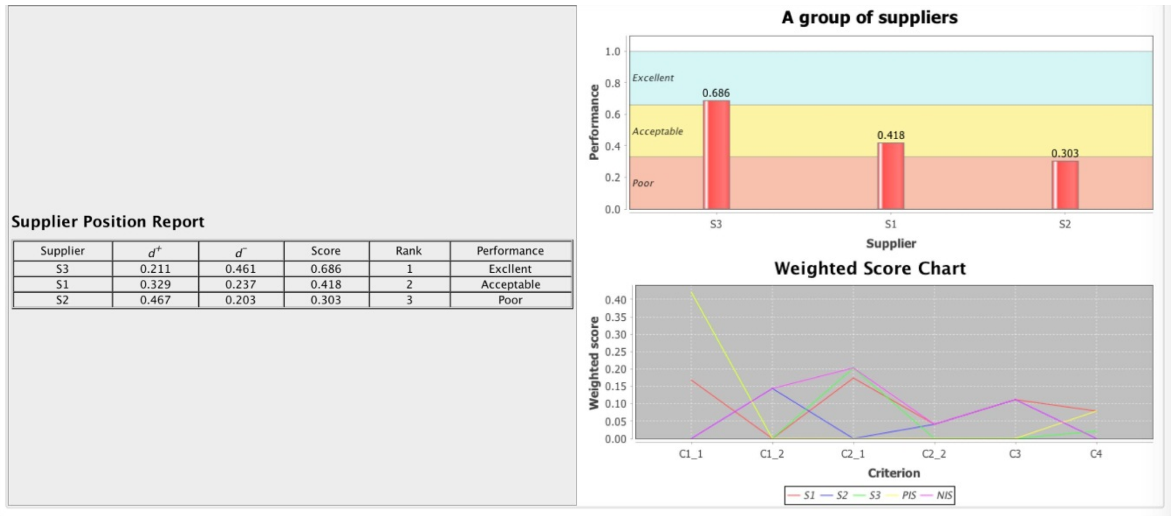


Figure 7-7 Display of pairwise comparison in PEPA

7.2.2 Display of assessment outcomes

The outcomes of performance assessment are overall performance values of a group of different suppliers. The aim of the assessment is to compare different suppliers. Figure 7-8 shows, on the left, the numeric results. On the right the outcomes are visualised by a column chart for overall comparison and a line chart for performance against the criteria. The column chart on the upper right gives an intuitive impression of supplier ranking.



Supplier Position Report

Supplier	d^+	d^-	Score	Rank	Performance
S3	0.211	0.461	0.686	1	Exclient
S1	0.329	0.237	0.418	2	Acceptable
S2	0.467	0.203	0.303	3	Poor

Figure 7-8 Display of assessment results

The line chart 'Weighted Score Chart' displays more details of the comparison, including (1) a comparison by criteria; (2) the fluctuation in performance for each supplier against the criteria which, in the illustration, indicates that suppliers have significant difference between their best and worst performances; (3) the values of the positive (PIS) and the negative (NIS) ideal solutions for performance with respect to each criterion, which are calculated from equations 6.5 and 6.6. For a single supplier without history no column chart is displayed.

The aim of the power assessment is also a comparison, but between one supplier and one buyer. Figure 7-9 illustrates this comparison. The left part shows the numeric results and overall conclusion about the relative power in the relationship. The column chart on the right, visualises the comparison of power and of dependence between the supplier and buyer.

Figure 7-9 Display of power assessment results

7.2.3 Display of SWOT analysis of supplier performance

The SWOT analysis described in section 5.2.3 graphically represents the distribution of the criteria applied to a supplier according to their weights and the corresponding scores for performance in four quadrants (see Figure 5-6). This quadrant analysis is based on the SWOT, in that it applies the terms Strengths, Weaknesses, Opportunities and Threats. For simplicity this analysis of performance is called a SWOT in this thesis. There is an issue for visualisation in locating the position of the criteria on the scales of 'low' and 'high' on the two axes. To define the axis of 'weight', *1/n* is used as the division between 'low' and 'high', where *n* is the number of criteria directly used in the performance calculation, 1 is the sum of normalised weights and *1/n* is the average level of weight. The upper boundary of weight is set as the largest value among all the criteria. The reason that 1 not set as the upper boundary is that in most cases the weight of a criterion is relatively far from 1. Even in the extreme case of two criteria where one is of extreme importance, the weight is 0.9. For the horizontal axis of 'score', according to the judgement scale in section 6.2, the values range from 0 to 8. The midpoint is taken as the division between high low and high.

An example (Table 7-2) shows how PEPA displays the SWOT. There are four criteria: quality (with two sub-criteria – reliability and defect), cost (with two sub-criteria – net price, logistics cost,), delivery and service. In Table 7-2 the weights of a supplier are shown alongside each criterion and the performance scores in the bottom row.

Criteria	*Quality*: 0.565		*Cost*: 0.244		*Delivery*: 0.112	*Service*: 0.079
Sub-criteria	*Reliability*: 0.421	*Defect*: 0.144	*Net price*: 0.203	*Logistics cost*: 0.041	-	-
Performance Score	6	*7*	*2.5*	*7*	5	2

Table 7-2 Example for illustration

There are six weights so the division point between 'low' and 'high' on the 'weight' axis is 1/6. The upper boundary is 0.565 which is the weight of quality rather than of its sub-criterion reliability. The SWOT quadrants are visualised as Figure 7-10 and the positions of each of the criteria indicated by small red squares.

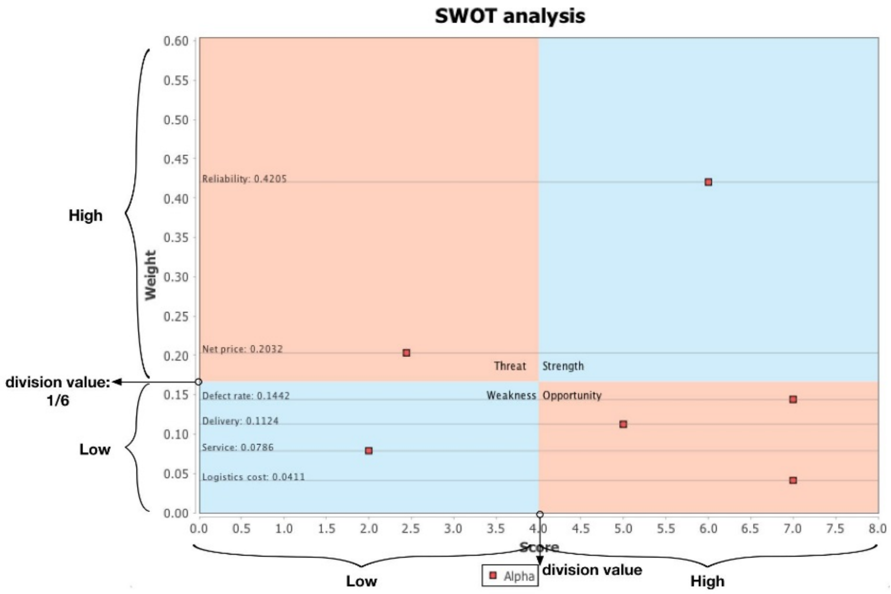


Figure 7-10 Display of SWOT analysis

7.2.4 Display of the power situation

The power relationship is combined with dependence in power situation analysis (see Section 5.3.3). This visualisation gives the user an intuitive image of the power and the dependence of suppliers and buyer. According to the judgement scale for power in section 6.1.3, the axes of 'supplier power' and 'buyer power' range from 0 to 8. As illustrated in Figure 7-11, the upper triangular area shows supplier dominance whilst the lower triangular area shows buyer dominance. The diagonal shows the area of power balance.

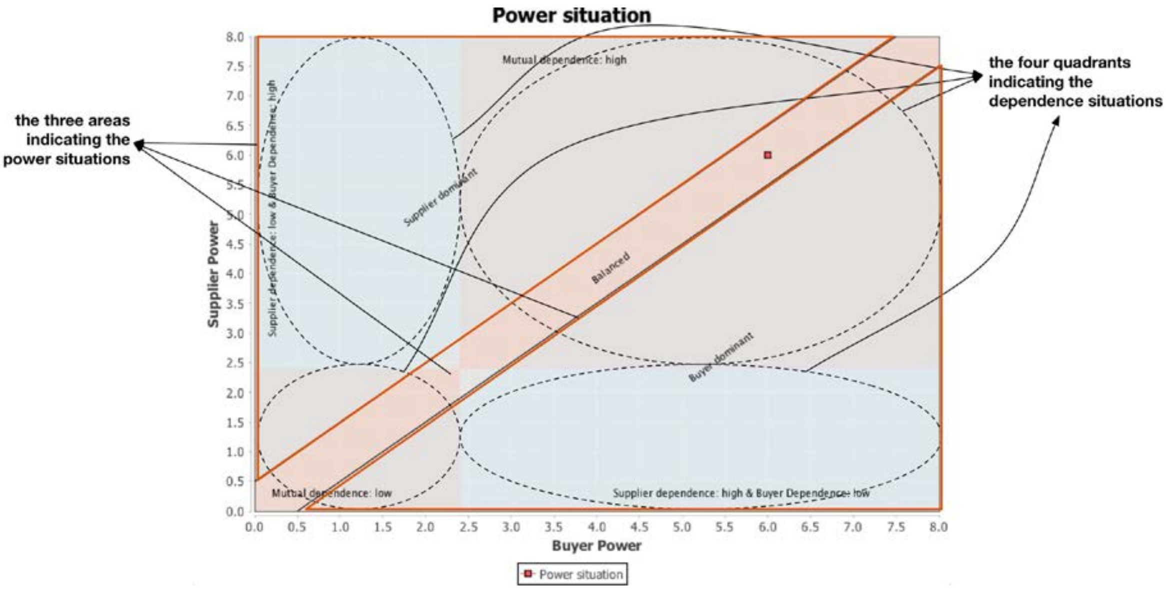


Figure 7-11 Display of power situation analysis with four 'quadrants' indicating scenarios of dependence.

Power is made up of both dependent and independent determinants. The dependence is considered high when its corresponding power is above average and no less than 60% of the power comes from dependence, i.e. when the value of dependence is above 2.4.

The four 'quadrants' in the background in Figure 7-11 display the four scenarios of dependence, which indicate the possible attitudes towards the collaboration as discussed in section 5.3.3.

7.2.5 Display of relative positioning

The display in Figure 7-12 of relative positioning integrates power and performance through visualising six scenarios (ideal, satisfying, tolerable, unfavourable, risky and tough) in nine squares (see Figure 5-13 and Section 5.4.1). Suppliers are positioned according to both performance and power and one supplier is shown on Figure 7-12 that is positioned in the tolerable scenario.

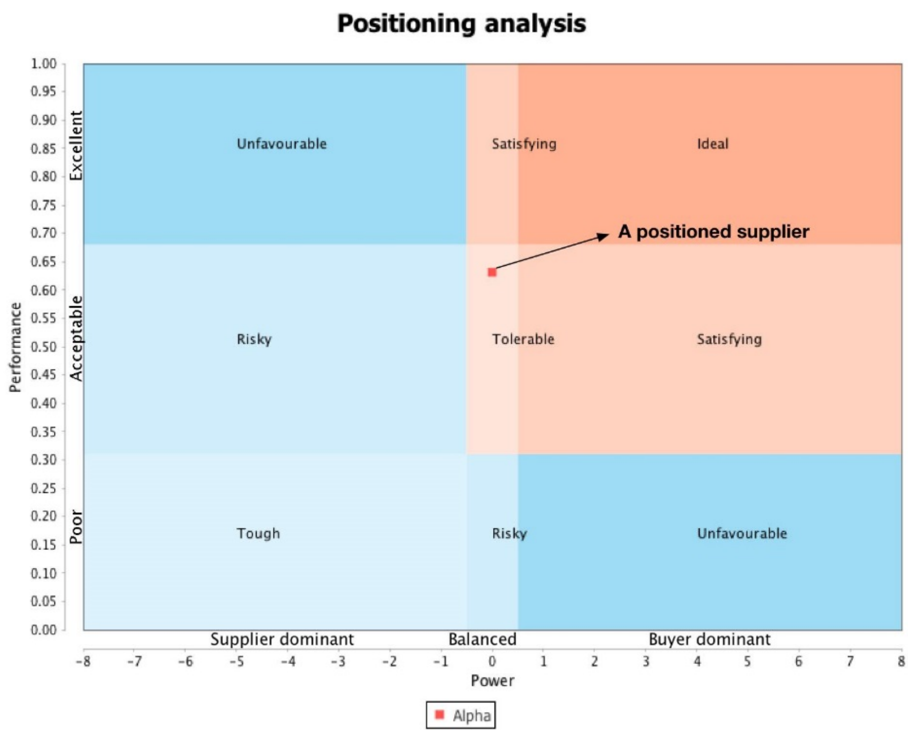


Figure 7-12 Display of relative positioning

When defining the range of 'performance' axis, two ways of calculation generate two different ranges which are aligned on a single [0,1] scale for the display through normalisation. In the case that all the input data is based on subjective judgements (for single supplier assessment without history and cross group assessment) the range extends from 0 to 8. If the input data is a mixture of actual numeric values and subjective judgement (for supplier assessment with history group assessment), the range is from 0 to 1. In order to place all suppliers in the display, the range [0, 8] is mapped to [0, 1] by linear normalisation. According to the judgement scale in section 6.1.3, the overall performance is treated as 'poor' when the value lies in [0, 2.5), as 'acceptable' in [2.5, 5.5], and as 'excellent' in (5.5, 8]. After normalisation the set 'poor' is [0, 0.31), 'acceptable' [0.31, 0.68] and 'excellent' (0.68, 1]. The square bracket means the boundary value are included whilst the round bracket means the boundary value is excluded. For example, [0, 2.5) is the range from 0 to 2.5 where 2.5 is not included.

The axis of 'power relationship' arranges 'supplier dominant', 'balanced' and 'buyer dominant' in sequence. [-8,-0.5) is 'supplier dominant', [-0.5, 0.5] is 'balanced' and (0.5,8] is 'buyer dominant'.

7.3 The software tool

The PEPA tool has been tested after the implementation to make sure it implements the proposed approach and the assessment models correctly. This section demonstrates how to apply the tool to select a suitable supplier. An illustrative case in the manufacturing industry is created. The buyer company, Gamma, is planning to expand its business to a new area and seeks a strategic partnership. There are three potential suppliers. Supplier Alpha is a newly founded local company in that area with local manufacturing facilities, who offers a good price. However, Gamma has never worked with Alpha. Supplier Beta is a big company whose business covers a range of fields. It has ready-made manufacturing facilities and its own market in this area. Thus Beta has good local market knowledge. Based on the past collaboration, Gamma knows Beta is capable to provide high quality products. However, Beta is somewhat hard to negotiate with on issues such as price, discount, and delivery. Supplier Delta is a relatively big company which has been established for a long time. During the collaboration with Delta, as one of its main clients, Gamma has received stable performance. The problem is that Delta does not have local manufacturing facilities.

Gamma has to make the decision carefully because this strategic collaboration will greatly influence the success of its new business. On the one hand, Gamma needs to make sure the partner is capable. On the other hand, it also needs to know whether the collaboration would be stable and easy to establish. Following the proposed analysis approach, an evaluation on the performance of these three potential suppliers is carried out, followed by the power analysis between each supplier and Gamma. The final relative positioning based on the two results points out a suitable choice of supplier.

7.3.1 Data requirement

Before showing the assessment process, this section explains the data required to populate the tool. The data comes from four areas, as the data model in Figure 7-13 shows.

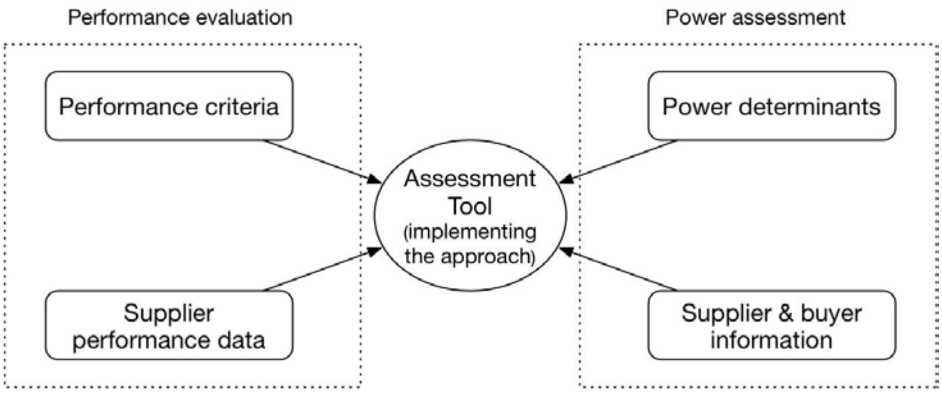


Figure 7-13 Data model for tool manipulation

The first area concerns the criteria. The decision makers from the buyer company (users of the tool) needs to determine what the criteria are for assessing performance. Table 7-3 gives templates for criteria and sub-criteria which they fill in. For each criterion in the 'Criterion List', the decision makers state whether it has sub-criteria. If does not, a numeric value will be provided or a qualitative judgement will be made. Otherwise, the second template 'Sub-criteria list' needs to be filled in. The tool uses the list of criteria set out in Figure 6-8 (section 6.3.1). Appendix D (D2 Definitions of the criteria) provides the definitions of all the criteria/sub-criteria collected from the literature. The decision makers can choose from the list. The IDs of the criteria will be automatically generated and used by the software tool to distinguish the criteria. The tool also gives the decision makers the flexibility to define new criteria.

Criteria list

Name	***ID***	***Sub-criteria (Y/N)***	***Input (Value/judgement)***
Product quality	C4_1	Y	-
Delivery	C4_2	Y	-
… …			

Sub-criteria List

Parent criterion	***Name***	***ID***	***Input (Value/judgement)***
Product quality	product reliability	C4_1_1	Judgement
Product quality	Defect	C4_1_2	Judgement
Product quality	quality control system	C4_1_5	Judgement
… …			

Table 7-3 Template of criteria list

The second area concerns the suppliers' performance. Table 7-4 needs to be filled with either numeric values for quantitative criteria such as price and delivery time, or the judgements of the decision makers like "Supplier A has a poor/fair/good/etc. performance with respect to a Criterion such as Product quality illustrated in Table 7-4". The scales for judgement have been introduced in section 6.1.3.

Supplier information						
	Product quality			*Delivery*		…
	product reliability	*Defect*	*quality control system*	…	…	…
Supplier 1	Good	Good	Medium good			
Supplier 2	Very good	Very good	Very good			
… …						

Table 7-4 Template of supplier information

The third area considers the power determinants. The decision makers decide what power determinants are to be used for power assessments. The models used to identify and to analyse the determinants have been introduced in section 5.3.1 and section 6.4.1 respectively. The decision makers provide the information for Table 6-20. The tool uses the determinants listed in section 6.4.1 which are collected from literature. The decision makers choose from the list. Again, the tool allows the decision makers the flexibility to add new determinants.

The last area deals with the judgement of the power values. The decision makers fill in Table 7-5 with the values for both supplier power determinants and buyer power determinants. They make judgements like "The number of available alternative buyers is *low/medium/high/etc*." The scales for judgement have been introduced in section 6.1.3. It might be difficult for the decision makers to determine these values for suppliers' power, because it depends on the quality and availability of the information about them. However, it is noted that how this information is acquired for these judgements is beyond the scope of this thesis.

Buyer power (Supplier dependence)		Supplier power (Buyer dependence)	
Determinant	***Value***	***Determinant***	***Value***
Available alternative buyers	Low	Available alternative suppliers	High
Purchase volume	Very high	Importance to buyer business	Very high
… …		… …	

Table 7-5 Template of power values

7.3.2 Cross-group assessment

In the illustrative example with a buyer Gamma, three suppliers Alpha, Beta and Delta are targeted for the same business, Gamma has information based on its contact with Alpha and history data for Beta and Delta. It can use the **cross-group assessment** function to get an overview of their performance. Since Gamma aims for a strategic relationship, according to the proposed four-level taxonomy in section 5.2.2, the following criteria at the strategic relationship level (criteria and levels are mapped in Figure 6-8 with further detail in Appendix D1 – Criteria mapping to the taxonomy with attribute analysis) are chosen. The detailed definitions of these criteria and sub-criteria are set out in Appendix D2 - Definitions of the criteria).

- **Product quality** with three sub-criteria: product reliability, defect and quality control system.
- **Delivery** with two sub-criteria: delivery time and set-up time for new product.
- **Cost** with two sub-criteria: net price, logistics cost.
- **Production capacity & facility** with two sub-criteria: production capacity, production planning system.
- **Geography** with one sub-criterion: geographical location.
- **Service** with one sub-criterion: repair service.
- **Technological and technical capability** with three sub-criteria: current technology, manufacturing capability and future technology development.
- **Financ**e with two sub-criteria: financial condition and financial asset available to put into the partnership.
- **Market** with two sub-criteria: local market knowledge and speed to market.

Figure 7-14 shows the criteria selection panel where the four quadrants on the left present criteria under the four levels of relationship and the table on the right shows criteria which are chosen.

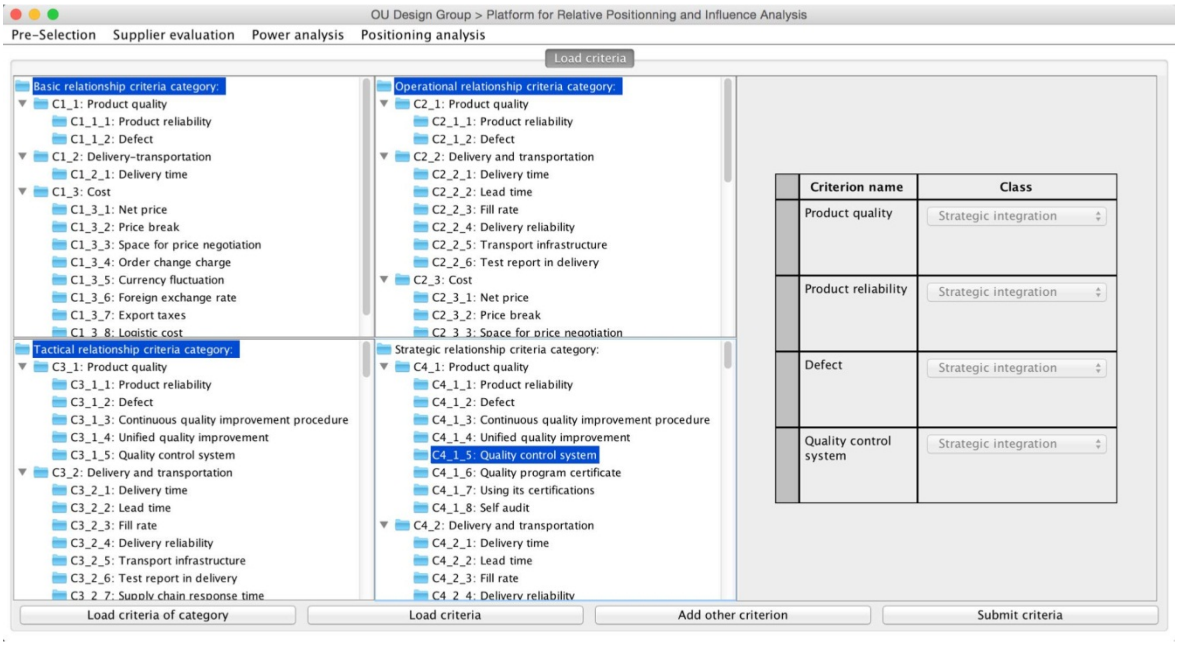


Figure 7-14 Choosing the criteria

After choosing the criteria and clicking the 'submit' button, all the selected criteria will be presented in a new panel so the decision makers can double check as seen in Figure 7-15.

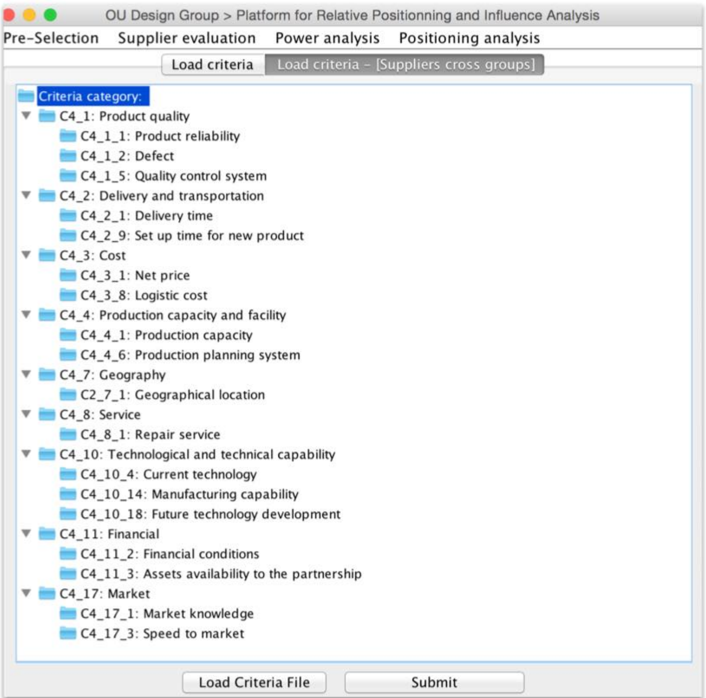
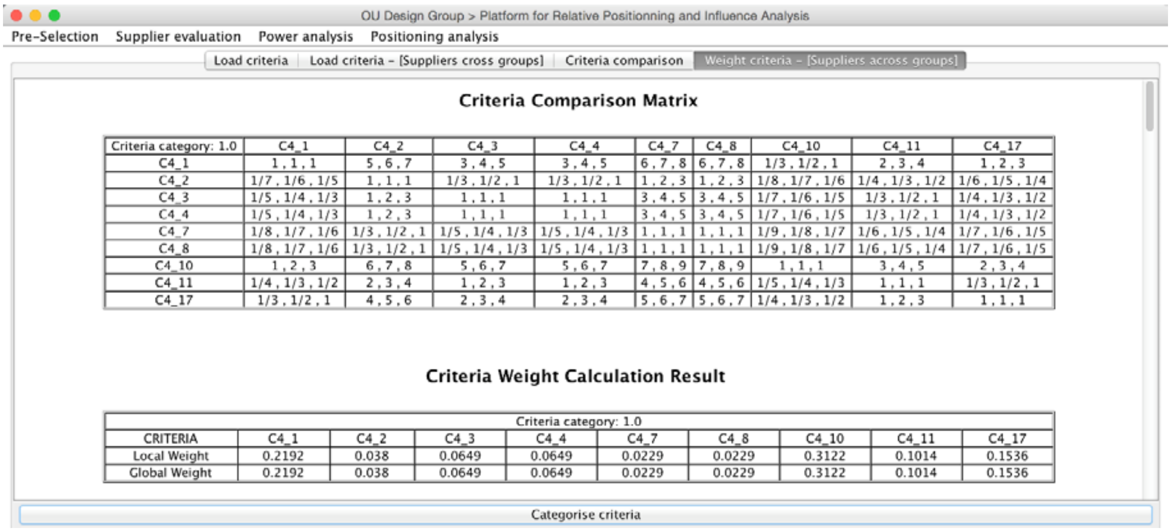


Figure 7-15 The chosen criteria

The tool allows multiple decision makers to make judgements which will be integrated for assessment (see section 6.2.3). This example assumes two decision makers from Gamma who pairwise compare the criteria and judge the performance of suppliers for qualitative criteria. Overall, technological and technical capability, product quality, and market are the three most important. Financial aspects, production capacity and facility and cost are more important than delivery, geography and service. After the pairwise comparison, the weights of these criteria are calculated as listed in Table 7-6. A screenshot for the main criteria weights is shown in Figure 7-16.

Main criteria (with ID in the tool)	***Weights***	***Sub-criteria (with ID in the tool)***	***Weight***
C4_1: Product quality	0.2192	C4_1_1: product reliability	0.1386
		C4_1_2: defect	0.0572
		C4_1_5: quality control system	0.0234
C4_2: Delivery	0.038	C4_2_1: delivery time	0.0133
		C4_2_9: set-up time for new product	0.0247
C4_3: Cost	0.0649	C4_3_1: net price	0.0325
		C4_3_8: logistics cost	0.03245
C4_4: Production capacity & facility	0.0649	C4_4_1: production capacity	0.03245
		C4_4_6: production planning system	0.03245
C4_7: Geography	0.0229	C4_7_1: geographical location	0.0229
C4_8: Service	0.0229	C4_8_1: repair service	0.0229
C4_10: Technological and technical capability	0.3122	C4_10_4: current technology	0.0815
		C4_10_14: manufacturing capability	0.1974
		C4_10_18: future technology development	0.0333
C4_11: Financial	0.1014	C4_11_2: financial condition	0.0843
		C4_11_3: financial asset availability to put into the partnership	0.0171
C4_17: Market	0.1536	C4_17_1: local market knowledge	0.0392
		C4_17_3: speed to market	0.1144

Table 7-6 The weights of the criteria



Criteria category: 1.0	C4_1	C4_2	C4_3	C4_4	C4_7	C4_8	C4_10	C4_11	C4_17
C4_1	1 , 1 , 1	5 , 6 , 7	3 , 4 , 5	3 , 4 , 5	6 , 7 , 8	6 , 7 , 8	1/3 , 1/2 , 1	2 , 3 , 4	1 , 2 , 3
C4_2	1/7 , 1/6 , 1/5	1 , 1 , 1	1/3 , 1/2 , 1	1/3 , 1/2 , 1	1 , 2 , 3	1 , 2 , 3	1/8 , 1/7 , 1/6	1/4 , 1/3 , 1/2	1/6 , 1/5 , 1/4
C4_3	1/5 , 1/4 , 1/3	1 , 2 , 3	1 , 1 , 1	1 , 1 , 1	3 , 4 , 5	3 , 4 , 5	1/7 , 1/6 , 1/5	1/3 , 1/2 , 1	1/4 , 1/3 , 1/2
C4_4	1/5 , 1/4 , 1/3	1 , 2 , 3	1 , 1 , 1	1 , 1 , 1	3 , 4 , 5	3 , 4 , 5	1/7 , 1/6 , 1/5	1/3 , 1/2 , 1	1/4 , 1/3 , 1/2
C4_7	1/8 , 1/7 , 1/6	1/3 , 1/2 , 1	1/5 , 1/4 , 1/3	1/5 , 1/4 , 1/3	1 , 1 , 1	1 , 1 , 1	1/9 , 1/8 , 1/7	1/6 , 1/5 , 1/4	1/7 , 1/6 , 1/5
C4_8	1/8 , 1/7 , 1/6	1/3 , 1/2 , 1	1/5 , 1/4 , 1/3	1/5 , 1/4 , 1/3	1 , 1 , 1	1 , 1 , 1	1/9 , 1/8 , 1/7	1/6 , 1/5 , 1/4	1/7 , 1/6 , 1/5
C4_10	1 , 2 , 3	6 , 7 , 8	5 , 6 , 7	5 , 6 , 7	7 , 8 , 9	7 , 8 , 9	1 , 1 , 1	3 , 4 , 5	2 , 3 , 4
C4_11	1/4 , 1/3 , 1/2	2 , 3 , 4	1 , 2 , 3	1 , 2 , 3	4 , 5 , 6	4 , 5 , 6	1/5 , 1/4 , 1/3	1 , 1 , 1	1/3 , 1/2 , 1
C4_17	1/3 , 1/2 , 1	4 , 5 , 6	2 , 3 , 4	2 , 3 , 4	5 , 6 , 7	5 , 6 , 7	1/4 , 1/3 , 1/2	1 , 2 , 3	1 , 1 , 1

Criteria category: 1.0									
CRITERIA	C4_1	C4_2	C4_3	C4_4	C4_7	C4_8	C4_10	C4_11	C4_17
Local Weight	0.2192	0.038	0.0649	0.0649	0.0229	0.0229	0.3122	0.1014	0.1536
Global Weight	0.2192	0.038	0.0649	0.0649	0.0229	0.0229	0.3122	0.1014	0.1536

Figure 7-16 Weights of the main criteria

The two decision makers then judge the performance of each supplier with respect to each criterion. Take product reliability for example. With the information on Supplier Alpha, one decision maker (DMU_1:Expert1) consider it having a high product reliability and describes it as 'Good' using the scales presented in Table 6-15. It is assumed that the other decision maker (DMU_2:Expert2) is more strict and describes it as 'Medium good'. Based on the past record, DMU_1:Expert1 describes the performance of Beta on reliability as 'Very good' and Delta as 'Good'. DMU_2:Expert2 describes the performance of Beta on reliability as 'Good' and Delta as 'Medium good'. Figure 7-17 shows the page presented to the two decision makers in order for them to make their judgements. More decision makers can be added by the tool as shown on the left upper in Figure 7-17.

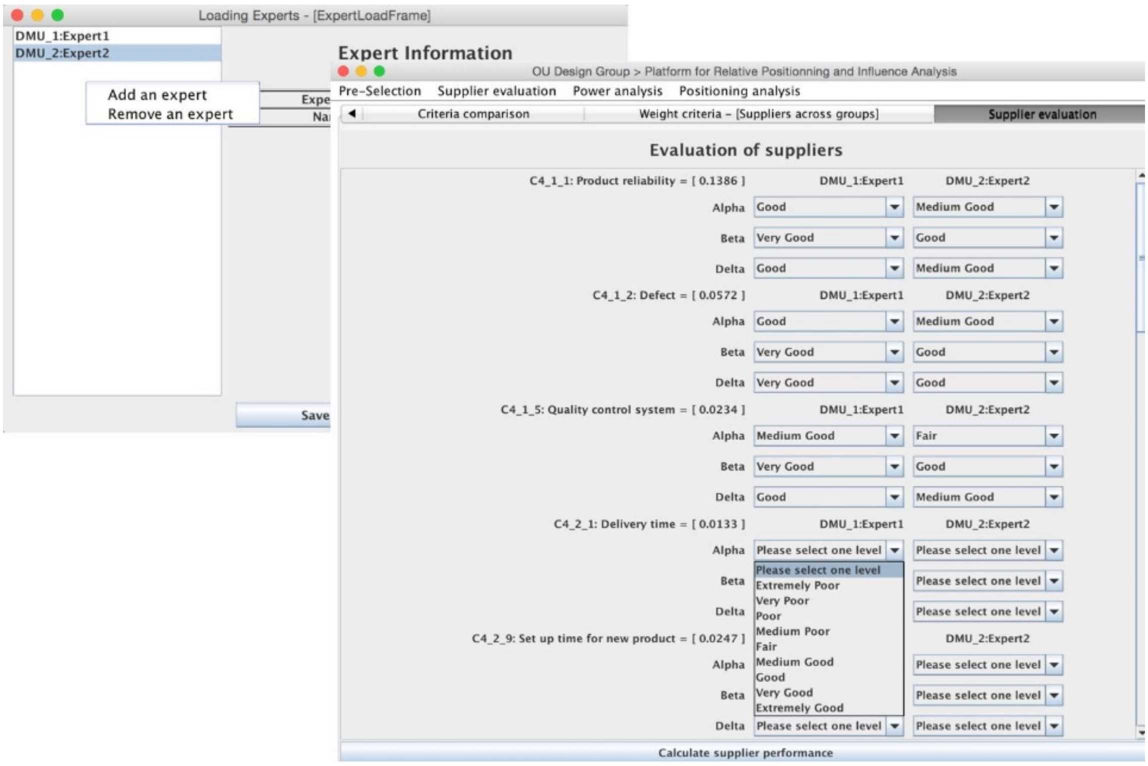


Figure 7-17 Performance judgements by two experts

When all the judgements are entered from the decision makers, the tool translates these to fuzzy triangular numbers and assesses the overall performance of the three suppliers using the method in section 6.3.4. Figure 7-18 is the screenshot showing the assessment results. The left hand panel presents the judgement about each criterion. The scrollbar on bottom presents more criteria and judgements as well as an overall result). The right hand panel shows the graphical view of the ranking. Beta is ranked at the top as its performance is excellent. The performances of Delta and Alpha are acceptable, while Delta is better and close to excellent.

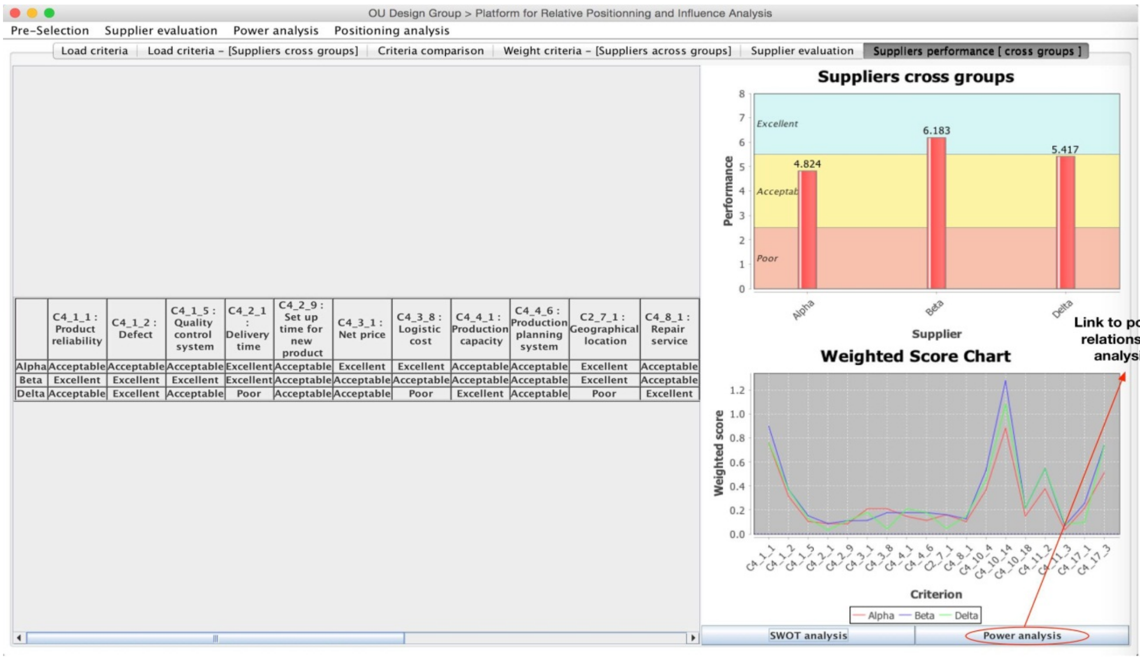


Figure 7-18 Results of performance assessment

7.3.3 Power relationship assessment

The previous assessment indicates which supplier has the potential to perform best. However, this does not ensure that the buyer Gamma will receive this performance, as this is influenced by the power relationship. The supplier who provides excellent performance may not be willing to collaborate and thereby makes negotiation difficult. An analysis of the power relationship between Gamma and Alpha, Beta and Delta is carried out. The power determinants are defined based on the determinant identification model in section 5.3.1. The tool provides a list of predefined determinants (as illustrated in Figure 7-19 where a decision maker scrolls down to get the complete list) based on the power determinants developed in 6.4.1.

The decision makers choose from the list and the power-dependence table (see section 6.4.1) is automatically created on the right. The attributes of the determinants can be edited with respect to V (value from the judgement of decision maker), SD (supplier dependence), BD (buyer dependence), SP (supplier power) and BP (buyer power). The power relationship analysis is linked directly from performance assessment as marked in Figure 7-18 (this analysis can also run separately by choosing ‘Power analysis’ from the menu bar). In this case, the suppliers are analysed in the order in which they are entered into the system during performance assessment, i.e. Alpha and Gamma will be analysed first and then Beta and Delta.

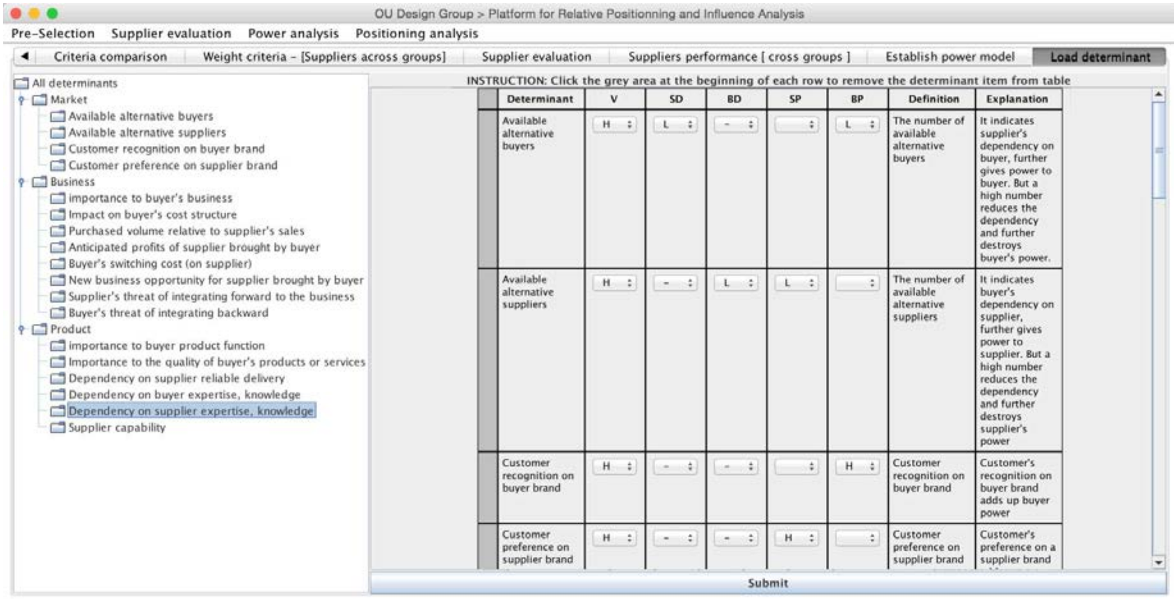


Figure 7-19 Formulating power determinants

Figure 7-20 shows the dependent determinants (those arising from a dependence of the buyer on the supplier or vice versa, see section 2.9.1) in the highlighted area.

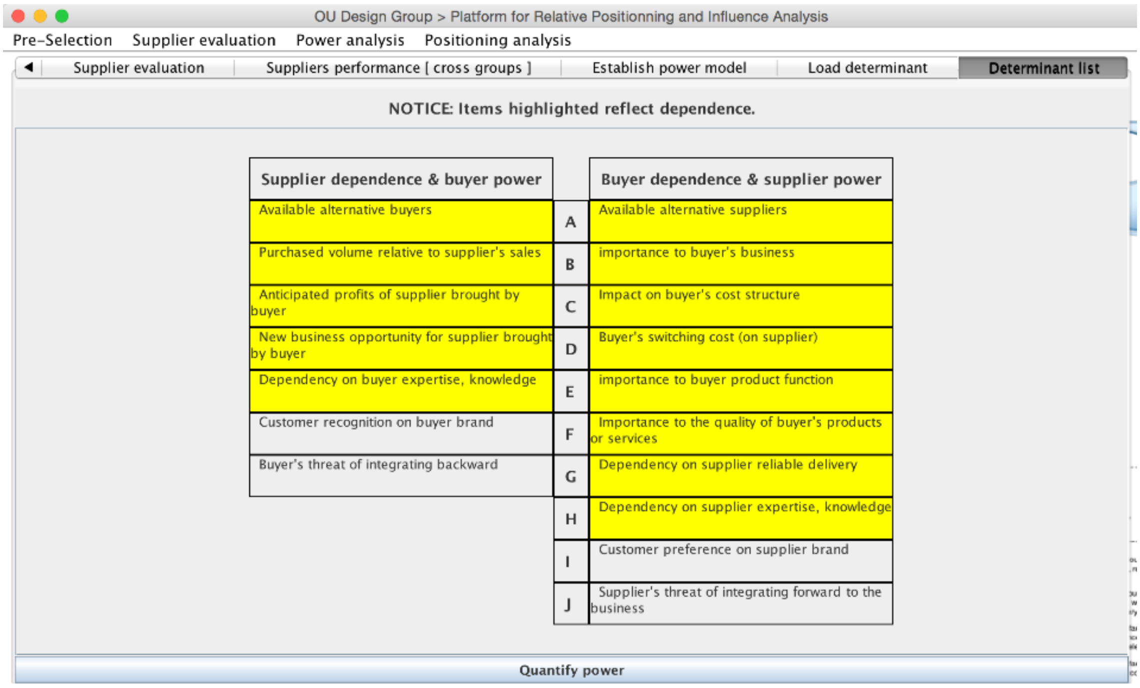


Figure 7-20 Power determinants for Alpha and Gamma

These determinants will be compared to calculate their weights. A percentage is added to indicate the possibility of how the supplier perceives the contribution of a determinant towards the relationship (as discussed in sections 5.3.2 and 6.4.3). For example, 100% is added to the determinant ‘Available alternative buyers’ when the buyer considers that the supplier would definitively consider this power determinant. 50% is added to ‘Anticipated profits brought by buyer’ when the buyer considers that the possibility of the supplier considering this determinant is 50-50. These percentages are used for the four types of estimations (Objective, Possibility, Optimistic and Pessimistic). They are judged by the decision makers from the buyer company. The determinants, against which these perceptions are added, are identified by the buyer company. The theoretical situation is that the supplier has the same perspective as the buyer company and uses the same power determinants. However, in practice there is a possibility that the supplier is not aware of some determinants. These perceptions are estimated by the decision makers when pairwise comparing these determinants, as illustrated in Figure 7-21 where the determinants of buyer power are compared.

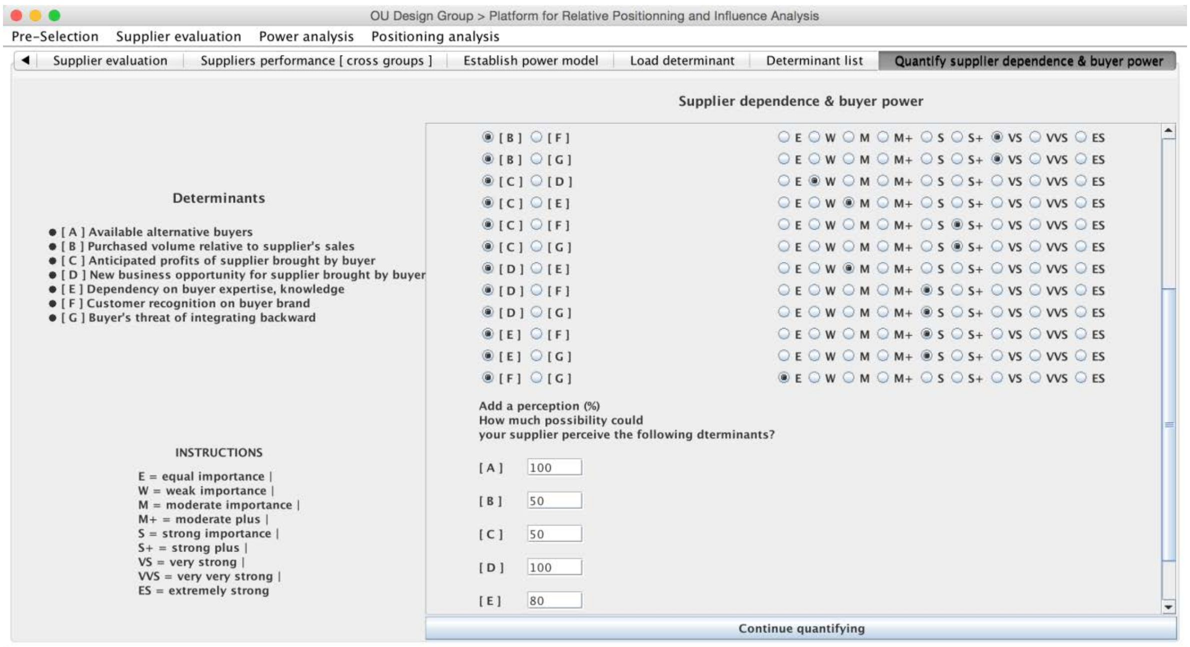
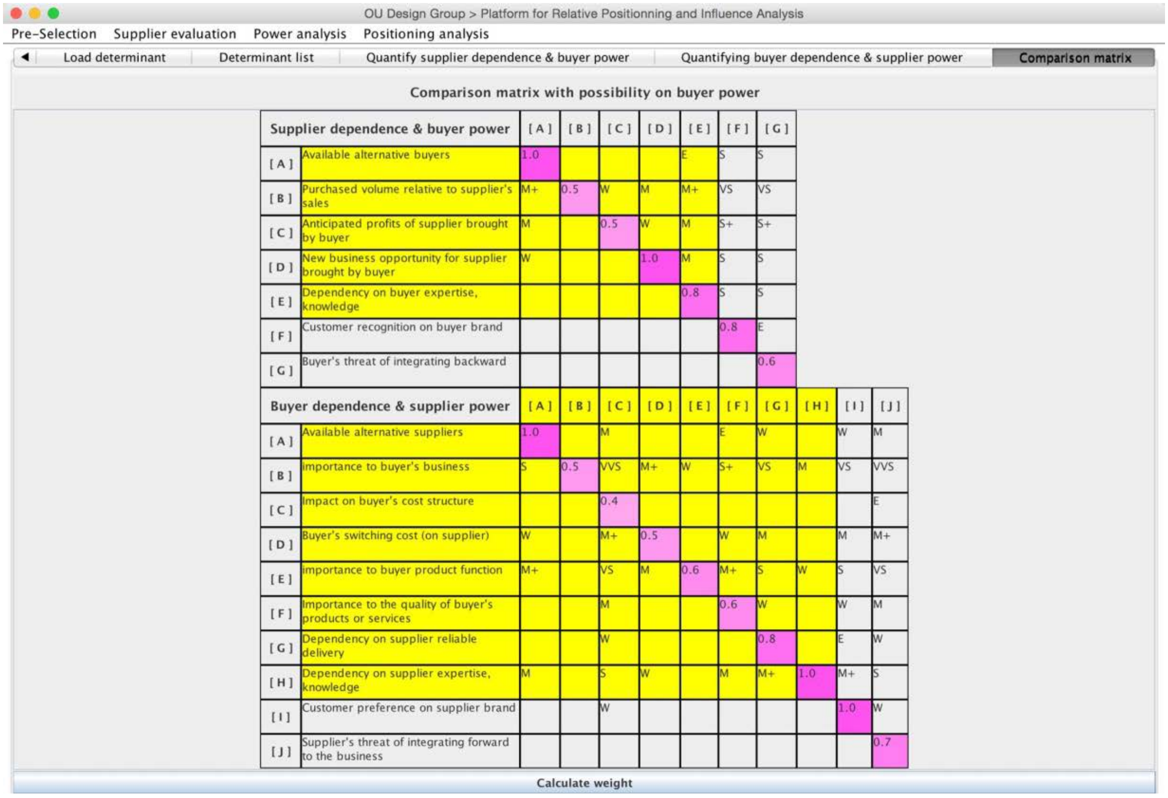


Figure 7-21 Comparing the determinants and adding perceptions

When the comparisons have been calculated, the two matrices (Figure 7-22) of buyer power (and supplier dependence) and supplier power (and buyer dependence) are generated by the tool. These are shown in Figure 7-22 where the diagonals indicate the perceptions of the supplier (with fractions of unity replacing the percentages in the screen in Figure 7-21, i.e. 100% is indicated by 1.0 and 50% by 0.5). Percentages are changed to fractions due to the space for the matrix display in the tool.

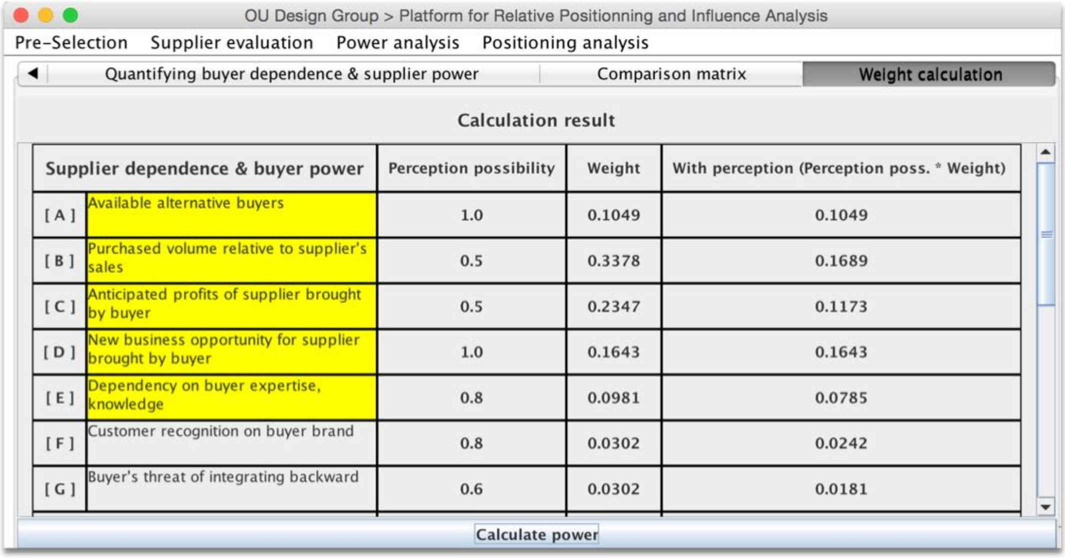


	Supplier dependence & buyer power	[A]	[B]	[C]	[D]	[E]	[F]	[G]
[A]	Available alternative buyers	1.0				E	S	S
[B]	Purchased volume relative to supplier's sales	M+	0.5	W	M	M+	VS	VS
[C]	Anticipated profits of supplier brought by buyer	M		0.5	W	M	S+	S+
[D]	New business opportunity for supplier brought by buyer	W			1.0	M	S	S
[E]	Dependency on buyer expertise, knowledge					0.8	S	S
[F]	Customer recognition on buyer brand						0.8	E
[G]	Buyer's threat of integrating backward							0.6

	Buyer dependence & supplier power	[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]
[A]	Available alternative suppliers	1.0		M			E	W		W	M
[B]	importance to buyer's business	S	0.5	VVS	M+	W	S+	VS	M	VS	VVS
[C]	Impact on buyer's cost structure			0.4							E
[D]	Buyer's switching cost (on supplier)	W		M+	0.5		W	M		M	M+
[E]	importance to buyer product function	M+		VS	M	0.6	M+	S	W	S	VS
[F]	Importance to the quality of buyer's products or services			M			0.6	W		W	M
[G]	Dependency on supplier reliable delivery			W				0.8		E	W
[H]	Dependency on supplier expertise, knowledge	M		S	W		M	M+	1.0	M+	S
[I]	Customer preference on supplier brand			W						1.0	W
[J]	Supplier's threat of integrating forward to the business										0.7

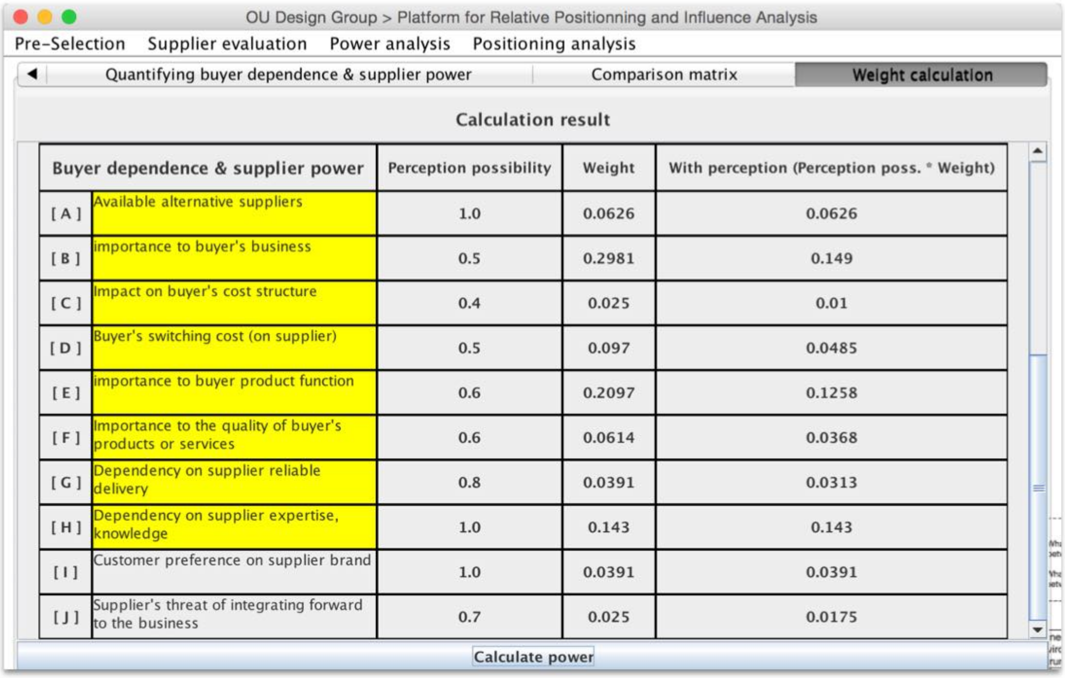
Figure 7-22 Comparison and perception analysis matrix.

The weights of these determinants are calculated once the 'Calculate weight' button is clicked. Figure 7-23 shows the weights of the determinants of (a) the buyer Gamma's power and (b) the supplier Alpha's power.



	Supplier dependence & buyer power	Perception possibility	Weight	With perception (Perception poss. * Weight)
[A]	Available alternative buyers	1.0	0.1049	0.1049
[B]	Purchased volume relative to supplier's sales	0.5	0.3378	0.1689
[C]	Anticipated profits of supplier brought by buyer	0.5	0.2347	0.1173
[D]	New business opportunity for supplier brought by buyer	1.0	0.1643	0.1643
[E]	Dependency on buyer expertise, knowledge	0.8	0.0981	0.0785
[F]	Customer recognition on buyer brand	0.8	0.0302	0.0242
[G]	Buyer's threat of integrating backward	0.6	0.0302	0.0181

(a)



	Buyer dependence & supplier power	Perception possibility	Weight	With perception (Perception poss. * Weight)
[A]	Available alternative suppliers	1.0	0.0626	0.0626
[B]	importance to buyer's business	0.5	0.2981	0.149
[C]	Impact on buyer's cost structure	0.4	0.025	0.01
[D]	Buyer's switching cost (on supplier)	0.5	0.097	0.0485
[E]	importance to buyer product function	0.6	0.2097	0.1258
[F]	Importance to the quality of buyer's products or services	0.6	0.0614	0.0368
[G]	Dependency on supplier reliable delivery	0.8	0.0391	0.0313
[H]	Dependency on supplier expertise, knowledge	1.0	0.143	0.143
[I]	Customer preference on supplier brand	1.0	0.0391	0.0391
[J]	Supplier's threat of integrating forward to the business	0.7	0.025	0.0175

(b)

Figure 7-23 (a) Weights of the buyer (Gamma) power determinants; (b) weights of a supplier (Alpha) power determinants

The two decision makers (DMU-1 and DMU-2) then judge the value with respect to each determinant as shown in Figure 7-24. For example, considering determinant ‘available alternative buyers’, Alpha will have few buyers because it is newly established and its market recognition is low. The value for this determinant will be ‘low’ with the scales in Table 6-15. Decision makers may have different opinions which can be integrated by the tool but in this example, the judgements from two decision makers are considered consistent.

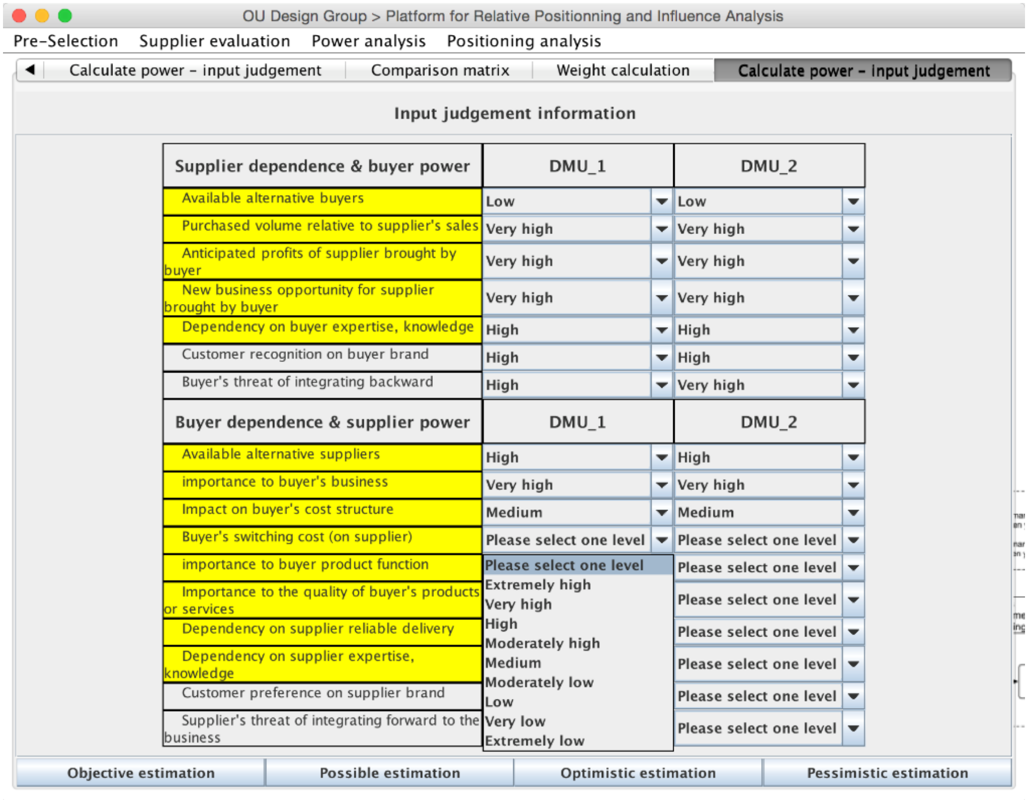


Figure 7-24 Value of power determinant judged by two experts

The power relationship is estimated based on the weights of determinants, the perceptions, and the aggregation of the judgements. The four buttons on the bottom of Figure 7-24 correspond to the four types of estimations (Objective, Possibility, Optimistic and Pessimistic) in section 6.4.3. Figure 7-25 presents the display of numerical results of the objective estimation of power of both supplier Alpha and buyer Gamma.

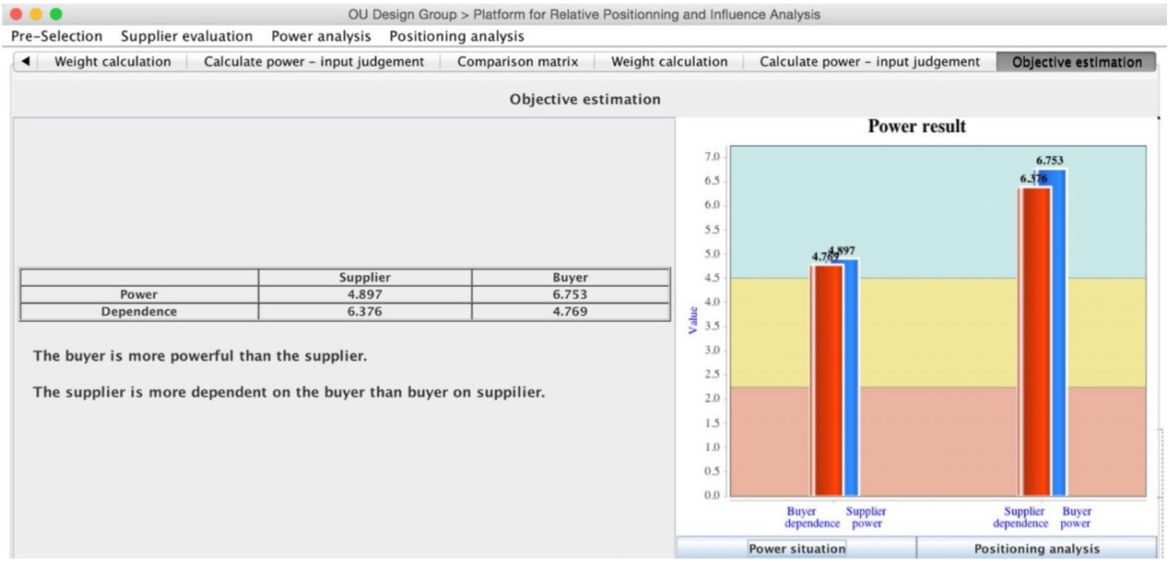


Figure 7-25 Numeric results of power assessment

After clicking 'power situation', the power relationship will be displayed based on this objective estimation. Figure 7-26 presents the power relationship between Alpha and Gamma using the numeric results of the four types of estimations (Objective, Possibility, Optimistic and Pessimistic). In this example the buyer Gamma dominates supplier Alpha under all types of estimation, except a pessimistic estimation where the power relationship is balanced, as shown in Figure 7-26. This indicates that Gamma generally has the power advantage over Alpha. Clicking on 'position analysis' in Figure 7-25, the tool will proceed to the assessment of the power relationship between Gamma and Alpha (Figure 7-26), Gamma and Beta (Figure 7-27) and between Gamma and Delta (Figure 7-28). It can be seen that Beta definitely has a power advantage over Gamma because it dominates Gamma under all scenarios. The relationship between Gamma and Delta is between relative balanced and leans to a power advantage of Gamma.

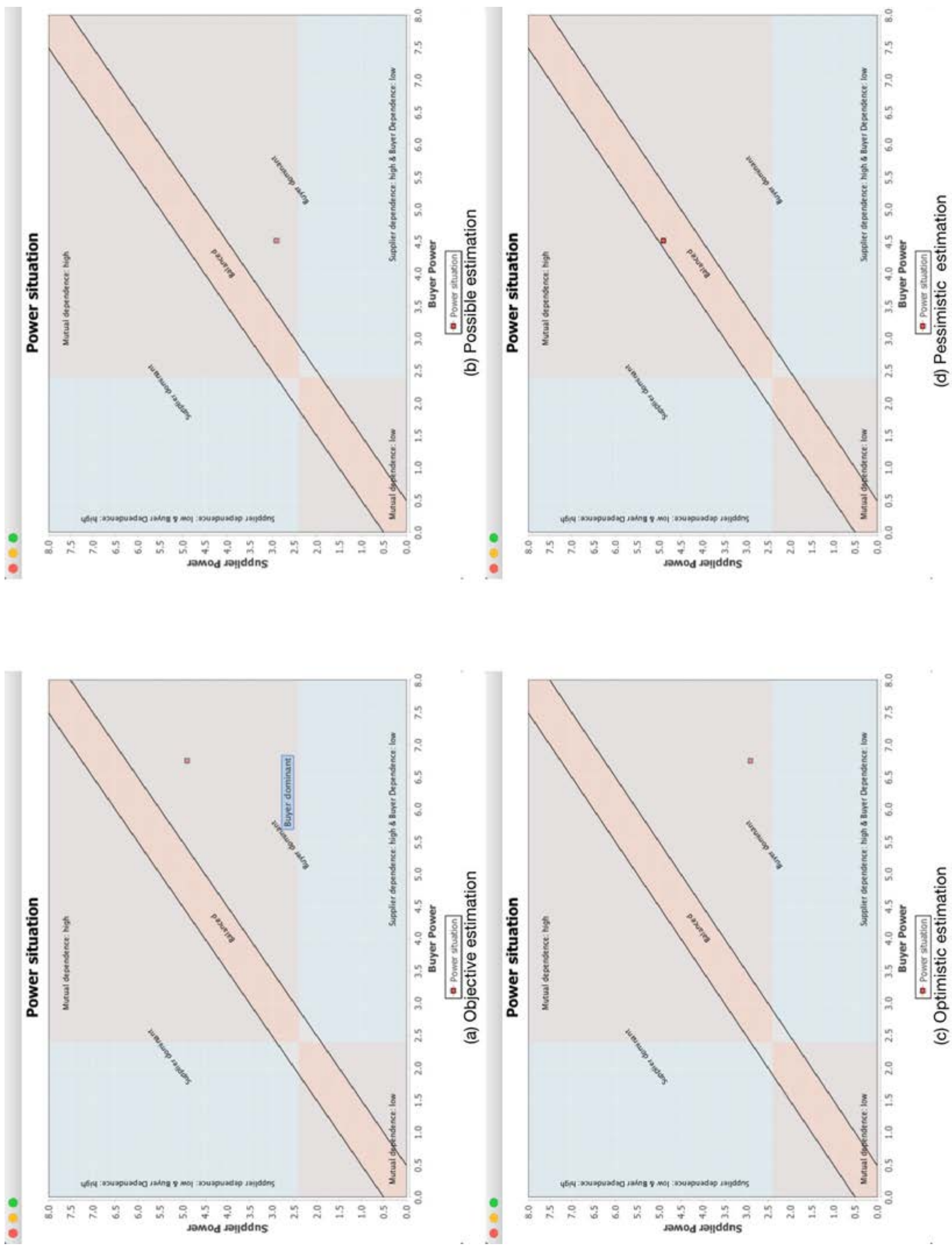
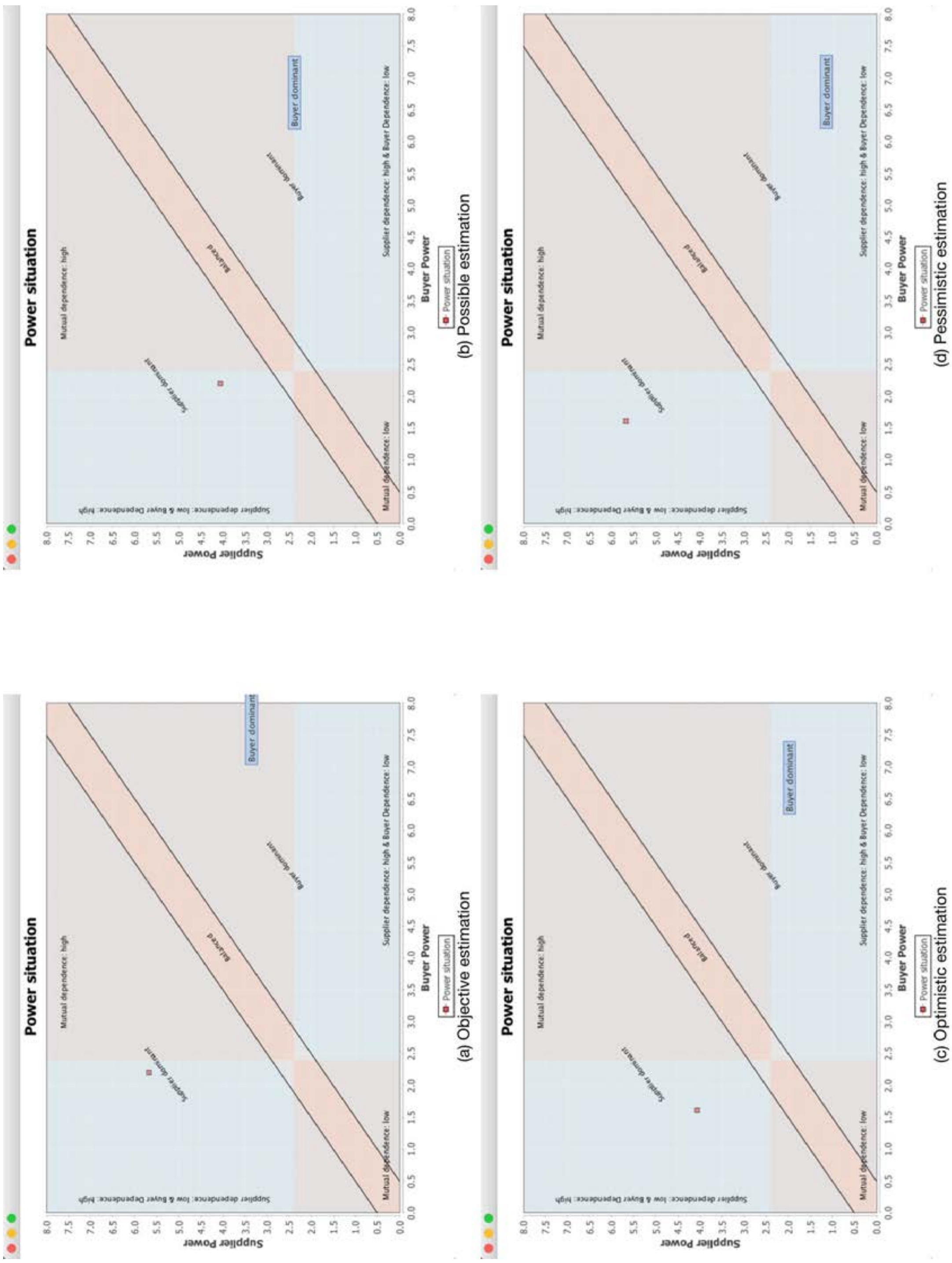


Figure 7-26 Power relationship between Gamma and Alpha under four estimations



(a) Objective estimation
(b) Possible estimation
(c) Optimistic estimation
(d) Pessimistic estimation

Figure 7-27 Power relationship between Gamma and Beta under four estimations

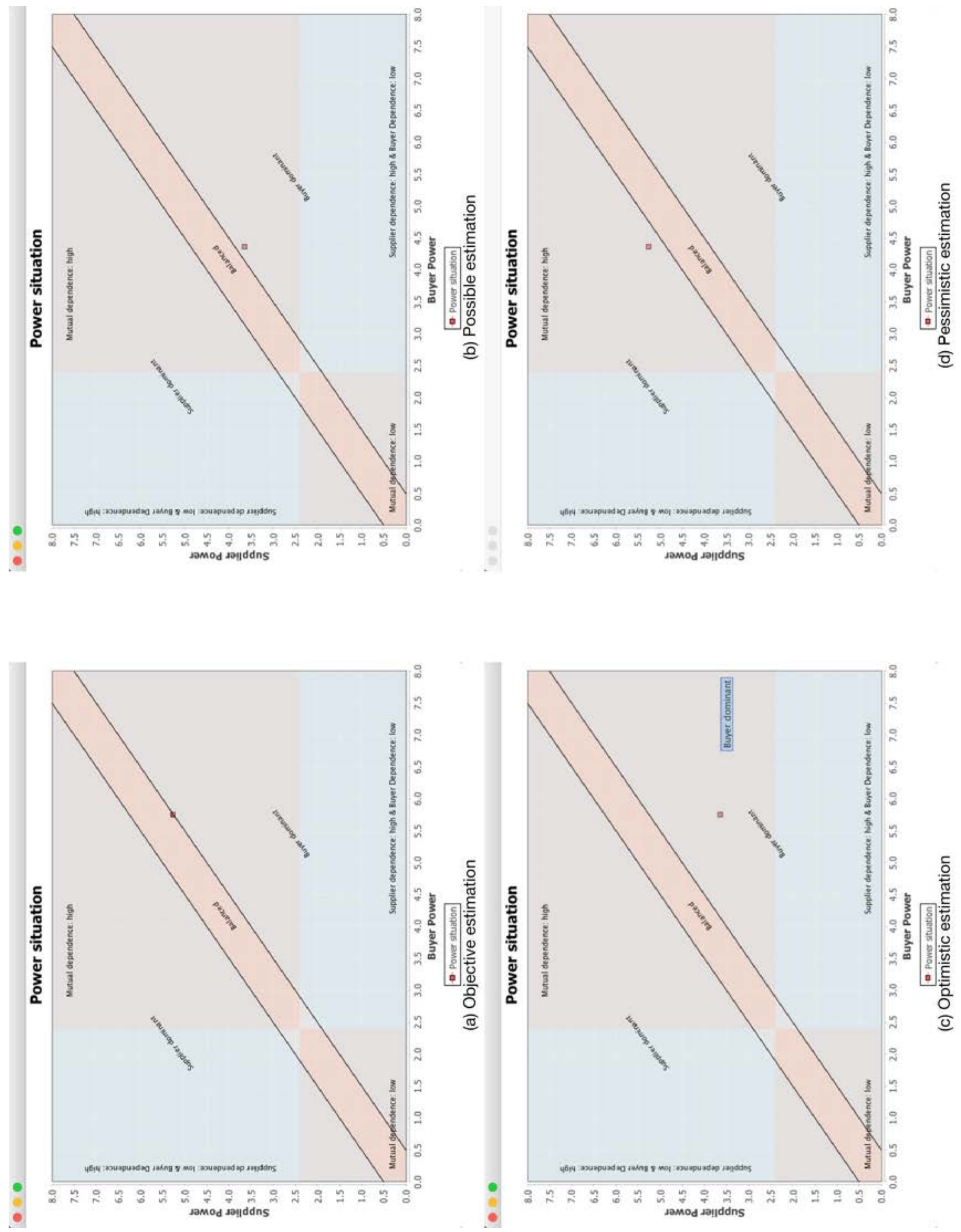


Figure 7-28 Power relationship between Gamma and Delta under four estimations

7.3.4 Relative positioning analysis and reverse analysis

In the illustrative example Gamma has a hard decision to make, because the performance assessment shows Beta can deliver an excellent performance, however, the power relationship points out that Beta absolutely has the advantage over Gamma. This means it would be difficult for Gamma to negotiate a good deal with Beta and excellent performance cannot be guaranteed. Supplier Alpha is dominated by Gamma. whose performance ranks at the bottom. Supplier Delta performs better than Alpha while the power relationship between Delta and Gamma is balanced.

The relative positioning analysis concludes the situations and positions Alpha, Beta and Delta. As shown in Figure 7-29, Beta sits in **Unfavourable**, which indicates Beta is not a good option. There is a high risk that Beta could seek to lower its performance or asks more favours. Alpha sits in **Satisfying**, which indicates Alpha is a suitable choice. Alpha performs at an acceptable level and Gamma could request a better performance. Delta is positioned at the boarder of **Tolerable** and **Satisfying**, which indicates Delta could also be a good choice.

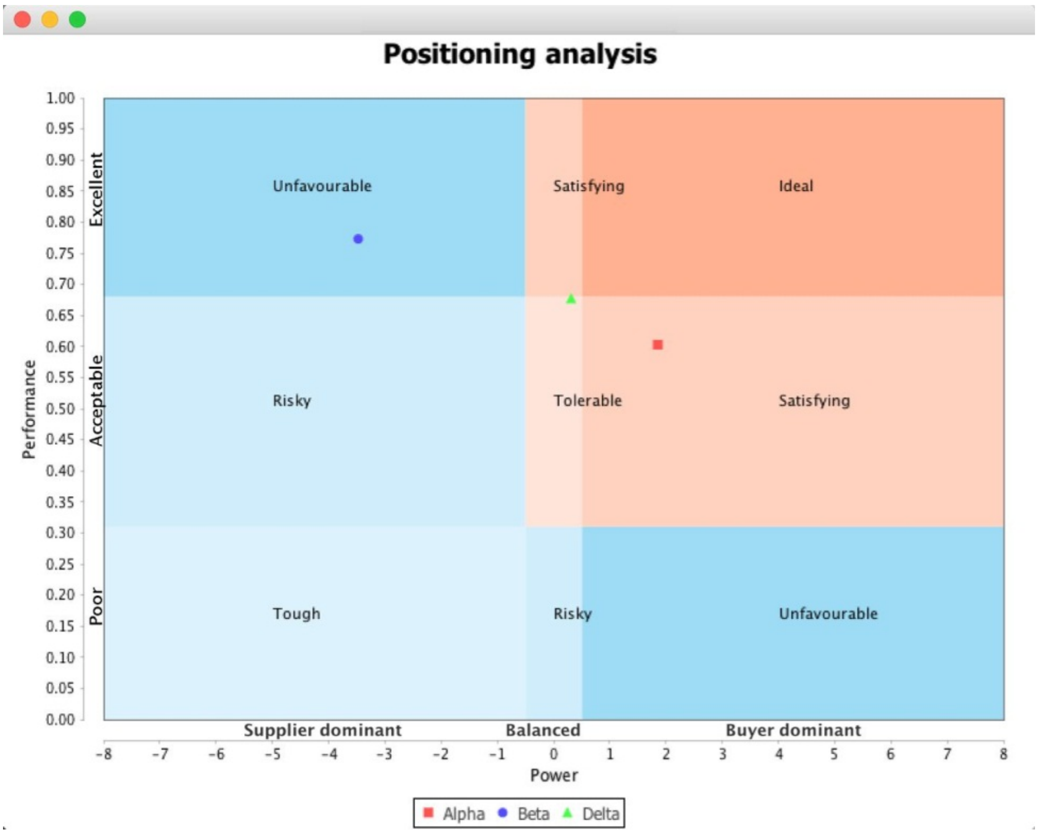


Figure 7-29 Relative poisoning of Alpha, Beta and Delta

Overall, it seems Alpha could be a better option than Delta. However, Alpha is a newly established company, whose performance could be limited by its capability. In this case, even if Gamma has power advantage over Alpha, it might be impossible for Gamma to receive a better performance. A reverse analysis (see section 5.4.2) for performance comparison between Alpha and Delta could help. As illustrated in Figure 7-30, the reverse analysis with respect to criteria important to Gamma, shows that Delta performs much better than Alpha in the **Strength** quadrant.

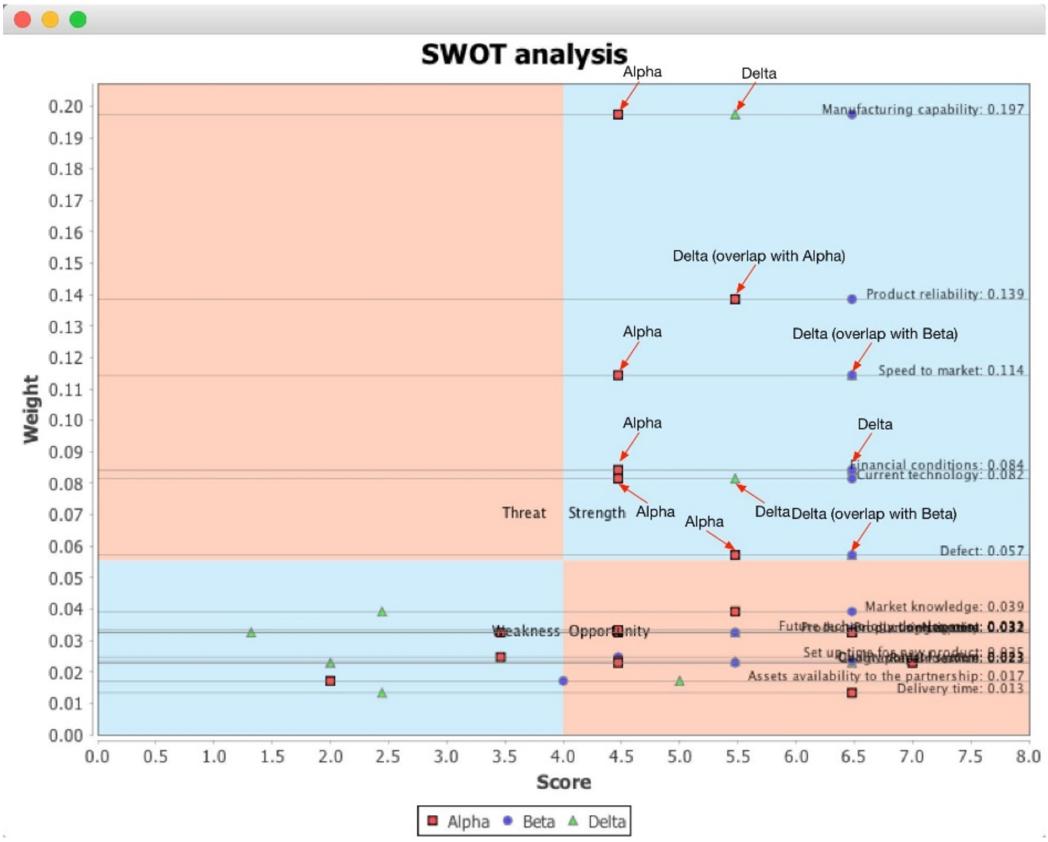


Figure 7-30 Reverse analysis based on SWOT

Since Gamma is looking for a strategic partner to open a new business, strong capability is important. Therefore, Delta is a more suitable choice for Gamma. Moreover, Gamma could think about developing Delta and investing in manufacturing facilities in the local area, which would benefit both. However, this investment could increase the switching cost, which could then lead to an increase of Delta's power. As a result the power relationship would move towards making Delta dominant, as illustrated in a **vertical transition** in Figure 7-31. This transition could be overcome by the dependence of Delta on Gamma for local market entrance and purchase volume.

In addition, keeping Alpha as a backup supplier can also increase Gamma's power over Delta, which will lead to a **horizontal transition**.

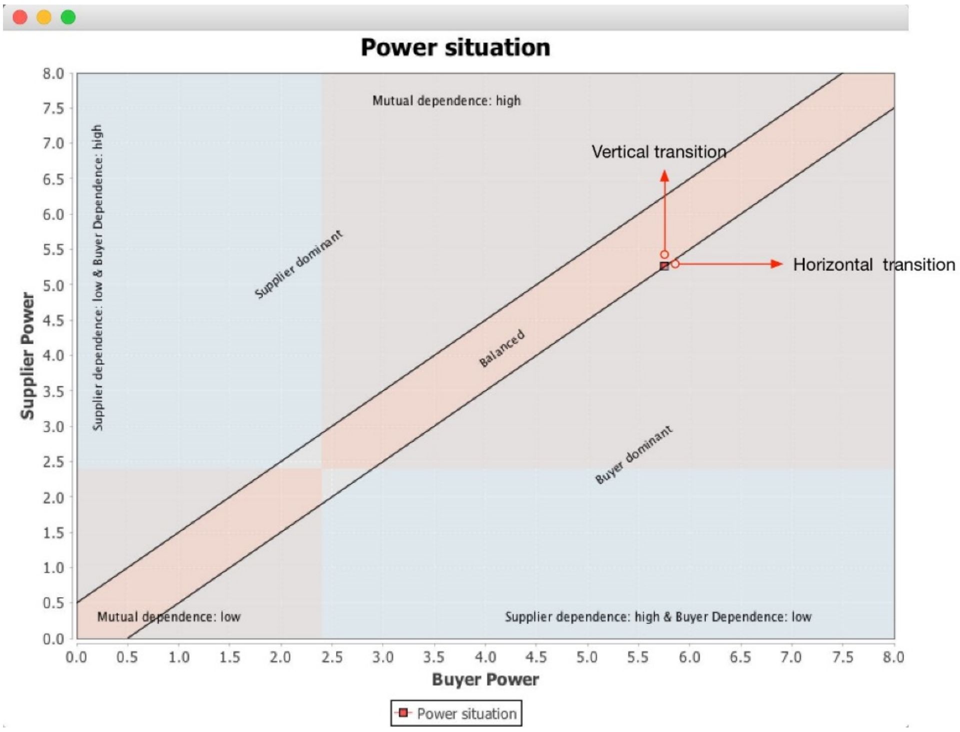


Figure 7-31 Potential transitions of power relationship between Gamma and Delta

7.4 Chapter conclusion

This chapter explains the development procedure of the tool PEPA from consideration of visualisation, to implementation and to verification. The tool is currently a prototype, focusing on the correctness of functionality. Robustness is not considered. For example, the tool cannot cope with erroneous input or other errors during the execution. This should be taken into account for future academic development and industrial application.

The application of the tool to the illustrative case presents an example of how to select a suitable supplier based on consideration of both performance and power relationship. The tool saves the decision makers the computational effort and guides them through the process. The graphical user interface and the results graphics give a visualisation for analysis. Meanwhile, the application process also indicates that the supplier selection is a complex decision problem, and the proposed approach helps reduce the complexity of this analysis. However, to consider only one aspect such as performance or power is not enough to make the decision. Returning to the illustrative case, on the basis of performance, Beta performs best and would be the best choice. However, Beta has a power advantage over the buyer Gamma, which pushes Gamma towards a non-beneficial situation. On the other hand, when taking these two aspects into account, a balance between them is required. In this case, Alpha and Delta are the both good choices as they are well balanced between performance and power relationship. In order to select between the two a more detailed analysis is required. The reverse analysis in the illustrative case clearly shows what are the important criteria and how Alpha and Delta perform with respect to them. Finally, a decision can be made. For this example, Delta is more suitable.

Chapter 8 Application and evaluation

Evaluation is generally required for new approaches, methods and tools to establish their validity. Two aspects in this thesis need to be evaluated: the approach and the tool. The approach is the logic of integrating performance and power for supplier selection. The tool implements the approach with graphics to make it user friendly. By applying the tool to cases, both the tool and approach can be validated. Further, the details in the tool including the human-computer interactions can be improved. However, it has proved difficult to obtain complete cases to validate the whole approach with the tool in this research, because supplier data is confidential and the proposed approach involves significant amounts of data.

This chapter describes how the tool is applied to a case from the research team at AgroParisTech, which compares the sustainable performance of farmers. It discusses the results and the extent of applicability. It concludes with a discussion of validation.

8.1 Supplier assessment in 'Sustainable agriculture' value chain

This section introduces the application of the tool to a real case. This case is from the PhD research of Gaelle Petit, under the supervision of Professor Gwenola Yannou Le-Bris, in the context of the Chaire Sustainable Demand – Supply Chain (Chaire SDSC) at AgroParisTech. Due to confidentiality, the value chain in this case is referred as the 'Sustainable agriculture' value chain.

The case was chosen because it enables an evaluation of the approach and tool with a realistic data set. Supplier data is an essential requirement, but is often confidential. The sustainable agriculture case was able to provide the data of the suppliers' performance with regard to the criteria. The PhD project systematically gathered data about pig farmers, who are part of the French sustainable pork value chain. The tool also provided useful insight into pig value chain for the French researchers. They were therefore interested in acting as experts in the evaluation of the tool. While the main empirical study of this thesis was in engineering, the core assessment method, the Fuzzy AHP-TOPSIS method, is a general mathematical method for supplier assessment, which is not restricted to a particular industry sector. Therefore, assessing suppliers for sustainability of pig farming can act as an exemplar for the tool use.

The goals of the pig study which aimed to increase the sustainability in agricultural value chains, meant that this case could only provide very limited data for power assessment. Nevertheless, interesting implications regarding power relationships were found. In particular, there was evidence of dependence even though it is claimed that power is not a factor in supplier assessment and selection.

8.1.1 Case description

The case concerns a value chain for sustainable pork in France. The value chain spans the activities from feeding pigs to delivering the pork and related products to consumers. Two organisations together establish this value chain, which are referred to in this thesis as Theta, the production cooperative, and Sigma, a cooperative supermarket chain. The structure of the value chain is shown in Figure 8-1.

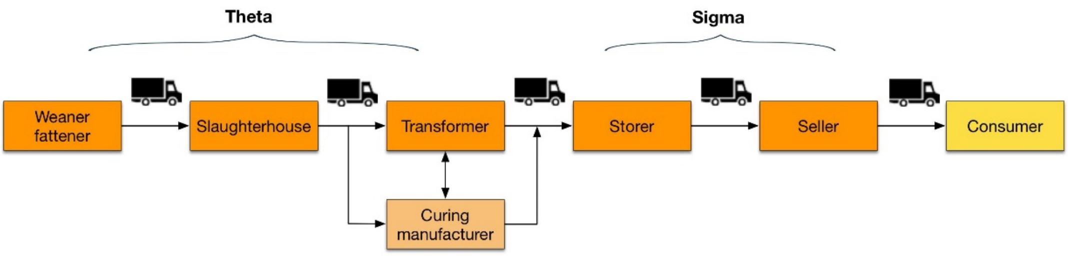


Figure 8-1 Value chain between Theta and Sigma

Theta is a cooperative food group, one of the major players in agriculture and agri-food in France. The three main parts of Theta in this value chain are weaner fatteners (farmers) feeding the pigs, slaughterhouses and transformers processing the meats into different products like sausage and smoked meat. Sigma is a French retail cooperative, consisting of two parts: the storer of supplies and the seller of the pork products to the consumers.

There are two characteristics of this value chain. It is set up to be **sustainable**, in terms of the social, economic and environmental impacts and **cooperative**, which means all members in the value chain have an equal position. For example, the farmers can join or quit a particular value chain as they wish and this decision does not influence their participation in other value chains as a member of Theta. The members work cooperatively and beneficially.

Farmers in the 'Sustainable agriculture' value chain

The farmers who feed and supply pigs for Theta play a significant role in achieving and maintaining the sustainability of the whole chain, because feed constitutes the largest economic, ethical and environmental burden in pig farming. Producing (including growing) the feed has a large impact on the environment. The farmers in this value chain can be categorised by whether and how they produce or procure the feed. Farmers who make the feed in their farms, noted as 'FAF' (fabrication à la ferme), are further classified according to the ingredients of their feed and their equipment for production. The research by Gaelle Petit identified twelve types of famers as listed in Table 8-1.

Main type	***Sub-type***	***Type No.***
Complete FAF, corn not dominant the constituent	Equipped with silo <2500T	S1
	Equipped silo >2500T	S2
Complete FAF, corn dominant	Equipped corridor silo <2500T	S3
	Equipped corridor silo >2500T	S4
	Equipped tower silo <2500T	S5
	Equipped tower silo >2500T	S6
Complementary FAF, corn not dominant the constituent	Equipped corridor silo	S7
	Equipped tower silo or hangar cell	S8
Complementary FAF, corn dominant	Equipped corridor silo	S9
	Equipped tower silo or hangar cell	S10
Complete purchasing feed, colza dominant	-	S11
Complete purchasing feed, soy dominant	-	S12

Table 8-1 Types of farmers in the value chain

The criteria for sustainable performance assessment are from the academic research work of the research team at AgroParisTech. They identified the following criteria:

- Environmental criteria: generated through the use of an LCA software (Simapro), from mapping the theoretical flows associated with each type;
- Social criteria: working hours is the only criterion, taken from the literature (Comparative advantage of feed systems in Breton pig, Nutrinoë, December 2015);
- Economic criteria: directly from the literature (Comparative advantage of feed systems in Breton pig, Nutrinoë, December 2015).

Table 8-2 shows the criteria for the environmental, social and economic impacts and the farmers' performance about each criterion when producing one pig equal to 116 kg of living weight.

Category of impact	ID	Criteria	Unit	Complete FAF		Complete FAF corn		Complementary FAF		Complementary FAF corn		Purchasing feeds colza	Purchasing feeds soy
C1: Environnemental	C1_1	Climate change	kg CO2 eq	147.1618		136.9499		158.4612		149.3755		104.7651	232.1681
	C1_2	Ozone depletion	kg CFC-11 eq	0.000007700431		0.000010710792		0.0000069437741		0.000014064306		0.0000022673906	0.0000025952217
	C1_3	Terrestrial acidification	kg SO2 eq	6.9315		6.8986		7.1515		7.6540		6.8746	11.7198
	C1_4	Freshwater eutrophication	kg P eq	0.1125		0.1232		0.0899		0.1121		0.0547	0.1768
	C1_5	Marine eutrophication	kg N eq	3.7539		3.6967		2.7645		2.7910		2.5194	8.1253
	C1_6	Human toxicity	kg 1,4-DB eq	558.8293		576.0546		664.4977		571.1216		226.1093	129.7839
	C1_7	Photochemical oxidant formation	kg NMVOC	0.4764		0.5030		0.5419		0.6056		0.3248	0.6344
	C1_8	Particulate matter formation	kg PM10 eq	0.9024		0.9041		0.9373		0.9974		0.8417	1.4272
	C1_9	Terrestrial ecotoxicity	kg 1,4-DB eq	5.1644		5.5663		12.2977		6.3098		2.4387	4.1652
	C1_10	Freshwater ecotoxicity	kg 1,4-DB eq	1.7179		2.0465		2.8994		2.3924		0.9285	1.8132
	C1_11	Marine ecotoxicity	kg 1,4-DB eq	421.0083		422.1625		548.0671		444.0208		181.5771	87.2245
	C1_12	Ionising radiation	kBq U235 eq	9.3366		12.9755		6.6529		15.2512		1.9413	2.7869
	C1_13	Agricultural land occupation	m2a	787.0643		733.8556		627.1029		455.5956		337.7896	1042.2715
	C1_14	Urban land occupation	m2a	0.7852		0.7852		1.2228		1.0124		0.3862	0.0933
	C1_15	Natural land transformation	m2	0.0902		0.0902		0.0940		0.0922		0.1381	0.1383
	C1_16	Water depletion	m3	36.3846		40.4855		18.0736		28.9868		3.7577	2.5259
	C1_17	Metal depletion	kg Fe eq	5.6632		5.6653		5.8518		4.3302		1.7535	0.5814
	C1_18	Fossil depletion	kg oil eq	20.3457		21.5397		23.2004		26.8823		13.9975	31.2093
C2: Social				**Corridor/tower silo**		**Corridor silo**	**Tower silo**	**Corridor silo**	**Tower silo/ hangar cell**	**Corridor silo**	**Tower silo/ hangar cell**		
	C2_1	work hours	h/T	0.17		0.33	0.17	0.5	0.17	0.5	0.17	0	0
C3: Economic	C3_1	Labour cost	€/T	3		6	3	9.5	3	9.5	3	0	0
				< 2 500T	**> 2 500T**	**< 2 500T**	**> 2 500T**						
	C3_2	FAF investment cost	€/T	14	18	14	18	10	14	10	14	0	0
	C3_3	Cost of feeds fabrication	€/T	30	30	39	39	31.3	31.3	38.5	38.5	0	0
	C3_4	Cost of feeding system	€/T	267	267	259	259	260	260	254	254	249	255
	C3_5	Shrinkage of storage	%	1	1	5	5	1	1	5	5	0	0

Table 8-2 Farmers performance with respect to each impact

8.1.2 Farmer evaluation

This section evaluates the farmers' performance in different scenarios. Farmers are a major part of Group Theta, whose sustainable performance greatly influences the sustainability of the whole chain. These farmers have chosen different ways of producing the feed, which leads to different sustainability performance. Therefore, Theta needs to know which types of farmers are better in terms of environmental, social and economic impact. In the evaluation process, Gaelle Petit plays the role of a decision maker to compare and decide the relative importance of the criteria, as she has done detailed research and empirical work on the sustainability indicators in this value chain.

Four scenarios are simulated with different emphasis on environmental and economic aspects and either selecting a number of criteria or using all criteria. Table 8-3 summarises the four scenarios. The first scenario has the economic impact as the most important aspect. It takes all the criteria in social (C2) and economic impact (C3). The following environmental impact criteria are selected because of their strong importance. These criteria are C1_1: climate change, C1_3: Terrestrial acidification, C1_4: depletion, C1_5: Marine eutrophication, C1_16: Water depletion, C1_17: Metal depletion, C1_18: Fossil depletion. Only one criterion of weak importance is considered, i.e., C1_2: Ozone deletion. The second scenario has environmental impact as the most important aspect and the same criteria as the first scenario. The third considers economic impact as most important, taking all the criteria of the three impacts into account. In the last scenario, environmental impact is considered to be the most important aspect whilst taking all the criteria into account.

No.	***Scenario name***	***Most import aspect***	***Criteria applied***		
			Environmental	**Social**	**Economic**
1	Economic with important environmental criteria	Economic impact	C1_1, C1_2, C1_3, C1_4, C1_5 and C1_16, C1_17, C_18	All	All
2	Environmental with important environmental criteria	Environmental impact	C1_1, C1_2, C1_3 C1_4, C1_5 and C1_16, C1_17, C_18	All	All
3	Economic with full criteria	Economic impact	All	All	All
4	Environmental with full criteria	Environmental impact	All	All	All

Table 8-3 Scenarios for the farmer evaluation

The calculation steps are introduced in detail for the first scenario to show the application procedure. For the remaining scenarios only the evaluation results are presented for later discussion.

Scenario 1: Economic with important environmental criteria

There are nine levels of judgement for the relative importance referring to section 6.1.3. These are summarised in Table 8-4, which lists the abbreviation, linguistic expression and corresponding fuzzy scales.

Abbreviation	***Linguistic expression***	***Fuzzy scales***
ES	Extremely strong importance	(8,9,9)
VVS	Intermediate (Very very strong)	(7,8,9)
VS	Very strong importance	(6,7,8)
S+	(Strong plus)	(5,6,7)
S	Strong importance	(4,5,6)
M+	Intermediate (Moderate plus)	(3,4,5)
M	Moderate importance	(2,3,4)
W	Intermediate (Weak importance)	(1,2,3)
E	Equal importance	(1,1,1)

Table 8-4 Judgement for relative importance

The relative importance among the environmental, social and economic impacts is shown in Table 8-5. Environmental impact has very strong importance (VS) compared with Social. 'VS' is entered as the entry of Environmental to Social and '1/VS' is entered at the entry of Social to Environmental. Economic is of very strong importance (VS) compared with Environmental and of very very strong importance (VVS) compared with Social.

Goal	Environmental	Social	Economic
Environmental	E	VS	1/VS
Social	1/VS	E	1/VVS
Economic	VS	VVS	E

Table 8-5 Pairwise comparison matrix of environmental, social and economic impacts in Scenario 1

The relative importance among the criteria under environmental (C1) and economic impacts (C3) is shown in Table 8-6 and Table 8-7 respectively.

Environmental	C1_1	C1_2	C1_3	C1_4	C1_5	C1_16	C1_17	C1_18
C1_1	E	VVS	E	E	E	M	M	M
C1_2	1/VVS	E	1/VVS	1/VVS	1/VVS	1/S	1/S	1/S
C1_3	E	VVS	E	E	E	M	M	M
C1_4	E	VVS	E	E	E	M	M	M
C1_5	E	VVS	E	E	E	M	M	M
C1_16	1/M	S	1/M	1/M	1/M	E	E	E
C1_17	1/M	S	1/M	1/M	1/M	1/M	E	E
C1_18	1/M	S	1/M	1/M	1/M	1/M	1/M	E

Table 8-6 Pairwise comparison matrix of criteria under environmental impact in Scenario 1

Economic	C3_1	C3_2	C3_3	C3_4	C3_5
C3_1	E	1/S+	1/VVS	1/S	M
C3_2	S+	E	1/M	W	VS
C3_3	VVS	M	E	M+	ES
C3_4	S	1/W	1/M+	E	S+
C3_5	1/M	1/VS	1/ES	1/S+	E

Table 8-7 Pairwise comparison matrix of criteria under economic impact in Scenario 1

The criteria are entered into the PEPA tool, as shown in Figure 8-2, where they can be further edited. The decision maker can also choose to load criteria from an XML file which has pre-defined criteria.

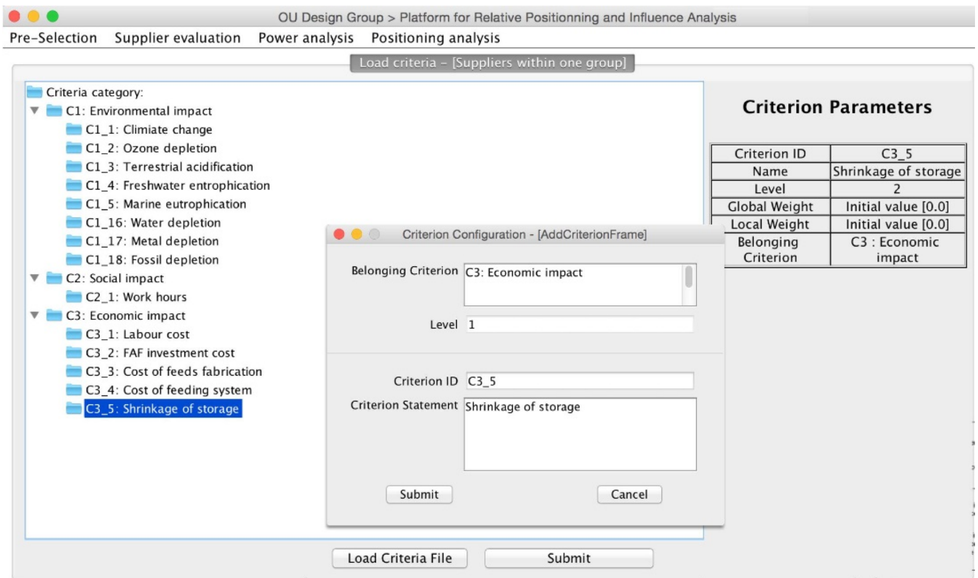


Figure 8-2 Input criteria

After deciding all the criteria clicking the 'submit' button will trigger the calculation of the weights. Figure 8-3 presents the pairwise comparison page and the weights of C1 (environmental impact), C2 (social impact) and C3 (economic impact). The weights of their sub-criteria are listed on the same page but not shown here.

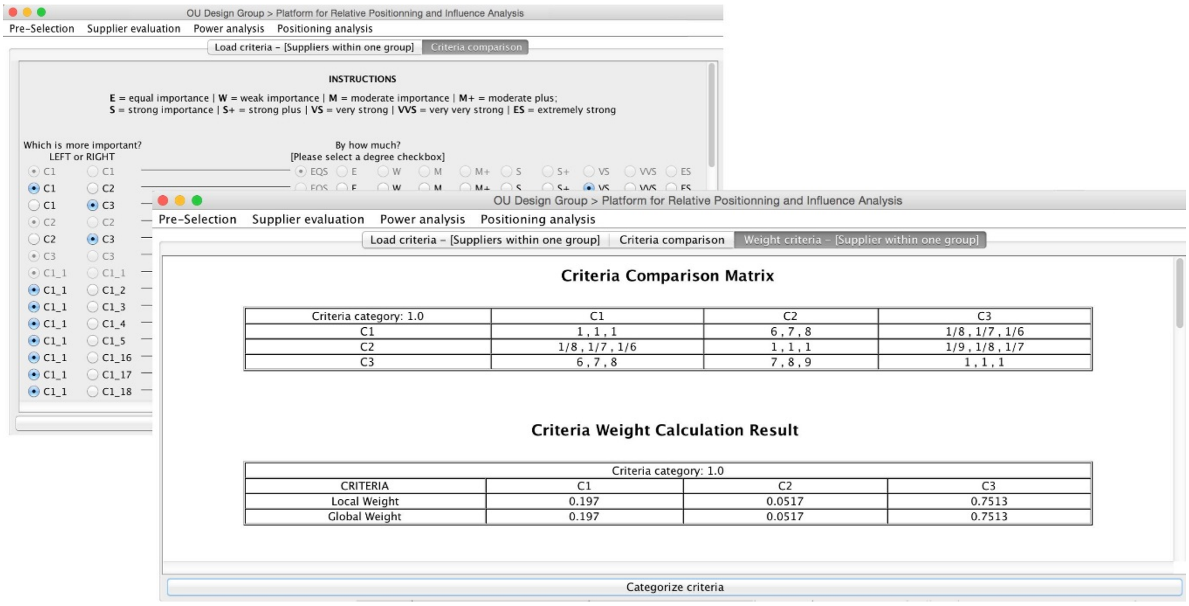


Figure 8-3 Pairwise comparison and the weights of C1(Environmental), C2(Social) and C3(Economic) impacts

Then the decision maker chooses the criteria that require judgement instead of actual data as input. As seen in Figure 8-4, the decision maker clicks the criteria from the list on the left, which then appears in the list for judgement on the right.

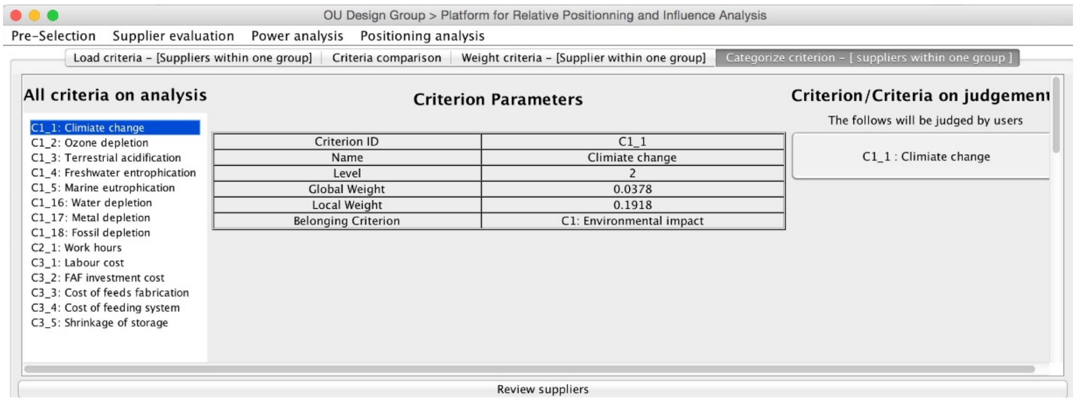
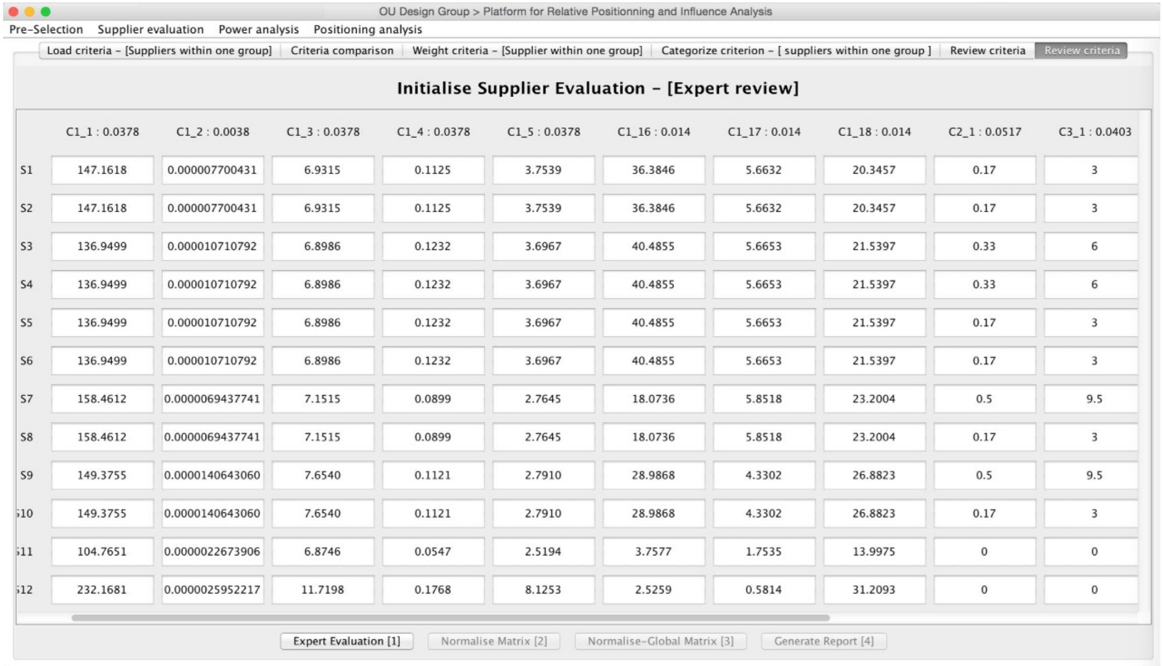


Figure 8-4 Select criteria having subjective input

Next comes the calculation process. Figure 8-5 shows the page to enter the supplier data, at the bottom of which there are four buttons – ‘Expert Evaluation [1]’, ‘Normalise Matrix [2]’, ‘Normalise-Global Matrix [3]’ and ‘Generate Report [4]’. The numbers [1] to [4] on the buttons remind the user the sequence of triggering these functions.



	C1_1 : 0.0378	C1_2 : 0.0038	C1_3 : 0.0378	C1_4 : 0.0378	C1_5 : 0.0378	C1_16 : 0.014	C1_17 : 0.014	C1_18 : 0.014	C2_1 : 0.0517	C3_1 : 0.0403
S1	147.1618	0.000007700431	6.9315	0.1125	3.7539	36.3846	5.6632	20.3457	0.17	3
S2	147.1618	0.000007700431	6.9315	0.1125	3.7539	36.3846	5.6632	20.3457	0.17	3
S3	136.9499	0.000010710792	6.8986	0.1232	3.6967	40.4855	5.6653	21.5397	0.33	6
S4	136.9499	0.000010710792	6.8986	0.1232	3.6967	40.4855	5.6653	21.5397	0.33	6
S5	136.9499	0.000010710792	6.8986	0.1232	3.6967	40.4855	5.6653	21.5397	0.17	3
S6	136.9499	0.000010710792	6.8986	0.1232	3.6967	40.4855	5.6653	21.5397	0.17	3
S7	158.4612	0.0000069437741	7.1515	0.0899	2.7645	18.0736	5.8518	23.2004	0.5	9.5
S8	158.4612	0.0000069437741	7.1515	0.0899	2.7645	18.0736	5.8518	23.2004	0.17	3
S9	149.3755	0.0000140643060	7.6540	0.1121	2.7910	28.9868	4.3302	26.8823	0.5	9.5
S10	149.3755	0.0000140643060	7.6540	0.1121	2.7910	28.9868	4.3302	26.8823	0.17	3
S11	104.7651	0.0000022673906	6.8746	0.0547	2.5194	3.7577	1.7535	13.9975	0	0
S12	232.1681	0.0000025952217	11.7198	0.1768	8.1253	2.5259	0.5814	31.2093	0	0

Figure 8-5 Input supplier data

'Expert Evaluation [1]' covers two issues. One is to indicate whether a criterion is a benefit (i.e. the higher the better) or a cost type of criterion (i.e. the lower the better). The other is to input expert judgements on the performance of all suppliers for qualitative criteria. In this particular case, all criteria are the cost type, as seen in Figure 8-6.

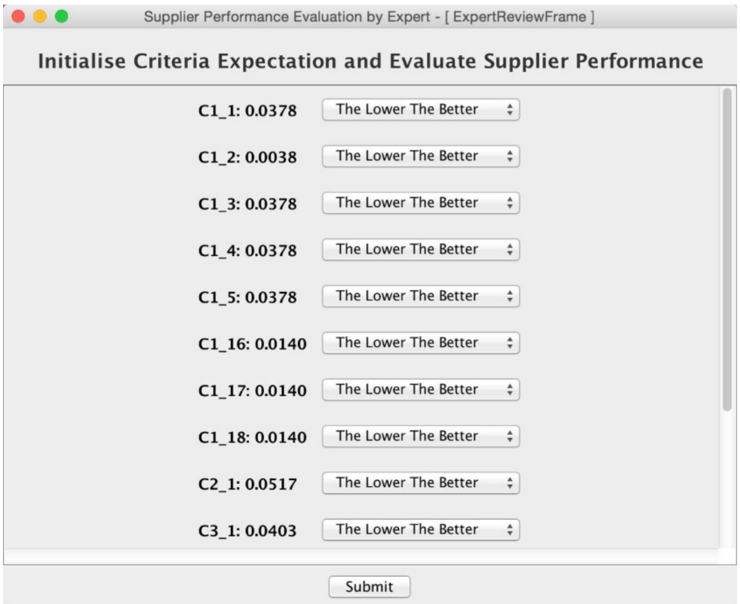


Figure 8-6 Criteria judgement

'Normalise Matrix [2]' normalises the decision matrix of supplier information (see step 7 in Fuzzy AHP-TOPSIS method in section 6.2.3) and 'Normalise-Global Matrix [3]' (see step 8 in Fuzzy AHP-TOPSIS method) adds the weights of the criteria to the normalised decision matrix. 'Generate Report [4]' invokes the calculation (see step 9, 10 and 11in Fuzzy AHP-TOPSIS method) and the results are shown in Figure 8-7.

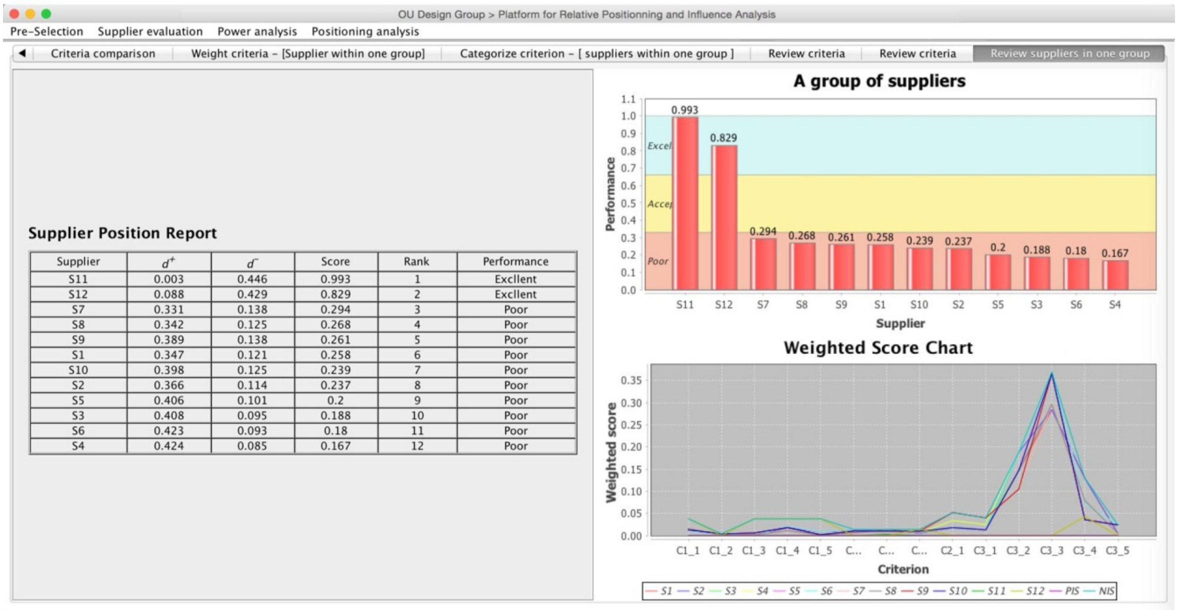


Figure 8-7 Evaluation results in scenario 1

The numerical values on the left are shown rounded to three decimal places, but the system keeps more than three decimal places. The column chart in the right upper corner ranks the 12 farming scenarios. The performance levels, i.e. 'Excellent', 'Acceptable', 'Poor', are highlighted by different background colours. The chart below shows how each type of farmer performs with respect to each criterion. The results show that 'farmer completely purchasing feed' (*S11* and *S12*) have excellent performance while the rest are rated poor.

Scenario 2: Environmental with important environmental criteria

The relative importance, in Scenario 2, between environmental, social and economic impacts is shown in Table 8-8. The relative importance between the criteria under environmental and economic impacts is the same as in Scenario 1 (as seen in Table 8-6 and Table 8-7).

Goal	Environmental	Social	Economic
Environmental	E	ES	S
Social	1/ES	E	1/VS
Economic	1/S	VS	E

Table 8-8 Pairwise comparison matrix of environmental, social and economic impacts in Scenario 2

The results of the evaluation are shown in Figure 8-8.

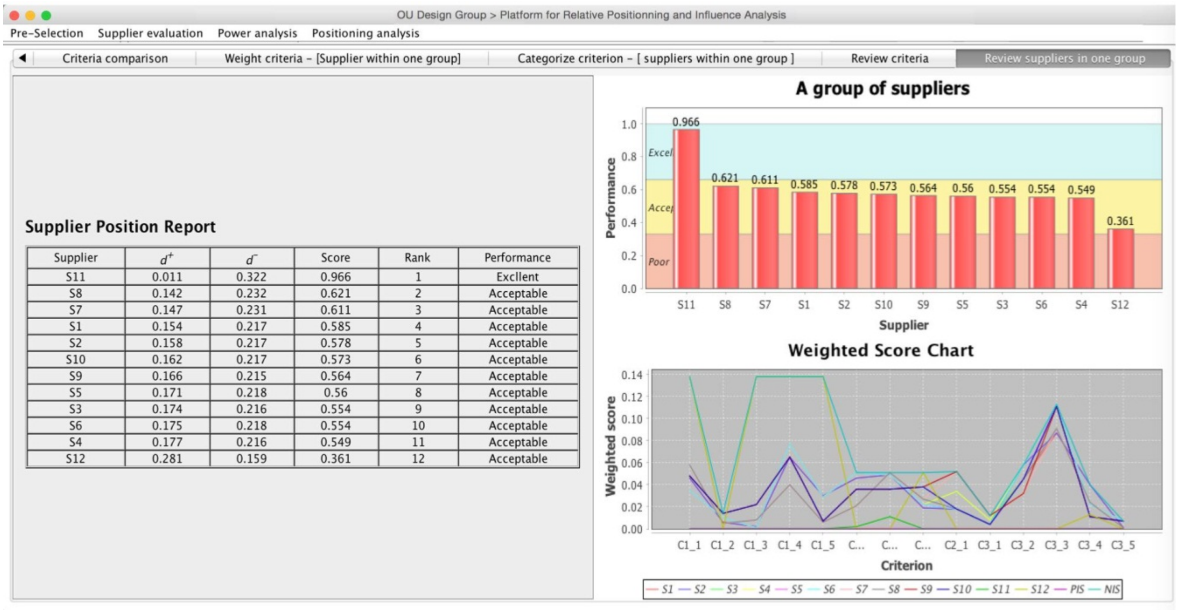


Figure 8-8 Evaluation results in scenario 2

It shows that 'farmer completely purchasing feed with colza dominant' (*S11*) is most favourable, as the performance is excellent**.** On the contrary, 'farmer completely purchasing feed with soy dominant' (*S12*) is the worst, with a performance rates as poor**.** The rest locates in the acceptable performance area.

Scenario 3: Economic with full criteria

The relative importance among environmental, social and economic impacts as well as the criteria ranking under economic impact is the same as in Scenario 1 (as seen in Table 8-5 and Table 8-7).

This scenario uses the complete list of environmental impact criteria. Their relative importance is shown in Table 8-9.

Environmental	C1_1	C1_2	C1_3	C1_4	C1_5	C1_6	C1_7	C1_8	C1_9	C1_10	C1_11	C1_12	C1_13	C1_14	C1_15	C1_16	C1_17	C1_18
C1_1	E	VVS	E	E	E	S	VVS	VVS	S	S	S	VVS	S	S	S	M	M	M
C1_2	1/VVS	E	1/VVS	1/VVS	1/VVS	1/M	M	M	1/M	1/M	1/M	M	1/M+	1/M+	1/M+	1/S	1/S	1/S
C1_3	E	VVS	E	E	E	S	VVS	VVS	S	S	S	VVS	S	S	S	M	M	M
C1_4	E	VVS	E	E	E	S	VVS	VVS	S	S	S	VVS	S	S	S	M	M	M
C1_5	E	VVS	E	E	E	S	VVS	VVS	S	S	S	VVS	S	S	S	M	M	M
C1_6	1/S	M	1/S	1/S	1/S	E	S	S	1/M	1/M	1/M	S	1/W	1/W	1/W	1/M+	1/M+	1/M+
C1_7	1/VVS	1/M	1/VVS	1/VVS	1/VVS	1/S	E	1/W	1/S	1/S	1/S	E	1/S+	1/S+	1/S+	1/VS	1/VS	1/VS
C1_8	1/VVS	1/M	1/VVS	1/VVS	1/VVS	1/S	W	E	1/S	1/S	1/S	W	1/S+	1/S+	1/S+	1/VS	1/VS	1/VS
C1_9	1/S	M	1/S	1/S	1/S	M	S	S	E	E	E	S	1/M	1/M	1/M	1/M+	1/M+	1/M+
C1_10	1/S	M	1/S	1/S	1/S	M	S	S	E	E	E	S	1/M	1/M	1/M	1/M+	1/M+	1/M+
C1_11	1/S	M	1/S	1/S	1/S	M	S	S	E	E	E	S	1/M	1/M	1/M	1/M+	1/M+	1/M+
C1_12	1/VVS	1/M	1/VVS	1/VVS	1/VVS	1/S	E	1/W	1/S	1/S	1/S	E	1/S+	1/S+	1/S+	1/VS	1/VS	1/VS
C1_13	1/S	M+	1/S	1/S	1/S	w	S+	S+	M	M	M	S+	E	E	E	1/M+	1/M+	1/M+
C1_14	1/S	M+	1/S	1/S	1/S	w	S+	S+	M	M	M	S+	E	E	E	1/M+	1/M+	1/M+
C1_15	1/S	M+	1/S	1/S	1/S	w	S+	S+	M	M	M	S+	E	E	E	1/M+	1/M+	1/M+
C1_16	1/M	S	1/M	1/M	1/M	M+	VS	VS	M+	M+	M+	VS	M+	M+	M+	E	E	E
C1_17	1/M	S	1/M	1/M	1/M	M+	VS	VS	M+	M+	M+	VS	M+	M+	M+	E	E	E
C1_18	1/M	S	1/M	1/M	1/M	M+	VS	VS	M+	M+	M+	VS	M+	M+	M+	E	E	E

Table 8-9 Pairwise comparison matrix of criteria under environmental impact in Scenario 3

The results of the evaluation are shown in Figure 8-9.

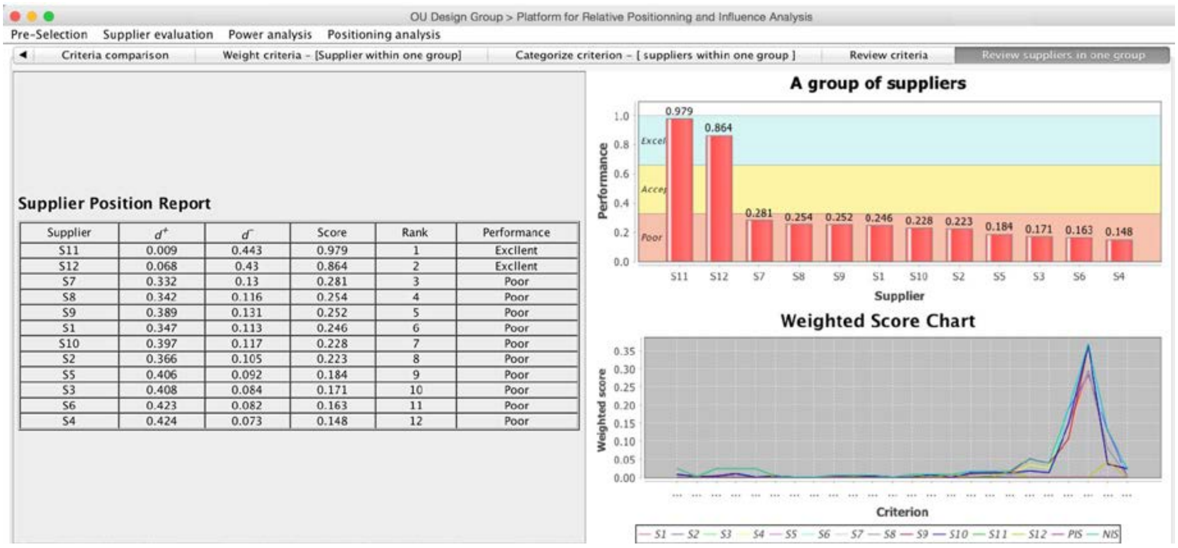
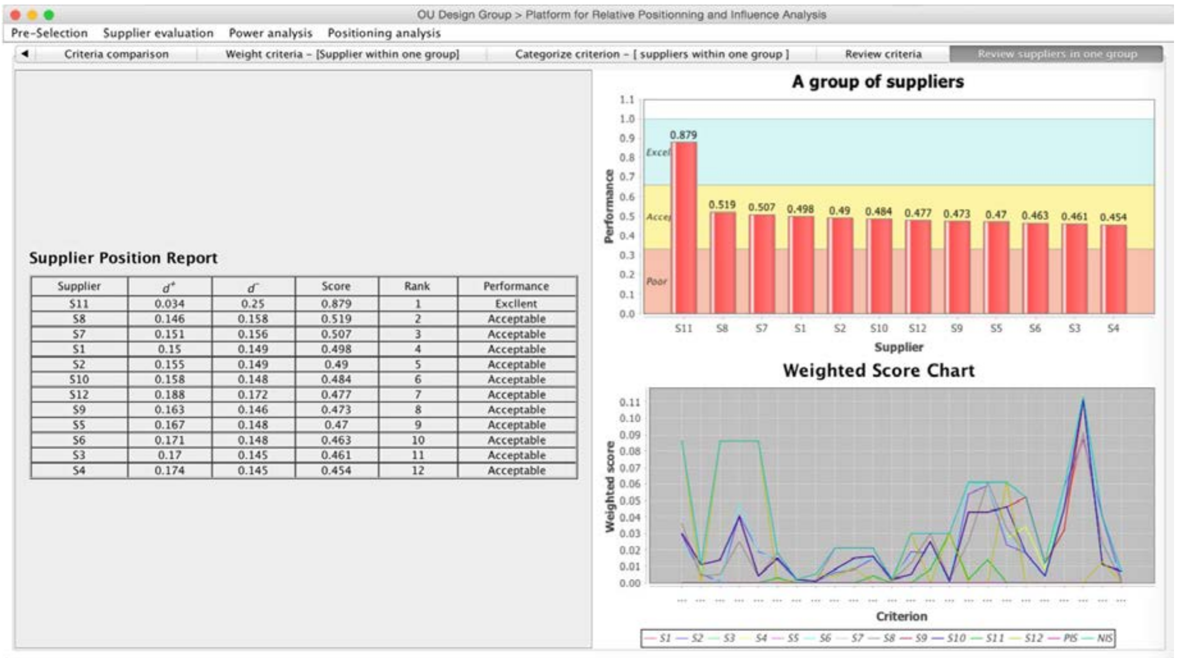


Figure 8-9 Evaluation results in scenario 3

Figure 8-9 shows that 'farmer completely purchasing feed' (*S11* and *S12*) is most favourable, with excellent performance. The remaining types of farmers locate in the poor performance area.

Scenario 4: Environmental with full criteria

The relative importance among environmental, social and economic impacts is the same as in Scenario 2 (see Table 8-8). The relative importance between criteria under environmental and economic impacts is shown in Table 8-9 and Table 8-7 respectively. The results of the evaluation are shown in Figure 8-10.



Supplier	d^+	d^-	Score	Rank	Performance
S11	0.034	0.25	0.879	1	Excllent
S8	0.146	0.158	0.519	2	Acceptable
S7	0.151	0.156	0.507	3	Acceptable
S1	0.15	0.149	0.498	4	Acceptable
S2	0.155	0.149	0.49	5	Acceptable
S10	0.158	0.148	0.484	6	Acceptable
S12	0.188	0.172	0.477	7	Acceptable
S9	0.163	0.146	0.473	8	Acceptable
S5	0.167	0.148	0.47	9	Acceptable
S6	0.171	0.148	0.463	10	Acceptable
S3	0.17	0.145	0.461	11	Acceptable
S4	0.174	0.145	0.454	12	Acceptable

Figure 8-10 Evaluation results in scenario 4

Figure 8-10 shows that ‘farmer completely purchasing feed with colza dominant’ (*S11*) is most favourable, as the performance is excellent. The rest is in the acceptable performance area. ‘Farmer completely purchasing feed with soy dominant’ (*S12*) ranks in the middle among all the suppliers.

8.1.3 Discussion of the results

At first, only two scenarios were designed to see if the slightly important criteria have an impact on the final result. Economic impact was considered most important. One scenario was created that used all important environmental criteria and one slightly important criterion (C1_2: Ozone deletion.). In the second scenario, all criteria were used.

However, the results of the evaluation seemed to contradict what many technical reports on sustainable feeding suggested. The results indicated that purchasing feed (as with suppliers S11 and S12) was recommended, while technical reports on pig feeding encourage the farmers to grow feed. Especially, feeding the pigs with a soy dominant (supplier S12) purchased feed is problematic because soya is mostly imported from outside Europe often under potential damaging environmental circumstances. Therefore, two additional scenarios were added where the environmental impact was changed to be the most important aspect.

Implication of the results

Which scenario produces sensible results: The results where the environmental impact is most important appeared more reasonable (Scenario 2: Environmental with important criteria and Scenario 4: Environmental with full criteria). The difference between ‘famers growing their feed’ (*S1* to *S10*) and ‘farmer completely purchasing feed’ (*S11* and *S12*) is much smaller than those in scenario 1 and scenario 3 where economic impact is emphasised more. Especially, supplier *S12* (complete purchasing feed, soy dominant) is not ranked at top any more in both Scenarios 2 and 4, but at bottom and in sixth correspondingly. Supplier *S11* (Complete purchasing feed, colza dominant) is still ranked at the top. After a careful examination on the data, we concluded that this is correct, because *S11* has the lowest values with respects to a majority of criteria.

Implications of Scenarios 2 and 4: (1) Feed without corn dominant is better than feed with corn dominant. Suppliers *S1*, *S2* (Complete FAF, corn not dominant the constituent) and *S7*, *S8* (Complementary FAF, corn not dominant the constituent) all rank before *S3* to *S6* (Complete FAF, corn dominant) and *S9*, *S10* (Complementary FAF, corn dominant); (2) Complementary FAF is better than complete FAF when the feeds are of same dominant crops. *S7*, *S8* rank before *S1*, *S2* while *S9*, *S10* are before *S3* to *S6*; (3) Under the main type, the farmers with tower silos or hangars perform better than those with corridor silos; and silos smaller than 2500T are better than those above. For example, for ‘Complete FAF, corn dominant’, the ranking of the sub-types is *S5* (Equipped tower silo <2500T), *S6* (Equipped tower silo >2500T), *S3* (Equipped corridor silo <2500T), *S4* (Equipped corridor silo >2500T).

Influences of slight criteria: The two scenarios with economic as the most important aspect (Scenarios 1 and 3) had the same ranking. In these scenarios, the environmental criteria generally have a low weight and adding a new criterion makes little difference. For the two scenarios with environment as the most important aspect (Scenarios 2 and 4), the only difference is that the ranking of *S12* moves from the bottom to the sixth while the rankings of the rest remain the same. Compared with others, *S12* has quite good performance with respect to most of the new added criteria. Larger weights of those criteria push *S12* to a better ranking in Scenario 4. This finding shows that criteria with very weak weights make little difference. It also shows the importance of examining a supplier by looking at the weights of the criteria and the performance under them (see the SWOT analysis in section 5.2.3).

Implications of power

The ‘Cooperative’ characteristic limits the suitability of power as a concept in this value chain context. Farmers have the freedom to join or leave this value chain without affecting their participation in other values chains of Theta. They also take part in the decision process of Theta and their opinions are respected. The profits are allocated in proportion to the operations each participant achieved. The two big groups Theta and Sigma are also in a cooperative relationship and neither would admit that a power relationship exists. Thus, this research was not suitable to evaluate the power assessment method proposed in section 6.4 and further the relative positioning approach proposed in Chapter 5.

However, it is observed that great dependence exists between farmers and Theta and as well as between Theta and Sigma. Theta needs Sigma to distribute their products and Sigma needs Theta to provide those ‘green’ products. ‘Sustainable Agriculture’ is a recognisable label, which closely links the two groups. Theta relies on its farmers to maintain the ‘sustainable’ behaviours and to explore innovations in areas such as soil conservation, water management, nutrition and plant protection, animal health and nutrition, and livestock buildings. Farmers also depend on Theta to get a better price and more profits. Big supermarkets often have power over small farmers and suppliers who supply them directly. However, by joining Theta, the farmers can avoid this kind of pressure from big supermarkets, because they work as a group.

This case gives a different picture of power. Though power does not explicitly exist in this case two issues related to power are revealed. First, although power is of limited application, dependence exists. In other words, high mutual dependence leads to a power balance situation. Second, while the individual suppliers (farmers in the case) are pressed under the power of their customers (the supermarket), the situation can be reversed when all the individual suppliers are united as a group.

8.2 Evaluation of the research work

The research work can be validated for its usefulness by case studies. However, due to the availability of data, this research was only applied comprehensively to a sustainable agriculture case presented in previous section. In this case the power assessment part of the proposed approach was not applicable. This section first describes a framework followed in validating both the proposed approach and the associated tool developed in this research. It then discusses the extent to which the various aspects of the approach have been validated.

8.2.1 Validation framework

The usefulness of research is associated with whether it provides solutions 'correctly' (effectiveness), and whether it provides 'correct' solutions (efficiency) (Pederson et al., 2000). The 'Validation Square' framework (Figure 8-11) proposed by Pederson et al. (2000) aims at evaluating the effectiveness and efficiency of the research based on qualitative and quantitative measures. Although this framework focuses particularly on validating methods, it is appropriate for validating research results in general (Pederson et al., 2000).

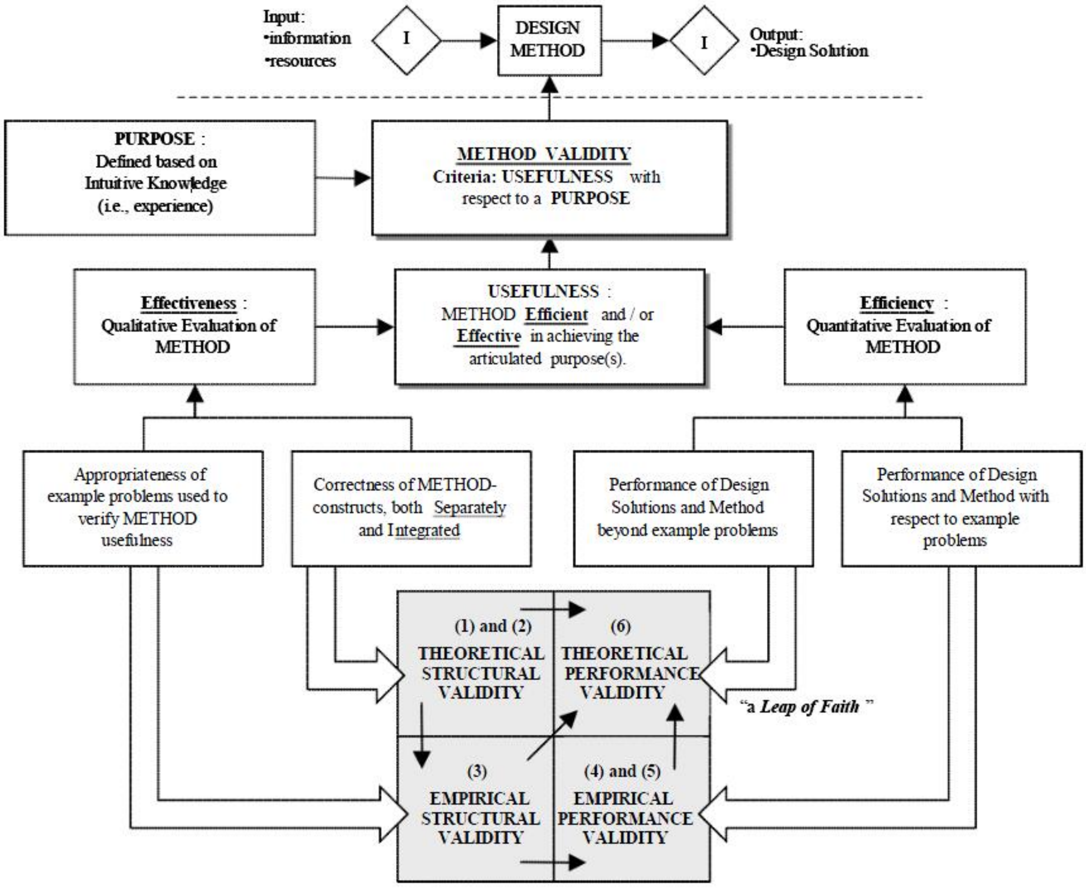


Figure 8-11 The validation square (Pederson et al., 2000)

The four quadrants in the square at the bottom is a combination of both theoretical and empirical aspects with structural and performance validations of the research results. The numbers (1) - (6) refer to various issues which arise in establishing validity. The arrows indicate the sequence of the four types of validations.

Theoretical structural validity considers two issues: (1) accepting the construct's validity, and (2) accepting method consistency. To build confidence in the validity of the individual constructs constituting the methods, Pederson et al. (2000) suggest using the literature to build acceptance based on well-established references. To build confidence in the way the constructs are put together, they suggest using a flowchart representation focusing on information flow. This can demonstrate clearly that for each step (construct) there is: (a) adequate input available, (b) that an anticipated output is likely to occur, and (c) that the anticipated output is an adequate input to another step (construct).

Empirical structural validity is concerned with the issue (3) of accepting the example problems as representative and relevant. It builds confidence in the appropriateness of the example problems used for verifying the method performance by reference to its documentation. Three questions are considered: (a) are the example problems similar to the problems where the constructs are generally accepted; (b) do the example problems represent the actual problems; and (c) can the data associated with the examples support the conclusions drawn?

Empirical performance validity deals with two issues: (4) accepting that the outcome of the method is useful for some example problems, and (5) accepting that usefulness is linked to applying the method. The usefulness of the methods is demonstrated through the extent to which a purpose has been achieved through the chosen example problems. Various purposes might be achieved by a method. From an academic perspective, the purpose is generally to produce more scientific knowledge. From an industry perspective, the purpose might be reducing cost and improving quality. Achieving a purpose needs to be linked to the application of the method. This can be established by evaluating the usefulness of each construct individually.

Theoretical performance validity concerns the issue (6) of accepting that the method is useful beyond the example problems. This confidence in generality can be built by using induction that involves the five steps from (1) to (5).

8.2.2 Research validation

The validation of the research outcomes is divided into two parts. In the first part the approach to analysing relative positioning is validated (Chapters 5 and 6). In the second part the tool that implements the approach is validated (Chapter 7). In each case the Validation Square presented in previous section is applied. Figure 8-12 indicates the aspects of the research framework adopted in chapter 3 which are realised by validated research outcomes.

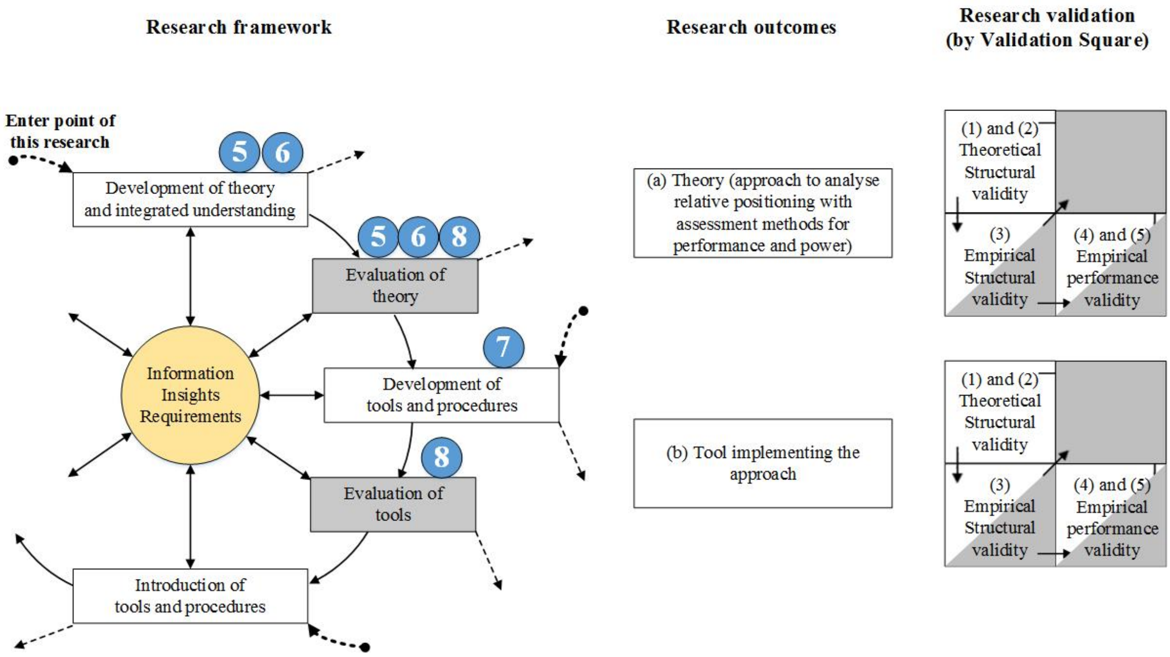


Figure 8-12 Research framework, outcomes and validation

The purpose of this research is providing a tool that integrates power and performance in supplier selection, which adds new knowledge to the supplier selection literature. The **theoretical structural validity** was achieved through extensive literature review in Chapter 2. The two constructs of the approach (as well as the tool) – performance and power, were considered individually and their logical connection was established. Performance, as the indicator for choosing the suppliers, is concerned with the question whether the supplier will meet the buyer's requirements and expectations. Power concerns the ability of a company to influence the quality of the relationship and the collaboration with a supplier. A supplier of high performance is usually preferred, but an imbalance in power distribution might affect whether the supplier will provide high performance. Performance and power are related and influence the decisions regarding supplier selection. Although only literature was suggested by (Pederson et al., 2000) for the theoretical structural validity, this research also carried on empirical studies that further proved the validity of the two construct and their connection (see Chapters 4 and 5).

Empirical structural validity of the approach has been partly achieved by accepting the sustainable agriculture case as an example problem. As discussed in section 8.2.3, it was claimed by the participants that the power relationship was not demonstrated to exist in the case. As a result, the case is not entirely appropriate to validate the overall approach. However, it is observed that this case is suitable to validate the assessment method for performance and acts as an exemplar for the tool use. The Fuzzy AHP-TOPSIS method is a general mathematical method for supplier assessment, which is not restricted to a particular industry sector. The case, which aims to assess the sustainable performance of farmers, contains multiple farmers, sustainable performance criteria and data, is similar to the problem of supplier selection. The Empirical structural validity of the tool has also been partly achieved. For software, validation checks whether the tool satisfies the user requirements. The sustainable agriculture case covers only the function of 'assessing a group of suppliers' where the tool implements the whole approach (assessing single supplier, a group and cross group of suppliers in section 6.3, assessing power in section 6.4, and positioning the suppliers in section5.4).

Empirical performance validity of the approach has been partly achieved by using the Fuzzy AHP-TOPSIS method to assess the farmers' performance in the sustainable agriculture case. The application produced useful results that shows which types of farming have better sustainable performance. These are described in detail below in the next subsection, Section 8.2.3. After presenting the assessment results to the research team at AgroParisTech they showed considerable interest the implications of the results. The data used in the case were collected based on their academic work rather than from their industrial partners. However, we have been told that even Theta (the main actor in the value chain) does not have the full data on their farmers in terms of all these criteria. Theta and Sigma (another main actor) both have some data to estimate the sustainability, but may not share this with each other. The assessment results from the tool could encourage Theta to collect more information from their farmers as the tool compares them and shows which type of farmer is better with what type of configuration. This is helpful to improve the performance of the whole value chain. It may also encourage the information exchange between Theta and Sigma. However, the limited power aspect in this case meant that the proposed approach which positions a supplier by both performance and power could not be directly validated. Empirical performance validity of the tool has also been partly achieved by applying its function ‘assessing a group of suppliers’ (which implements the Fuzzy AHP-TOPSIS method, as seen in section 6.3.3). The tool provided the decision makers (the researchers at AgroParisTech) with automatic computation of the method and produced both numeric and graphical results. The numeric results allowed them to examine the details of a famer’s performance against the criteria, and the graphical representations gave an intuitive ranking of all the farmers. The latter could enhance their communication with their industry partners in the project. Some unfriendly user interfaces were also noticed such as presenting criteria ID rather than their names (see Figure 8-3, Figure 8-5 and Figure 8-6), which leads to looking back frequently to the criteria definition page (Figure 8-2).

Theoretical performance validity could not be carried out (and is left blank in Figure 8-12) due to the incomplete achievement of Empirical structural validity and Empirical performance validity.

8.2.3 Self-evaluation of the approach and the tool

Given the lack of data and appropriate cases to validate the approach and the tool, this research tried to partially compensate for this incomplete validation by self-evaluation according to the thirteen criteria by De Boer and Van der Wegen (2003). These criteria as listed in Table 8-10 that take the form of questions C1-C13. These are used to evaluate the decision models for supplier selection. They evaluate the degree to which a model fits the complexity of the situation and brings cost and benefit. The five questions under ‘Complexity-fit’ examine whether a decision model has sufficient data. The seven questions under cost/benefit analyse how useful a decision model might be.

Dimensions	***Criteria***
Complexity-fit	C1: Does the model aggregate information in a proper way?
	C2: Does the model sufficiently utilise available information?
	C3: Is it (to a satisfactory extent) possible to incorporate opinions and beliefs?
	C4: Is it (to a satisfactory extent) possible to achieve a fair participation of individual members in case of a group decision?
	C5: Is the model sufficiently flexible for changes in the decision situation?
Cost/benefit	C6: Is the outcome of the decision model useful?
	C7: Is the outcome of the decision model acceptable?
	C8: Are the required investment justifiable?
	C9: Is the model sufficiently user-friendly?
	C10: Is the way the decision model works sufficiently clear?
	C11: Does the decision model increase the insight in the decision situation?
	C12: Does the decision model contribute to the communication about the justification of the decision?
	C13: Does the decision model contribute to the decision-making skills?

Table 8-10 Criteria for evaluation of the decision models (De Boer and Van der Wegen, 2003)

The following list proceeds through the evaluation criteria and the corresponding questions, indicating how this research responds to each of the questions.

For C1: Does the model aggregate information in a proper way?

The approach aggregates performance and power relationship by analysing their interactions through literature and empirical studies (see Section 5.1). When quantifying the performance and the power relationship, values with respect to different performance criteria and power determinants are aggregated through well proven techniques (AHP and TOPSIS) (see Section 6.2).

For C2: Does the model sufficiently utilise available information?

As long as supplier performance information and judgements on buyer power and supplier power are provided, the approach is able to quantify them and position a supplier (see Section 5.4). Especially, the performance assessment method is applicable in three assessment scenarios in which both judgement and actual values can be used (see Section 6.3). The power assessment method uses information from three aspects (market, business and product) to determine power determinants (see Section 5.3) and takes judgement from each participant's perspective into consideration when assessing the relationship (see Section 6.4).

For C3: Is it (to a satisfactory extent) possible to incorporate opinions and beliefs?

The approach and the assessment methods incorporate subjective judgements from multiple decision makers.

For C4: Is it (to a satisfactory extent) possible to achieve a fair participation of individual members in case of a group decision?

Group decision is considered by aggregating all individual judgement into a meaningful 'average' opinion.

For C5: Is the model sufficiently flexible for changes in the decision situation?

The approach allows the decision maker to evaluate the supplier in three different assessment scenarios (see Section 6.3). It also allows changes in the number and the content of the criteria, determinants and weights. The tool implementing the approach also allows the decision makers to define new criteria and new power determinants.

For C6: Is the outcome of the decision model useful?

The outcome of the approach (as well as the tool) indicates to what extent a supplier is a suitable, shows its performance and who has advantage in the supplier-buyer relationship. The outcome should prove useful.

For C7: Is the outcome of the decision model acceptable?

If the input data are correct, the output should be acceptable.

For C8: Are the required investment justifiable?

It saves the decision makers computational efforts.

For C9: Is the model sufficiently user-friendly?

The tool has included graphics to make it more user-friendly. During the application to the sustainable agriculture case, the graphical representations of the results give an intuitive impression. However, the details regarding user interfaces would require much more testing and improvement, which will be picked up in further work

For C10: Is the way the decision model works sufficiently clear?

The decision makers do not have to understand the exact formulas. The principle of the approach (i.e. integrating power and performance for supplier selection) is not hard to understand. In particular, the tool separates the decision maker with the details of the formal method and its associated calculations.

For C11: Does the decision model increase the insight in the decision situation?

It provides an alternative view on selecting the suppliers by incorporating the power relationship. The approach (as well as the tool) also encourages the decision makers to categorise criteria by integration levels (see Section 5.2). It gives a rational picture of the power relationship, and allows decision makers to include subjective data.

For C12: Does the decision model contribute to the communication about the justification of the decision?

The graphical representations of the assessment results can be used in presentations.

C13: Does the decision model contribute to the decision-making skills?

It will push the decision makers to think rationally through formulating the criteria/determinants and comparing them pairwise.

8.3 Chapter conclusion

This chapter describes the application of the tool to the sustainable agriculture case. The results showed that supplier *S11* (Complete purchasing feed, colza dominant) could be the best choice for feeding the pigs to maintain the sustainable performance. ‘Feed without corn dominant’ is better than ‘feed with corn dominant’, whereas ‘complementary FAF’ is better than ‘complete FAF when the feeds are of same dominant crops’. The application partly validates the research work. However, considering the appropriateness of the case, the validation requires efforts in future work. The tool also needs to be improved regarding the user interfaces. These will be discussed in the next chapter.

Chapter 9 Conclusions and future work

This chapter concludes the thesis. It outlines the main conclusions and highlights the research contributions made by this work. The chapter also explains how the research questions defined in the introduction chapter, have been answered. Limitations of the work are discussed along with opportunities for future work.

9.1 Main conclusions

- Supplier assessment and selection is a complex decision problem. It involves multiple criteria with different types of data and multiple subjective judgements. Work to date has mainly focused on how to build an assessment and selection model with performance criteria such as quality, cost, delivery and technology. In the literature review, power is identified as a significant factor in supplier selection, for example, Cox (2001, 2004) and Lee (2009). However, the integration of power assessment with performance assessment has received limited attention in the literature (Chapter 2).
- Power has been studied in detail in social science. Research on power in supply chains has mainly focused on its influence on the buyer-supplier relationship. However, an analysis of the wider literature on power reveals that power can be measured and quantified. Few studies have included such quantifications of power in supplier assessment except Cho and Chu (1994), Cox (2001, 2004) and Zolghadri et al. (2011b). Deficiencies exist in these studies to quantify power for supplier selection (Chapter 2).
- In industry practice, suppliers are analysed and categorised in terms of their criticality to the buyer’s business, whilst power (of the buyer and their potential suppliers) is used in negotiation to enhance the possibility of collaboration or to reduce cost. A systematic way of understanding, measuring and applying power has the potential to assist supplier assessment and selection (Chapter 4).

- Integrating assessment of supplier performance and power relationships provides a relative positioning analysis on suppliers. This integration presents an innovative solution for the problems of supplier assessment and selection, which explicitly shows the extent to which a supplier is suitable for collaboration (Chapter 5).
- Assessing supplier performance through the application of a core method, which employs a Fuzzy AHP-TOPSIS method, across different assessment scenarios (single, group, and cross group suppliers) enables the decision makers to deal with the supplier assessment problem more flexibly (Chapter 6). This method is Fuzzy AHP-TOPSIS method shown to work in an industry case (Chapter 8).
- Quantifying the power relationship with perceptions (objective, optimistic, pessimistic) from the suppliers provides insights on who has advantage in the relationship. It can also assist suppliers in determining the effects of perceptions of power on a buyer supplier relationship (Chapter 6).
- A software solution implementing the theoretical results has been developed to make the methods and models in this thesis accessible or both industry and academia (Chapter 7).

9.2 Research contributions

This section presents the contributions of the thesis from methodological, theoretical and practical aspects.

Methodological contributions

This research proposes an approach to enhance supplier selection by indicating whether a supplier is ‘suitable’ to collaborate. This is the first key contribution.

Contribution 1: An approach for relative position analysis.

This approach integrates the results of two types of assessment – performance of suppliers and power relationships. Performance and power are related and affect the selection of suppliers. **The interaction model** is established in section 5.1.3. It demonstrates how power may influence the performance and how performance indirectly contributes to power. Following this approach, supplier performance is assessed against a set of criteria and then profiled. **Three assessment scenarios** (single, group and cross group suppliers) have been derived from the literature (i.e. De Boer et al. (2001)) and empirical studies (Section 5.2.1). Building on Ghodsypour and O'Brien (1998) and Chan (2003), **a four-level taxonomy** based on supplier integration (no relationship, operational, tactical and strategic relationships) has been proposed for categorising criteria (Section 5.2.2). **A quadrants analysis** (based in SWOT - Strengths, Weaknesses, Opportunities and Threats) is suggested to profile a supplier according to its performance and the weights of the criteria (Section 5.2.3). Power relationship analysis then determines who possesses the advantage, the buyer or the supplier. Power is assessed against a set of power determinants. **A model to identify power determinants** is proposed, which derives the determinants from market, business and product aspects (Section 5.3.1). **Three types of perceptions** (objective, optimistic and pessimistic) are used to establish the power relationship from the perspective of the supplier (Section 5.3.2). **The situations of the power relationship** (supplier dominance, buyer dominance and balanced) are determined by comparing the power of the both the supplier and the buyer (Section 5.3.3). With the results of performance and power relationship analyses, **six scenarios** (ideal, satisfying, tolerable, unfavourable, risky and tough) in nine squares are used to position a supplier (Section 5.4.1). **A reverse analysis** is suggested to review the performance profiles and the power situations when more than one supplier seem suitable to work with (Section 5.4.2).

The second key contribution is the mix of decision making methods for supplier assessment.

Contribution 2: A Fuzzy AHP-TOPSIS method.

This thesis integrates Triangular Fuzzy Numbers (TFNs), AHP and TOPSIS to develop an assessment model (Section 6.2). This thesis is not the first to propose this combination, which is used, for example, by Wang et al. (2009a), Kannan et al. (2013) and Lima Junior and Carpinetti (2016). As presented in sections 2.3, previous research only takes subjective judgements for evaluation, which leads to objective data being abandoned. Some researchers such as Kahraman et al. (2003), Chan and Kumar (2007), Lee (2009), and Lima Junior et al. (2014) apply the Extent Analysis Method (EAM) proposed by Chang (1996) to aggregated TFNs and then defuzzify the TFNs, which is shown to have significant shortcomings (Section 6.2.2). **The Fuzzy AHP-TOPSIS method** is proposed in this thesis. It is able to accept both subjective and objective data for qualitative and quantitative criteria, allowing multiple judgements. **Further issues** in the combinations of judgements (i.e. aggregating TFNs, defuzzifying TFNs, and checking the consistency of fuzzy judgement) have also been discussed and solved.

Theoretical contributions

The extensive literature review has indicated that power can be quantified. This indicates the potential for including power assessments in supplier selection. The thesis contributes to the development of theory in supplier selection. Criteria for supplier assessment and selection are discussed in terms of their changes (Section 2.2.1), classification (Section 2.2.2), and properties (Section 2.2.3). Methods are discussed in terms of their data requirements and ease of use (Sections 2.3, 2.4 and 2.5). Software tools are explored according to whether they are dedicated to suppler selection (Section 2.6). The literature review on power contributes to studies on power as well as supplier selection. It explores power across its definitions (Section 2.7), main theories (Section 2.8), determinants and measurements (Section 2.9).

Based on the literature, this research is able to propose an approach and assessment methods. The third key contribution is about assessing performance and power.

Contribution 3: Assessment methods for performance and power relationship.

The **performance assessment methods** calculate values of supplier performance in the three assessment scenarios (Sections 6.3.2, 6.3.3 and 6.3.4). The Fuzzy AHP-TOPSIS is adapted for these scenarios, so that this research can deal with the assessment for a single supplier as well as multiple suppliers in one or more groups. To assist the assessment, the criteria collected from the literature are grouped in a four-level taxonomy (strategic, tactical, operational and no relationship).

The power assessment method calculates the values of supplier power and buyer power and quantifies the power relationship (Section 6.4.2). In contrast to Cho and Chu (1994), Cox (2001, 2004) and Zolghadri et al. (2011b), the proposed method provides a systematic way to assess power against power determinants. To analyse the power determinants, a dependence-power table is suggested and applied to the determinants from literature (Section 6.4.1). To determine the power relationship from the perspective of the supplier, three estimations of the supplier's perceptions (objective, optimistic and pessimistic) are incorporated in the calculation (Section 6.4.3).

These assessment methods are not limited to supplier assessment and selection. They could also be used to evaluate an existing supplier.

Practical contributions

To facilitate the application of the theoretical results, this research developed a software prototype, which is the fourth key contribution.

Contribution 4: A dedicated software tool for supplier selection.

As discussed in section 2.6, researchers either choose generic tools to assist the calculation, for example Yang and Chen (2006), Kulshrestha et al. (2007) and Pitchipoo et al. (2012) use Excel for their AHP models; or they apply the dedicated tools which implement only a single decision making method such as Chan (2003), Chan and Chan (2010), and Labib (2011), who use Expert Choice to solve their AHP models for supplier assessment and selection. This research develops a dedicated tool based on hybrid decision making methods. The tool implements the proposed analysis approach and the assessment methods (Chapter 7). It reduces the effort and improves the efficiency of decision makers in selecting a 'suitable' supplier by applying the research results. Although it is a prototype, the tool is complete and suitable to be used with expert assistance. The consideration of the extensibility of the software allows the academic research community or industry to modify and extend the tool by reusing the functions provided in the software.

9.3 Response to the research questions

Although some of the research questions have been partially answered in the previous sections, each question will now be addressed in turn.

Research question 1 (Q1): How can supplier selection be enhanced by including the considerations of power relationship?

The answer to this question is essentially Contribution 1 and detailed in Chapter 5, where the relative positioning analysis approach is developed. The answer is further supported by the software tool presented in Chapter 7 and illustrated with the application in Chapter 8. Performance and power relationships are dimensions on which a supplier can be judged. The findings in the literature review show that power affects aspects such as pricing strategy (Munson et al., 1999; Kwak et al., 2006), inventory strategy (Bichescu and Fry, 2009) and information exchange (Ke et al., 2009; Cai et al., 2013) as well as the quality of the relationship (Benton and Maloni, 2005; Zhao et al., 2008). The results of the interviews corroborate these influences. Power plays an important role in negotiations with suppliers and to increase the possibility of collaboration. The interaction between power and performance is established based on the practical findings in Chapter 4. In general, suppliers with good performance and low power would be preferable to the buyer. Especially when the dependence of suppliers on the buyer (focal) company is high, the collaboration should be relatively easy to establish. However, to understand where the suppliers' good performance and power come from, and further what distinguishes them, a reverse analysis to examine their profiles is necessary. The proposed approach fills Research Gap 1: *Limited work has been published that explicitly takes power into account when assessing and selecting suppliers.*

Research question 2 (Q2): How can qualitative and quantitative criteria and both subjective and objective data be integrated in a robust supplier assessment method?

The answer to this question lies in Contribution 2. This question is mainly answered in Chapter 6 where the Fuzzy AHP-TOPSIS method is developed and in Chapter 7 where it is implemented in the software tool. The exploration on the assessment techniques in Chapter 2 supports how this question is addressed. Fuzzy numbers are chosen to represent linguistic variables of subjective judgements; AHP is used to prioritise the criteria and power determinants; TOPSIS is applied to calculate the performance data. In order to accept both subjective and objective data for calculation, this thesis highlights and addresses two issues: (1) calculating the weights of criteria in Fuzzy AHP by geometric mean (Aczel and Saaty, 1983; Barzilai, 1997; Dong et al., 2010), and (2) defuzzifying TFNs in fuzzy TOPSIS by Yager's approach (Yager, 1981; Facchinetti et al., 1998). The Fuzzy AHP-TOPSIS method is further tailored to assess supplier performance and power relationship. The proposed model fills research gap 2: *There is a need for a decision method, which can deal with the multiple criteria, multiple judgements with uncertainty, as well as both objective and subjective data.*

Research question 3 (Q3): How can the power distribution between the buyer and the supplier be assessed?

The answer to this question lies in Contribution 3. This question is answered in Chapter 5 where a power analysis model is proposed and in Chapter 6 where the assessment method is developed. The first step in assessing the power distribution is to determine the power determinants of the buyer and potential suppliers. The analysis model helps the decision makers to identify the determinants. The second step is to quantify buyer power and supplier power and the last step is to compare them. The assessment method for power relationship integrates various estimations of the perceptions of suppliers. The buyer can create an overall picture of who owns the advantage and have an idea about how to respond under different power scenarios. In addition, an exploration of theories and the factors determining the power relationship in Chapter 2 supports how this question is addressed. Chapter 4 enhances the understanding of power from a practical perspective. The proposed model and method fill research gap 3: *A effective quantitative assessment is missing for power in the (potential) buyer-supplier relationship.*

Research question 4 (Q4): How can a software tool supporting supplier selection be developed?

The answer to this question lies in Contribution 4. This question is answered in Chapter 7 which presents the implementation process. Chapter 5 and Chapter 6 provide the theoretical foundation as well as the technical specification for the software tool. The tool, PEPA, implements the proposed relative positioning approach and the assessment methods for performance and power distribution. It incorporates the supplier selection criteria and the power determinants collected from the literature, as well as the proposed four-level taxonomy for criteria. Meanwhile, it allows the decision maker to define their own criteria and determinants. The implementation of the software tool fills research gap 4: *There is a lack of software tools dedicated to supplier assessment and selection.*

9.4 Limitations of this work

Alongside the contributions described above, the research also has limitations. Overcoming them will offer scope for improvement in the method and tool. This section covers some of these limitations.

The limitation of the empirical studies

Although interviews were carried out to justify the research gaps, case studies were not performed to specifically identify the decision tool requirements in industry. The limitation is also reflected in the selection of the companies and the data collected. The interviews at the first stage provided only general information. The interviews in the second stage, especially at the engine company, gathered more information about the supplier selection and power. There is scope for more interviews to be conducted.

The validation of the research work

The validation has not been performed for the power assessment methods. The only detailed case study that this research obtained access to is the sustainable agriculture case which is not an appropriate validation example for the power assessment methods as discussed in section 8.2.2. Although the importance of power relationship was emphasised by the interviewed companies it could not be realistically validated by this case due to the collaborative principles on which the supply chain was based. Further, it is remarked that multiple cases are required for full validation.

The generalisation of the results

The generalisation of the results has not been proved. The initial direction of the research and its findings are based mainly on interviews in high tech manufacturers. However, the application of the research results is carried out in an agriculture value chain and this indicated, to some extent, the potential for wider applicability. During the agriculture application, it was noticed that the power analysis is not suitable to estimate the relationship between the farmers and Theta in this special value chain which based on collaborative principles. To some extent this is contradicted by the findings in the interviews where the relevance of power considerations was recognised. Analysis of additional industry fields or sectors would be required to confirm the generality of the research findings across multiple contexts.

The robustness of the software tool

The current version of the software tool only focuses on the realisation of the functions rather than the robustness. It is not able to cope with errors during execution such as invalid or unexpected inputs. User-testing of the tool by industrial practitioners has not been performed.

9.5 Future work

The future work will focus on improving the approach for relative positioning and influence analysis and examining its full application through the whole supplier selection process from negotiation to supplier development.

Validation of the power relationship, the approach and the tool

This research investigated how to extend supplier selection to include power relationships. However, as discussed in the previous section, the power part could not be validated, which leads to the incomplete validation of the approach and the tool. Thus additional case studies represent the first piece of future work. These case studies could follow two directions.

- Case studies in manufacturing industry, ideally in high technology, to validate the power relationship, where the decision makers' supplier selection process is shadowed with the tool to see whether it can be enhanced.
- The second direction is to extend the case studies to other industry sectors. The aim is to investigate the importance of power relationship in sectors such as food and textiles, and to analyse whether and how the proposed approach in this thesis can be applied.

Extension in modelling of power

During the practical study two implicit phenomena related to power were noticed, which could improve the power model. The first is the distinction between having power and exerting power. When discussing the power influence in the European engine company, the company manager mentioned that power would not be used to force their suppliers. Instead, they would negotiate with those suppliers by implying they have more power. Cho and Chu (1994) mentioned in their paper the exertion of power and proposed several factors influencing the exertion. However, it might be hard to differentiate those factors from the factors which directly constitute power.

The other phenomenon is the intervention of the customer, i.e. explicit control of second-tier suppliers. For the engine company, its parent company, who is also a customer of the engine company, sometimes selects suppliers for the engine company. However, this was not studied in detail in this research due to time constraints. In the current power model, only customer recognition of brand is considered. However, this inspires a new research question on how the intervention of a third party influences the power relationship.

Power propagation and multiple relations through the supply chains

Cox et al. (2001) argued that to understand the supply chain better, the power relationship should be considered beyond the first-tier suppliers. They suggested hypothetical power networks consisting of raw material suppliers, components suppliers, assemblers and customers and how value might be exchanged along the networks. However, their construction of the power networks is still based on the dyadic power relationship, which could be influenced by power propagation. When supplier A has power over the buyer and the buyer has power over supplier B, does supplier A have a power over supplier B? When the buyer has power over customer C, does supplier A have a power over customer C? The possible influence between relationships among suppliers and the buyer triggers the need to consider the power propagation through the relations between different supply chain members.

The current consideration of the power relationship lies in a single buyer-supplier relationship where the supplier is involved in one project or provides one product. In practice, there are suppliers taking part in multiple projects or supplying various aspects. An example is the supplier to the engine company, who delivers both electronic systems and fuel systems. The question arises as to whether the company considers electronic and fuel system suppliers together. Because the electronic system and the fuel system are two different divisions in the company and happen at different locations, they are not put together but awareness of this could lead to a different discussion during the negotiation. This does encourage further research on when and how the multiple relations should be considered not only in power analysis but also in the supplier assessment.

Reference points in the Fuzzy AHP-TOPSIS method

Another area for future work on the approach adopted here is to improve the core assessment model by adding a preference level between the two reference points – the positive ideal solution (PIS) and negative ideal solution (NIS). The core assessment model, Fuzzy AHP-TOPSIS, applied in this work, is a compromise model due to the property of TOPSIS. It compares and ranks the alternatives according to the distances to the two reference points. The ideal alternative should have the shortest distance to PIS and farthest distance to NIS. However, in most cases the one having the shortest distance to PIS does not have the farthest distance to NIS. The way to solve this problem in TOPSIS is to aggregate the two distances by equation $C_i^* = D_i^- \big/ (D_i^* + D_i^-)$, where C_i^* is the relative closeness of alternative i as ranking reference, D_i^* is the distance to PIS and D_i^- is the distance to NIS. This solution assumes that the preference between the two reference points is the equal. To integrate a preference level into the aggregation of the two references could better express the decision-making problem and provide more information for decision making.

A platform for supplier analysis

Long term research based on this thesis is to develop the approach as well as the tool into a platform for supplier analysis. Two important aspects of supplier analysis – performance and power are considered in the thesis. While other aspects, such as risk, might also affect the decision on collaboration. Empirical analysis on the factors which affect collaboration will contribute to the knowledge about supplier analysis and in establishing more effective and efficient approaches for companies to make supplier selection decisions.

During the case studies, it is also noticed that there are many independent tools used by companies to analyse suppliers. For example, there are tools to understand the external environment of supplier and tools to analyse the criticality of supplier. This motivates two questions for research:

(1) whether the results from one tool can be used in another tool; (2) whether these tools can be integrated into one platform. The answer to the questions requires a close cooperation with a company, probably involving a collaborative research project.

The use of enterprise data

Another piece of potential long-term work is to use the enterprise data to generate useful information for the models in this thesis. The input for the supplier assessment model is the supplier information. The tool requires well-structured input for each criterion. Companies, such as the engine company, often select new suppliers from their basis of existing suppliers. This raises the question whether the date required by the tool could partially be extracted from existing data. In practice data on multiple situations and contexts with different histories of supplier positioning could be explored in future research addressing how ‘big data’ might help strategic decision making.

References

ACZEL, J. & SAATY, T. L. 1983. Procedures for synthesizing ratio judgements. *Journal of mathematical Psychology,* 27**,** 93-102.
AGARWAL, G. & VIJAYVARGY, L. 2013. Modeling of intangibles: An application in supplier selection in supply chain - a case study of multinational food industry. *International Journal of Management and Innovation,* 5**,** 61-79.
AGHAI, S., MOLLAVERDI, N. & SABBAGH, M. S. 2014. A fuzzy multi-objective programming model for supplier selection with volume discount and risk criteria. *The International Journal of Advanced Manufacturing Technology,* 71**,** 1483-1492.
AGUILAR, F. J. 1967. *Scanning the business environment*, Macmillan.
AHMADY, N., AZADI, M., SADEGHI, S. A. H. & SAEN, R. F. 2013. A novel fuzzy data envelopment analysis model with double frontiers for supplier selection. *International Journal of Logistics Research and Applications,* 16**,** 87-98.
ALINEZAD, A., SEIF, A. & ESFANDIARI, N. 2013. Supplier evaluation and selection with QFD and FAHP in a pharmaceutical company. *The International Journal of Advanced Manufacturing Technology,* 68**,** 355-364.
AMID, A., GHODSYPOUR, S. H. & O'BRIEN, C. 2006. Fuzzy multiobjective linear model for supplier selection in a supply chain. *International Journal of Production Economics,* 104**,** 394-407.
AMID, A., GHODSYPOUR, S. H. & O'BRIEN, C. 2009. A weighted additive fuzzy multiobjective model for the supplier selection problem under price breaks in a supply chain. *International Journal of Production Economics,* 121**,** 323-332.
AMIN, S. H. & ZHANG, G. 2012. An integrated model for closed-loop supply chain configuration and supplier selection: Multi-objective approach. *Expert Systems with Applications,* 39**,** 6782-6791.
AMINDOUST, A., AHMED, S., SAGHAFINIA, A. & BAHREININEJAD, A. 2012. Sustainable supplier selection: A ranking model based on fuzzy inference system. *Applied Soft Computing,* 12**,** 1668-1677.
ANDERSON, J. C. & NARUS, J. A. 1990. A model of distributor firm and manufacturer firm working partnerships. *Journal of Marketing,* 54**,** 42-58.
ARBEL, A. 1989. Approximate articulation of preference and priority derivation. *European Journal of Operational Research,* 43**,** 317-326.
ARIKAN, F. 2013. A fuzzy solution approach for multi objective supplier selection. *Expert Systems with Applications,* 40**,** 947-952.
ATHAWALE, V. M. & CHAKRABORTY, S. 2011. Application of Grey Relational Analysis Method in Solving Supplier Selection Problems. *The IUP Journal of Operations Management,* 10**,** 18-28.
ATHAWALE, V. M., MUKHERJEE, P. & CHAKRABORTY, S. 2009. Supplier selection using multi-criteria decision-making methods. *The IUP Journal of Operations Management,* 8**,** 41-60.
AYDıN KESKIN, G., İLHAN, S. & ÖZKAN, C. 2010. The Fuzzy ART algorithm: A categorization method for supplier evaluation and selection. *Expert Systems with Applications,* 37**,** 1235-1240.
AZADNIA, A. H., SAMAN, M. Z. M. & WONG, K. Y. 2014. Sustainable supplier selection and order lot-sizing: an integrated multi-objective decision-making process. *International Journal of Production Research,* 53**,** 383-408.
B Y K ZKAN, G. 2012. An integrated fuzzy multi-criteria group decision-making approach for green supplier evaluation. *International Journal of Production Research,* 50**,** 2892-2909.

BALEŽENTIS, A. & BALEŽENTIS, T. 2011. An innovative multi-criteria supplier selection based on two-tuple MULTIMOORA and hybrid data. *Economic Computation & Economic Cybernetics Studies & Research,* 45**,** 37-56.

BARRATT, M. 2004. Understanding the meaning of collaboration in the supply chain. *Supply Chain Management,* 9**,** 30-42.

BARUA, A., RAVINDRAN, S. & WHINSTON, A. B. 1997. Efficient selection of suppliers over the Internet. *Journal ofManagement Information Systems,* 13**,** 117-137.

BARZILAI, J. 1997. Deriving weights from pairwise comparison matrices. *Journal of the operational research society,* 48**,** 1226-1232.

BASNE, C. & WEINTRAUB, A. 2009. A genetic algorithm for a bicriteria supplier selection problem. *International Transactions in Operational Research,* 16**,** 173-187.

BAYAZIT, O. 2006. Use of analytic network process in vendor selection decisions. *Benchmarking: An International Journal,* 13**,** 566-579.

BENNETT, D. & KLUG, F. 2012. Logistics supplier integration in the automotive industry. *International Journal of Operations & Production Management,* 32**,** 1281-1305.

BENTON, W. & MALONI, M. 2005. The influence of power driven buyer/seller relationships on supply chain satisfaction. *Journal of Operations Management,* 23**,** 1-22.

BENYOUCEF, L., XIE, X. & TANONKOU, G. A. 2013. Supply chain network design with unreliable suppliers: a Lagrangian relaxation-based approach. *International Journal of Production Research,* 51**,** 6435-6454.

BEVILACQUA, M., CIARAPICA, F. E. & GIACCHETTA, G. 2006. A fuzzy-QFD approach to supplier selection. *Journal of Purchasing and Supply Management,* 12**,** 14-27.

BEVIS, T. 2012. *Java Design Pattern Essentials*, Ability First Limited.

BICHESCU, B. C. & FRY, M. J. 2009. Vendor-managed inventory and the effect of channel power. *OR spectrum,* 31**,** 195-228.

BLAU, P. M. 1964. *Exchange and power in social life*, J. Wiley.

BLESSING, L. T. M. & CHAKRABARTI, A. 2009. *DRM, a Design Research Methodology*, Springer.

BOER, L. D., WEGEN, L. V. D. & TELGEN, J. 1998. Outranking methods in support of supplier selection. *European Journal of Purchasing & Supply Managemen,* 4**,** 109-118.

BORAN, F. E., GEN , S., KURT, M. & AKAY, D. 2009. A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. *Expert Systems with Applications,* 36**,** 11363-11368.

BOWERSOX, D. J., CLOSS, D. J. & STANK, T. P. 1999. *21st Century Logistics: Making Supply Chain Integration a Reality*, Council of Logistics Management.

BROWN, J. R., LUSCH, R. F. & NICHOLSON, C. Y. 1996. Power and relationship commitment: their impact on marketing channel member performance. *Journal of retailing,* 71**,** 363-392.

BUCKLEY, J. J. 1985. Fuzzy hierarchical analysis. *Fuzzy sets and systems,* 17**,** 233-247.

BÜYÜKÖZKAN, G. & ÇIF I, G. 2012. A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications,* 39**,** 3000-3011.

ÇAĞLIYAN, V. 2011. The level of meeting supplier selection criteria by the sub-industry: the case of Turkish automotive industry. *Suleyman Demirel University Journal of Faculty of Economics & Administrative Sciences,* 16**,** 467-478.

CAI, S., GOH, M., DE SOUZA, R. & LI, G. 2013. Knowledge sharing in collaborative supply chains: twin effects of trust and power. *International Journal of Production Research,* 51**,** 2060-2076.

CAKRAVASTIA, A. & TAKAHASHI, K. 2004. Integrated model for supplier selection and negotiation in a make-to-order environment. *International Journal of Production Research,* 42**,** 4457-4474.

CANI LS, M. C. & GELDERMAN, C. J. 2007. Power and interdependence in buyer supplier relationships: A purchasing portfolio approach. *Industrial Marketing Management,* 36**,** 219-229.

CANI LS, M. C. & ROELEVELD, A. 2009. Power and dependence perspectives on outsourcing decisions. *European Management Journal,* 27**,** 402-417.

CAO, Y., LUO, X., KWONG, C. K. & TANG, J. 2014. Supplier pre-selection for platform-based products: a multi-objective approach. *International Journal of Production Research,* 52**,** 1-19.

CHAI, J., LIU, J. N. K. & NGAI, E. W. T. 2013. Application of decision-making techniques in supplier selection: A systematic review of literature. *Expert Systems with Applications,* 40**,** 3872-3885.

CHAMODRAKAS, I., BATIS, D. & MARTAKOS, D. 2010. Supplier selection in electronic marketplaces using satisficing and fuzzy AHP. *Expert Systems with Applications,* 37**,** 490-498.

CHAN, F. T. S. 2003. Interactive selection model for supplier selection process: an analytical hierarchy process approach. *International Journal of Production Research,* 41**,** 3549-3579.

CHAN, F. T. S. & CHAN, H. K. 2004. Development of the supplier selection model--a case study in the advanced technology industry. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 218**,** 1807-1824.

CHAN, F. T. S. & CHAN, H. K. 2010. An AHP model for selection of suppliers in the fast changing fashion market. *The International Journal of Advanced Manufacturing Technology,* 51**,** 1195-1207.

CHAN, F. T. S. & KUMAR, N. 2007. Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega,* 35**,** 417-431.

CHAN, F. T. S., KUMAR, N., TIWARI, M. K., LAU, H. C. W. & CHOY, K. L. 2008. Global supplier selection: a fuzzy-AHP approach. *International Journal of Production Research,* 46**,** 3825-3857.

CHANG, B., CHANG, C.-W. & WU, C.-H. 2011. Fuzzy DEMATEL method for developing supplier selection criteria. *Expert Systems with Applications,* 38**,** 1850-1858.

CHANG, C.-H. 2013. An intelligent supplier selection system based on self organizing map, rough set theory, and bayesian belief network. *International Journal of Electronic Business Management,* 11**,** 100-112.

CHANG, C.-T., CHEN, H.-M. & ZHUANG, Z.-Y. 2014. Integrated multi-choice goal programming and multi-segment goal programming for supplier selection considering imperfect-quality and price-quantity discounts in a multiple sourcing environment. *International Journal of Systems Science,* 45**,** 1101-1111.

CHANG, D.-Y. 1996. Applications of the extent analysis method on fuzzy AHP. *European journal of operational research,* 95**,** 649-655.

CHAUDHRY, S. S. 1993. Vendor selection with price breaks. *European Journal of Operational Research,* 70**,** 52-66.

CHAURASIA, S. 2014. An empirical analysis of power in retailer-manufacturer supply chain relationship: A resource dependency perspective. *IUP Journal of Supply Chain Management,* 11**,** 52-66.

CHE, Z. H. 2010. A genetic algorithm-based model for solving multi-period supplier selection problem with assembly sequence. *International Journal of Production Research,* 48**,** 4355-4377.

CHE, Z. H., CHIANG, T.-A., TU, C. & CHIANG, C.-J. 2010. A supplier selection model for product design changes. *International Journal of Electronic Business Management,* 8**,** 20-30.

CHEN, C.-T., LIN, C.-T. & HUANG, S.-F. 2006. A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics,* 102**,** 289-301.

CHEN, P.-S. & WU, M.-T. 2013. A modified failure mode and effects analysis method for supplier selection problems in the supply chain risk environment: A case study. *Computers & Industrial Engineering,* 66**,** 634-642.

CHEN, Y.-H. & CHAO, R.-J. 2012. Supplier selection using consistent fuzzy preference relations. *Expert Systems with Applications,* 39**,** 3233-3240.

CHEN, Y.-J. 2011. Structured methodology for supplier selection and evaluation in a supply chain. *Information Sciences,* 181**,** 1651-1670.

CHINOWSKY, B. 2009. *Getting Started with VBA in Excel 2010* [Online]. Available: https://msdn.microsoft.com/en-us/library/office/ee814737(v=office.14).aspx.

CHO, D.-S. & CHU, W. 1994. Determinants of bargaining power in OEM negotiations. *Industrial Marketing Management* 23**,** 343-355.

CHOI, T. Y. & HARTLEY, J. L. 1996. An exploration of supplier selection practices across the supply chain. *Journal of operations management,* 14**,** 333-343.

CHOU, S. & CHANG, Y. 2008. A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach. *Expert Systems with Applications,* 34**,** 2241-2253.

CHOUDHARY, D. & SHANKAR, R. 2014. A goal programming model for joint decision making of inventory lot-size, supplier selection and carrier selection. *Computers & Industrial Engineering,* 71**,** 1-9.

CHRISTOPHER, M. 2011. Logistics, the supply chain and competitive strategy. *Logistics & Supply Chain Management.* Fourth edition ed.: Pearson Education.

CLARK, K. B. & FUJIMOTO, T. 1991. *Product development performance: Strategy, organization, and management in the world auto industry*, Harvard Business Press.

CNV, S., K, V. R. & V, V. R. 2010. Investigations on supplier selection for e-manufacturing: A case study. *International Journal of Business Insights & Transformation,* 3**,** 63-77.

COOL, K. & HENDERSON, J. 1998. Power and firm profitability in supply chains: French manufacturing industry in 1993. *Strategic Management Journal,* 19**,** 909-926.

COSTANTINO, N., DOTOLI, M., FALAGARIO, M. & FANTI, M. P. 2011. Using fuzzy decision making for supplier selection in public procurement. *Journal of Public Procurement,* 11**,** 403-427.

COX, A. 1999. Power, value and supply chain management. *Supply Chain Management: An International Journal,* 4**,** 167-175.

COX, A. 2001. Understanding buyer and supplier power: A framework for procurement and supply competence. *Journal of Supply Chain Management,* 37**,** 8-15.

COX, A. 2004. The art of the possible: relationship management in power regimes and supply chains. *Supply Chain Management: An International Journal,* 9**,** 346-356.

COX, A., SANDERSON, J. & WATSON, G. 2001. Supply chains and power regimes: toward an analytic framework for managing extended networks of buyer and supplier relationships. *Journal of Supply Chain Management,* 37**,** 28-35.

DAHL, R. 1957. The concept of power. *Systems Research and Behavioral Science* 2**,** 201-215.

DAI, J. & BLACKHURST, J. 2012. A four-phase AHP–QFD approach for supplier assessment: a sustainability perspective. *International Journal of Production Research,* 50**,** 5474-5490.

DAS, A., NARASIMHAN, R. & TALLURI, S. 2006. Supplier integration - Finding an optimal configuration. *Journal of Operations Management,* 24**,** 563-582.

DE BOER, L., LABRO, E. & MORLACCHI, P. 2001. A review of methods supporting supplier selection. *European Journal of Purchasing & Supply Management,* 7**,** 75-89.

DE BOER, L. & VAN DER WEGEN, L. 2003. Practice and promise of formal supplier selection: a study of four empirical cases. *Journal of Purchasing and Supply Management,* 9**,** 109-118.

DEMIRTAS, E. A. & ÜST N, Ö. 2008. An integrated multiobjective decision making process for supplier selection and order allocation. *Omega,* 36**,** 76-90.

DENG, S., AYDIN, R., KWONG, C. K. & HUANG, Y. 2014a. Integrated product line design and supplier selection: A multi-objective optimization paradigm. *Computers & Industrial Engineering,* 70**,** 150-158.

DENG, X., HU, Y., DENG, Y. & MAHADEVAN, S. 2014b. Supplier selection using AHP methodology extended by D numbers. *Expert Systems with Applications,* 41**,** 156-167.

DICKSON, G. W. 1966. An analysis of vendor selection systems and decisions. *Journal of Purchasing,* 2**,** 5-17.

DING, H., BENYOUCEF, L. & XIE, X. 2005. A simulation optimization methodology for supplier selection problem. *International Journal of Computer Integrated Manufacturing,* 18**,** 210-224.

DONG, Y., ZHANG, G., HONG, W.-C. & XU, Y. 2010. Consensus models for AHP group decision making under row geometric mean prioritization method. *Decision Support Systems,* 49**,** 281-289.

DOTOLI, M. & FALAGARIO, M. 2012. A hierarchical model for optimal supplier selection in multiple sourcing contexts. *International Journal of Production Research,* 50**,** 2953-2967.

DULMIN, R. & MININNO, V. 2003. Supplier selection using a multi-criteria decision aid method. *Journal of Purchasing and Supply Management,* 9**,** 177-187.

DURSUN, M. & KARSAK, E. E. 2013. A QFD-based fuzzy MCDM approach for supplier selection. *Applied Mathematical Modelling,* 37**,** 5864-5875.

ECHTELT, F. E. A. V., WYNSTRA, F., WEELE, A. J. V. & DUYSTERS, G. 2008. Managing supplier involvement in New Product Development: A multiple-case study. *Journal of Product Innovation Management,* 25**,** 180–201.

ECKERT, C., STACEY, M. & CLARKSON, P. J. The lure of the measurable in design research. the 8th International Design Conference, 2004.

ECKERT, C. M., STACEY, M. & CLARKSON, P. The spiral of applied research: a methodological view on integrated design research. the 14th International Conference on Engineering Design, 2003.

EKICI, A. 2013. An improved model for supplier selection under capacity constraint and multiple criteria. *International Journal of Production Economics,* 141**,** 574-581.

EL-ANSARY, A. I. & STERN, L. W. 1972. Power measurement in the distribution channel. *Journal of Marketing research,* 9**,** 47-52.

EMERSON, R. M. 1962. Power-dependence relations. *American sociological review,* 27**,** 31-41.

ERTAY, T., KAHVECI, A. & TABANLı, R. M. 2011. An integrated multi-criteria group decision-making approach to efficient supplier selection and clustering using fuzzy preference relations. *International Journal of Computer Integrated Manufacturing,* 24**,** 1152-1167.

ETGAR, M. 1976. Channel domination and countervailing power in distributive channels. *Journal of marketing research,* 13**,** 254-262.

FACCHINETTI, G., RICCI, R. G. & MUZZIOLI, S. 1998. Note on ranking fuzzy triangular numbers. *International Journal of Intelligent Systems,* 13**,** 613-622.

FALSINI, D., FONDI, F. & SCHIRALDI, M. M. 2012. A logistics provider evaluation and selection methodology based on AHP, DEA and linear programming integration. *International Journal of Production Research,* 50**,** 4822-4829.

FARZIPOOR SAEN, R. 2010. Developing a new data envelopment analysis methodology for supplier selection in the presence of both undesirable outputs and imprecise data. *The International Journal of Advanced Manufacturing Technology,* 51**,** 1243-1250.

FAZLOLLAHTABAR, H., MAHDAVI, I., ASHOORI, M. T., KAVIANI, S. & MAHDAVI-AMIRI, N. 2010. A multi-objective decision-making process of supplier selection and order allocation for multi-period scheduling in an electronic market. *The International Journal of Advanced Manufacturing Technology,* 52**,** 1039-1052.

FEKETE, Z. A. & HANCU, L.-V. 2010. A supplier selection model for software development outsourcing. *Annals of the University of Oradea, Economic Science Series,* 1**,** 1190-1195.

FELLER, A., SHUNK, D. & CALLARMAN, T. 2006. Value chains versus supply chains. *BPTrends, March***,** 1-7.

FENG, B. 2012. Multisourcing suppliers selection in service outsourcing. *Journal of the Operational Research Society,* 63**,** 582-596.

FERREIRA, L. & BORENSTEIN, D. 2012. A fuzzy-Bayesian model for supplier selection. *Expert Systems with Applications,* 39**,** 7834-7844.

FLANAGAN, T. 2006. *Supporting design planning through process model simulation.* Ph.D. Thesis, Cambridge University.

FRENCH, J. R., RAVEN, B. & CARTWRIGHT, D. 1959. The bases of social power. *Classics of organization theory***,** 311-320.

GANESAN, S. 1994. Determinants of long-term orientation in buyer-seller relationships. *Journal of Marketing,* 58**,** 1-19.

GARC A, N., PUENTE, J., FERN NDEZ, I. & PRIORE, P. 2013. Supplier selection model for commodities procurement. Optimised assessment using a fuzzy decision support system. *Applied Soft Computing,* 13**,** 1939-1951.

GENOVESE, A., LENNY KOH, S. C., BRUNO, G. & ESPOSITO, E. 2013. Greener supplier selection: state of the art and some empirical evidence. *International Journal of Production Research,* 51**,** 2868-2886.

GERICKE, K., ECKERT, C. & STACEY, M. What do we need to say about a design method? International Conference on Engineering Design, 2017. the Design Society.

GHODSYPOUR, S. H. & O'BRIEN, C. 1998. A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming. *International Journal of Production Economics,* 56-57**,** 199-212.

GHODSYPOUR, S. H. & O’BRIEN, C. 2001. The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint. *international Journal of Production Economics,* 73**,** 15-27.

GHOLIPOUR, R., JANDAGHI, G. & RAJAEI, R. 2014. Contractor selection in MCDM context using fuzzy AHP. *Iranian Journal of Management Studies,* 7**,** 151-173.

GHORBANI, M., MOHAMMAD ARABZAD, S. & SHAHIN, A. 2013. A novel approach for supplier selection based on the Kano model and fuzzy MCDM. *International Journal of Production Research,* 51**,** 5469-5484.

GNANASEKARAN, S., VELAPPAN, S. & A, S. 2008. Development of a supplier selection system by combining Analytic Hierarchy Process and Grey Relational Analysis: An automobile industry case study. *ICFAI Journal of supply chain management,* 4**,** 82-94.

GUNASEKARAN, A., PATEL, C. & MCGAUGHEY, R. E. 2004. A framework for supply chain performance measurement. *International Journal of Production Economics,* 87**,** 333-347.

GUNERI, A. F. & KUZU, A. 2009. Supplier selection by using a fuzzy approach in just-in-time: A case study. *International Journal of Computer Integrated Manufacturing,* 22**,** 774-783.

HA, S. H. & KRISHNAN, R. 2008. A hybrid approach to supplier selection for the maintenance of a competitive supply chain. *Expert Systems with Applications,* 34**,** 1303-1311.

HADI-VENCHEH, A. 2011. A new nonlinear model for multiple criteria supplier-selection problem. *International Journal of Computer Integrated Manufacturing,* 24**,** 32-39.

HADI-VENCHEH, A. & NIAZI-MOTLAGH, M. 2011. An improved voting analytic hierarchy process–data envelopment analysis methodology for suppliers selection. *International Journal of Computer Integrated Manufacturing,* 24**,** 189-197.

HANDFIELD, R., WALTON, S. V., SROUFE, R. & MELNYK, S. A. 2002. Applying environmental criteria to supplier assessment: A study in the application of the Analytical Hierarchy Process. *European Journal of Operational Research,* 141**,** 70-87.

HARLAND, C. M. 1996. Supply chain management: relationships, chains and networks. *British Journal of management,* 7**,** S63-S80.

HELANDER, A. & M LLER, K. 2008. System supplier's roles from equipment supplier to performance provider. *Journal of Business & Industrial Marketing,* 23**,** 577-585.

HERBON, A., MOALEM, S., SHNAIDERMAN, H. & TEMPLEMAN, J. 2012. Dynamic weights approach for off-line sequencing of supplier selection over a finite planning horizon. *International Journal of Physical Distribution & Logistics Management,* 42**,** 434-463.

HO, W., XU, X. & DEY, P. K. 2010. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research,* 202**,** 16-24.

HOBBES, T. 1651. *Leviathan,, Part I: "Of Man", Chapters 10–16.*

HSU, B.-M., CHIANG, C.-Y. & SHU, M.-H. 2010. Supplier selection using fuzzy quality data and their applications to touch screen. *Expert Systems with Applications,* 37**,** 6192-6200.

HSU, C. C., KANNAN, V. R., KEONG LEONG, G. & TAN, K. C. 2006. Supplier selection construct: instrument development and validation. *The International Journal of Logistics Management,* 17**,** 213-239.

HU, X., MUNSON, C. L. & FOTOPOULOS, S. B. 2012. Purchasing decisions under stochastic prices: Approximate solutions for order time, order quantity and supplier selection. *Annals of Operations Research,* 201**,** 287-305.

HUANG, J.-D. & HU, M. H. 2013. Two-stage solution approach for supplier selection: A case study in a Taiwan automotive industry. *International Journal of Computer Integrated Manufacturing,* 26**,** 237-251.

HUANG, S. H. & KESKAR, H. 2007. Comprehensive and configurable metrics for supplier selection. *International Journal of Production Economics,* 105**,** 510-523.

HUMPHREYS, P., MCCLOSKEY, A., MCIVOR, R., MAGUIRE, L. & GLACKIN, C. 2006. Employing dynamic fuzzy membership functions to assess environmental performance in the supplier selection process. *International Journal of Production Research,* 44**,** 2379-2419.

HUNT, S. D. & NEVIN, J. R. 1974. Power in a channel of distribution: sources and consequences. *Journal of marketing Research,* 11**,** 186-193.

HWANG, C. L. & YOON, K. 1981. *Multiple attribute decision making, methods and applications,* Now York, Springer-Verlag.

INEMEK, A. & TUNA, O. 2009. Global supplier selection strategies and implications for supplier performance: Turkish suppliers' perception. *International Journal of Logistics Research and Applications,* 12**,** 381-406.

IRELAND, R. D. & WEBB, J. W. 2007. A multi-theoretic perspective on trust and power in strategic supply chains. *Journal of Operations Management,* 25**,** 482-497.

JADIDI, O., ZOLFAGHARI, S. & CAVALIERI, S. 2014. A new normalized goal programming model for multi-objective problems: A case of supplier selection and order allocation. *International Journal of Production Economics,* 148**,** 158-165.

JAFARI SONGHORI, M., TAVANA, M., AZADEH, A. & KHAKBAZ, M. H. 2010. A supplier selection and order allocation model with multiple transportation alternatives. *The International Journal of Advanced Manufacturing Technology,* 52**,** 365-376.

JAIN, V., WADHWA, S. & DESHMUKH, S. G. 2007. Supplier selection using fuzzy association rules mining approach. *International Journal of Production Research,* 45**,** 1323-1353.

JAJIMOGGALA, S., RAOB, V. V. S. K. & BEELA, S. 2011. Supplier evaluation using fuzzy Analytical Network Process and fussy TOPSIS. *Jordan Journal of Mechanical and Industrial Engineering,* 5**,** 543-551.

JARRATT, T. A. W. 2004. *A model-based approach to support the management of engineering change.* Ph.D. Thesis, Cambridge.

JEON, J., LEE, H. & PARK, Y. 2011. Implementing technology roadmapping with supplier selection for semiconductor manufacturing companies. *Technology Analysis & Strategic Management,* 23**,** 899-918.

JOHNSEN, T. E. 2009. Supplier involvement in new product development and innovation: Taking stock and looking to the future. *Journal of Purchasing & Supply Management,* 15**,** 187-197.

K HK NEN, A.-K. & VIROLAINEN, V. M. 2011. Sources of structural power in the context of value nets. *Journal of Purchasing and Supply Management,* 17**,** 109-120.

KABIR, G. & SUMI, R. S. 2010. An ontology-based intelligent system with AHP to support supplier selection. *Suranaree J. Sci. Technol,* 17**,** 249-257.

KAHRAMAN, C., CEBECI, U. & ULUKAN, Z. 2003. Multi-criteria supplier selection using fuzzy AHP. *Logistics Information Management,* 16**,** 382-394.

KAMATH, R. R. & LIKER, J. K. 1994. A second look at Japanese product development. *Harvard Business Review,* 72**,** 154-154.

KANG, H.-Y., LEE, A. H. I. & YANG, C. Y. 2012. A fuzzy ANP model for supplier selection as applied to IC packaging. *Journal of Intelligent Manufacturing,* 23**,** 1477-1488.

KANNAN, D., KHODAVERDI, R., OLFAT, L., JAFARIAN, A. & DIABAT, A. 2013. Integrated fuzzy multi criteria decision making method and multi-objective programming approach for supplier selection and order allocation in a green supply chain. *Journal of Cleaner Production,* 47**,** 355-367.

KAPLINSKY, R. & MORRIS, M. 2001. Chapter 2 What is a value chain. *A handbook for value chain research.* IDRC Ottawa.

KARANDE, P. & CHAKRABORTY, S. 2012. Decision making for supplier selection using the MOORA method. *The IUP Journal of Operations Management,* 11**,** 6-18.

KARSAK, E. E. & DURSUN, M. 2016. Taxonomy and review of non-deterministic analytical methods for supplier selection. *International Journal of Computer Integrated Manufacturing,* 29**,** 263-286.

KASIRIAN, M. N. & YUSUFF, R. M. 2013. An integration of a hybrid modified TOPSIS with a PGP model for the supplier selection with interdependent criteria. *International Journal of Production Research,* 51**,** 1037-1054.

KE, W., LIU, H., WEI, K. K., GU, J. & CHEN, H. 2009. How do mediated and non-mediated power affect electronic supply chain management system adoption? The mediating effects of trust and institutional pressures. *Decision Support Systems,* 46**,** 839-851.

KERMANI, M. A. M. A., NAVIDI, H. & ALBORZI, F. 2012. A novel method for supplier selection by two competitors, including multiple criteria. *International Journal of Computer Integrated Manufacturing,* 25**,** 527-535.

KHORRAMSHAHGOL, R. 2012. An integrated strategic approach to supplier evaluation and selection. *International Journal of Information Technology & Decision Making,* 11**,** 55-76.

KILIC, H. S. 2013. An integrated approach for supplier selection in multi-item/multi-supplier environment. *Applied Mathematical Modelling,* 37**,** 7752-7763.

KIM, D. Y. & WAGNER, S. M. 2012. Supplier selection problem revisited from the perspective of product configuration. *International Journal of Production Research,* 50**,** 2864-2876.

KIM, M. & BOO, S. 2010. Understanding supplier-selection criteria: meeting planners' approaches to selecting and maintaining suppliers. *Journal of Travel & Tourism Marketing,* 27**,** 507-518.

KLEINDORFER, P. R., KUNREUTHER, H. & SCHOEMAKER, P. J. H. 1993. *Decision Sciences: An Integrative Perspective*, Cambridge University Press.

KLIR, G. & YUAN, B. 1995. *Fuzzy sets and fuzzy logic*, Prentice Hall New Jersey.

KOUFTEROS, X., VICKERY, S. K. & DR GE, C. 2012. The effects of strategic supplier selection on buyer competitive performance in matched domains: does supplier integration mediate the relationships? *Journal of Supply Chain Management,* 48**,** 93-115.

KULSHRESTHA, R., KULSHRESTHA, M., BHATNAGAR, S. P. & KATIYAR, C. K. 2007. Supplier performance evaluation and selection in the herbal industry. *Supply Chain Forum,* 8**,** 46-55.

KUMAR, A., JAIN, V. & KUMAR, S. 2014. A comprehensive environment friendly approach for supplier selection. *Omega,* 42**,** 109-123.

KUMAR, M., VRAT, P. & SHANKAR, R. 2004. A fuzzy goal programming approach for vendor selection problem in a supply chain. *Computers & Industrial Engineering,* 46**,** 69-85.

KUMAR, N., SCHEER, L. K. & STEENKAMP, J.-B. E. 1995. The effects of perceived interdependence on dealer attitudes. *Journal of marketing research,* 32**,** 348-356.

KUO, R. J. & LIN, Y. J. 2012. Supplier selection using analytic network process and data envelopment analysis. *International Journal of Production Research,* 50**,** 2852-2863.

KWAK, T. C., KIM, J. S. & MOON, C. 2006. Supplier–buyer models for the bargaining process over a long-term replenishment contract. *Computers & Industrial Engineering,* 51**,** 219-228.

LA LONDE, B. J. & MASTERS, J. M. 1994. Emerging logistics strategies: blueprints for the next century. *International Journal of Physical Distribution & Logistics Management,* 24**,** 35-47.

LABIB, A. W. 2011. A supplier selection model: a comparison of fuzzy logic and the analytic hierarchy process. *International Journal of Production Research,* 49**,** 6287-6299.

LAI, Y.-J., LIU, T.-Y. & HWANG, C.-L. 1994. Topsis for MODM. *European Journal of Operational Research,* 76**,** 486-500.

LAMBERT, D. M., COOPER, M. C. & PAGH, J. D. 1998. Supply chain management: Implementation issues and research opportunities. *The International Journal of Logistics Management,* 9**,** 1-20.

LASETER, T. M. & RAMDAS, K. 2002. Product types and supplier roles in product development: an exploratory analysis. *Engineering Management, IEEE Transactions on Engineering Management,* 49**,** 107-118.

LEE, A. H. I. 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Systems with Applications,* 36**,** 2879-2893.

LI, D.-Q., WANG, J.-Y. & LI, H.-X. 2009. Note on "On the normalization of interval and fuzzy weights". *Fuzzy Sets and Systems,* 160**,** 2722-2725.

LI, F., LI, L., JIN, C., WANG, R., WANG, H. & YANG, L. 2012a. A 3PL supplier selection model based on fuzzy sets. *Computers & Operations Research,* 39**,** 1879-1884.

LI, G.-D., YAMAGUCHI, D. & NAGAI, M. 2007. A grey-based decision-making approach to the supplier selection problem. *Mathematical and Computer Modelling,* 46**,** 573-581.

LI, Y., LIU, X. & CHEN, Y. 2012b. Supplier selection using axiomatic fuzzy set and TOPSIS methodology in supply chain management. *Fuzzy Optimization and Decision Making,* 11**,** 147-176.

LIAO, C.-N. & KAO, H.-P. 2011. An integrated fuzzy TOPSIS and MCGP approach to supplier selection in supply chain management. *Expert Systems with Applications,* 38**,** 10803-10811.

LIAO, M.-Y., WU, C.-W. & WU, J.-W. 2013. Fuzzy inference to supplier evaluation and selection based on quality index: a flexible approach. *Neural Computing and Applications,* 23**,** S117-S127.

LIKERT, R. 1932. A technique for the measurement of attitudes. *Archives of psychology*.

LIMA JUNIOR, F. R. & CARPINETTI, L. C. R. 2016. Combining SCOR® model and fuzzy TOPSIS for supplier evaluation and management. *International Journal of Production Economics,* 174**,** 128-141.

LIMA JUNIOR, F. R., OSIRO, L. & CARPINETTI, L. C. R. 2014. A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. *Applied Soft Computing,* 21**,** 194-209.

LIMA JUNIOR, R. F., OSIRO, X. & CARPINETTI, R. L. C. 2013. A fuzzy inference and categorization approach for supplier selection using compensatory and non-compensatory decision rules. *Applied Soft Computing* 13**,** 4133–4147.

LIN, C.-T., CHEN, C.-B. & TING, Y.-C. 2011. Business process re-engineering for supplier selection in electronics industry. *The Journal of Grey System,* 2**,** 175-182.

LIN, R.-H. 2012. An integrated model for supplier selection under a fuzzy situation. *International Journal of Production Economics,* 138**,** 55-61.

LINN, R. J., TSUNG, F. & ELLIS, L. W. C. 2006. Supplier Selection Based on Process Capability and Price Analysis. *Quality Engineering,* 18**,** 123-129.

LIOU, J. J. H., CHUANG, Y.-C. & TZENG, G.-H. 2014. A fuzzy integral-based model for supplier evaluation and improvement. *Information Sciences,* 266**,** 199-217.

LIU, F.-H. F. & HAI, H. L. 2005. The voting analytic hierarchy process method for selecting supplier. *International Journal of Production Economics,* 97**,** 308-317.

LIU, H., KE, W., WEI, K. K. & HUA, Z. 2015. Influence of power and trust on the intention to adopt electronic supply chain management in China. *International Journal of Production Research,* 53**,** 70-87.

LIU, P. & ZHANG, X. 2011. Research on the supplier selection of a supply chain based on entropy weight and improved ELECTRE-III method. *International Journal of Production Research,* 49**,** 637-646.

LIU, Y. & ZOLGHADRI, M. Power interaction in non-hierarchical supply chain network. 17th International Conference on Concurrent Enterprising (ICE), 2011. IEEE.

LORENTZ, H., PUNNIYAMOORTY, M., MATHIYALAGAN, P. & LAKSHMI, G. 2012. A combined application of structural equation modeling (SEM) and analytic hierarchy process (AHP) in supplier selection. *Benchmarking: An International Journal,* 19**,** 70-92.

LUENBERGER, D. G. & YE, Y. 2008. *Linear and nonlinear programming*, Springer Science & Business Media.

LUO, X. G., KWONG, C. K., TANG, J. F., DENG, S. F. & GONG, J. 2011. Integrating supplier selection in optimal product family design. *International Journal of Production Research,* 49**,** 4195-4222.

LYSONS, K. & FARRINGTON, B. 2012. *Purchasing and Supply Chain Management*, Pearson Education Limited.

MA, R., YAO, L., JIN, M. & REN, P. 2014. The DEA game cross-efficiency model for supplier selection problem under competition. *Applied Mathematics & Information Sciences,* 8**,** 811-818.

MAK, K. L., CUI, L. X. & SU, W. 2011. Optimal supplier selection and order allocation for multi-period multi-product manufacturing incorporating customer flexibility. *Engineering Letters,* 19**,** 331-338.

MALONI, M. & BENTON, W. C. 2000. Power influences in the supply chain. *Journal of Business Logistics,* 21**,** 49-74.

MARTIN, R. C. 2012. *Agile software development: principles, patterns, and practices*, Pearson Prentice Hall.

MASELLA, C. & RANGONE, A. 2000. A contingent approach to the design of vendor selection systems for different types of co-operative customer/supplier relationships. *International Journal of Operations & Production Management,* 20**,** 70-84.

MATHWORKS, T. 2014. *Fuzzy logic toolbox user's guide*, The Mathworks Inc.

MCCUTCHEON, D. & STUART, F. I. 2000. Issues in the choice of supplier alliance partners. *Journal of Operations Management,* 18**,** 279-301.

MEHRALIAN, G., GATARI, A. R., MORAKABATI, M. & VATANPOUR, H. 2012. Developing a suitable model for supplier selection based on supply chain risks: An empirical study from Iranian pharmaceutical companies. *Iranian Journal of Pharmaceutical Research,* 11**,** 209-219.

MENTZER, J. T., DEWITT, W., KEEBLER, J. S., MIN, S., NIX, N. W., SMITH, C. D. & ZACHARIA, Z. G. 2001. Defining supply chain management. *Journal of Business logistics,* 22**,** 1-25.

MıZRAK ÖZFIRAT, P., TUNA TAŞOGLU, G. & TUN EL MEMIŞ, G. 2014. A fuzzy analytic hierarchy process methodology for the supplier selection problem. *Journal of Enterprise Information Management,* 27**,** 292-301.

MUNSON, C. L., ROSENBLATT, M. J. & ROSENBLATT, Z. 1999. The use and abuse of power in supply chains. *Business Horizons,* 42**,** 55-65.

NAIMI SADIGH, A., FALLAH, H. & NAHAVANDI, N. 2013. A multi-objective supply chain model integrated with location of distribution centers and supplier selection decisions. *The International Journal of Advanced Manufacturing Technology,* 69**,** 225-235.

NARASIMHAN, R. & TALLURI, S. 2006. Multiproduct, Multicriteria Model for Supplier Selection with Product Life-Cycle Considerations. *Decision Sciences,* 37**,** 577-603.

NG, E. 2010. Understanding B2B supplier selection relationships: The case of Taiwan agribusinesses. *Journal of Business-to-Business Marketing,* 17**,** 149-172.

NG, W. L. 2008. An efficient and simple model for multiple criteria supplier selection problem. *European Journal of Operational Research,* 186**,** 1059-1067.

NOORUL HAQ, A. & KANNAN, G. 2006a. Design of an integrated supplier selection and multi-echelon distribution inventory model in a built-to-order supply chain environment. *International Journal of Production Research,* 44**,** 1963-1985.

NOORUL HAQ, A. & KANNAN, G. 2006b. Fuzzy analytical hierarchy process for evaluating and selecting a vendor in a supply chain model. *The International Journal of Advanced Manufacturing Technology,* 29**,** 826-835.

NYAGA, G. N., LYNCH, D. F., MARSHALL, D. & AMBROSE, E. 2013. Power asymmetry, adaptation and collaboration in dyadic relationships involving a powerful partner. *Journal of Supply Chain Management,* 49**,** 42-65.

OMURCA, S. I. 2013. An intelligent supplier evaluation, selection and development system. *Applied Soft Computing,* 13**,** 690-697.

ÖN T, S., KARA, S. S. & IŞIK, E. 2009. Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Systems with Applications,* 36**,** 3887-3895.

OPRICOVIC, S. & TZENG, G.-H. 2004. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research,* 156**,** 445-455.

ORDOOBADI, S. M. 2009. Development of a supplier selection model using fuzzy logic. *Supply Chain Management: An International Journal,* 14**,** 314-327.

PAI, F.-Y. & YEH, T.-M. 2010. The effects of inter-firm power and supply partner assessment on supply chain integration. *African Journal of Business Management,* 4**,** 1308-1319.

PANG, B. & BAI, S. 2013. An integrated fuzzy synthetic evaluation approach for supplier selection based on analytic network process. *Journal of Intelligent Manufacturing,* 24**,** 163-174.

PEARN, W. L. & WU, C. H. 2013. Supplier selection critical decision values for processes with multiple independent lines. *Quality and Reliability Engineering International,* 29**,** 899-909.

PEARSON, J. N. & ELLRAM, L. M. 1995. Supplier selection and evaluation in small versus large electronics firms. *Journal of Small Business Management,* 33**,** 53-65.

PEDERSON, K., EMBLEMSVAG, J., BAILEY, R., ALLEN, J. K. & MISTREE, F. Validating design methods & research: The Validation Square. ASME Design Engineering Technical Conference, 2000 Baltimore, Maryland.

PETERSEN, K. J., HANDFIELD, R. B. & RAGATZ, G. L. 2005. Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of Operations Management,* 23**,** 371-388.

PETRONI, A. & PANCIROLI, B. 2002. Innovation as a determinant of suppliers' roles and performances: an empirical study in the food machinery industry. *European Journal of Purchasing & Supply Management,* 8**,** 135-149.

PFEFFER, J. & SALANCIK, G. R. 2003. *The external control of organizations: A resource dependence perspective*, Stanford University Press.

PICKTON, D. W. & WRIGHT, S. 1998. What's swot in strategic analysis? *Strategic change,* 7**,** 101-109.

PIDDUCK, A. B. 2006. Issues in supplier partner selection. *Journal of Enterprise Information Management,* 19**,** 262-276.

PITCHIPOO, P., VENKUMAR, P. & RAJAKARUNAKARAN, S. 2012. A distinct decision model for the evaluation and selection of a supplier for a chemical processing industry. *International Journal of Production Research,* 50**,** 4635-4648.

PITCHIPOO, P., VENKUMAR, P. & RAJAKARUNAKARAN, S. 2013. Fuzzy hybrid decision model for supplier evaluation and selection. *International Journal of Production Research,* 51**,** 3903-3919.

PORTER, M. E. 1979. How competitive forces shape strategy. *Harvard business Review***,** 137-145.

PORTER, M. E. 2008. The five competitive forces that shape strategy. *Harvard business Review***,** 79-93.

QIAN, L. 2014. Market-based supplier selection with price, delivery time, and service level dependent demand. *International Journal of Production Economics,* 147**,** 697-706.

RADFAR, R. & SALAHI, F. 2014. Evaluation and ranking of suppliers with fuzzy DEA and PROMETHEE approach. *Int. J. Industrial Mathematics,* 6**,** 189-197.

RAMANATHAN, R. 2006. Data envelopment analysis for weight derivation and aggregation in the analytic hierarchy process. *Computers & Operations Research,* 33**,** 1289-1307.

RAMANATHAN, R. 2007. Supplier selection problem: integrating DEA with the approaches of total cost of ownership and AHP. *Supply Chain Management: An International Journal,* 12**,** 258-261.

RATNASINGAM, P. 2000. The influence of power on trading partner trust in electronic commerce. *Internet Research,* 10**,** 56-63.

RAUT, R. D. 2011. Environmental performance: A hybrid method for supplier selection using AHP-DEA. *International Journal of Business Insights & Transformation,* 5**,** 16-29.

RAUT, R. D., BHASIN, H. V. & KAMBLE, S. S. 2010. Exploring critical criteria for supplier selection by CNG/LPG kit manufacturers in India-selection of suppliers for compressed natural gas and liquefied petroleum gas kit manufacturers: A case study and proposed methodology. *International Journal of Business Insights & Transformation,* 3**,** 35-45.

RAVINDRAN, A. R., UFUK BILSEL, R., WADHWA, V. & YANG, T. 2010. Risk adjusted multicriteria supplier selection models with applications. *International Journal of Production Research,* 48**,** 405-424.

RAZMI, J. & RAFIEI, H. 2010. An integrated analytic network process with mixed-integer non-linear programming to supplier selection and order allocation. *The International Journal of Advanced Manufacturing Technology,* 49**,** 1195-1208.

RAZMI, J., RAFIEI, H. & HASHEMI, M. 2009. Designing a decision support system to evaluate and select suppliers using fuzzy analytic network process. *Computers & Industrial Engineering,* 57**,** 1282-1290.

REZAEI, J. & DAVOODI, M. 2012. A joint pricing, lot-sizing, and supplier selection model. *International Journal of Production Research,* 50**,** 4524-4542.

REZAEI, J. & ORTT, R. 2012. A multi-variable approach to supplier segmentation. *International Journal of Production Research,* 50**,** 4593-4611.

ROBBINS, S. P. & BARNWELL, N. 2006. *Organisation theory: Concepts and cases*, Pearson Education Australia.

ROSTAMIYAN, E., TOHIDI, G. & MORADIFAR, A. 2013. Supplier selection in supply chain management with OWA operator weights. *International Journal of u- and e- Service, Science and Technology,* 6**,** 169-180.

ROUTROY, S. 2008. Decision framework for supplier evaluation and selection in supply chain. *ICFAI Journal of supply chain management,* 5**,** 19-32.

ROY, B. 1991. The outranking approach and the foundations of ELECTRE methods. *Theory and decision,* 31**,** 49-73.

RUIZ-TORRES, A. J., MAHMOODI, F. & ZENG, A. Z. 2013. Supplier selection model with contingency planning for supplier failures. *Computers & Industrial Engineering,* 66**,** 374-382.

SAATY, T. L. 1980. The analytic hierarchy process: planning, priority setting, resources allocation. *New York: McGraw*.

SAATY, T. L. 1990. How to make a decision: the analytic hierarchy process. *European journal of operational research,* 48**,** 9-26.

SAATY, T. L. 2005. *Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks*, RWS publications.

SAATY, T. L. 2008. Relative measurement and its generalization in decision making why pairwise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process. *RACSAM-Revista de la Real Academia de Ciencias Exactas, Fisicas y Naturales. Serie A. Matematicas,* 102**,** 251-318.

SAATY, T. L. 2012a. Section: Establishing priorties: Consistency. *Decision making for leaders: the analytic hierarchy process for decisions in a complex world.* Third edition ed.: RWS publications.

SAATY, T. L. 2012b. Section: Establishing priorties: Making judgments. *Decision making for leaders: the analytic hierarchy process for decisions in a complex world.* Third edition ed.: RWS publications.

SADEGHI, M., RASHIDZADEH, M. A. & SOUKHAKIAN, M. A. 2012. Using analytic network process in a group decision-making for supplier selection. *INFORMATICA,* 23**,** 621-643.

SADEGHIEH, A., DEHGHANBAGHI, M., DABBAGHI, A. & BARAK, S. 2012. A genetic algorithm based grey goal programming (G3) approach for parts supplier evaluation and selection. *International Journal of Production Research,* 50**,** 4612-4630.

SAMANTRA, C., DATTA, S., MAHAPATRA, S., BANERJEE, S. & BANDYOPADHYAY, A. 2011. Multi-Attribute Group Decision Making for Supplier Selection Using Grey Analysis and Rough Set Theory. *International Journal of Business Insights & Transformation,* 5**,** 60-69.

SARKAR, A. & MOHAPATRA, P. K. 2006. Evaluation of supplier capability and performance: A method for supply base reduction. *Journal of Purchasing and Supply Management,* 12**,** 148-163.

SARKIS, J. & TALLURI, S. 2002. A model for strategic supplier selection. *Journal of Supply Chain Management,* 38**,** 18-28.

SARODE, A. D., KHODKE, P. M. & JAWED, M. 2010. Exploring criteria for selecting supplier as a 'Partner' in Indian manufacturing sector. *CURIE,* 3**,** 20-27.

ŞEN, C. G., ŞEN, S. & BAŞLıGIL, H. 2010. Pre-selection of suppliers through an integrated fuzzy analytic hierarchy process and max-min methodology. *International Journal of Production Research,* 48**,** 1603-1625.

ŞEN, S., BAŞLIGIL, H., ŞEN, C. G. & BARAÇLI, H. 2008. A framework for defining both qualitative and quantitative supplier selection criteria considering the buyer–supplier integration strategies. *International Journal of Production Research,* 46**,** 1825-1845.

SEPEHRIAR, A., ESLAMIPOOR, R. & NOBARI, A. 2013. A new mixed fuzzy-LP method for selecting the best supplier using fuzzy group decision making. *Neural Computing and Applications,* 23**,** S345-S352.

SEVKLI, M. 2010. An application of the fuzzy ELECTRE method for supplier selection. *International Journal of Production Research,* 48**,** 3393-3405.

SEVKLI, M., LENNY KOH, S. C., ZAIM, S., DEMIRBAG, M. & TATOGLU, E. 2007. An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey. *International Journal of Production Research,* 45**,** 1973-2003.

SHARMA, S. & BALAN, S. 2013. An integrative supplier selection model using Taguchi loss function, TOPSIS and multi criteria goal programming. *Journal of Intelligent Manufacturing,* 24**,** 1123-1130.

SHEMSHADI, A., SHIRAZI, H., TOREIHI, M. & TAROKH, M. J. 2011. A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting. *Expert Systems with Applications,* 38**,** 12160-12167.

SHEN, C.-Y. & YU, K.-T. 2012. An integrated fuzzy strategic supplier selection approach for considering the supplier integration spectrum. *International Journal of Production Research,* 50**,** 817-829.

SHEU, J.-B. 2014. Green supply chain collaboration for fashionable consumer electronics products under third-party power intervention—A resource dependence perspective. *Sustainability,* 6**,** 2832-2875.

SHU, M.-H. & WU, H.-C. 2009. Quality-based supplier selection and evaluation using fuzzy data. *Computers & Industrial Engineering,* 57**,** 1072-1079.

SIMATUPANG, T. M. & SRIDHARAN, R. 2002. The collaborative supply chain. *International Journal of Logistics Management,* 13**,** 15-30.

SKJOETT-LARSEN, T., THERN E, C. & ANDRESEN, C. 2003. Supply chain collaboration: Theoretical perspectives and empirical evidence. *International Journal of Physical Distribution & Logistics Management,* 33**,** 531-549.

SMITH, A. D. 2007. Effective supplier selection and management issues in modern manufacturing and marketing service environments. *Services Marketing Quarterly,* 29.

STADTLER, H. 2007. A general quantity discount and supplier selection mixed integer programming model. *OR Spectrum,* 29**,** 723-744.

STREMERSCH, S., WUYTS, S. & FRAMBACH, R. T. 2001. The purchasing of full-service contracts:: An exploratory study within the industrial maintenance market. *Industrial Marketing Management,* 30**,** 1-12.

TAHERA, K. 2014. *The role of testing in engineering product development processes.* Ph.D. Thesis, The Open University.

TAHRIRI, F., OSMAN, M. R., ALI, A. & YUSUFF, R. M. 2008. A review of supplier selection methods in manufacturing industries. *Suranaree J. Sci. Technol,* 15**,** 201-208.

TALLURI, S. & DECAMPOS, H. A. 2013. Supplier rationalization: A sourcing decision model. *Decision Sciences,* 44**,** 57-86.

TALLURI, S. & LEE, J. Y. 2010. Optimal supply contract selection. *International Journal of Production Research,* 48**,** 7303-7320.

TING, S. C. & CHO, D. I. 2008. An integrated approach for supplier selection and purchasing decisions. *Supply Chain Management: An International Journal,* 13**,** 116-127.

TZENG, G.-H. & HUANG, J.-J. 2011. *Multiple attribute decision making: methods and applications*, CRC press.

VAHDANI, B., IRANMANESH, S. H., MOUSAVI, S. M. & ABDOLLAHZADE, M. 2012. A locally linear neuro-fuzzy model for supplier selection in cosmetics industry. *Applied Mathematical Modelling,* 36**,** 4714-4727.

VIJAYVAGY, L. 2012. Decision framework for supplier selection through multi criteria evaluation models in supply chain. *International Journal of Management and Innovation,* 4**,** 16-28.

VINODH, S., RAMIYA, R. A. & GAUTHAM, S. G. 2011. Application of fuzzy analytic network process for supplier selection in a manufacturing organisation. *Expert Systems with Applications,* 38**,** 272-280.

VISWANADHAM, N. & SAMVEDI, A. 2013. Supplier selection based on supply chain ecosystem, performance and risk criteria. *International Journal of Production Research,* 51**,** 6484-6498.

VPSOLUTIONS 2013. *Visual PROMETHEE 1.4 Manual*.

WANG, D., TIAN, Y. & HU, Y. 2005. Empirical study of supplier selection practices in supply chain management in manufacturing companies. *International Journal of Innovation and Technology Management,* 2**,** 391-409.

WANG, F., ZENG, S. & ZHANG, C. 2013. A method based on intuitionistic fuzzy dependent aggregation operators for supplier selection. *Mathematical Problems in Engineering,* 2013**,** 1-9.

WANG, J.-W., CHENG, C.-H. & HUANG, K.-C. 2009a. Fuzzy hierarchical TOPSIS for supplier selection. *Applied Soft Computing,* 9**,** 377-386.

WANG, Y.-M., CHIN, K.-S. & LEUNG, J. P.-F. 2009b. A note on the application of the data envelopment analytic hierarchy process for supplier selection. *International Journal of Production Research,* 47**,** 3121-3138.

WANG, Y.-M. & ELHAG, T. M. 2006. On the normalization of interval and fuzzy weights. *Fuzzy sets and systems,* 157**,** 2456-2471.

WANG, Y.-M., LUO, Y. & HUA, Z. 2008. On the extent analysis method for fuzzy AHP and its applications. *European Journal of Operational Research,* 186**,** 735-747.

WATSON, G. 1999. Power and value appropriation in the direct-marketing publishing supply chain. *Supply Chain Management: An International Journal,* 4**,** 192-198.

WEBER, C. A. 1996. A data envelopment analysis approach to measuring vendor performance. *Supply Chain Management: An International Journal,* 1**,** 28-39.

WEBER, C. A., CURRENT, J. R. & BENTON, W. C. 1991. Vendor selection criteria and methods. *European journal of operational research,* 50**,** 2-18.

WEI, J., ZHAO, J. & LI, Y. 2013. Pricing decisions for complementary products with firms' different market powers. *European Journal of Operational Research,* 224**,** 507-519.

WELBORN, C. 2010. Applying Failure Mode and Effects Analysis to Supplier Selection. *The IUP Journal of Supply Chain Management,* 7**,** 7-14.

WHETTEN, D. A. 2002. Modelling-as-theorizing: A systematic methodology for theory development. *Essential skills for management research.* London: Sage.

WU, C.-W., LIAO, M.-Y. & YANG, T.-T. 2013a. Efficient methods for comparing two process yields – strategies on supplier selection. *International Journal of Production Research,* 51**,** 1587-1602.

WU, F., LI, H. Z., CHU, L. K. & SCULLI, D. 2013b. Supplier selection for outsourcing from the perspective of protecting crucial product knowledge. *International Journal of Production Research,* 51**,** 1508-1519.

WU, L. C. 2009. Supplier selection under uncertainty: a switching options perspective. *Industrial Management & Data Systems,* 109**,** 191-205.

WU, M. & WENG, Y. 2010. A study of supplier selection factors for high-tech industries in the supply chain. *Total Quality Management,* 21**,** 391-413.

WU, T. & BLACKHURST, J. 2009. Supplier evaluation and selection: an augmented DEA approach. *International Journal of Production Research,* 47**,** 4593-4608.

WU, W.-Y., LIN, C.-T. & KUNG, J.-Y. 2013c. Supplier selection in supply chain management by using fuzzy multiple-attribute decision-making method. *Journal of Intelligent & Fuzzy Systems,* 24**,** 175-183.

XIA, W. & WU, Z. 2007. Supplier selection with multiple criteria in volume discount environments. *Omega,* 35**,** 494-504.

XIAO, Z., CHEN, W. & LI, L. 2012. An integrated FCM and fuzzy soft set for supplier selection problem based on risk evaluation. *Applied Mathematical Modelling,* 36**,** 1444-1454.

Y CEL, A. & G NERI, A. F. 2011. A weighted additive fuzzy programming approach for multi-criteria supplier selection. *Expert Systems with Applications,* 38**,** 6281-6286.

Y CENUR, G. N., VAYVAY, Ö. & DEMIREL, N. Ç. 2011. Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment. *The International Journal of Advanced Manufacturing Technology,* 56**,** 823-833.

YAGER, R. R. 1981. A procedure for ordering fuzzy subsets of the unit interval. *Information sciences,* 24**,** 143-161.

YANG, C. C. & CHEN, B. S. 2006. Supplier selection using combined analytical hierarchy process and grey relational analysis. *Journal of Manufacturing Technology Management,* 17**,** 926-941.

YEUNG, J. H. Y., SELEN, W., ZHANG, M. & HUO, B. 2009. The effects of trust and coercive power on supplier integration. *International Journal of Production Economics,* 120**,** 66-78.

YU, P.-L. 1973. A class of solutions for group decision problems. *Management Science,* 19**,** 936-946.

ZADEH, L. A. 1965. Fuzzy sets. *Information and control,* 8**,** 338-353.

ZELENY, M. & COCHRANE, J. L. 1973. *Multiple criteria decision making*, University of South Carolina Press.

ZHANG, J.-L. & CHEN, J. 2013. Supplier selection and procurement decisions with uncertain demand, fixed selection costs and quantity discounts. *Computers & Operations Research,* 40**,** 2703-2710.

ZHANG, X., LEE, C. K. M. & CHEN, S. 2012. Supplier evaluation and selection: a hybrid model based on DEAHP and ABC. *International Journal of Production Research,* 50**,** 1877-1889.

ZHAO, X., HUO, B., FLYNN, B. B. & YEUNG, J. H. Y. 2008. The impact of power and relationship commitment on the integration between manufacturers and customers in a supply chain. *Journal of Operations Management,* 26**,** 368-388.

ZHU, K.-J., JING, Y. & CHANG, D.-Y. 1999. A discussion on extent analysis method and applications of fuzzy AHP. *European journal of operational research,* 116**,** 450-456.

ZOLGHADRI, M., AMRANI, A., ZOUGGAR, S. & GIRARD, P. 2011a. Power assessment as a high-level partner selection criterion for new product development projects. *International Journal of Computer Integrated Manufacturing,* 24**,** 312-327.

ZOLGHADRI, M., ECKERT, C., ZOUGGAR, S. & GIRARD, P. 2011b. Power-based supplier selection in product development projects. *Computers in Industry,* 62**,** 487-500.

ZOUGGARI, A. & BENYOUCEF, L. 2012. Simulation based fuzzy TOPSIS approach for group multi-criteria supplier selection problem. *Engineering Applications of Artificial Intelligence,* 25**,** 507-519.

Appendix A Criteria used in the literature of supplier assessment and selection

	Dickson's Criteria – (Weber et al., 1991)	*Pearson and Ellram (1995) (electronic firms)*	*Choi and Hartley (1996) (auto industry)*
1	Quality		Conformance quality [1], quality philosophy [1] product liability[4]
2	Delivery		Consistent delivery[1] Short delivery lead time[3], short set-up time[3]
3	Performance history		
4	Warranties and claim policies		
5	Production facilities and capacity		Product volume changes[3]
6	Price	cost	Low initial price
7	Technical capability	Design capabilities, current technology, Assessment of future technology	Design ability[5], technical capability[5]. Incremental improvement[4]
8	Financial position	Economic performance	Financial conditions[6], profitability of supplier[6], financial records disclosure[6], performance awards[6]
9	Procedural compliance		
10	Communication system		Communication openness[2]
11	Reputation and position in industry		Reputation for integrity[3]
12	Desire for business		
13	Mgt and organization	Mgt compatibility, Organizational structure	
14	Operating controls		
15	Repair service		Prompt response [1]. After-sale support[7], sales rep's competence[7]
16	Attitude		
17	Impression		
18	Packaging ability		
19	Labour relations record		
20	Geographical location	Location/proximity	
21	Amount of past business		
22	Training aids		
23	Reciprocal arrangements		
Other criteria		Speed to market, Manufacturing process, Visitation to supplier facilities	[1]Those are criteria under *"Consistency"* group. [2]*Relationship:* other criteria - Long-term relationship, relationship closeness. [3]*Flexibility:* Conflict resolution. [4]*Reliability* [5]*Technological capability*. [6] *Finances*. [7] *Service*
		Survey, electronic firms	Survey, automobile, assembler supplier

	McCutcheon and Stuart (2000) (manufacturing & service)	***Wang et al. (2005)***	***Pidduck (2006)***
1		Quality of products/services[1], product design and quality[2]	
2		Delivery performance[1][2]	
3	History of positive interactions		
4			
5		Greater order size flexibility[2]	
6		Price bid[1], lower selling price[2]	
7	Criticality of non-core technology to buyer, dynamism of input technology, forecasted technology discontinuities	Evaluation of supplier potential[1], Ability to provide innovation and co-design[1], A wider product range[2], More frequent newer products[2]	Technical capabilities, unique competencies
8			Financial assets availability to put into the partnership
9			
10			communications
11			
12	Supplier's view of potential benefits[1]	Willingness to disclose cost/other info[1]	Personal interest in the alliance, willingness to share expertise and teaching resources
13			
14			
15		Superior customer service[2]	
16			
17			Personal contact
18			
19			
20		Physical proximity/with region[1]	
21			
22			
23			
Other criteria	Potential of supplier as a future competitor, [1]factors in developing relationship : use of coercive power & hostage, buyer actions for foster trust	[1]*those are criteria of supplier selection*: legal/contractual terms, [2]*those are factors facilitating winning orders:* Environmentally sound products	previous knowledge, people or machines needed for the alliance, flexibility and willingness to adjust, local market knowledge, access Note: there are 6 issues affecting the choice: Specific (necessary) requirements or skills or constraints, Resource availability, Social network, Reputation, Politics, Ambiguity
	Interview, telecommunication. manufacturing	Survey, within division of fabricated metal products, machinery and equipment. manufacturing	Interview

	(Hsu et al., 2006) (USA&European firms)	***Şen et al. (2008)***
1		Defects(2), quality of support services(2), quality systems used by supplier(2), quality team visits(2)
2	Ability to meet delivery due dates(2)	Delivery(3), Order cycle time(1)
3		Performance history(4)
4	Commitment to quality(1), commitment to continuous improvement(1)	Warranties and claim policies(3)
5		Production facilities and capacity(3) response to changes(3), ability to fill emergency orders(3)
6	Price of materials, parts and services(2)	Price(1), price break(1), operating cost(1), maintenance cost(1)
7	Testing capability(1), technical expertise(1)	Technical capability(6), supplier's technological system(6), future technology development(6), design/process improvement(6), future manufacturing capabilities(6). Product range(4), supplier's expertise(4). Speed in development(5)
8	Financial stability and staying power(3)	Financial position(4)
9		Procedural compliance(1)
10	Honest and frequent communications(3)	Communication system(5)
11	References/reputation(3)	Reputation and position in industry(5)
12	Willingness to share confidential info(3)	Desire for business(5)
13		Mgt and organisation
14		Operational controls(2)
15	Flexible contract terms and conditions(2). Reserve capacity to respond to unexpected demand(2)	Repair service(3)
16		Attitude(3)
17		Impression(4)
18		Packaging ability(2)
19		Labour relations record(4)
20	Geographical compatibility/proximity(2)	Geographical location(1)
21		Amount of past business(4)
22		Training aids(3)
23		Reciprocal arrangements(5)
Other criteria	(1)*Supplier quality:* Supplier's process capability, scope of resources, industry knowledge. (2)*Supplier service*: (3)*Strategic/managerial fit:* Open to site evaluation, cultural match between the companies, past and current relationship with supplier, supplier has strategic importance.	(1)*Cost:* Foreign exchange rate, export taxes. (2)*Quality* (3)*Service* (4)*Reliability:* Process capability, process flexibility. (5)*Mgt & organisation:* Cultural similarity. (6)*Technology*
	Survey	It collected Dickson's 23 criteria and some factors from other researchers into above 6 groups and 5 levels.

	Inemek and Tuna (2009)		***Ng (2010)***
1	Quality system certificates(8), product quality(8)(11), process quality(8)(11)		Quality systems and processes(1), Quality(3)
2	Lead time(3)(11), delivery on time(3)(11), product development time(3)(12)		Delivery(2)
3	Past performance(9)		Performance history(1)
4	Commitment(6)		Warranties and claim policies(2)
5	Flexibility to volume changes (3)(11)		Customer support (production facilities)(2)
6	Production cost(1)(13), Unite price(10). Logistics cost(4)		Price(4)
7	Information technology(1), Engineering & design capability(2)(12), research & development capability(2)(12), manufacturing capability(2)(12), flexibility to respond design changes(2)(12), potential for innovation(2)	(5)*Financial &political stability:* Currency fluctuations, exchange rate, political situation, tariffs & customs. (6)*Commitment & trust:* Trust, country regulations & standards. (7)*Continuous improvement capability:* Problem-solving capability, Continuous improvement (8)*Quality* (9)*Long-term supply capability:* Past relationships, long-term supply potential. (10)*Price* (11)*Operational performance* (12)*Technical performance* (13)*Financial performance:* Return on investment, profits as percent of sales, market share, annual sales growth. Note: (1) – (10) are the factors for supplier evaluation and selection, (11) – (13) are the factors for supplier performance. This article discussed the relationship between evaluation and selection strategy and suppliers' performance regarding operational, technical and financial.	Technical capability(1), innovativeness(1)
8	Financial position(1)		Financial position(1)
9			
10			
11			Reputation and position in industry(1)
12	Willingness for info sharing(7)		Desire for business(1), willingness to cooperate(1)
13	Organisational structure & system(1), mgt capability(1)		Managerial capacity(1)
14			
15	Quick response(3)(11), Customer satisfaction(11)		Repair service(2), follow-up(2)
16			
17			
18			
19			
20	Geographic location(4)		Country of origin(1), geographical location(1)
21			
22			
23			
Other criteria	(1)*Organisational strategy:* Purchasing strategy, relationships with sub-suppliers, cultural match, environmental awareness, work force skills, investment records and plan. (2)*Technical capability* (3)*delivery capability:* (4)*Logistics:* Transport infrastructure		(1)*Supplier criteria:* Relationships (guanxi), support resources. (2)*Service performance criteria:* Professionalism, customer satisfiers. (3)*Product performance criteria:* Environmentally friendly features, ease of use, handling. (4)*Cost criteria*
	Literature		Survey, agribusiness

	Wu and Weng (2010)	***Kim and Boo (2010)***
1	Quality control programme[(2)], product quality yield[(2)], product reliability[(2)], continuous quality improvement[(2)], unified quality improvement procedure[(2)], product quality[(2)]	Ability for quality specifications[(1)]
2	Test report of the materials in the delivery[(2)]. Capability to deliver expected orders[(4)], deliver orders on time[(4)], lead time[(4)], stable supplies[(4)]	Ability to meet specified delivery schedule[(1)]
3	Business performance history[(8)]	Performance history[(1)]
4		Warranties and claim policies[(2)]
5		
6	Reasonable price[(1)], space for price negotiation[(1)], reduced cost on price[(1)], competitive price offer[(1)]	Price including service charge[(1)]
7	Technical capability[(3)], design capability[(3)], innovation capability[(3)], continuous improvement[(3)], technological support capability[(3)]	Technical capability[(1)].Products that reflect current trends[(2)]
8	Asset-liability ratio[(8)], income statement[(8)], financial ratio[(8)]	
9		Procedural compliance[(2)]
10		
11		Position in industry[(3)]
12	Willingness to cooperate to reduce cost[(1)]	
13	Complete and sound organisational structure[(6)]	
14		
15		Responsiveness to your needs[(1)], Support services[(2)]
16	Report on non-conformities of incoming materials and responses[(2)], Real-time enquiry of order processing status[(4)], Quickly reaction to order change[(5)], Process of dealing with customer complaints[(7)], quickly processing customer complaints[(7)], service attitude[(7)]	
17		Impression[(3)]
18		
19	Employee turnover rate[(6)], relationships with employees[(6)]	
20		Geographical location[(3)]
21		Amount of past business[(3)]
22		
23		
Other criteria	[(1)]*Price response capability* [(2)]*Quality mgt capability* [(3)]*Technological capability* [(4)]*Delivery capability:* Capability to process urgently needed materials. [(5)]*Flexible capability:* Willingness to change productivity on demand, willingness to advance delivery, willingness to accept order change. [(6)]*Mgt capability:* Compatibility of buyer's and supplier's management Concepts, compatibility of buyer's and supplier's corporate cultures. [(7)]*Commercial image* [(8)]*Financial capability* Note: It concluded Dickson's 23 criteria and other factors from other researchers into above 8 types of factors.	*MICE: Meetings, Incentives, Conventions & Exhibitions [(1)]*Rational* [(2)]*Sensitivity to environment* [(3)]*Reliability & interpersonal:* Social bonds with supplier. Note: all these items are criteria for initial supplier selection as well as the criteria for maintaining relationships with suppliers but with different weights.
	Collected from literature but testify the interrelationships between criteria through survey, high-tech industry	Referred to Dickson's 23 criteria

	Sarode et al. (2010)	*Çağliyan (2011)*	*Koufteros et al. (2012)*
1	Quality mgt practices(3)	Quality of product	Certification program(2), quality performance(2), quality practices(2)
2	Ability to meet delivery due dates(4)	Fast delivery, delivering in the promised time, Power to be able to meet the commitment given about the distribution	
3	Past delivery performance(3)		
4	Commitment to continuous improvement in product and process(1), Commitment to quality(4)		
5	Production flexibility(8)	Ablity to meet demand fluctuation and many demands quickly	
6	Price of materials, parts, and services (4)	Lower cost, cost reducing programs	Cost(3)
7	Strong R&D(2). Creative thinking(3). Technical /Engineering support(5), technical expertise level(5)	Quality control techniques, ability to meet product diversity, technological support, R&D activities	Product development capabilities(1), innovation capabilities(1)
8	Economic advantage(2), Financial strength(3)		
9			
10	Honest and frequent communications(1)		
11	Reputation and position in industry(2), Credit rating(6)		
12			
13			
14			
15	Customized services(5), professional behaviour(5), Modification support(7)		
16	Cooperative attitude(1)		
17			
18	Protective packaging(8)		
19			
20			
21			
22			
23			
Other criteria	(1)*Communication & commitment:* Ethical practices, trust and commitment. (2)*Partnering adequacy:* Providing key market/industry info, Supplier has strategic importance. (3)*Adequacy of corporate* (4)*Quality, price & performance:* Quick decision making. (5)*Technology & support:* Skilled workforce employed. (6)*Supplier integration:* Respect confidentiality, is accessible. (7)*Modification support* (8)*Professionalism:* Knowledgeable in logistics.		(1)*New product development capability* (2)*Quality capability* (3)*Low cost capability* Survey to test the interrelations of the criteria
	Survey, manufacturing	Survey, Turkish automobile	Survey

	Rezaei and Ortt (2012)	***Ordoobadi (2009)***
1	Quality[(1)], product reliability[(1)], Commitment to quality[(2)]	Quality control[(4)], rejection rate[(4)], customer rejection rate[(4)]
2	Delivery[(1)]	Lead time[(1)], compliance with due date[(1)], fill rate[(1)]
3	Performance history[(1)]	
4	Warranties and claims[(1]	
5	Production[(1)], manufacturing/ transformation facilities and capacity[(1)]	
6	Price/cost[(1)], cost control[(1)]	Purchase price[(5)]
7	Design capability[(1)], technical capability[(1)], technology monitoring[(1)], technology development[(1)], innovation[(1)], availability of clean technologies[(1)]; supplier's order entry and invoicing system including EDI[(1)]	Competence[(2.2)]. Product range[(3)], new product availability[(3)]
8	Profit impact of supplier[(1)], financial position[(1)], performance awards[(1)]	
9	Biding procedural compliance[(2)]	
10	Communication system[(1)], Honest & frequent communications/ communication openness[(2)]	Communication[(2.1)]
11	Reputation and position in industry[(1)]	Credibility[(2.2)]
12	Desire for business[(1)], willingness to co-design & participate in new product development[(2)], willingness to integrate scm relationship[(2)], willingness to share info, idea, tech, cost savings[(2)]	
13	Mgt and organisation[(1)], human resource mgt[(1)],	
14	Operational controls[(1)]	
15	Repair service[(1)], after sale support[(1)], Consistency and follow-through[(2)]	Responsiveness[(2)]
16	Attitude[(2)], mutual respect & honesty[(2)]	Courtesy[(2.2)]
17	Impression[(2)]	
18	Packaging ability[(1)], environmentally friendly product packaging[(1)]	
19	Labour relations record[(1)]	
20	Geographical location/proximity[(1)]	
21	Amount of past business[(1)]	
22	Training aids[(1)]	
23	Reciprocal arrangements[(2)]	
Other criteria	[(1)] *Variables of suppliers' capabilities for possible supplier segmentation :* Reserve capacity, industry knowledge, supplier process capability, impact on energy utilisation, ease of maintenance design, market sensing, customer linking, environmental health and safety, public disclosure of environmental record, hazardous waste management, pollution reduction capability, ISO 14000 and 14001 certification, recycling and reverse logistics, hazardous air emissions management. [(2)] *Variables of willingness for possible supplier segmentation:* Relationship closeness, open to site evaluation, prior experience with supplier, ethical standards, effort in eliminating waste, effort in promoting JIT principles, Dependency, willingness to invest in specific equipment, long-term relationship	[(1)] *Delivery:* Flexibility (3 sub-criteria: change in delivery date, special requests, meeting fluctuations in demand) [(2)]*Service:* Reliability, [(2.1)]empathy(other sub-criteria: access, understanding), [(2.2)]assurance. [(3)]*Product:* Additional features (2 sub-criteria: recycled materials, ergonomic features) [(4)]*Quality* [(5)]*Cost*
	Collected from literature	Collected from literature

	Lee (2009)	***Aydın Keskin et al. (2010)***
1	Yield rate[(1)], product reliability[(1)], quality of support services[(1)], quality system[(1)], Distribution network quality[(3)]	
2	Order lead time[(3)], on time delivery[(3)], delivery reliability[(3)]	Existent dispatching performance or dispatching problems
3	Bad performance history & reputation[(10)]	
4		
5	Volume flexibility[(2)], Capacity limit(production capacity and facilities)[(8)].	Adequate production capacity
6	Cost-reduction capability[(4)], Product price[(6)], freight cost[(6)], extra cost[(6)], Cost of forming relationship[(7)], Variation in price[(9)]	Suitable price policy and payment periods
7	Product mix flexibility[(2)], customisation[(2)], Technological system[(4)], future technology development[(4)], future manufacturing capabilities[(4)], Capability limit[(8)]	Existing test capability, measurement & control apparatus, ability of managing diversification, ability of design and improvement
8	Financial risk[(10)]	Financial capability to reach raw material, semi-finished product and other resources
9		
10	Ease of communication[(5)]	
11		
12		
13		
14		
15	flexibility in services[(2)]	
16		
17		
18		Ability of packing, transportation and logistic demands
19		Applications of work safety and labor health
20		Geographical location
21		
22		
23		
Other criteria	*Benefits:* [(1)]quality, [(2)]flexibility (other sub-criteria: process flexibility, Emergency order processing), [(3)]Delivery. *Opportunities:* [(4)]supplier's technology, joint growth(acquisition of supplier's knowledge and Technology, complementarities of capabilities, Joint product/technology development), [(5)]relationship building(other: stabilized relationship, Closeness of relationship),[(6)]cost, [(7)]cost of relationship(other: time to forming relationship), [(8)]supply constraint(other: supplier's raw material acquisition difficulties), [(9)]buyer-supplier constraint(other: bargaining power, incompatibility between buyer&supplier), [(10)]supplier's profile(other: inadequate environmental controls & programs)	Technically adequate employee & equipment, producing critical/safety part, producing similar part, using/providing its certificates effectively, Environmental effects and preventive actions
	TFT-LCD industry	*Automotive*

	Ravindran et al. (2010)	***Vinodh et al. (2011)***	***Chen (2011)***
1	Defective rate	Low defect rate(3)	Return rate(1), discount rate(1)
2	Accuracy in meeting the delivery time(1), lead time(1)	On time delivery(4)	Lead time(3), on-time deliver rate(3), delivery flexibility(3)
3			
4		Commitment to quality(3)	
5	Capacity(1)	Supplier capacity(4)	
6	Unite cost(4), order change & cancellation charges(4)		Gross profit rate(2), quantity discount(2)
7	Online(5), EDI(5), R&D activities(6)		Improvement capability(4), R&D rate(5)
8	Financial status(2)	Financial strength(1)	
9			
10			
11		Reputation of industry(1)	
12		Sharing of expertise(2)	
13		Mgt ability(1)	
14			
15	Responsiveness(3). Improvement programs(6)	Quick responsiveness(4)	Service standard(4), responsiveness(4)
16			
17			
18			
19			
20			
21			
22			
23			
	(1)*Delivery* (2)*Business performance:* Compatibility of business strategy (3)*Quality* (4)*Cost* (5)*Info technology* (6)*Long-term improvement* (7)*Risk:* Risk score	(1)*Business improvement:* Organisation customers. (2)*Extend of fitness:* Flexible practices, diversified customers. (3)*Quality:* Improved process capability (4)*Service* (5)*Risks:* Supply constraint, buyer supplier constraint, supplier's profile	(1)*Quality* (2)*Cost* (3)*Delivery time* (4)*Service* (5)*Technical & production capability:* Process capability (6)*Relation combination:* Technique cooperation, market cooperation, cooperative time. (7)*Organisational mgt:* Inventory turnover ratio, operating expense rate (1) – (4) are criteria for supplier performance, (5) – (7) are organisation factors.
	IT	Indian electronics	

	Vahdani et al. (2012)	***Zouggari and Benyoucef (2012)***	***Amin and Zhang (2012)***
1	Quality control system, appropriate quality management	Quality(1)	reject rate(2.1)
2		Delivery(2)	Lead time(1)
3			Performance history
4			Warranties and claim policies
5	Appropriate equipment for sustainable manufacturing, production planning system		Production facilities and capacity
6		Pricing(1)	Capital investment(1.1), maintenance cost(1.1), cost of support service(1.1). Price(2)
7		R&D(3)	Technology(1), innovation(1), R&D(1). Design process(3)
8	Financial strength		Financial position(1)
9			Procedural compliance
10			Communication system
11		Age and position in industry(1)	Reputation(1)
12			Desire for business
13			Mgt(1)
14			Operating controls
15	Responsiveness, after-sale service, maintenance management system	After-sale service(2), preventive actions(2), corrective actions(2). Service innovation(3)	Responsiveness(1), customer service(1)
16			Attitude
17			Impression
18	Packaging quality and transportation services		Green packaging(2.1)
19			Labour relations record
20	Distance	Geographical location(4)	Geographical location(1)
21			Amount of past business
22			Training(1)
23			Reciprocal arrangements
Other Criteria	Suitable storage space, sanitation in production operations, work experience, professional workforce	(1)*Performance strategy:* Environmental engagement. (2)*Quality of service* (3)*Innovation* (4)*Risk:* Political & economical stability They said from literature but did not list the literature	(1)*Supplier-related:* Experience, transport infrastructure, environmental related certificates, social responsibility, number of personnel, (1.1)cost. (2)*Part-related:* (2.1) quality (other sub-criteria: light weight, strength, durability, recyclable, reusable, part safety). (3)*Process-related:* Process capability, process flexibility, process safety, process improvement, mgt for hazardous substances, environmental criteria (reduction of waste, using of clean technology, using of environmental friendly materials, pollution reduction capability, energy consumption)
	Cosmetics industry		

	Omurca (2013)	***Kasirian and Yusuff (2013)***	***Kumar et al. (2014)***
1	Quality mgt practices & systems, quality performance	Customer rejection(2), defect rate(2)	Grade and finishing (finish quality and the ability to meet quality specifications)
2	Delivery performance	Delivery performance(3), fill rate(3), order fulfilment lead time(3), perfect order fulfilment(3)	Lead time
3			Performance history
4			
5		Production flexibility(4). Efficient machinery(5)	
6	Cost reduction capability, price performance, cost reduction performance	Total SCM cost(1), value added productivity(1), warranty cost(1), cost of goods sold(1)	Net price
7	Process/ manufacturing capability, design & development capabilities	Technical problem solving(5), business skill(5), product range(5)	
8			
9			
10		Ease of communication(6)	Past business and communication
11			Industry position and rating
12			
13	Mgt		
14			
15			
16		Attitude(6)	
17		Honesty(6)	
18			
19			
20			Distance
21			
22			
23			
Other criteria	Self-audit,	(1)*Cost/Price* (2)*Quality* Factory audit. (3)*Delivery reliability* (4)*Flexibility & responsiveness* Process flexibility, supply chain response time. Response against quality problem (5)*Professionalism* (6)*Long-term relationship*	Shelf life or longevity of product supplied, carbon footprint Note: this paper is related to green supplier selection.
			Automobile spares manufacturer

Appendix B Literature classification of supplier evaluation and selection

B1 Individual methods: Multiple-criteria decision-making (MCDM) techniques, mathematical programming (MP) techniques, artificial intelligent (AI) techniques, theory-based techniques.

B1.1 MCDM techniques: pairwise comparison methods, outranking methods, compromise methods.

B1.1.1 Pairwise comparison methods (in total, 16 articles): AHP (12 articles used AHP, 2 article proposed an innovative method based on AHP for weights definition), ANP (4 articles).

Note: (a) For the column "cited", it list how many times this article has been cited. "No data" means no cited data, "No" means that that article was not found in Google scholar. (b) The times cited were from Google scholar by the time the author read the article (mainly from September 2014 to end 2015). (c) The above explanations are also adapted to all the tables in this appendix.

Citation	*Method/technique*	*Contribution*	*Cited*
Handfield et al. (2002)	AHP	Use the AHP for supplier selection problems; demonstrate the benefits and weakness of using AHP in this manner by carrying out three cases.	554
Chan (2003)	AHP with software Expert choice	Method called Chain of Interaction to solve the subjective judgements in determining the importance of selection factors; Interactive Selection Model used to supplier selection including determining buyer-supplier relationship and formation of criteria; AHP to assess.	254
Chan and Chan (2004)	AHP	Illustrate an innovative model adopting AHP and quality management system principles to solve the supplier selection problem by a reporting a case study.	134
Kulshrestha et al. (2007)	AHP	Propose the AHP method with the decision matrix for supplier evaluation and selection; Use mean aggregation method to aggregate judgemental values of the experts.	1
Athawale et al. (2009)	Multi-criteria decision making method (MCDM): SAW, WPM, AHP, TOPSIS, GTMA	Use five MCDM methods to evaluate supplier. Note: Simple additive weighting method (SAW), weighted product method (WPM), AHP, Technique for order preference by similarity to ideal solution(TOPSIS), Graph theory and matrix approach(GTMA)	No
Chan and Chan (2010)	AHP	Use AHP to solve supplier selection problem; implement the system with the aid of the commercial software package Expert choice.	43
Kabir and Sumi (2010)	AHP	Develop an intelligent agent system for the specific application of supplier selection that use web ontology language to process the semantic content of gathered supplier information and use AHP for decision making.	4
Zolghadri et al. (2011a)	A method based on AHP	Propose an innovative method to assess suppliers' power, using AHP to determine the preference; compare the	7

Citation	*Method/technique*	*Contribution*	*Cited*
		results with performance-based evaluation.	
Jeon et al. (2011)	AHP	Extend technology roadmap (TRM) to include supplier selection consideration in semiconductor manufacturing companies; use AHP to evaluate supplier.	4
Labib (2011)	Fuzzy logic, AHP	Compare the fuzzy logic method and AHP method in selecting suppliers; provide a single unit of scale for both ranking suppliers and understanding of the difference in scale between different suppliers. Note: this paper extended the model proposed by Ordoobadi (2009) and used the same example for comparison.	23
Wu et al. (2013b)	AHP for weight Mainly focuses on grouping suppliers by Kraljic's portfolio approach	Develop an approach based on Kraljic's portfolio approach by assessing supplier's capability of technological innovation and supplier's practices in protecting the clients' intellectual property rights; valid the approach by empirical study for 401 parts, 216 suppliers and 36 manufacturing companies in China.	4
Dai and Blackhurst (2012)	AHP and quality function deployment (QFD)	Develop an integrated method combing AHP and QFD, taking into account the impact of business objectives and requirements of company stakeholders on the supplier evaluation criteria.	16
Bayazit (2006)	ANP	Use ANP in evaluating supplier selection process.	160
Sarkis and Talluri (2002)	Analytic network process (ANP)	Propose an ANP model for strategic supplier selection with the consideration of strategic, operational, tangible, and intangible measures in the evaluation process.	465
SADEGHI et al. (2012)	ANP	Use ANP to select the supplier in a group decision-making.	1
Agarwal and Vijayvargy (2013)	ANP	Use ANP with the help of software "SUPER DECISIONS" to select suppliers with the consideration of tangible and intangible criteria in a multinational food company.	No data

B1.1.2 Outranking methods (in total: 3 articles): ELECTRE (2 articles),PROMETHEE (1 article)

Citation	*Method/techniques*	*Contribution*	*Cited*
Boer et al. (1998)	ELECTRE I	Overview existing methods for supplier selection; show by ELECTRE I that an outranking method might be suited as decision making tool, which had not been used in purchasing decisions before.	261
Liu and Zhang (2011)	ELECTRE Ⅲ	Propose an improved ELECTRE Ⅲ method to deal with supplier selection.	41
Dulmin and Mininno (2003)	method – PROMETHEE /GAIA	Investigate PROMETHEE/GAIA in solving supplier selection problems.	244

B1.1.3 Compromise methods (in total: 1 article): TOPSIS (1 article), VIKOR

Citation	*Method/techniques*	*Contribution*	*Cited*
Athawale et al. (2009)	Multi-criteria decision making method (MCDM): SAW, WPM, AHP, TOPSIS, GTMA	Use five MCDM methods to evaluate supplier. Note: Simple additive weighting method (SAW), weighted product method (WPM), AHP, Technique for order preference by similarity to ideal solution(TOPSIS), Graph theory and matrix approach(GTMA)	No

B1.1.4 Other methods (in total: 2 articles): SMART, DEMATEL, MAUT (2)

Citation	*Method/techniques*	*Contribution*	*Cited*
Fekete and Hancu (2010)	Multi attribute utility theory (MAUT)	Present a multi-criteria decision making model - MAUT for supplier selection for software development outsourcing.	No data
Huang and Keskar (2007)	Supplier performance metrics for configuration, but MAUT for evaluation	Provide a set of comprehensive and configurable metrics to make sure the decision-making method such as AHP and MAUT are used effectively.	202

B1.2 MP techniques (in total: 25 articles): mixed integer programming (9 articles), goal programming (4 articles), DEA (6 articles), linear programming (4), multi-objective programming (2 article)

Citation	*Method/techniques*	*Contribution*	*Cited*
Chaudhry (1993)	Linear and mixed binary integer programming	Propose a linear and mixed binary integer programming model for vendor performance measures.	244
Stadtler (2007)	Mixed integer programming	Present a MIP model for exploiting quantity discount in supplier selection problem.	37
Basne and Weintraub (2009)	Mixed integer programming; multi-population genetic algorithm	Present a MIP model for minimization of cost and minimization of the number of suppliers that quality and delivery performance are used as constrains; present a population genetic algorithm to generate Pareto-optimal solutions of the problem; compare the performance of the two methods.	10
Talluri and Lee (2010)	Mixed-integer programming	Present a methodology based on a mixed-integer programming model for contract selection: long-term, medium-term and short-term contract.	13
Mak et al. (2011)	Mixed integer programing	Develop a new mathematical model in form of MIP model to maximize the manufacturers' profile by determining the production quantity and by selecting the most suitable suppliers; use a hybrid algorithm including constraint programming (CP) and simulated annealing (SA) to solve this complex NP-hard problem.	1
Zhang and	Mixed integer programming	Use the MIP to solve the supplier selection and	2

Citation	***Method/techniques***	***Contribution***	***Cited***
Chen (2013)		order quantity allocation problem.	
Ghodsypour and O'Brien (2001)	Mixed integer programming	Present a mixed integer non-linear programming model to solve supplier selection problem with the consideration total cost of logistics including net price, storage, transportation and ordering costs.	501
Ekici (2013)	Mixed integer programming	Modify the model proposed by Ghodsypour and O' Brien (2001) and propose their mixed integer non-linear programming model; compare the results from the two model and conclude that the new model is easier to solve than the model proposed by Ghodsypour and O' Brien (2001).	8
Benyoucef et al. (2013)	Mixed integer programming	Propose a Non-linear mixed integer programming approach based on Lagrangian relaxation to solve the facility location/supplier selection and facility location/supplier reliability problem in supply chain design.	1
Ravindran et al. (2010)	Goal programming	Develop supplier selection models based on Multi-criteria optimization approach, taking risk into account; solve the supplier selection problem using four GP variants.	56
Chang et al. (2014)	Goal programming	Propose a model for integrating multi-choice goal programming and multi-segment goal programming with the consideration of imperfect-quality discount and price-quantity discount to solve the supplier selection problems.	no
Choudhary and Shankar (2014)	Goal programming	Propose a multi-objective integer linear programming model to solve supplier selection problem; using three variants of goal programming approach to solve the multi-objective optimization problem.	No data
Jadidi et al. (2014)	Normalized goal programming	Model the supplier selection problem as a fuzzy multi-objective optimization problem (MOOP); develop a normalized goal programming to solve this fuzzy MOOP; compare the method with weighted goal programming, compromise programming TOPSIS, weighted objectives, min-max goal programming and weighted max-min models.	3
Wu and Blackhurst (2009)	Data development analysis (DEA)	Propose a method based on an extension of DEA for supplier evaluation and selection	43
Farzipoor Saen (2010)	DEA	Propose a data envelopment analysis methodology for supplier selection, considering both undesirable outputs and imprecise data.	33
Kim and Wagner	DEA	Address supplier selection from the perspective of product configuration; extend MCDA with	no

Citation	*Method/techniques*	*Contribution*	*Cited*
(2012)		the consideration the supplier-supplier relationships; introduce the supplier configuration graph to provide a clear picture of the problem.	
Talluri and DeCampos (2013)	DEA	Propose a novel approach anchored in cross efficiency analysis in DEA for measuring supplier performance diversity during supplier base rationalization.	1
Kumar et al. (2014)	DEA	Propose an approach based on DEA with carbon footprints monitoring, which was built with weight restrictions and dual role factors for supplier selection problem.	9
Ma et al. (2014)	DEA	Propose a game cross efficiency approach based on DEA to assess supplier performance considering the competition between the suppliers.	No data
Ng (2008)	Weighted linear programming	Propose a weighted linear model for supplier selection problem with multiple criteria.	207
Herbon et al. (2012)	Linear programming Dynamic weights approach	Develop a methodology based on qualitative and quantitative description in dynamic business environment; develop a visual representation of the methodology of the Impacts for the decision maker.	3
Qian (2014)	Linear functions	Propose a supplier selection approach for profit maximization based on linear function models of price, guaranteed delivery time, service level and other quality-like performance.	2
Ruiz-Torres et al. (2013)	Linear Decision-tree method	Utilize the decision tree approach with the consideration of supplier failure and contingency planning in the decision process.	4
Narasimhan and Talluri (2006)	Multi-objective programming	Propose a mathematical model taking into account the product life cycle when evaluating and selecting suppliers.	137
Karande and Chakraborty (2012)	Multi-objective optimization on the basis of ratio analysis (MOORA)	Apply MOORA to solve two real-time supplier selection problems. Note: in the conclusion, it mentioned that the method is not affected by the criteria weights and by the normalization procedure adopted.	3

B1.3 AI techniques (In total: 6 articles): GA (5 articles), PSO (1)

Note: GA for using genetic algorithm, NN for neural network

Citation	*Method/techniques*	*Contribution*	*Cited*
Ding et al. (2005)	Simulation optimization methodology using genetic algorithm (GA)	Simulation optimization methodology composed of GA optimizer, a discrete-event simulator and supply chain modelling framework; GA provides possible configurations of selected suppliers and	111

Citation	*Method/techniques*	*Contribution*	*Cited*
		evaluation of each configuration for KPI; the implementation procedure of the simulator was presented.	
Basne and Weintraub (2009)	Mixed integer programming (MIP); multi-population genetic algorithm	Present a MIP model for minimization of cost and minimization of the number of suppliers that quality and delivery performance are used as constrains; present a population genetic algorithm to generate Pareto-optimal solutions of the problem; compare the performance of the two methods.	10
Che (2010)	Guided-Pareto genetic algorithm (Gu-PGA)	Develop a multi-period supplier evaluation model based on Gu-PGA.	26
Naimi Sadigh et al. (2013)	Genetic algorithm	Propose a modified genetic algorithm to obtain Pareto optimal solution; integrate supplier selection problem with production decision and distributor location problems.	2
Deng et al. (2014a)	Genetic algorithm NSGA Ⅱ	Integrate product line design and supplier selection; formulate the integration problem as a multi-objective optimization problem; solve the problem by using NSGA Ⅱ.	2
Che et al. (2010)	Particle swarm optimization (PSO)	Propose a two-phase model for selection of green suppliers: using WEEE and RoHS for the first selection; then using Particle swarm optimization (PSO) to select the supplier with the minimum total costs; develop a decision-making support system.	9

B1.4 Theory-based techniques (in total: 16 articles): fuzzy set theory (14 articles), rough set theory, grey theory (2 articles)

Citation	*Method/techniques*	*Contribution*	*Cited*
Bevilacqua et al. (2006)	Fuzzy set theory Facchinetti et al. (1998)	Suggest a fuzzy quality function development approach to the supplier selection process; implement the whole procedure by using fuzzy numbers, and use fuzzy suitability index for a final ranking.	203
Humphreys et al. (2006)	Method using dynamic fuzzy membership functions (fuzzy if-then rules)	Develop a fuzzy system to aid management in assessing a supplier's environmental performance in the supplier selection process; introduce environmental criteria into the existing supplier selection process.	41
Shu and Wu (2009)	Fuzzy set theory	To deal with fuzzy data of quality, use resolution identity theorem which is widely used in fuzzy set theory to help construct membership functions; extend an existing fuzzy ranking method of Yuan (1991) to select suppliers.	23
Ordoobadi	Fuzzy set theory	Elicit the decision makers' preference on criteria	67

Citation	Method/techniques	Contribution	Cited
(2009)		and their perception of suppliers' performance with respect to these criteria; propose a methodology based on fuzzy logic to evaluate suppliers that can deal with linguistic terms; the methodology is multidisciplinary.	
Guneri and Kuzu (2009)	Fuzzy set theory	Briefly introduce the selection criteria and the selection method; Perform a method with a case based on fuzzy logic that calculates a fuzzy suitability index for alternatives and ranks the fuzzy indices to select the best.	13
Hsu et al. (2010)	Fuzzy set theory (fuzzy preference)	Apply the resolution identity result, a well-known method used in fuzzy set theory, to evaluate and select suppliers; the method is quality-based with fuzzy quality data.	23
Labib (2011)	Fuzzy logic, AHP	Compare the fuzzy logic method and AHP method in selecting suppliers; provide a single unit of scale for both ranking suppliers and understanding of the difference in scale between different suppliers. Note: this paper extended the model proposed by Ordoobadi (2009) and used the same example for comparison.	23
Amindoust et al. (2012)	Fuzzy set theory (fuzzy inference system)	Propose a ranking method based on fuzzy inference system for supplier selection problem; determine selection criteria and sub-criteria for sustainable supplier selection.	44
Li et al. (2012a)	Fuzzy set theory	Propose an indicator system and a method of data integration; propose a fuzzy evaluation method for third party logistic partner.	19
Shen and Yu (2012)	Fuzzy set theory	Propose a fuzzy approach to aggregate the total scores of individual suppliers with the consideration of strategic factors and operational factors as well as supplier integration spectrum.	5
Lima Junior et al. (2013)	Fuzzy set theory Fuzzy inference: if-then rules	Propose a method applying fuzzy inference combined with the simple fuzzy grid method to sort suppliers.	6
Liao et al. (2013)	Fuzzy inference	Develop a method based on fuzzy inference with process capability index C_{pk} for supplier evaluation and selection.	1
García et al. (2013)	Fuzzy decision support system	Develop a fuzzy decision support system to solve supplier selection problem, allowing joint assessment and comparison among new and historical suppliers.	4
Wang et al. (2013)	Fuzzy aggregation operators	Develop two new intuitionistic fuzzy aggregation operators: dependent intuitionistic fuzzy ordered weighted averaging (DIFOWA) and dependent intuitionistic fuzzy hybrid weighted aggregation (DIFHWA); present a method based on DIFHWA for multiple attribute decision making.	1
Li et al. (2007)	Grey-based approach	Propose a grey-based approach to deal with	160

Citation	Method/techniques	Contribution	Cited
	(grey theory)	supplier selection problems: use grey numbers to express weights and ratings of attributes described by linguistic variables; use a grey possibility degree to determine the ranking order.	
Athawale and chakraborty (2011)	Grey relational analysis (GRA) method	Apply GRA method to select the most suitable supplier.	5

B1.5 Other individual methods (in total: 7 articles): cost/price-based (2), CpkMPZone chart-based (1), switching options (1), FMEA (1), Quotient test statistic (1), ration test statistic (1)

Citation	Method/techniques	Contribution	Cited
Barua et al. (1997)	Cost-based method	An analytic model to maximize the payoff (factors are transformed to cost when assessing). Assess the suitability of sequential evaluation and biding system (two types of selection strategies) for selecting suppliers. Develop a minimum announcement mechanism to increase the efficiency when using biding strategy.	95
Linn et al. (2006)	Based on the extension from CpkMPZone chart	The method using capability index and price comparison (CPC) chart that integrates the process capability and price information.	28
Wu (2009)	Switching options theory	Use Margrabe's (1978) switching options formula to evaluate two alternatives; analyse suppliers from an economic view with the consideration of uncertainty.	32
Welborn (2010)	Failure mode and effects analysis (FMEA)	Apply FMEA to evaluate suppliers by taking risk into account.	1
Hu et al. (2012)	Price-based analysis	Model purchasing strategies for flexible contract from a single supplier; extend the models for multiple suppliers in order to make a choice, taking risk into account.	3
Pearn and Wu (2013)	Quotient test statistic	Propose a two-phase procedure on the basis of the quotient test statistic for supplier selection problem, using S_{pk}^{m} index.	4
Wu et al. (2013a)	Ration test statistic based on the normal approximation (RN), difference test statistic based on the normal approximation (DN), the capability ratio based on the GCI (RG), the capability difference based on the GCI (DG)	Provide four methods, i.e., RN, DN, RG and DG, to select supplier based on the quality and process yield; compare the results from the four methods and provide recommendations for selecting efficient methods based on simulation results of test size and selection power. Note: selection power is the ability to distinguish the existing difference in the capability of two processes.	7

B2 Fuzzy individual methods: fuzzy MCDM techniques, fuzzy MP techniques, fuzzy AI techniques

B2.1 Fuzzy MCDM techniques (in total: 26 articles): fuzzy AHP (13), fuzzy ANP (3 articles), fuzzy ELECTRE (2 articles), fuzzy TOPSIS (6 articles), fuzzy VIKOR (1 article), fuzzy SMART (1 article), fuzzy DEMATEL (1 article), fuzzy MULTIMORRA (1 article)

Citation	***Method/techniques***	***Contribution***	***Cited***
Kahraman et al. (2003)	Fuzzy AHP (Extent analysis method)	Use fuzzy AHP to select the best supplier.	549
Noorul Haq and Kannan (2006b)	Fuzzy AHP	Use fuzzy AHP to evaluate vendor selection; develop the model using the evidence from an empirical study.	126
Chan and Kumar (2007)	Fuzzy extended AHP (Extent analysis method)	Discuss some of the important criteria; develop A fuzzy extended AHP based method for assessment; the model can be used for selection and deploying the organization's strategy.	586
Chan et al. (2008)	Fuzzy AHP (Extent analysis method)	Use fuzzy AHP to assess quantitative and qualitative decision factors in supplier selection.	230
Lee (2009)	Fuzzy AHP (Extent analysis method)	Construct a fuzzy AHP model to evaluate various aspects of suppliers, incorporating the benefits, opportunities, costs and risks.	203
Chamodrakas et al. (2010)	Fuzzy AHP	Propose a two-stage method: applying satisficing method to reduce the initial set of suppliers; then applying a modified FPP method to rank the suppliers. Use Fuzzy preference programming (FPP) to derive the priorities of AHP	110
Yücenur et al. (2011)	Fuzzy AHP, Fuzzy ANP (Extent analysis method)	Apply fuzzy AHP and fuzzy ANP to evaluate suppliers; compare the results from fuzzy AHP and fuzzy ANP methods.	26
Costantino et al. (2011)	Fuzzy AHP	Use fuzzy AHP to address the supplier selection decision problem in the public procurement sector.	6
Chen and Chao (2012)	FAHP	Use AHP and CFPR to solve the supplier selection problem. Use consistent fuzzy preference relations (CFPR) to denote the comparison preference and still use AHP method to derive the weights	35
Alinezad et al. (2013)	Fuzzy AHP and quality function deployment (QFD)	Combine fuzzy AHP and QFD for supplier evaluation and ranking.	3
Mızrak Özfirat et al. (2014)	Fuzzy AHP (Use fuzzy priorities method by Mikhailov (2004) to derive weights, similar to FPP)	Propose a fuzzy AHP approach for supplier selection: determine the criteria according to company's objectives; make the pairwise comparison on a fuzzy basis; then compared the alternatives by fuzzy means. Note: 1. This paper stated that they are the first one to employ fuzzy AHP using fuzzy prioritization method. 2. Software can be downloaded from	No data

Citation	***Method/techniques***	***Contribution***	***Cited***
		www.ibm.com/developerworks/university/ academicinitiative/ for free.	
Gholipour et al. (2014)	Fuzzy AHP (Extent analysis method)	Use fuzzy AHP to solve the contractor selection problems.	No data
Lima Junior et al. (2014)	Fuzzy AHP, fuzzy TOPSIS (Extent analysis method)	Compare the two methods fuzzy AHP and fuzzy TOPSIS based on the factors: adequacy to changes of alternatives or criteria, agility in decision process, computational complexity, adequacy to support group decision making, the number of alternative suppliers and criteria, the modeling of uncertainty; conclude that fuzzy TOPSIS is better in regard to changes of alternatives or criteria, agility and number of alternative suppliers and criteria.	1
Vinodh et al. (2011)	Fuzzy ANP	Apply ANP for the supplier selection process; develop a conceptual model encompassing various criteria and sub-criteria; validate the application through questionnaire.	82
Kang et al. (2012)	Fuzzy ANP	Propose a fuzzy ANP model to evaluate suppliers, which considers the feedback and interdependency of factors in a network, taking uncertainty into account.	29
Pang and Bai (2013)	Fuzzy ANP	Propose a methodology combing fuzzy ANP and fuzzy synthetic evaluation to evaluate and select the most suitable suppliers.	21
Sevkli (2010)	Fuzzy ELECTRE	Propose a fuzzy ELECTRE method to assess suppliers in order to deal with imprecise and linguistic data; compare the results from crisp ELECTRE and fuzzy ELECTRE. (note: since the results are different for the same case, it worth wondering why and which is better)	42
Sepehriar et al. (2013)	Fuzzy ELECTRE	Develop a novel fuzzy ELECTER method to multiple sourcing conditions for supplier selection problem.	No data
Chen et al. (2006)	Fuzzy set theory, TOPSIS	Propose a hierarchical MCDM model based on fuzzy set theory for supplier selection problems; define a closeness coefficient according to the concept of TOPSIS to determine the ranking order.	788
Boran et al. (2009)	TOPSIS, intuitionistic fuzzy set	Propose a TOPSIS method combined with intuitionistic fuzzy set to select appropriate supplier in group decision environment; use intuitionistic fuzzy weighted averaging operator to aggregate individual opinions for rating the importance of criteria and alternatives.	325
CNV et al. (2010)	Hierarchical fuzzy TOPSIS algorithm	Examine the selection criteria in e-manufacturing and use Hierarchical fuzzy TOPSIS algorithm to rank suppliers	1
Mehralian et al. (2012)	Fuzzy TOPSIS	Determine the risk factors in supply chain of pharmaceutical industry; formulate the factors using fuzzy TOPSIS for supplier selection problem.	8
Wu et al.	Fuzzy TOPSIS	Utilize an improved fuzzy TOPSIS approach to solve	No

Citation	*Method/techniques*	*Contribution*	*Cited*
(2013c)		supplier selection problem by identifying the quantitative and qualitative attributes and their weights.	data
Shemshadi et al. (2011)	Fuzzy VIKOR	Propose a fuzzy VIKOR method with a mechanism to extract and deploy objective weights based on Shannon entropy concept for supplier selection.	78
Chou and Chang (2008)	Fuzzy SMART	Apply a fuzzy SMART to evaluate suppliers, dealing with the ratings of both qualitative and quantitative criteria.	173
Chang et al. (2011)	Fuzzy DEMATEL	Design a fuzzy DEMATEL to evaluate supplier performance to find influential factors in selecting suppliers.	100
BALEŽENTIS and BALEŽENTIS (2011)	(MULTIMOORA)	Extend MULTIMOORA with 2-tuple linguistic representation for supplier selection, aiming to solve both crisp and fuzzy data. Fuzzy multi-objective analysis by ratio analysis plus the full multiplicative form	15

B2.2 Fuzzy MP techniques (in total: 8 articles): fuzzy goal programming (1 article), fuzzy linear programming (6 articles), fuzzy DEA (1 article)

Citation	*Method/techniques*	*Contribution*	*Cited*
Kumar et al. (2004)	Fuzzy goal programming	Formulate the vendor selection problem as a fuzzy mixed integer goal programming model with the consideration of buyers' demand, vendors' capacity, vendors' quota flexibility, etc.	378
Amid et al. (2006)	Fuzzy multiobjective linear model	Develop a fuzzy multiobjective linear model for supplier selection problems with the consideration of vagueness of information.	310
Yücel and Güneri (2011)	Fuzzy multi-objective linear model	Use fuzzy logic to deal with linguistic expression and weights assessment of factors; develop a fuzzy multi-objective linear model to overcome the selection problem and assign order quantities	61
Dursun and Karsak (2013)	Fuzzy linear programming Fuzzy multi-criteria group decision making, QFD	Develop a fuzzy multi-criteria group decision making approach that makes use of quality function deployment; Use fuzzy weighted average to compute the bounds of weights of criteria and rating of suppliers; use a fuzzy number ranking method to rank suppliers.	18
Amid et al. (2009)	Fuzzy weighted additive and mixed integer linear programming	Formulate a fuzzy multi-objective model simultaneously consider imprecise information and determine the order quantities based on price breaks; develop a fuzzy weighted additive and mixed integer linear programming.	124
Ahmady et al. (2013)	Fuzzy DEA	Develop a novel fuzzy DEA approach with double frontiers to identify the best suppliers without the need to impose any weight restriction or the need to calculate the cross-efficiency matrix, compared with the traditional DEA.	2
Arikan (2013)	Fuzzy multi objective	Develop a fuzzy multi objective linear	18

	linear programming	programming model to solve the multiple sourcing supplier selection problem.	
Aghai et al. (2014)	Fuzzy multi-objective programming (mixed integer nonlinear programming)	Propose a fuzzy multi-objective programming model to select suppliers with the consideration of quantitative, qualitative and risk factors; more specifically, obtain the mixed integer derivative nonlinear programming from fuzzy multi-objective programming model.	No data

B2.3 Fuzzy AI techniques (in total 3 articles) : fuzzy ART (1 article), LLNF (1 article), fuzzy-bayesian (1 article)

Citation	***Method/techniques***	***Contribution***	***Cited***
Aydın Keskin et al. (2010)	Fuzzy adaptive resonance theory (Fuzzy ART)	Propose a method using fuzzy ART to select the most appropriate suppliers and cluster the suppliers according to their similarities.	75
Vahdani et al. (2012)	Locally linear neuro-fuzzy (LLNF) Note: an AI approach	Introduce LLNF to predicate performance rating of suppliers; compare this AI method with other three intelligent methods, i.e. multi-layer perceptron (MLP) neural network, radial basis function (RBF) neural network and least square-support vector machine (LS-SVM)	16
Ferreira and Borenstein (2012)	Fuzzy-bayesian	Propose a novel model based on the integration of influential graph and fuzzy logic to rank and evaluate suppliers; embed the model into an information system to assist managers to analysis the strength and weakness of suppliers, to set the priorities of conflicting criteria and to identify a preferred course of action.	20

B2.4 Other fuzzy individual methods (in total: 2 article): fuzzy association rule mining –based (1 article)

Citation	***Method/techniques***	***Contribution***	***Cited***
Jain et al. (2007)	Fuzzy association rule mining –based approach	Develop a Fuzzy association rule mining –based approach to support the decision-makers for evaluating suppliers by enhancing the flexibility in making decisions.	46

B3 Hybrid methods: hybrid AHP/fuzzy AHP, hybrid ANP/fuzzy ANP, hybrid TOPSIS/fuzzy TOPSIS, hybrid MP, hybrid theory-based

B3.1 Hybrid AHP/fuzzy AHP (in total: 37 articles): AHP&LP (3), AHP&GRA (3), DEA&AHP (7), AHP&RST&MIP (1), DEA&TCO&AHP (1), AHP&PVA (1), AHP&DEA&NN (1), AHP&TOPSIS (2), SEM&AHP (1), GP&AHP (1), AHP&DEA&LP (1), DAHP&ABC (1), AHP&MFMEA (1), D-AHP&Fuzzy logic (1), AHP&Reliability matrix&GA (1), Fuzzy

AHP&Max-min approach (1), Fuzzy AHP&ELECTRE (1), Fuzzy AHP&Fuzzy TOPSIS (3), AFS&Fuzzy AHP&TOPSIS (1), Fuzzy AHP&FAD (1), Fuzzy AHP&Fuzzy TOPSIS&LP (1), Fuzzy kano&Fuzzy AHP&Fuzzy TOPSIS (1), Fuzzy AHP&GRA (1), FAHP+GA(1)

Citation	***Method/techniques***	***Contribution***	***Cited***
Ghodsypour and O'Brien (1998)	AHP, linear programming	Propose a hybrid method integrating AHP and linear programming with the consideration of tangible and intangible factors for supplier selection and order allocation.	888
Raut et al. (2010)	AHP, linear programming	Apply AHP into the evaluation process to handle the qualitative process; use mathematical linear programming method to allocate the number of unites to supplier after selection.	1
Ting and Cho (2008)	AHP, multi-objective linear programming (MOLP)	Propose an integrated approach combing AHP and MOLP: use AHP to deal with supplier selection problems; use MOLP for order allocation.	96
Yang and Chen (2006)	AHP, GRA	Propose an integrated model combing AHP and GRA for supplier selection; implement the AHP-GRA model in Excel to automate the selection process.	102
Gnanasekaran et al. (2008)	AHP, GRA	Develop a decision support system based on the integration of AHP and GRA for supplier selection; use the additive normalization method to calculate the priority vector; validate the method by case study.	6
Pitchipoo et al. (2012)	AHP, GRA	Propose a hybrid model comprising three stages: select the most influential criteria by mutual-informational-based feature selection in stage one; determine the weights of attributes using AHP in stage two; determine the best supplier using GRA in stage three.	4
Liu and Hai (2005)	DEA, AHP	Propose a hybrid method combing DEA and AHP, called voting AHP, which presents a novel weighting procedure in place of AHP's compared comparison for supplier selection.	375
Hadi-Vencheh (2011)	New Voting AHP + DEA Based on (Liu and Hai, 2005)	Propose a new weighted nonlinear model to solve supplier selection problem, incorporating multiple criteria and maintaining the effects of weights.	14
Ramanathan (2006)	DEA, AHP	Apply DEA to generate the weights of alternatives when applying AHP to rank the alternatives. It is said in this paper that this DEAHP does not suffer from rank reversal problem.	182
Sevkli et al. (2007)	Data envelopment AHP (DEAHP)	Apply DEAHP to a Turkish firm named BEKO and concluded that the DEAHP method outperformed the AHP method in selecting suppliers. *(note: whether this conclusion can be drawn just*	117

Citation	***Method/techniques***	***Contribution***	***Cited***
		by applying to one firm is worth wondering)- Wang et al. (2009) reexamined the method and case, demonstrating the invalidity of the conclusion.	
Wang et al. (2009b)	DEAHP	Reexamined the method and case by Sevkli et al. (2007), demonstrating the invalidity of the conclusion of that paper that the DEAHP method outperformed the AHP method in selecting suppliers.	19
Raut (2011)	AHP, DEA	Use a hybrid AHP-DEA method to evaluate environmental performance of suppliers, i.e. AHP for weights calculation and DEA for ranking; present a real case using 10 main criteria and 50 sub-criteria.	6
Xia and Wu (2007)	AHP, rough sets theory, multi-objective mixed integer programming	Propose an integrated approach combing AHP, rough sets theory and multi-objective mixed integer programming for supplier selection and order allocation.	330
Ramanathan (2007)	DEA, total cost of ownership (TCO), AHP	Propose an integrated approach combing DEA, TCO and AHP to selection appropriate suppliers.	124
Routroy (2008)	AHP-Performance value analysis (PVA)	Use AHP-PVA to capture and analyse indicators; Propose a framework to decide the significant categories and performance indicators for selection.	No
Ha and Krishnan (2008)	AHP, DEA, neural network (NN)	Propose an integrated approach combing AHP, DEA and NN: use AHP for qualitative data evaluation; use DEA and NN for measuring performance efficiency.	198
Fazlollahtabar et al. (2010)	AHP, TOPSIS	Integrate AHP and TOPSIS for supplier selection, i.e. use AHP to calculate the priorities and apply TOPSIS to rank suppliers; apply multi- objective nonlinear programming for multi-period shipment allocation process.	19
Vijayvagy (2012)	AHP, TOPSIS	Use AHP and TOPSIS for supplier selection; compare the results from AHP and those from TOPSIS; have 19 criteria in 7 groups	2
Hadi-Vencheh and Niazi-Motlagh (2011)	Voting AHP (VAHP), DEA	Propose an integrated VAHP-DEA methodology to evaluate alternatives. Note: this paper is based on model proposed by Liu and Hai (2005), an extension version of the model.	12
Lorentz et al. (2012)	Structural equation modeling (SEM), AHP	Develop a model using SEM and AHP for supplier selection; Find out the attributes' weightage by using cluster analysis that the strength and weakness of suppliers on the influential factor was found.	5
Khorramshahgol (2012)	Goal programming (GP), AHP	Propose an integrated method using GP and AHP to evaluate, screen and select best suppliers and determine the amount to be purchased from the	3

Citation	***Method/techniques***	***Contribution***	***Cited***
		selected suppliers.	
Falsini et al. (2012)	AHP, DEA, linear programming	Propose a hybrid mathematical method combing AHP, DEA and linear programming for the evaluation of third party logistics service providers.	17
Zhang et al. (2012)	DEAHP and activity-based costing (ABC)	Propose a methodology combing DEAHP and ABC for supplier evaluation.	5
Chen and Wu (2013)	AHP, modified failure mode and effects analysis (MFMEA)	Propose a MFMEA method to select new suppliers with the consideration of risk; apply AHP to determine the weights of criteria.	4
Deng et al. (2014b)	D numbers-AHP (D-AHP), fuzzy logic	Propose a D-AHP for supplier selection problem; use fuzzy preference relation to construct the decision matrices of pairwise comparison.	32
Cao et al. (2014)	AHP, Reliability matrix, genetic algorithm NSGA Ⅱ	Apply AHP and Reliability matrix to evaluate the supply risk of suppliers; adopt NSGA Ⅱ to solve the established optimization model.	No data
Şen et al. (2010)	Fuzzy AHP, a max-min approach	Propose a methodology integrating fuzzy AHP, max-min approach, non-parametric statistical test for determining the weights of criteria, maximizing and minimizing the performance and identifying an effective supplier set respectively.	28
Ertay et al. (2011)	Fuzzy AHP and ELECTRE Ⅲ	Use AHP to weight the established decision criteria and ELECTRE Ⅲ to evaluate, rank and classify the performance of suppliers; conduct a case in a pharmaceutical company.	16
Wang et al. (2009a)	Fuzzy AHP, Fuzzy TOPSIS	Propose a fuzzy hierarchical TOPSIS for supplier selection, which is suited for evaluating fuzziness and uncertainty and provides more objective and accurate criterion weights.	221
Zouggari and Benyoucef (2012)	Fuzzy AHP, fuzzy TOPSIS	Use fuzzy AHP for supplier selection through four classes: performance strategy, quality of service, innovation and risk; then apply fuzzy TOPSIS based simulation for order allocation.	44
Viswanadham and Samvedi (2013)	Fuzzy AHP, fuzzy TOPSIS	Propose a two-step approach using fuzzy AHP and fuzzy TOPSIS to select and rank suppliers with the consideration of risk for the design of a resilient supply chain.	No data
Li et al. (2012b)	Axiomatic fuzzy set clustering (AFS) method, fuzzy AHP, TOPSIS	Use AFS method and fuzzy AHP to cluster and evaluate suppliers, and determine the weight of criteria; employ TOPSIS to select the final suppliers; present an example of 30 suppliers and 6 criteria.	8
Büyüközkan (2012)	Fuzzy AHP, Axiomatic design-based fuzzy group decision making (FAD)	Use fuzzy AHP to determine the relative weights of the criteria; use an axiomatic design-based fuzzy group decision-making approach to rank the green suppliers.	17
Kannan et al. (2013)	Fuzzy AHP, fuzzy TOPSIS, multi-objective linear	Apply fuzzy AHP and fuzzy TOPSIS to analyse the importance of criteria and determine the best green suppliers; use a multi-objective linear	24

Citation	*Method/techniques*	*Contribution*	*Cited*
	programming	programming model to formulate various constraints such as quality control and capacity.	
Ghorbani et al. (2013)	Fuzzy kano model, fuzzy AHP, fuzzy TOPSIS	Propose a three-phase approach for supplier selection: using fuzzy Kano questionnaire and fuzzy AHP to calculate the importance weight of the criteria in the first phase; use fuzzy TOPSISI to screen out in capable suppliers and rank the suppliers in the second and third phases.	1
Noorul Haq and Kannan (2006a)	Fuzzy AHP + GA for distribution inventory	Use fuzzy AHP for supplier selection and a genetic algorithm for building the multi-echelon distribution inventory model.	84
Pitchipoo et al. (2013)	Fuzzy AHP, grey relational analysis (GRA)	Propose a hybrid decision model combing fuzzy AHP and GRA to solve the supplier selection problems: use fuzzy AHP to calculate the weights of the criteria and GRA to rank the suppliers.	8

B3.2 Hybrid ANP/fuzzy ANP (in total: 10 articles): ANP&LP (1), ANP&NLP (1), ANP&DEA (1), DEMATEL&ANP&VIKOR (1), Fuzzy ANP&NLP (1), Fuzzy ANP&Fuzzy TOPSIS (2), Fuzzy DEMATEL&FANP&Fuzzy TOPSIS (1), Fuzzy ANP&FMOLP (1), Fuzzy ANP&GP&DNP(1)

Citation	*Method/techniques*	*Contribution*	*Cited*
Demirtas and Üstün (2008)	ANP, multi-objective mixed integer linear programming (MOMILP)	Propose an integrated approach of ANP and MOMILP to consider both tangible and intangible factors in suppler selection and quantities definition.	246
Kuo and Lin (2012)	ANP, DEA	Integrate ANP and DEA for supplier selection problem with the consideration of green issues.	15
Liou et al. (2014)	ANP, DEMATEL & VIKOR	Propose a fuzzy integral-based model to address the interdependence among the criteria for supplier evaluation; use a hybrid method DANP combing DEMATEL and ANP to develop the structure of the relationship among the criteria and their weights.	3
Razmi and Rafiei (2010)	ANP+non-linear Programming	Develop an ANP sub-model to evaluate suppliers regarding qualitative attributes; present a mixed-integer non-linear sub-model to simultaneously allocate order quantities to the chosen suppliers.	28
Razmi et al. (2009)	Fuzzy ANP, non-linear programming	Develop a fuzzy ANP model to evaluate and select suppliers; augment the model with model with a non-linear programming model to elicit eigenvectors from fuzzy comparison matrices.	75
Önüt et al. (2009)	Fuzzy ANP, fuzzy TOPSIS	Develop a supplier evaluation approach based on ANP and fuzzy TOPSIS; use triangular fuzzy numbers in pairwise comparison matrices contrary to conventional fuzzy ANP.	184

Citation	***Method/techniques***	***Contribution***	***Cited***
Jajimoggala et al. (2011)	Fuzzy ANP, TOPSIS	Use fuzzy ANP to solve the problem of supplier evaluation; use TOPSIS to rank suppliers.	3
BÜYÜKÖZKAN and Çifçi (2012)	Fuzzy DEMATEL, fuzzy ANP, fuzzy TOPSIS	Propose a hybrid model combing Fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers.	102
Lin (2012)	Fuzzy ANP, fuzzy multi-objective linear programming (FMOLP)	Adopt fuzzy ANP to identify top suppliers by considering the interdependence among selection criteria; integrate fuzzy ANP with FMOLP to select the best suppliers for achieving optimal order allocation under fuzzy environment.	24
Huang and Hu (2013)	Fuzzy ANP process-goal programming (FANP-GP) and De Novo programming (DNP)	Propose a two stages method for supplier selection and evaluation in Taiwan automotive industry: use FANP-GP to select the best supplier and to decide the optimal order quantity in the first stage; evaluate the selected suppliers based on DNP method.	3

B3.3 Hybrid TOPSIS/fuzzy TOPSIS (in total: 8 articles): SWOT&DEA&TOPSIS (1), TOPSIS&LP (1), TOPSIS&Game theory (1), DEA&TOPSIS&LP (1), TOPSIS&PGP (1), TLF& TOPSIS&GP (1), Fuzzy TOPSIS&GP (1), Fuzzy TOPSIS&LP (1)

Citation	***Method/techniques***	***Contribution***	***Cited***
Chen (2011)	SWOT, DEA, TOPSIS	Use SWOT to identify enterprise competitive strategy in order to establish criteria; use DEA and TOPSIS to filter out and evaluate suppliers; conduct a case in the Taiwanese textile industry.	105
Feng (2012)	TOPSIS, linear programming Fuzzy	Extend TOPSIS to aggregate numerical values, interval numbers and linguistic variables; use bi-objective 0-1 linear programming model to select the desired supplier portfolio, aiming to minimize the supplier number and maximize supplier performance.	5
Kermani et al. (2012)	TOPSIS and game theory	Apply a combination of TOPSIS and an extension of the ordinal game theory to find the Nash equilibrium for selection the right supplier.	4
Dotoli and Falagario (2012)	DEA, TOPSIS, linear programming	Use a hierarchical extension of DEA to evaluate the efficiency of supplier; use TOPSIS to rank the suppliers; a linear programming method to determine the quantities of order.	12
Kasirian and Yusuff (2013)	TOPSIS, preemptive goal programming	Propose a hybrid method combing TOPSIS and preemptive goal programming model, with the consideration of the dependency of the criteria; compare the results from the proposed model and AHP and conclude that the proposed model provides a higher total value of purchasing and the same value total cost of purchasing.	6
Sharma and Balan (2013)	Taguchi loss function (TLF), TOPSIS, multi criteria goal	Propose a three stages model: use Taguchi loss function to identify losses in the first stage; use TOPSIS to identify factors with the weights; develop	13

Citation	***Method/techniques***	***Contribution***	***Cited***
	programming	a multi criteria goal programming to identify the best performing supplier in the third stage; compare the method with DEA.	
Liao and Kao (2011)	Fuzzy TOPSIS and Multi-choice goal programming (MCGP)	Propose integrated fuzzy techniques for TOPSIS and MCGP approach to solve supplier selection problem; conduct a case study in watch firm.	69
Kilic (2013)	Fuzzy TOPSIS, mixed integer linear programming	Develop an integrated approach including fuzzy TOPSIS and a mixed integer linear programming model for supplier selection.	12

B3.4 Hybrid MP (in total: 9 articles): NLP&IWT (1), DEA&Multi-objective MIP (1), LP&GA&TS (1), GRA&LP (1), Fuzzy set theory&LP (1), GA& Grey GP (1), GA& Multi-objective NLP (1), OWA&LP (1), Fuzzy DEA& PROMETHEE (1)

Citation	***Method/techniques***	***Contribution***	***Cited***
Cakravastia and Takahashi (2004)	Multi-objective (and non-liner) model	The model can be used to generate different kinds of effective alternatives to support negotiation process in each negotiation period. Combine the Interactive Weighted Tchebycheff (IWT) method and Benders decomposition method	68
Jafari Songhori et al. (2010)	DEA, multi-objective mixed integer programming	Use DEA to determine the relative efficiency of suppliers and transportation alternatives; use a multi-objective mixed integer programming to determine the allocation.	19
Luo et al. (2011)	linear programming model, genetic algorithm (GA), tabu search (TS)	Formulate a mixed-integer non-linear programming model to maximise the total product family profit; A linear programming embedded genetic algorithm (LPEGA) for solving the optimization model; Consider supplier selection while product design.	11
Lin et al. (2011)	GRA, linear programming (LP)	Propose a business process re-engineering model, including two parts: GRA and LP; Apply GRA to rank alternatives and LP to quote an optimal order quantity.	2
Amin and Zhang (2012)	Fuzzy set theory, mixed-integer linear model	Propose a two-stage model: a fuzzy method to evaluate suppliers in a closed-loop supply chain and a multi-objective mixed integer linear programming model to determine the suppliers and refurbishing sites and numbers of parts.	45
Sadeghieh et al. (2012)	Genetic algorithm based grey goal programming	Propose an integrated genetic algorithm based grey goal programming to solve the part supplier selection problem.	5
Rezaei and Davoodi (2012)	Genetic algorithm, multi-objective nonlinear programming	Use a multi-objective nonlinear programming model to formulate the integrated problem, i.e. total profit, inconsistency and deficiency. Propose a genetic algorithm named NSGA-Ⅱ to provide a number of Pareto-optimal solutions; compare NSGA-Ⅱ and SPEA2.	21
Rostamiyan et	OWA operator weights,	Propose a OWA operator weights method to solve	No

Citation	*Method/techniques*	*Contribution*	*Cited*
al. (2013)	linear programming	the supplier selection problem; use the linear programming model to compute the efficiency rating for decision making units.	data
Radfar and Salahi (2014)	Fuzzy DEA, PROMETHEE	Propose a two-stage fuzzy DEA PROMETHEE model: use fuzzy DEA to evaluate suppliers in the first stage; use PROMETHEE to rank the suppliers.	No

B3.5 Hybrid theory-based (in total: 4 articles): GRA&RST (1), FC-Map&Fuzzy soft set (1), FC-means&RST (1), SOM&RST&BBN (1)

Citation	*Method/techniques*	*Contribution*	*Cited*
Samantra et al. (2011)	GRA, rough set theory	Apply GRA coupled with rough set theory for supplier selection.	No data
Xiao et al. (2012)	Fuzzy cognitive map (FCM), fuzzy soft set model	Integrate FCM and fuzzy soft set model for supplier selection problem, considering the dependencies and feedback among criteria and uncertainty; give a case study considering risk factor.	31
Omurca (2013)	Fuzzy c-means (FCM) and rough set theory (RST)	Propose a hybrid method combing FCM and RST for supplier evaluation, selection and development problem.	15
Chang (2013)	Self organizing map (SOM), rough set theory (RST), Bayesian belief network (BBN)	Use three intelligent methods to solve supplier selection problems, which are clustering with SOM, charactering with RST and mutually negotiating with BBN based multi-agent system, for details: apply SOM to cluster suppliers according their evaluation criteria; employ RST to characterize each cluster for recognizing each cluster's average performance; develop BBN based multi-agent system to find the best suppliers and refine the strategies.	1

Appendix C Questionnaires for the interviews

This appendix presents the questionnaires prepared for the two stage interviews. However, due to the open discussion, interviewees were not required to stick on these questions and not all the questions have been answered.

C1 Questionnaire for the first stage interviews

Basic information	
1	what is your role in the company? What business are you in charge of? What is your role in interacting with suppliers/customers? *(The interviewee)*
2	What products do you produce? *(Ask even if I know to see how they present themselves)*
3	How many products/product lines does your company have?
4	What is the type of the production? ETO (engineer to order), MTO (make to order), ATO (assembly to order) or MTS (make to stock)? *(They will probably have a mix, therefore phrase to get at this mix. If I find they do things differently I can ask them about this during the interview)*
5	Do you have a supplier database for selection? How many suppliers do you have? How do you establish your supplier database? When you use a supplier from the database, how to choose if there are several alternative suppliers? *(Again ask them for the mix of supplier relationship, e.g. when do you use a supplier from the catalogue and when do you select one.)*
6	Do you have different types of supplier? Do you classify your suppliers? Do you use this classification in practical way? What is the reference for classification? Why to classify? *(Maybe first ask whether they have different types oappef suppliers and then ask whether they use this classification in a practical way or what the differences are between the different types of suppliers.)*
7	When do you pick suppliers and what determines when you do it? Do you have suppliers you work with all the time (what kind of suppliers and why)? Do you have strategic suppliers?
8	Does your supplier participate in the design and development process? Which phase? How do they participate, providing technique or…?
Supplier selection	
1	Do you keep your suppliers from one project to a future one?
2	What is the process for selecting the suppliers? *(Is that the selection between two suppliers for the same component/service. There is a*

	temporal process of when to select all the suppliers for the product and then the more local process of selecting a supplier for a particular part.)
3	What makes the company to decide which supplier to choose, the price, the reputation…? Do you have any criteria? How do you use these criteria? Do these criteria have preference? Do you have essential, desired and optional criteria? What ones are these? Are they different for all suppliers? *(Ask the whether these criteria vary between suppliers or types of relationship, should also work on finding out what criteria they are using and get them to be specific. For each of the criteria that they mention try to find out how they measure this, how they know, how they describe it. This will help build up an example. If they can't tell, I might need to make up an example related to their product and ask them how they would go about it.)*
4	How does the company negotiate with the suppliers?
5	Is the selection different for a company you have previously worked with and one you had not?
Supplier influence	
1	Do the suppliers have influence on the decision of the company? Do they have influence on the design and development process? What are the influences? How they influence?
2	Is the influence different at different phases of the design process? Is it different under time pressure?
3	Is there any very important supplier? What makes the company to consider which supplier is important (and which is not). How does the company treat those important suppliers? How about those less important ones?
4	Did you ever meet any supplier that had some requirements the company could not refuse? Could you please describe this type of suppliers and the requirements? Why couldn't the company refuse?
Power	
1	Before the cooperation, do you consider who is the stronger partner? Do you still consider this question during the cooperation?
2	What is power in your point of view? (The understanding of power)
3	What makes the company feel that the partner is stronger or weaker? (Criteria of power) and all these considerations are of same importance? (The weights of criteria)

C2 Questionnaire for the engine company

1	Who select suppliers?

	1.1 Generally, it is a group of people, so which function/department are they from? 1.2 With different backgrounds, how could people achieve an agreement about the decision? Do they only focus on the part they are expert on and then there are someone else who make the aggregation of all the opinions?
2	What types of supplier do you have? 2.1 What are the differences? 2.2 Do you categorise suppliers according to the importance of products provided by them? 2.3 Do you categorise suppliers according to relationship?
3	Do you have supplier bases for different types of suppliers? 3.1 Under what circumstance you have or do not have supplier bases? 3.2 Under what circumstance you will add or eliminate a supplier from the base? 3.3 What kind of supplier will be added or eliminated? What determines that?
4	How do you select supplier? 1.1 For one type of product needed from supplier, how many suppliers are usually selected as the final product providers? 1.2 Do you have backup suppliers? 1.3 Will you keep a supplier from one project to another? What kind of supplier? What makes a supplier to be kept from one project to another? 1.4 Is there any circumstance that you think about the relationship before selecting the suppliers? For example, I want a long-term supplier then start to select suppliers.
5	When do you pick suppliers? 5.1 What determines when you do it? 5.2 Does supplier selection take place at all phases of product development? 5.3 Do the selection principles differ from different phases? 5.4 Is there a temporal process of when to select all the suppliers for the product and then the more local process of selecting a supplier for a particular part?
6	Do you have very powerful suppliers? 6.1 What makes you think they are powerful? 6.2 Do they have the same influence throughout the whole product development process?
7	When do you have an image of the power of your suppliers? Before selection or after? 7.1 Will this image influence the choice of supplier? Or the willingness to continue the cooperation? 7.2 Do you think they have influence on the company?

8	Have you ever had suppliers that did not perform as they should? 8.1 What kind of suppliers? 8.2 What made them to behave like that? 8.3 What were the influence on the company brought by their behaviours?

C3 Follow-up questions at the engine company

Power	
1	Do you consider power by taking all the factors into account?
2	Is power a perception of the ability to leverage?
3	What can be treated as the leverage?
4	Does power come from dependence?
5	How do you define dependence?
6	What aspects are you looking at on your side and your supplier(customer) side when preparing negotiation?
7	Do suppliers have impacts on your cost structure?
8	Do different types of suppliers have different impacts on the dependence?
Supplier analysis	
1	Is there any circumstance that the company evaluate these suppliers from tier2 and tier 3?
2	Do you have suppliers during the new product implementing process and suppliers for release phase? Are they different? Do you analyse differently?
3	When introducing a new supplier, does it start from the first step of the category management? (*Refer to Figure 4-3*)
4	Is the supplier preference analysis according to how the category fit to supplier business rather than Perkins business? *(Refer to Figure 4-5*)
5	Regarding supplier preference analysis, is this an analysis of how the supplier is attracted rather than the preference of the company on the suppliers?
6	Regarding the component portfolio analysis, do you categorise components according to the importance of the function to the whole product function? Is this equal to the value to the enterprise? (*Refer to Figure 4-6*)
7	Is my understanding correct? Suppliers of small business quite rely on volume predication. They want a tight contract. But big companies won't have this problem. But after the contract, it could be difficult to require big companies for a volume shift like double the volume. In this case, who could be the final choice to work with?

Appendix D Criteria mapping to the taxonomy

D1 Criteria mapping to the taxonomy with attribute analysis

Level 1: basic relationship (no integration); Level 2: operational relationship; Level 3: tactical relationship; Level 4: strategic relationship; Quant: quantitative; Qual: qualitative

Criteria	*Sub-criteria*	*Collaboration level*				*Attribute*	
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Quant*	*Qual*
Product quality	Product reliability	√	√	√	√		√
	Defect	√	√	√	√	√	
	Continuous quality improvement			√	√		√
	Unified quality improvement procedure			√	√		√
	Quality control system			√	√		√
	Quality system/ program certifications				√		√
	Using/providing its certifications				√		√
	Self-audit				√		√
Delivery & Transporta-tion	Delivery time	√	√	√	√	√	
	Lead time		√	√	√	√	
	Fill rate		√	√	√	√	
	Delivery reliability		√	√	√		√
	Transport infrastructure		√	√	√		√
	Test report in the delivery		√	√	√		√
	Supply chain response time			√	√	√	
	Knowledge in logistics			√	√		√
	Set-up time for new product				√	√	
Cost	Net price	√	√	√	√	√	
	Price break	√	√	√	√	√	√
	Space for price negotiation	√	√	√	√		√
	Order change & cancelation charge	√	√	√	√	√	
	Currency fluctuation	√	√	√	√		√
	Foreign exchange rate	√	√	√	√	√	
	Export taxes	√	√	√	√	√	
	Logistics cost	√	√	√	√	√	
	Warranty cost	√	√	√	√	√	
	Variation in price			√	√		√
	Operating cost			√	√	√	
	Maintenance cost			√	√	√	
	Production cost			√	√	√	
Production capacity & facility	Production capacity		√	√	√	√	
	Volume size flexibility		√	√	√		√
	Inventory turnover ratio			√	√	√	
	Reserve capacity to respond to unexpected demand			√	√	√	

Criteria	***Sub-criteria***	***Collaboration level***				***Attribute***	
		Level 1	***Level 2***	***Level 3***	***Level 4***	***Quant***	***Qual***
	Production/manufacturing facilities			√	√		√
	Production planning system			√	√		√
	Production flexibility				√		√
Packaging	Packaging ability		√	√	√		√
	Environmentally friendly packaging				√		√
Product profile	Ease of use		√	√	√		√
	Handling		√	√	√		√
	Light weight			√	√		√
	Reusable				√		√
	Product range				√	√	
	Frequency of newer product				√	√	
Geography	Geographical location		√	√	√		√
Service	Repair service		√	√	√		√
	Training aids		√	√	√		√
	Customised service			√	√		√
	Flexibility in service			√	√		√
	Professionalism			√	√		√
	Responsiveness			√	√		√
	Quick decision making			√	√		√
	Service innovation				√		√
	Customer satisfaction				√		√
	Process of dealing with customer complaints				√		√
Commit-ment	Warranties & claim policies		√	√	√		√
	Commitment to continuous improvement			√	√		√
	Trust			√	√		√
Technolo-gical & technical capability	Technical capability			√	√		√
	Supplier's technological system			√	√		√
	R&D capability			√	√		√
	Current technology			√	√		√
	Technology capability limit			√	√		√
	Technical problem solving			√	√		√
	Complementarities of capabilities			√	√		√
	Customisation			√	√		√
	Criticality of non-core technology to buyer			√	√		√
	Technological/ engineering support			√	√		√
	Design/co-design capability			√	√		√
	Product development capability			√	√		√
	Test capability			√	√		√

Criteria	***Sub-criteria***	***Collaboration level***				***Attribute***	
		Level 1	***Level 2***	***Level 3***	***Level 4***	***Quant***	***Qual***
	Manufacturing capability			√	√		√
	Innovativeness				√		√
	Dynamism of input technology				√		√
	Future technology development				√		√
	Future manufacturing capability				√		√
	Availability of clean technology				√		√
	Cost reducing capability				√		√
Financial	Financial position			√	√		√
	Financial conditions			√	√		√
	Financial assets availability to put into the partnership			√	√		√
	Financial risk			√	√		√
	Profitability				√	√	
	Return on investment				√	√	
	Investment records & plans				√		√
	Financial strength				√		√
Attitude	Attitude to the organisation			√	√		√
	Cooperative attitude			√	√		√
	Honesty			√	√		√
	Respect confidentiality			√	√		√
	Impression			√	√		√
Desire	Procedural compliance			√	√		√
	Willingness to cooperate to reduce cost			√	√		√
	Willingness to change productivity on demand			√	√		√
	Willingness to accept order change			√	√		√
	Willingness to advance delivery			√	√		√
	Willingness to solve conflict			√	√		√
	Willingness to disclose cost/expertise/resource info				√		√
Management & organisation	Management & organisation status			√	√		√
	Management compatibility			√	√		√
	Management capability			√	√		√
Reputation	Reputation in industry			√	√		√
	Position in industry			√	√		√
	Age in industry			√	√	√	
Process	Design/manufacturing process capability			√	√		√
	Process flexibility			√	√		√

Criteria	***Sub-criteria***	***Collaboration level***				***Attribute***	
		Level 1	***Level 2***	***Level 3***	***Level 4***	***Quant***	***Qual***
Market	Local market knowledge				√		√
	Providing key market/industry info				√		√
	Market share				√	√	
	Speed to market				√	√	
	Annual sales growth				√	√	
	Amount of past business				√	√	
	Diversification of customer				√		√
Communi-cation	Communication system				√		√
	Communication ease				√		√
	Frequency of communication				√	√	
	Access to system				√		√
Relation	Past and current relationship				√		√
	Time in forming relationship				√	√	
	Compatibility of business				√		√
	Reciprocal arrangement				√		√
Labour	Labour relation record				√		√
	Employee turnover rate				√	√	
	Application of work safety & labour health				√		√
Social issues	Country regulations & standards				√		√
	Political & economical stability				√		√
	Social responsibility				√		√
	Ethical practices				√		√
Green	Environmental control & programs				√		√
	Impact on energy utilization				√		√
	Public disclosure of environmental record				√		√
	Environmental related certification				√		√
	Recycling and reverse logistics				√		√

D2 Definitions of the criteria

Criteria	***Sub-criteria***	***definition***
Product quality	Product reliability	Consistent conformance to specification
	Defects	Percentage of unqualified parts
	Continuous quality improvement	The possibility of the supplier to continuously improve the quality
	Unified quality improvement procedure	How effective the procedure is
	Quality control system	The quality control system used by suppliers
	Quality system/ program certifications	The level of the system or program certifications the supplier has

Criteria	***Sub-criteria***	***definition***
	Using/providing its certifications	How effectively the supplier uses or provides the certifications
	Self-audit	How well the self-audit is carried on
Delivery & Transporta-tion	Delivery time	The promised delivery time
	Lead time	The latency between the placement of the order and the delivery
	Fill rate	The percentage of demand satisfied by inventory on hand
	Delivery reliability	The ability to meet the delivery schedules
	Supply chain response time	The supplier's supply chain response time
	Transport infrastructure	The wellness of the transport infrastructure
	Test report in the delivery	Whether the supplier provides test report during the delivery.
	Knowledge in logistics	The knowledge the supplier has in logistics
	Set-up time for new product	Set-up time for new product
Cost	Net price	Net price
	Price break	The discount in price for large quantity purchase
	Space for price negotiation	Space for price negotiation
	Order change & cancelation charge	The charge for order change and cancelation
	Currency fluctuation	Currency fluctuation but it can be calculated through the currency exchange rate (this is for international purchase)
	Foreign exchange rate	Foreign exchange rate (this is for international purchase)
	Export taxes	Export taxes (this is for international purchase)
	Logistics cost	Cost for logistics
	Warranty cost	Cost for warranty
	Variation in price	The possibility of having an increasing-trend product price in compared with other suppliers in the future
	Operating cost	Supplier's operating cost (for long-term relationship)
	Maintenance cost	Supplier's maintenance cost (for long-term relationship)
	Production cost	Supplier's production cost (for long-term relationship)
Production capacity & facility	Production capacity	Production capacity
	Volume size flexibility	The ability to meet the fluctuation in demands
	Inventory turnover ratio	Inventory turnover ratio
	Reserve capacity to respond to unexpected demand	Reserve capacity to respond to unexpected demand
	Production/manufacturing facility	Production facility
	Production planning system	The maturity of the production planning system
	Production flexibility	The flexibility of production line, i.e., the ability to switch the production from one type of product to another
Packaging	Packaging ability	The ability of supplier to meet the packaging requirements for this product
	Environmentally friendly packaging	Whether the supplier can provide Environmentally friendly packaging
Product profile	Ease of use	Ease of use of the product
	Handling	Ease of handling of the product
	Light weight	Light weight of the product
	Reusable	Whether the product is reusable
	Product range	The product range of the supplier
	Frequency of newer product	The frequency of newer product that the supplier produces
Geography	Geographical location	Geographical location
Service	Repair service	The level of the provided service

Criteria	***Sub-criteria***	***definition***
	Training aids	The level of the provided training aides
	Customised service	The level of the customised service
	Flexibility in service	Flexibility in service
	Professionalism	Professionalism
	Responsiveness	How quick the supplier response to any change
	Quick decision making	How quick the decision can be made
	Service innovation	Service innovation
	Customer satisfaction	Customer satisfaction records of the supplier
	Process of dealing with customer complaints	The way of supplier to process customer complaints
Commit-ment	Warranties & claim policies	Warranties & claim policies
	Commitment to continuous improvement	Commitment to continuous improvement
	Trust	How much trust between the supplier and the buyer
Technolo-gical & technical capability	Technical capability	The mature of supplier's technical capability
	Supplier's technological system	The technological system that can facilitate technology development of products
	R&D capability	The research & development capability
	Current technology	The present technology of products
	Technology capability limit	The constraints in technology capability
	Technical problem solving	The capability of supplier to solve technical problem
	Complementarities of capabilities	The ability to complement each other's capabilities
	Customisation	The capability to customise product as demanded by the buyer
	Criticality of non-core technology to buyer	Criticality of non-core technology to buyer
	Technological/ Engineering support	1. Whether the supplier can provide technological or engineering support to buyer 2. if yes, the depth of support to be provided
	Design/co-design capability	Design/co-design capability
	Product development capability	Product development capability
	Test capability	Test capability
	Manufacturing capability	Manufacturing capability
	Innovativeness	The innovation capability
	Dynamism of input technology	How dynamic the supplier's technology that can be provided
	Future technology development	The expected technology development of products in the near future
	Future manufacturing capability	Future manufacturing capability
	Availability of clean technology	Availability of clean technology
	Cost reducing capability	The possibility of reducing manufacturing costs of the supplier
Financial	Financial position	The supplier's financial position
	Financial conditions	Asset-liability ratio
	Financial assets availability to put into the partnership	Financial assets availability to put into the partnership
	Financial risk	Financial risk
	Profitability	Profits as percent of sales
	Return on investment	Return on investment

Criteria	***Sub-criteria***	***definition***
	Investment records & plans	Investment records & plans
	Financial strength	Financial strength
Attitude	Attitude to the organisation	Attitude toward the supplier's organisation
	Cooperative attitude	Attitude toward the cooperation
	Honesty	Honesty
	Respect confidentiality	The attitude toward respecting confidentiality
	Impression	The impression made by supplier in personal contact
Desire	Procedural compliance	Compliance or likelihood of compliance with The buyer's procedures (both bidding and operating)
	Willingness to disclose cost/expertise/resource info	Willingness to disclose cost/expertise/resource info
	Willingness to cooperate to reduce cost	Willingness to cooperate to reduce cost
	Willingness to change productivity on demand	Willingness to change productivity on demand
	Willingness to accept order change	Willingness to accept order change
	Willingness to advance delivery	Willingness to advance delivery
	Willingness to solve conflict	Willingness to solve conflict
Manage-ment & organisation	Management & organisation status	Current management and organisation status of supplier
	Management compatibility	Management style and organisation culture compatibility with buyer
	Management capability	Management capability
Reputation	Reputation in industry	The reputation of the supplier company in industry
	Position in industry	The position of the supplier company in industry
	Age in industry	The age of the supplier company in industry
Process	Design/manufacturing process capability	The capability of the supplier to manage its design/manufacturing process
	Process flexibility	The ability to adjust design/manufacturing process as demanded
Market	Local market knowledge	How much local market knowledge the supplier has
	Providing key market/industry info	1. whether supplier is able to provide key market/industry info 2. if yes, how much info can be provided
	Market share	The market share the supplier owns
	Speed to market	The speed that the supplier puts the product to market
	Annual sales growth	Annual sales growth
	Amount of past business	Amount of past business has been done
	Diversification of customer	Diversification of customer
Communi-cation	Communication system	The communication system (with information on progress data of orders) the supplier uses and provides
	Communication ease	The ability to maintain a good communication channel and negotiability with the supplier
	Frequency of communication	Honest and frequent communications
	Access to system	The accessibility to the communication system
Relation	Past and current relationship	The condition of the past and current relationship
	Time in forming relationship	The duration of time required to form a satisfactory buyer–supplier relationship
	Reciprocal arrangement	The possibility of future purchases the supplier will make

Criteria	***Sub-criteria***	***definition***
		from your firm
Labour	Labour relation record	Labour relation record
	Employee turnover rate	Employee turnover rate
	Application of work safety & labour health	Application of work safety & labour health
Social	Country regulations & standards	How much difficulties the country regulations & standards could bring to the relationship (for international trade relation)
	Political & economical stability	The political & economical stability of the country the supplier locates (for international trade relation)
	Social responsibility	The social responsibility of the supplier
	Ethical practices	The ethical practices and standards of the supplier
Green	Environmental control & programs	Environmental control & programs
	Impact on energy utilization	Impact on energy utilization
	Public disclosure of environmental record	Public disclosure of environmental record
	Environmental related certification	Environmental related certification
	Recycling and reverse logistics	Recycling and reverse logistics