A context-aware approach for business-to-business collaboration

Tan, Puay Siew

2010

Tan, P. S. (2010). A context-aware approach for business-to-business collaboration.
Doctoral thesis, Nanyang Technological University, Singapore.

<https://hdl.handle.net/10356/42393>

<https://doi.org/10.32657/10356/42393>

A Context-aware Approach for Business-to-Business Collaboration

School of Computer Engineering
School of Mechanical and Aerospace Engineering

A thesis submitted to the Nanyang Technological University
in fulfillment of the requirement for the degree of
Doctor of Philosophy

By
Tan Puay Siew (Ms)
2010

Abstract

Businesses operate in value chains to pursue a common goal. Information Technology (IT) is used pervasively to support such complex globalised chains, underlined by Business-to-Business (B2B) collaboration activities. Existing B2B collaborations are often inhibited by costs and long setup time. One of the key challenges is to pervasively connect partners across the entire value chain, with the appropriate service offerings. Thus, it is vital to quickly identify potential partners to form new B2B collaboration or to support formed collaborations with swift decision making abilities.

This research proposes a *context-aware* approach to support such B2B collaboration. Context-awareness relates to the use of situational information (e.g. location of user/company, time and date of expected cargo arrival) for decision-making. The decision could be very computing- centric such as a context-aware database query and search for example. In B2B, the action (or decision) could be when to schedule the next delivery or how to identify suitable partners for collaboration. To realise this *context-aware* approach, several issues have been addressed:

- Understanding and identifying relevant *context* in B2B collaborations, thereby formulating an appropriate *B2B Context Model*,
- Identifying a relevant context representation and reasoning technique to process the model, and
- Developing a method to support decision making, based on a given *context* of collaboration.

This thesis documents the investigations conducted to establish the viability of this context-aware approach for B2B collaboration. A review of existing context-aware literature revealed that existing context elements defined in other application domains are insufficient for B2B collaboration. Hence, there was a need to further identify B2B

A Context-aware Approach for Business-to-Business Collaboration

specific contexts, where inspiration was taken from existing literature on supplier selection criteria. A *B2B Context Model* to support context-aware B2B collaboration was then formulated based on the reviews. This model is anchored on the three main aspects of context, namely *User*, *Temporal* and *Location*. To ensure that the model is able support different B2B applications, it was verified for completeness with the PIPs (Partner Interface Processes) specifications of RosettaNet, an industry *de-facto* B2B collaboration standard. Description Logic (DL) was then explored as a theoretical underpinning of the representation and reasoning of context information. This is to ensure decidability and completeness in the reasoning. The *B2B Context Model* was realised using a DL-safe version of OWL (Web Ontology Language). Experiments conducted using the OWL knowledge base showed that such applications are not scalable. As such, though DL-safe representation ensures sound reasoning, further empirical investigations in this research are based on an XML schema representation, for performance reasons.

The next part of this research investigated the use of multi-criteria decision making (MCDM) techniques to support this context-aware approach. For this purpose, an evaluation framework to assess the suitability of various MCDM techniques is proposed. Based on the assessment using this framework, a new MCDM technique, *Deviation Measure* is proposed to address the specific needs of B2B collaboration. Finally, a holistic hybrid approach for context-aware B2B collaboration is proposed. The viability of this hybrid approach was investigated empirically through a case study. Results showed that this proposed hybrid approach is viable, with *Deviation Measure* performing the best among the short-listed MCDM techniques.

Acknowledgements

First off, to a lady that I hold in high-regard, *Professor Angela Goh*. She has been my source of inspiration in trying to juggle family, work and this PhD pursuit. I really do admire her no-nonsense and go-getter attitude. Her eye for details has also never failed to amaze me. Above all, her “infinite” patience in dealing with this part-time pursuit is incredible, timing her rather painful but essential reminders very well.

Another person that I am eternally grateful to is *Associate Professor Stephen Lee*. This would have not started, let alone continue without his encouragement. He kept me going through all those “dark” times. The lunches and tea sessions were priceless, especially when I was seriously questioning my own wisdom in starting this. Last but not least, I really appreciate his thoroughness and patience with my write-ups. That is something not many students have the privilege to enjoy.

So to both of you, my heartfelt and sincere **THANK YOU**.

I would also like to say a big **thank you** to the people whom I have the privilege to work with and whom have lent me a helping hand one way or another, in this “crazy” journey. The list is long and if I inadvertently missed anyone, my sincere apologies; Eng Wah, Karel, Roland, Sun Jin, Anson, Jake, Edwin, Viet Phu, Bingyuan, Chin Teck, Wei Wah and Suran amongst the many. Also, my sincere **thanks** to the companies that have kindly agreed to the numerous sessions of questions and survey, in order to ensure that my research is accurate and reflective of industry practices. Special thanks to Basil and Albert.

Last but not least, to my husband and daughter. Both of you have been immensely wonderful in your own ways. To Edward, **THANK YOU** for your support, encouragement

A Context-aware Approach for Business-to-Business Collaboration

and looking after our daughter, especially during my examinations. To Gracelynn, you have been my constant source of motivation. You reinforced my determination and kept me “sane” through this journey.

THANK YOU everyone!

Table of Contents

Abstract.....	ii
Acknowledgements.....	iv
List of Figures	xi
List of Tables	xiii
1 Introduction	1
1.1 Business-to-Business (B2B) Background	2
1.2 Challenges in facilitating B2B Collaboration	5
1.3 Research Objective and Scope	7
1.4 Thesis Outline	8
2 Literature Review	11
2.1 Understanding Context	12
2.1.1 Ubiquitous Computing.....	13
2.1.2 Information Management	14
2.1.3 Cognitive-based Computing.....	15
2.1.4 Business.....	15
2.1.5 Summary	16
2.2 Classification of Context Information	17
2.3 Understanding Context-aware Pre-requisites in B2B Collaboration	23
2.3.1 Constituents of B2B Context.....	24
2.3.2 Supplier Selection Criteria	25
2.4 Chapter Summary.....	28
3 A Context Model to support B2B collaboration	30

A Context-aware Approach for Business-to-Business Collaboration

3.1	Analysis of existing context information's relevance to B2B collaboration	31
3.2	Identifying supplier selection criteria relevant to B2B collaboration	34
3.3	Proposed B2B Context Model (Version 1.0)	37
3.4	Verifying Model Completeness using RosettaNet	39
3.4.1	RosettaNet Standards Overview.....	40
3.4.2	Verification Methodology	42
3.4.3	Mapping Results.....	44
3.5	Refined B2B Context Model (Version 2.0)	46
3.6	Industry Verification of the Model.....	49
3.7	Potential Applications of the B2B Context Model in B2B Collaboration	51
3.8	Chapter Summary.....	52
4	Representation and Reasoning of the B2B Context Model.....	54
4.1	Using the B2B Context Model	55
4.2	Overview of Relevant Concepts	57
4.2.1	Description Logic (DL)	57
4.2.2	Ontology and the Web Ontology Language (OWL)	66
4.2.3	Semantic Web Rule Language (SWRL)	68
4.3	Modelling the <i>B2B Context Model</i> as an Ontology	70
4.3.1	Design Considerations	71
4.3.2	Ontology Structuring.....	71
4.3.3	Extending the Ontology through SWRL	73
4.4	Experimental Investigation and Analysis of Ontology-based Representation ..	74
4.4.1	Prototype Development	74
4.4.2	Experimental Setup.....	75

A Context-aware Approach for Business-to-Business Collaboration

4.4.3	Results and Analysis.....	76
4.5	Chapter Summary.....	79
5	Decision Making Techniques to Support Context-aware B2B Collaboration	81
5.1	Overview of Multi-Criteria Decision Making (MCDM) Techniques.....	82
5.1.1	Alternatives	82
5.1.2	Decision Criteria	83
5.1.3	Decision Type	84
5.2	Selecting Suitable MCDM Techniques	85
5.2.1	Brief Review of Existing Work	86
5.2.2	Important Considerations for supporting Context-aware B2B Collaboration	87
5.2.3	Proposed Evaluation Framework.....	89
5.3	Multi-Attribute Utility Theory (MAUT) Techniques	92
5.3.1	AHP.....	92
5.3.2	VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje)	93
5.3.3	TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)..	93
5.3.4	An assessment of the three MAUT techniques	94
5.3.5	Proposed Deviation Measure	97
5.4	Outranking Techniques	99
5.4.1	ELECTRE Methods	100
5.4.2	PROMETHEE Methods	103
5.4.3	Assessing the suitability of the Outranking techniques	104
5.5	Proposed MCDM Approach	106
5.5.1	Weights Determination	107

A Context-aware Approach for Business-to-Business Collaboration

5.5.2	Fuzzification of Qualitative Criteria	108
5.5.3	Processing Nominal Criteria.....	115
5.5.4	Soundness of the Normalisation Methods Adopted	115
5.6	Chapter Summary.....	120
6	Realisation of Context-aware Hybrid Decision Making Approach.....	122
6.1	Overview	123
6.2	Prototype Implementation of Cognitive Advisor	124
6.2.1	Architecture	124
6.2.2	Usage Flow	126
6.3	Multi-criteria Partner Evaluation and Selection – A Case Study.....	127
6.3.1	Motivating Scenario	127
6.3.2	Evaluation Considerations and Options Available	129
6.4	Suitability of Candidate MCDM techniques	130
6.4.1	Overall Experimental setup	130
6.4.2	Rank Completeness.....	132
6.4.3	Rank Correlation	133
6.4.4	Rank Reversal.....	137
6.4.5	Sensitivity Analyses	139
6.4.6	Summary of Empirical Analyses.....	142
6.5	Fuzzy Verification	144
6.5.1	Experimental setup	144
6.5.2	Discussion of Test Results	145
6.6	Industry Study	147
6.6.1	Experimental setup	147

A Context-aware Approach for Business-to-Business Collaboration

6.6.2	Results and Discussion	149
6.7	Chapter Summary.....	152
7	Conclusion.....	154
7.1	Research Contributions.....	154
7.2	Future Work	156
	References	158
	Publications Derived From This Research.....	175
	Appendices.....	A-1
Appendix 1:	Classification of Context Elements	A-2
Appendix 2:	Supplier Selection Criteria – Categorisation and Analysis.....	A-8
Appendix 3:	Details on RosettaNet Mapping	A-17
Appendix 4:	Detailed Description of B2B Context Model Version 2.0	A-23
Appendix 5:	An OWL-based Ontology for B2B Context Model	A-28
Appendix 6:	Formula and Elicitations Steps of MCDM Techniques	A-37
Appendix 7:	Fuzzy Models of the Qualitative Criteria in B2B Context Model.....	A-54
Appendix 8:	Empirical Testing of Candidate MCDM Techni.....	A-58
Appendix 9:	Worked Examples.....	99
Appendix 10:	Large-scale Empirical Testing of DMO and PROMETHEE II	105

List of Figures

Figure 1-1: A Basic Supplier Chain	1
Figure 1-2: Customer driven B2B Collaborations	2
Figure 1-3: Standards-based B2B Collaborations	3
Figure 1-4: Composition and outline of thesis.....	8
Figure 2-1: Elements within the Physical Aspect.....	19
Figure 2-2: Elements within the Cognitive and Information Management Aspects	21
Figure 2-3: Mapping of <i>Cognitive</i> elements to <i>Physical</i> elements/sub-elements.....	22
Figure 2-4: A mind-map of selection criteria for supplier identification	26
Figure 3-1: <i>B2B Context Model</i> (version 1.0)	38
Figure 3-2: Schematic representation of the verification methodology	43
Figure 3-3: Mapping flow for Step (1).....	44
Figure 3-4: B2B Context Model (version 2.0).....	48
Figure 4-1: Realisation of the model as <i>context-aware profiles</i>	55
Figure 4-2: A diagrammatic illustration of the semantics in DL (<i>ALC</i>)	60
Figure 4-3: Example of using the Tableau Algorithm to create a tree-like model	65
Figure 4-4: Classes and Object Properties in the ontology for <i>B2B Context Model</i>	73
Figure 4-5: A high-level architecture of the Cognitive Advisor.....	75
Figure 4-6: Time taken to perform the different tasks in the CIM module (Test 1).....	77
Figure 4-7: Total time taken for different criteria (Test 2)	78
Figure 4-8: Comparison of total time taken between ontology-based and XML-based implementations (Test 3).....	79
Figure 5-1: A deviation measure from the preferred values.....	97
Figure 5-2: Family of ELECTRE methods	100
Figure 5-3: Triangular interval of Type-2 Membership Function	108
Figure 5-4: Fuzzy Model of <i>On-Time_Delivery</i>	110
Figure 5-5: Fuzzy Model of <i>Quality_Certification</i>	111
Figure 5-6: Fuzzy Model of <i>Business_Profile</i>	112

A Context-aware Approach for Business-to-Business Collaboration

Figure 5-7: Fuzzy Model of <i>Quality</i>	112
Figure 5-8: Calculation of crisp value based on the <i>Business Profile</i> fuzzy model	114
Figure 6-1: High-level architecture of Cognitive Advisor	125
Figure 6-2: Usage flow of Cognitive Advisor	126
Figure 6-3: Hierarchical Structure of the Experimental Setup.....	131
Figure 6-4: Weights for each criterion used for the sensitivity analysis tests.....	139
Figure 6-5: Effects of Fuzzification (FTest-1).....	145
Figure 6-6: Effects of Fuzzification on the OSS	146
Figure 6-7: Ranking of candidate partners by companies in industry study	150
Figure 6-8: MCDM techniques ranking results (sub-set of Set1-1-2)	151

List of Tables

Table 3-1: Mapping of <i>User</i> category elements into B2B requirements.....	32
Table 3-2: Mapping of <i>Location</i> category elements into B2B requirements.....	32
Table 3-3: Mapping of <i>Temporal</i> category elements into B2B requirements	33
Table 3-4: Clusters and segments in RosettaNet PIPs	40
Table 3-5: Influencing Factors' relevance for inclusion into B2B Context Model	45
Table 4-1: Tableau expansion rules for $\mathcal{ALC}$	63
Table 5-1: Comparison of relevant MAUT methods using the evaluation framework	95
Table 5-2: Comparison of relevant Outranking methods using the evaluation framework	104
Table 5-3: Rank values used.....	111
Table 6-1: 5Kell's Blanket PO Scope of Product and Pricing.....	128
Table 6-2: Sample result from Set 1-3-4 (W4) used to calculate rank completeness for DMO	132
Table 6-3: Summary of rank completeness scores for the 4 candidate techniques	133
Table 6-4: Summary of providers used in each test step - S2	134
Table 6-5: Summary of providers used in each test step - S3	135
Table 6-6: Sample calculation for <i>rank correlation</i> score - using Set 2-1-2 (W1) data for DMM	135
Table 6-7: Summary of rank correlation scores.....	136
Table 6-8: Sample calculation for rank reversal score - using Set 2-1-2 (W1) data	137
Table 6-9: Summary of rank reversal (degree of disagreement) scores	138
Table 6-10: Summary of the empirical evaluation of candidate MCDM techniques	143
Table 6-11: Sample Data for Fuzzy Verification.....	144
Table 6-12: The Weights for each Criterion.....	144
Table 6-13: The five candidate partners' pertinent values.....	147
Table 6-14: Preferred Values of QuickLite.....	147
Table 6-15: Calculated Values.....	148

A Context-aware Approach for Business-to-Business Collaboration

1 Introduction

Today, businesses do not operate as individual companies. Instead, they form and operate in value chains. This is especially evident for manufacturing related businesses. The present-day globalised and networked economy increases the complexity of manufacturing operations, as manufacturing shifts from North America and Western Europe to Asia in particular [1]. As businesses now operate across geographical regions, such value chains are becoming even more pervasive. One such value chain is the ubiquitous supply chain, often characterized by Business-to-Business (B2B) collaboration activities, ranging from supplier selection to transaction-type activities like purchase orders to inventory information sharing. Supply chains typically have many partners. A simple basic model of supplier-manufacturer-customer supply chain is illustrated in Figure 1-1. The *supplier* denotes a party/organisation that provides or sells a product/service to another party, a *manufacturer* in this case. In turn, the *manufacturer* is someone who uses tools and labour to create value-added products or services for sale to *customers*. In this basic example, *manufacturer* is a “supplier” to *customer*. Each of these entities in turn could also be a supplier or customer to other partners, and function in multiple roles simultaneously.

Figure 1-1: A Basic Supplier Chain

The next section of this chapter discusses the issues that confront current B2B collaboration. These issues pose a significant challenge in using Information Technology (IT) to pervasively support increasingly complex globalised supply chains. The notion of *context* to support B2B collaboration across the supply chain is introduced. The

Introduction

challenges of using this context-aware technique to support B2B collaborations will also be briefly discussed.

1.1 Business-to-Business (B2B) Background

Businesses collaborate with one another in pursuit of a common goal and to benefit from competitive advantage through shorter time-to-market, reduced cycle times and enhanced customer service [2]. Traditionally, such collaboration takes place through phone calls, faxes or even face-to-face communication, all of which can be error-prone and time consuming. Manufacturers/suppliers now scour the world for the best partners that can produce high quality goods/services at the lowest cost [3]. As a consequence of this globalisation [4], the number of supply chain partners has increased, partners are more geographically dispersed and operate in different time-zones, rendering traditional collaboration methods inefficient. Thanks to the Internet, easy information access and effective remote communication have facilitated real-time business transactions. Geographically dispersed corporations can now collaborate anytime and integrate their business processes. However, such integration poses a major challenge, especially for supra-national corporations or multi-national corporations (MNCs) that have hundreds of trading partners [5].

Figure 1-2: Customer driven B2B Collaborations

Introduction

Such MNCs drive and dictate B2B collaborations as supply chain masters [6]. In Singapore for example, these MNCs typically have suppliers which are local enterprises consisting of both promising local enterprises (PLEs) and small-medium enterprises (SMEs). To illustrate a typical B2B collaboration, consider a customer, Enterprise-A, requesting for information on product quality from one of its suppliers, Enterprise-B, as shown in Figure 1-2. Enterprise-B is a PLE headquartered in Singapore but has geographically-dispersed manufacturing plants in Malaysia and China. Hitherto, each manufacturing plant submits information on product quality directly to the customer, and ironically headquarters receives this information from the customer, instead of its own subsidiaries. This is common in many supply chain master driven B2B collaborations, resulting in a lack of information exchange control between the customer and headquarters, latency in the information exchange, and dodgy data tracking and consolidation. Furthermore, suppliers like Enterprise-B are often compelled to maintain multiple collaboration systems, one for each big MNC customer.

Figure 1-3: Standards-based B2B Collaborations

With Web Services, these impediments can be overcome [7]. A Web Service is basically a lightweight, standards-based, service-oriented-architecture implementation that

Introduction

leverages on the Internet infrastructure [8]. It uses an XML-based message exchange standard called SOAP as the main form of communication. Through Web Services, suppliers like Enterprise-B are now able to provide up-to-date information to their customers, as illustrated in Figure 1-3. As infrastructure requirements for Web Services are lighter, the cost of integration is relatively lower, be it internally (to subsidiaries) or to external parties (other suppliers). Furthermore, being standards-based, such systems (or services) need only be built once but can be reused.

Although the total cost of operating this infrastructure is lower (as compared to that of full-fledged RosettaNet¹ implementations for example), such connections take time to build and are expensive too. This is largely due to the fact that such connections are still very *static* and require significant manual intervention, e.g. identifying the types of connectivity (whether portal access or direct connection), the types of information to be shared and to how to share them. Substantial upfront investment, adequate IT infrastructure and in-house IT skills are needed to operate such implementations. These reasons make such connectivity economically viable only between the MNC and its first-tier, as in the example, or at best second-tier business partners. This fact is borne out by a survey of local enterprises in Singapore conducted in late 2004 [6]. This is also corroborated by another unrelated survey on the adoption of business-to-business electronic commerce in Singapore [9]. It found that 80% of adopters were companies with annual revenue exceeding S\$50 million.

Effective B2B collaborations in a supply chain depend on B2B connectivity across the entire value chain. Such connectivity is needed not only to expedite transactions and thereby reduce costs, but also to seize opportunities in a rapidly-changing business environment. In a 2007 report by Aberdeen for example [4], the foremost motivator for companies to globally invest in supply chain applications has been “the need to

¹ RosettaNet is a business standard for B2B collaboration. It is becoming a de-facto standard, in particular for the high-tech industry.

Introduction

change and adapt business processes over time". In another report [10], the two main drivers were "improve the response to market demand" and "better manage variability in the supply chain". These trends are forcing companies to improve their supply chain responsiveness, to "quickly identify and react to changes in supply, demand and execution threats/opportunities" [11]. Furthermore, there is greater volatility in demand, resulting in uncertainty of demand forecasts [12]. Because of this, *sense and respond manufacturing* is gaining recognition [13], with outsourcing identified as one of the key activities [14]. Paradoxically, the globalisation of supply chains has resulted in increased lead-times (because of the geographical dispersion) [12]. Real-time collaboration with partners is critical to empower *sense and respond manufacturing*, supported by a synchronised supply chain [13]. Thus, it is crucial to identify potential partners (based on the current outlook or goal) and form the partnerships quickly (plug-n-play being desirable) [15].

1.2 Challenges in facilitating B2B Collaboration

The ability to quickly identify and connect potential partners is a key enabler of a synchronised supply chain in a *sense and respond manufacturing* environment. Partners can be identified either by a restricted search (e.g. those who have been pre-qualified earlier) or by an open search. Towards this end, the concept of virtual enterprise has been investigated extensively for both approaches. A virtual enterprise is an *ad hoc* alliance of enterprises that come together to exploit core competencies and resources in order to seize business opportunities. Much research has concentrated on integrating a number of heterogeneous IT components from different IT platforms and tools to support Virtual Enterprises [5]. The efforts can be broadly divided into 3 categories: layers super-imposed on the various platforms; distributed multi-agent systems; and plug-n-play services of service-based frameworks based on standardised service interfaces to enable interoperability with other services (from requesting companies).

Introduction

The Service-Oriented Architecture (SOA) paradigm and Web Services underpin such service-based frameworks.

However, current capabilities, such as the Universal Description, Discovery and Integration (UDDI) of Web Services, being syntactic and non-semantic by nature, are not able to match services offered by potential partners in a SOA environment well. Semantics is necessary because services (representing partners) with the same meaning but different keywords cannot be identified. Much research into the semantic approach to overcome this problem has been reported [16]. Semantics presumes the existence of ontology, a formal representation of a set of concepts within a domain and the relationships between those concepts. It is unrealistic to assume that every organisation or partner has an ontology, given the diverse nature of partners in a supply chain.

Another challenge is the acquisition of timely information to dynamically identify and match potential partners' services. Most B2B activities are process-governed but dominated by the exchange of business documents. In a typical supply chain, examples of such documents include purchase orders (POs), goods receive notes (GRNs) and advance shipment notes (ASNs). These documents are rich in contextual information. Some typical contextual information include the company's name, address (billing, delivery etc), date of delivery (or receipt), location of the goods, the status of payment or invoice, and other information like inventory level and expected demand of particular items. Such contextual information is invaluable for supporting B2B collaboration, for example identifying and matching suitable partners. The contextual information serve as a good platform for exploring the *context-aware* approach, given a known goal and criteria (context) of collaboration.

In the next section, the research objective and scope of work are discussed. These are identified based on the assumption that *services* represent company offerings and are available to be used once the connectivity between the companies is established. The

Introduction

business contexts of these *services* are expected to be advertised as *context-aware profiles*. This is further discussed in Chapter 4.

1.3 Research Objective and Scope

Given the challenges outlined earlier, the main research objective is *to investigate into and formulate a context-aware B2B collaboration approach, supported by relevant quantitative decision technique(s)*. The outcome of this research would be used to support the formation of new B2B collaboration and/or formed collaborations with quick decision making abilities.

To realise this context-aware approach, this research focused on using the *context information* together with quantitative *decision making* techniques to create context-enabled B2B collaborations. With this objective in mind, the scope of work includes:

- *Modelling of context information for B2B Collaboration*
 - This entails understanding what constitutes context information in B2B collaborations and creating a suitable *B2B Context Model* to model the relationships between the different elements of context information.
- *Formal theory to support reasoning using the B2B Context Model*
 - Context information needs to be extracted and processed. A reasoning technique (based on formal theory) must also be identified or developed.
- *Identifying suitable multi-criteria decision making (MCDM) techniques* to support this context-aware approach
 - The *context information* is used to support the formation of new B2B collaboration and/or formed collaborations, with automated decision making abilities using MCDM techniques.
 - However, these MCDM techniques need to be assessed for their suitability to support B2B decision making in an automatic manner.

Introduction

- *Validation of this context-enabled B2B collaboration approach*
 - The context-aware B2B collaboration approach has to be validated. This entails a system implementation, designing and conducting suitable tests, and analysing the results obtained.
 - For the purpose of validation, partner matching and selection are identified as a specific application of B2B collaboration.

These have been investigated, and the outcome will be discussed in the rest of this thesis. The next section provides the roadmap of the discussions.

1.4 Thesis Outline

The nature of B2B collaboration is such that both computer science and operations research knowledge is brought to bear on this proposed research. Figure 1-4 provides a graphical representation of the research roadmap for this candidature, in which computer science to operations research is roughly in the ratio of 3:2.

Figure 1-4: Composition and outline of thesis

Introduction

The rest of this thesis is organised into six chapters. Chapter 2 provides a detailed analysis of the current literature in context-aware computing. It includes a discussion on the varied forms of context definitions and an analysis of the context information in existing literature and a classification of these diverse elements, with a view of how they can be used in the proposed *B2B Context Model*. Thereafter, the author endeavoured to further discover constituents of B2B context. Supplier selection criteria were used as a source for discovering such B2B context. A categorisation of supplier selection criteria was also discussed, and together with the identified relevant contexts from context-aware computing research, forms the foundation for the formulation of a *B2B Context Model*.

Chapter 3 analyses the pre-requisites for context-enabled B2B collaboration. Arising from that, a *B2B Context Model* to support such collaboration is proposed. The completeness of this model was evaluated against RosettaNet's Partner Interface Processes (PIPs), a de facto B2B standard of the industry, in particular high-tech manufacturing industry. From the refined *B2B Context Model*, the completeness of the model was further established through an industry verification.

Chapter 4 discusses the representation and reasoning of context information in the *B2B Context Model*. Description Logic (DL) was proposed as the underlying formalism to ensure the decidability and computational completeness in the reasoning of the context information. This formalism was then realised through the Ontology Web Language (OWL). Experimental investigations into the scalability and performance issues of reasoning with OWL were also conducted.

Chapter 5 examines the suitability of various multi-criteria decision making (MCDM) techniques to support the context-aware approach for B2B collaboration. An evaluation framework for determining the most suitable candidates is proposed; which analyses each MCDM technique from the **Model Formulation, Automation Practicality** and

Introduction

Quality of Solution perspectives. Two main categories of MCDM techniques were investigated; Multi-Attribute Utility Theory (MAUT) and Outranking techniques. To address the limitations of existing MAUT techniques in supporting B2B activities, a new *Deviation Measure* technique was also developed. Finally, a hybrid approach towards enabling context-aware B2B collaboration is proposed.

Chapter 6 investigates the viability of the proposed approach empirically using a case study. The **Quality of Solution** from each of the short-listed MCDM techniques were tested with the metrics defined. The hybrid approach was also tested with results confirming its viability. Furthermore, an industry study was undertaken to determine the usefulness of this proposed context-aware approach to support B2B collaboration, in particular for partner evaluation and selection.

Finally, chapter 7 concludes this thesis with a summary of the research contributions and pointers for further research.

2 Literature Review

In order to formulate a context model to support context-aware B2B collaboration, there is a need to understand context. The next step is to review existing context elements used in context-aware computing across different application domains. These elements are classified and analysed to distill useful context elements for B2B collaboration. As only one context-aware business application was found, there is a need to expand the scope of review to include more elements of B2B context.

The needs and the constituents of B2B context are characterised through an example. Thereafter, a key activity in B2B collaboration, supplier selection is used as the foundation to establish relevant B2B context elements. These twin foundations of existing context elements from context-aware computing and supplier selection criteria form the basis for the formulation of a *B2B Context Model*.

2.1 Understanding Context

The Cambridge dictionary defines *context* as [17] “the situation within which something exists or happens, and that can help explain it”. Much understanding of context in context-aware computing is aligned with this line of thought, but adapted for specific applications. This led to widely varied definitions and interpretations. Bazire and Brézillon [18] analysed 150 definitions of *context* and tried to find relationships between the various definitions using latent semantic analysis (LSA) and STONE techniques. They concluded that context definition is very varied, and depends very much on the discipline involved.

Hence, the word *context* has invoked many interpretations and definitions. Some of these interpretations are contradictory in nature. For example, Hess and Campbell [19, 20] considered *context* in *situations* in which data is made available to the applications. Likewise, Crowley *et al.* [21] viewed *context* as elements that must be observed to model a situation. On the other hand, Yau *et al.* [22] viewed *context* as any detectable and relevant attribute of a device, where context is a single element state. Unlike Crowley *et al.*, Yau *et al.* regard *situation* as a collection of context over a period of time (or past records). Lueg [23] viewed *context* as an interpretation of a *situation*, which cannot be re-interpreted to a lower state. *Situation* is considered by Lueg as an observer-independent and potentially unlimited resource that is inherently open to re-interpretation. Then there are Coutaz *et al.* [24] who simply defined *context* as a specific set of *situations* amongst other things. Such divergent interpretations do not lead to a better understanding of context.

An initial review by the author of 75 papers on context definitions revealed at least 25 different definitions. Some examples of the varied definitions are discussed next, using work in ubiquitous computing, information management, cognitive-based computing

Literature Review

and business domains to discuss the variations and aspects of context information involved. The purpose is to understand how context is defined and then used.

2.1.1 Ubiquitous Computing

The first context-aware (CA) computing applications were in ubiquitous computing. Here, initial work and definitions were focused on *location* (geographical) context. In relative terms, *location* can mean nearby, within a radius of 1km or explicitly through GPS (Geographical Positioning System) or postal address for example. It could also be defined in logical concepts such as a building or a room, augmenting both the relative and explicit concepts. One early example was from Schilit and Theimer [25] who considered any object or entity that has an associated physical location as a located-object. Examples include persons, printers, terminals and location-dependent services. This was then expanded [26] to include *where* you are, *who* you are with, and *what* resources are nearby as context information. Later context definitions also included other aspects such as the user's *identity*, *environment* and *temporal* aspects. *Temporal* refers to time-related context information, be it an indication of time (e g: when an event occurs) or duration (e g: how long an event lasts). One such definition was from Ryan *et al.* [27], who interpreted context as user's location, identity and time whereas Brown *et al.* [28] viewed context as embracing the sum total of the user's environment.

Dey [29, 30] treated context as information (whether implicit or explicit) that characterizes an entity's physical, social, emotional or informational states, where an entity is a person, place, or object. Based on this definition, context information would include *identity*, *location*, *activity* and *time*. *Activity* refers to what is occurring in a given situation, and together provides a good definition of when and where an activity takes place, and also who is involved. Dey replaced the environment aspect defined by Ryan *et al.* with activity, as he deemed environment as synonymous with context. In another twist, Zimmer [31] viewed context from a processing and more technical point-

Literature Review

of-view. He defined *context* as a piece of information that is composed of at least one piece of sensor data and one piece of meta-information used to interpret the sensor reading. In his work, he used a hierarchical model to aggregate context data from sensors into useful context information termed as higher order context.

However, Dey's definition of context is the most widely accepted, and formed the basis for other works in this area. One such example is the work of Mostefaoui and Hirsbrunner [32] who viewed context as *any information* that can be used to define the situation of an entity in a service-oriented environment. Wang [33] adapted Dey's definition and defined the *learning context* as any information that can be used to characterize the situation of learning entities that are considered relevant to the interactions between a learner and an application. Through this definition, additional context information related to educational facilities, learner and community dimensions are added.

2.1.2 Information Management

In information and knowledge management, the definitions are rather different. Klemke [34] viewed context as *meaning of information* for managing organisation memory, with person (identity), location, time and activity as important context dimensions. Huang & Tao [35] defined context of an entity (object, event or process) as a *collection of semantic situational information* that characterises the entity's internal features or operations and external relations under a specific situation, for the purpose of knowledge management. They viewed context to include the context focus (entity in-focus), semantic information (including abstract concepts of knowledge) and other meta-data pertaining to information (e.g. title, author, key words and literal statements). John *et al.* [36] viewed context as a subset of *static and dynamic knowledge about the enterprise*, which in turn comprises of the enterprise, user and application context.

Literature Review

Rupnik & Krisper [37] on the other hand defined context as complete information on *situation of a user (mobile), information needs of systems and technical descriptions* of usage. These descriptions could potentially include information about the devices and places. This definition covers both the ubiquitous computing and information management dimensions. In another work, Beale and Lonsdale [38] defined context to support both the ubiquitous computing and information management (learning) needs also. They defined context as a *dynamic process with historical dependencies* and uses both the user-centred and technological perspective to define a generic context hierarchy.

2.1.3 Cognitive-based Computing

Context is again viewed differently in cognitive-based approaches work. For example, Brézillon [39] considered context as *constraints of a problem* which do not impact its solution explicitly. He used context for the purpose of problem solving. Prekop and Burnett [40] proposed an *activity-centric* context where they defined context as *starting and ending with an activity*. This work also has the concept of a contextual focus (i.e. when a user is on a specific activity), and linked this *activity-centric* context back to aspects like location, time and sequence of activities.

2.1.4 Business

To date, only one context definition in the business related arena has been uncovered [41]. This definition embraces context as *providing relevant information and/or services* to the user *based on the user's tasks*, from a system or application perspective. The work here used both user and business context information for an e-commerce recommendation engine. The *user context* is further broken down into current and analysed context. The current context consists of personal, task and environment elements, whereas the analysed context is for storing derived context such as social status and lifestyle of a user. This is akin to the profile of a user, derived from personal

Literature Review

data such as age, annual income, location, profession and preferences. The *business context* are realised as business rules and product context. Examples of business rules include “Recommend a product that has second highest price” and “Don’t recommend a product which is already very saleable”. Product context consists of information like the target audience and current offers on products.

2.1.5 Summary

It is quite apparent that whilst ubiquitous computing’s context definitions are centred on the physical aspect (e g: user, location, time and environment), other definitions are less so. In information management, the slant is towards the management of meta-data of information (e g: semantic meanings of words, linkages and literals between words). In cognitive-based work, context is applied to identify and scope a problem or situation (activity), and may not be related to any physical aspect of context.

Later research works attempted to provide a more universal definition for context, but they tend to be from the perspective of a single/personal user interacting with some system, rather than that between systems or services. One such example is the work of Bradley and Dunlop [42] who defined context as a “process whereby a person consciously or unconsciously compares an external context with acquired personal experiences or knowledge, to form goals for undertaking concise actions, possibly with other people and/or objects.” The context here includes *task*, *physical*, *social* and *temporal* dimensions. It is clear that such a “universal” context definition is still not directly relevant to B2B collaboration.

As stated in section 2.1.4, there is only one example of context application in business. One possible reason for the lack of context-aware computing applications in business is the difficulty in defining and modeling business information as context information. Business information is often inter-related and is best portrayed in a complex hierarchical model. The work of Kumar *et al.* [41] is an indication of such complexity.

Literature Review

From a business context point-of-view, a simple element like *order lead-time* is a common context. The basis for considering such information as context is discussed in Section 2.3.1. It is related to many other aspects, such as sales basis of a product or service, manufacturing lead-time and delivery lead-time. In turn, manufacturing lead-time is dependent on other aspects, such as the frequency of production and order lead-times for raw material. Through this simple example, it is quite apparent that a *B2B Context Model* for supporting B2B collaboration is not going to be as straight-forward as those discussed in other domains.

In this research, context is considered from a B2B perspective. As such, **context** is defined as ***any information that characterises the situation of a participant*** in an interaction, including the user and the application themselves.

2.2 Classification of Context Information

As in context definitions, context is classified in diverse ways. Some are very generic or abstract concepts like physical-virtual [43-45] and primary-secondary categories [46]. Others differentiate the models through the ways the information is obtained [41, 47]; namely manual (user input), automatic (sensed) or derived (also known as indirect context). These high-level classifications typically are in pairs (termed as contextual pairs), to broadly classify them into 2 groups. Such contextual pairs tend to have different names, though they may represent the same aspect of context information. Table A1-1 (Appendix 1) provides a detailed listing of such contextual pairs.

In context classification, such contextual pairs can also be viewed as attributes or properties of context information. For example, Korpipaa *et al.* [48] used context attributes to describe and define context types. These attributes include type (refers to context category), value (semantic or absolute value), confidence (uncertainty

Literature Review

associated with context, probability of fuzzy membership), source (context origin) and timestamp (the most recent time when the context occurred). Similarly, Ling *et al.* [49] used attributes to specify contextual dimensions, but through a mathematical formulation instead. Zimmer [31] on the hand used attributes to specify the Quality of Context (QoC). He divided the attributes into 2 categories; fine-grained (for relevance, reliability and history) and coarse-grained (for validity). Then there is Harroud *et al.* [45] who used context type (simple, composite or collection) as an attribute to characterise the context information.

Then there are other research works that built context levels; such as raw context (typically from sensed data), preliminary context, integrated context and even final context (or context focus) [50, 51]. Some built complex hierarchies and even ontologies to represent contextual information to suit particular applications [52-54]. Such abstract classification and attributes, though not particularly relevant to this research, nonetheless complete the spectrum of understanding of context.

For the rest of this section, the varied and diverse facets of context information elements across ubiquitous computing, information and knowledge management and other related fields of work are analysed. The objective of this analysis is to identify the prevalent categories or elements present in these definitions and, in the process, define and build a context model for B2B applications that can support enterprise collaborations. For this, a total of 78 papers were reviewed. In order to systematically extract and group the various elements of context information, the following procedure was adopted:

- (1) Elements of contextual information were extracted from the papers reviewed
- (2) The information was grouped based on their similarities (themes)
- (3) A common phrase/word was adopted to broadly define the various themes
- (4) Sub-groups were created if a group is too big, by repeating step (2) and step (3)

Figure 2-1: Elements within the Physical Aspect

Arising from this exercise, the context elements are broadly categorised into *Physical*, *Information* and *Cognitive* aspects. As the majority of the papers are related to ubiquitous computing, it is not surprising that most of the elements are of a physical nature.

Figure 2-1 shows a mind map of the elements within the *Physical* aspect, where five distinct categories were uncovered, namely *User*, *Location*, *Temporal*, *Activity* and *Others*. Each of the categories is further sub-grouped into elements and sub-elements. An *element* typically represents a *context concept*, and where relevant, is further broken down into sub-elements.

Literature Review

A quick inspection of the mind map (Figure 2-1) reveals that each category typically has a basic element (User Expression, Location Expression, Time Expression and Activity Expression), with the exception of the *Others* category. These are also the most oft-reported context concepts, with *Location Expression* being the most popular. This is not surprising as most tend to only specify fairly generic elements like *user*, *who*, *agent* or *identity* for *User Expression*, just *location* for *Location Expression* and just *time* for *Time Expression*. In the *Activity* category, the *Activity Expression* is more detailed, with a clear breakdown into *activity*, *tasks* that are related to an overall process and *action* taken by users. It is interesting to note that likewise, the *Temporal::History*² element has more specific definitions (sub-elements) with historical records from the activities' and users' perspective. The rest like temperature and humidity for example are grouped under *Temporal::History::Others* sub-element, as these elements are also time related. Table A1-2 (Appendix 1) provides a detailed documentation on each of the elements (or sub-elements).

Beyond that, the other more utilised elements are *User::Profile* and *User::Preference*, where most of the context information is used for personalisation purposes. Examples of such work include Anhalt *et al.* [55] and Jameson *et al.* [56]. The *User::Role* and *User::Current_State* elements complete the *User* category. The *Location* category is supplemented by the *Location::Definition* (e.g. symbolic or geometric), *Location::Profile* (e.g. description of location, including information like nearby services) and *Location::Abstract_Categorisation* (e.g. meeting place) elements. The *Activity* category on the hand also captures the intent (*Activity::Intent*) and the way information is acquired or captured (*Activity::Input_Method*). The *Activity::Others* element is for storing artifacts that are either related or arising from an activity (e.g. documents).

² The notation used is in the form of Category::Element::Sub-element

Literature Review

In the *Others* category, the popular elements or sub-elements are *Social_Environment*, *Physical_Environment*, *Computing_Environment::System* and *Computing_Environment::Device*. It is interesting that the social aspect was highlighted, where active considerations are given to how the interaction between a user and its human environment affect CA computation. Examples of work that have such considerations include Bradley & Dunlop [57] and Rupnik and Krisper [37].

Under the *Cognitive* aspect, the context information is viewed from a cognitive or decision making viewpoint instead. The relevant context information categories are *User/Role*, *Activity*, *Intent*, *History (Time-based)*, *Social*, *Emotional/Mental* and *Others* elements (Figure 2-2a). A description of each element and relevant past research work are detailed in Table A1-3 of Appendix 1. Here the context information specified by researchers like Prekop [40] and Kaenampornpan [58] are activity-centric in nature, with the main focus being the activities performed by users. This gives rise to the dominance of elements like intent, emotional/mental and even social (e.g: community, fellow students). These activities are then captured as historical data [42, 58]. The *Others* element consists of other artifacts in a decision making process (e.g: tools to aid decision making).

Figure 2-2: Elements within the Cognitive and Information Management Aspects

Literature Review

Upon examination, most of *Cognitive* elements can be mapped into the various elements or sub-elements in the *Physical* category, as illustrated in Figure 2-3, except for the *Emotional/Mental* element. This *Emotional/Mental* [42, 59] element is very relevant when dealing with individual users, where the state of mind (e.g: emotional state, mental readiness or confidence level) can greatly influence how an activity or task is performed. From a B2B collaboration perspective, this is not quite relevant, as collaborations are usually between organisations rather than individuals. The “psyche” or health of an organisation has to be determined from other perspectives such as the financial health and skill levels of staff. Hence in developing the *B2B Context Model*, the *Emotional/Mental* element is not relevant. Furthermore, since the rest of the elements are already represented in the *Physical* aspect, this *Cognitive* aspect can be dropped.

Figure 2-3: Mapping of *Cognitive* elements to *Physical* elements/sub-elements

Not many related work was found for the *Information* aspect, but of those found, the type of context information can be divided into *Information* (scope of data where computation takes place), *Domain* (including organisation role of user or domain specific data) and *Meta-data* (tagged information) elements, as illustrated in Figure 2-2b. The details are also provided in Table A1-3. In this area, most of the CA work is on how to

Literature Review

organise information for further processing [34, 35]. Here, the *Information* element is akin to the *Others::Computing_Environment* element in the Physical aspect. Likewise, the *Domain* element can be represented by the *User::Role*. The *Meta-data* element is too generic to be useful representation for the *B2B Context model*. As such, this Information aspect is also dropped.

In *summary*, the classification of the context information revealed that there are three main aspects of context information, namely *Physical*, *Cognitive* and *Information*. Of these three, the *Physical* aspect showed the most promise as a starting point in developing a *B2B Context Model* to support B2B collaboration.

With this as the foundation, a review of applications across different domains, to understand what types of and how context information have been used was conducted. This review includes application of existing context-aware applications in the domain of ubiquitous computing, information-cum-knowledge management and others like medical, eLearning, software development and business domains. From the review, the *Physical* aspect of context information is found to be prevalent in most of the applications, with several exceptions that include [58] and [33]. This further confirmed that indeed the *Physical* aspect of context information is the most dominant, and would most likely to be useful for B2B collaboration too.

2.3 Understanding Context-aware Pre-requisites in B2B Collaboration

Section 2.2 reviewed and classified existing context information from past research efforts. Useful context information that can be employed to support B2B collaboration was discovered, namely the *Physical* aspect containing *User*, *Location*, *Temporal*,

Literature Review

Activity and *Others* categories. However, there were not many context-aware business applications. In fact only one was uncovered in the review [41].

Therefore, Sub-section 2.3.1 will examine the needs of B2B context through an example. Then the pre-requisites for context-aware B2B collaboration are discussed. For this, inspirations were derived from the area of pre-qualification and selection of suppliers, as this is one of the key activities in enabling pervasive B2B collaboration in supply chains.

2.3.1 Constituents of B2B Context

As previously discussed in Section 2.1.5, from a B2B perspective, *context* is defined as *any information that characterises the situation of a participant* in an interaction, including the user and the application themselves. For example, the needs of a requestor for a service or product are considered as context. The ability of partners (providers) to satisfy requestors' requirements is also considered as context. From this viewpoint, B2B context requirements are illustrated through an example. Consider a company sourcing for a raw material for its products. The company needs 10 tonnes of the raw material, and is willing to pay up to \$850/tonne, inclusive of delivery to its manufacturing plant in Batam, Indonesia. Also, the company would like to have the raw material in 7 days. The company has two quotations:

Supplier-1

Company Location: Shanghai, China

Price: \$400/tonne, with a minimum order quantity of 20 tonnes

Price is quoted based on FOB (Freight-On-Board) to any Asian port

Quotation Validity: 2 weeks

Order lead-time: 10 days from order confirmation

Supplier-2

Company Location: Johor Bahru, Malaysia

Price: \$390/tonne, with a minimum order quantity of 20 tonnes

Price is quoted based on EXW (Ex-works, or ex-factory)

Transportation charges: \$70/tonne to any ASEAN³ port

³ ASEAN refers to the Association of South-East Asian Nations. More information available at <http://www.aseansec.org/>

Literature Review

Quotation Validity: 2 weeks

Order lead-time: 7 days from order confirmation

From this example, it is apparent that *location* (Batam of Indonesia, Asian, ASEAN) and *temporal* (*lead-time* of 7 days and 14 days) contexts are needed. However, in deciding which supplier to choose, other contexts must be considered; *total cost* of the order which in turn is related to other contexts, namely *order quantity* (10 tonnes), *minimum order quantity* (20 tonnes) and *sales basis* (FOB, EXW). Furthermore, depending on the *sales basis*, *transportation charges* may be incurred. From this example, the total cost for Supplier-1 is \$8000 whilst for Supplier-2 is \$8200. The other factor to consider is the *lead-time*; although Supplier-1 is cheaper overall, it cannot meet the preferred *order lead-time* of 7 days. Furthermore, the company might also consider the *proximity* (distance of suppliers to delivery location) as a pertinent factor. This example illustrates the complex linkages of contexts in the B2B domain and why the elements from the supplier selection criteria such as price/cost, order quantity, transportation costs and lead-time are needed to provide a holistic representation of B2B context. This is discussed next.

2.3.2 Supplier Selection Criteria

This section reports on published supplier (or vendor) selection criteria, including supplier pre-qualification and selection. From a literature review of 68 pertinent publications, 6 major categories, namely *Cost*, *Ability-to-Deliver*, *Capability*, *Quality*, *Organisational* and *Environmental*, were ascertained. In each category, different selection criteria were specified. A mind-map of the categories and the respective criteria is shown in Figure 2-4. The criteria in each category are not exhaustive but provide a reflection of factors uncovered during the literature review. A detailed listing, including relevant references of the mind-map is documented in Appendix 2, Table A2-1.

Literature Review

The evaluation criteria in the *Cost* category are based on the price of a product or service (*Price*), *Total Logistics Cost* associated with ordering the product (including associated storing, holding, ordering/outsourcing costs), *Pricing Structure* (which include applicable discounts) and other related costs of the product or service such as transportation (*Logistics*), *Tariffs* and *Custom* duties, landed cost, warranty and foreign exchange fluctuation (grouped under *Other Costs*). Another important facet is the *Payment Terms* of the product or service. In retail commerce, payment terms often refer to credit or some other forms of payment. However, in B2B transactions, deferred payment (e.g. 30 or 60 days after receipt of goods) and letter of credit (LC) are the typical modes.

Figure 2-4: A mind-map of selection criteria for supplier identification

The *Ability-to-Deliver* category measures a company's performance in terms of its speed, responsiveness and capacity to deliver. For instance, the *Order Lead Time* (including manufacturing and delivery lead times) measures the length of time taken to

Literature Review

deliver a product or service. *Responsiveness-to-Changes* measures a company's ability to accommodate changes such as design and demand for example, and the amount of time needed to effect the changes (*Response Time*). Meanwhile, *Delivery Performance* measures the speed, reliability, flexibility and compliance with respect to ordered quantity, including on-time delivery. *Production Capacity* and *Fill Rate* criteria indicate a company's capacity to deliver. These are augmented by *Proximity* (distance between the manufacturing sites and customers' locations) and *Logistics Capability* (including distribution capacity, transportation modes, frequency etc.).

The *Capability* category outlines the ability of a company to deliver a product or service. Factors like technical capability including know-how and problem solving skills (*Technical*), innovation and co-design capability (*Design*) and research and development (*R&D*) including patent portfolio and qualifications of employees are important. These are complemented by *Manufacturing* capabilities which include production *Technology* know-how and *Competency* (such as ability in applying JIT⁴ or lean manufacturing). Other *Operational* factors like the use of Information-Communication Technologies (*ICT*) applications and *Production Planning* facilities are also considered. Beyond these, the *Service* aspect is also an important concern, including *Customer Service* (pre-sales), *After-Sales-Service* (post sales) and *Customer Intelligence* (or relationship management).

In the *Quality* category, *Product Quality* features prominently, followed by the *Quality Infrastructure*, which includes the *Strategy and Management* of the quality system instituted and the *Corrective Actions* in place to remedy or respond to quality issues. As part of this, the *Quality Certification* (e.g. ISO 9000 certification) factor is also important. *Product Performance* is also another key criterion. This includes the *Reject/Defect Rate* and *Reliability* of the product. On-site evaluation of a candidate supplier's physical infrastructure and processes (categorised under *Others*) is a common

⁴ JIT refers to the Just-In-Time manufacturing philosophy

Literature Review

activity of supplier selection, particularly during supplier pre-qualification. However, this is not often identified in the literature surveyed. This could be due to the fact that it is activity-based, hard to quantify and often precedes the actual supplier selection.

At times, in particular for potential partners with no prior business liaison or from a different country/region, the *Organisational* aspects are key considerations. In this category, the overall standing of the company may be assessed, including *Financial Status*, *Profitability*, *Reputation*, *Industry Knowledge* and the *Risks* associated with the company. Where past business relationships exist, then past business experience (*History*) and the trust built are useful considerations. In this day and age, *Cultural Compatibility* and *Societal Consciousness* are gaining importance, especially when there is a need to work closely (e.g. co-design to roll out a new product) and the policies of a company relating to issues like recycling and other environmental issues.

Environmental (or green) considerations are also fast gaining importance, with new awareness and legislations, in particular for products that are targeted for the European Union market. Under the *Environmental* category, the *Policies and Programs* of a company relating to issues like recycling and other environmental conservation efforts, the type of *Certification* (e.g. ISO 14001) achieved and *Compliance* with regulatory requirements could be crucial, especially for industries like medical devices manufacturing. Where co-design work is needed, the *Green Design Considerations* is also gaining traction.

2.4 Chapter Summary

From the review and classification of context information, three major context aspects were identified, namely *Physical*, *Cognitive* and *Information*. The *Physical* aspect is clearly the most dominant, present not only in all ubiquitous computing applications,

Literature Review

but also in applications of other domains like information/knowledge management, medical applications, software development and eLearning. Under the *Physical* aspect, the major categories of context are *User*, *Location*, *Temporal* and *Activity*. The *Physical* context elements were found to encompass the *Cognitive* aspect's elements, with the exception of the *Emotional/Mental* element from the *Cognitive* aspect. This element is ignored in this research as it is not relevant to B2B collaboration. Likewise, since *Information* context is too generic to be of use in *B2B Context*, it too was dropped. Therefore, only the *Physical* context was chosen for further analysis to develop a *B2B Context Model*. This aspect provides a good basis for the identification of fundamental context elements.

However, in B2B collaboration, other contexts besides the *Physical* aspect are also significant. Thus inspirations were drawn from a review of existing supplier selection criteria. Six major categories of selection criteria were distilled; *Cost*, *Ability-to-Deliver*, *Capability*, *Quality*, *Organisational* and *Environmental*. A quick comparison of these criteria with the context elements of the *Physical* aspect revealed that the current context information is inadequate for B2B collaboration, even though the *Physical* context is the most relevant. Thus, a combination of contexts from both the *Physical* context and selection criteria is needed to formulate a *B2B Context Model*. Further analysis and proposal of the model is discussed next in Chapter 3.

3 A Context Model to support B2B collaboration

Chapter 2 reviewed existing work in the area of context-aware computing in an attempt to identify suitable context information for B2B collaboration. As very few context-aware B2B applications were discovered, existing literature from supplier selection criteria was also reviewed in an attempt to identify other B2B contexts. This chapter analyses these context information's relevance in the formulation of a *B2B Context Model*.

A *B2B Context Model* (version 1.0) is proposed with three main facets of *User*, *Temporal* and *Location* contexts. This model is then verified for completeness using the Rosettanet's Partner Interface Processes (PIPs) specifications. Arising from this verification, a refined *B2B Context Model* (version 2.0) is proposed next. An industry survey to verify the practicality of this model was also conducted and presented. Finally, sample applications of this model are discussed, with the usage of the context information illustrated through examples.

3.1 Analysis of existing context information's relevance to B2B collaboration

To recapitulate, the *Physical* context themed in Section 2.2 has five major categories, namely *User*, *Location*, *Temporal*, *Activity* and *Others*. In each category, the elements are analysed based on the following:

- (1) B2B requirement(s) that the element can potentially fulfill
- (2) Level of sufficiency - the extent to which the element can fulfill the identified B2B requirement; *Concept* (this pertains to the notion of the context information represented) and *Detail* (this relates to the exact type of information represented in the element)
- (3) Based on (1) and (2), a decision is made whether to include an element into the *B2B Context Model* to be developed.

Table 3-1 details the analysis of the *User* category based on the conditions discussed. In the *User* category, there are 5 elements: *User Expression*, *Role*, *Profile*, *Preference* and *Current State*. *User Expression* and *Profile* were adopted because they are elements that are mapped to the B2B requirements directly, though modifications are needed. *Role* is typically “pre-identified” in B2B collaboration (e.g. requestor or provider). A requestor is typically the customer or initiator of collaboration, whereas the potential providers are the candidate partners. This *Role* representing an organisation’s role in business process centric B2B collaboration [15] could complement the elements identified in the *Activity* category (discussed later) with more specific role definitions. *Preference*, in particular user’s preferences which are important in personalised or ubiquitous computing, is not so relevant in B2B. For B2B collaboration, this is identified as collaboration criteria instead. For example, in partner selection this is articulated as a requestor’s selection criteria. By the same argument, *Current State* element is not

A Context Model to support B2B collaboration

relevant as it typically represents the state of context information for a device or user. In B2B, a much more complex concept is needed.

Table 3-1: Mapping of *User* category elements into B2B requirements

Context Element	B2B Requirement	Sufficiency		Adopted?
		Concept	Detail	
User Expression	Partner Information	Yes	No	Yes, with changes
Role	No explicit requirement but could be used to support an organisation's role in business process centric B2B	Yes	Yes	No (could be included later)
Profile	Financial Stability, Level of Trust, Cultural Compatibility, Company size, Societal Consciousness and Risks	Yes	No	Yes, with changes
Preference	Requestor collaboration criteria	No	-	No (articulated as requestor collaboration criteria)
Current State	State of company (e.g. financial, capability)	No	-	-

Table 3-2: Mapping of *Location* category elements into B2B requirements

Context Element	B2B Requirement	Sufficiency		Adopted?
		Concept	Details	
Location Expression	Partner Information (location details)	Yes	No	Yes, with changes
Definition	Proximity of company	Yes	No	Yes, with changes
Profile	Profile of company with respect to location (e.g. Risks, Tariffs)	No	-	-
Abstract Categorisation	Determining applicability of additional costs (e.g. tariffs)	Yes	No	Yes, with changes

For the *Location* category, the elements are *Location Expression*, *Definition*, *Profile* and *Abstract Categorisation* (see Table 3-2). Of these, *Profile* (of location) is not relevant, as, unlike context-aware computing for ubiquitous computing, location-based services do not feature highly in the needs of B2B collaboration. Since an organisation may have location related preferences like location-related risks and tariffs (or taxes), this needs to be examined in greater detail. This *Profile* element as-is is not sufficient to

A Context Model to support B2B collaboration

represent such context information. The other elements can be adopted, but the context information needs to be suitably customised.

Under the *Temporal* category, *Time Expression* and *Granularity* are important concepts for capturing lead-time related requirements. The *History* element is potentially helpful for tracking past business transactions with candidate partners, though modifications are needed. These are summarised in Table 3-3.

Table 3-3: Mapping of *Temporal* category elements into B2B requirements

Context Element	B2B Requirement	Sufficiency		Adopted?
		Concept	Details	
Time Expression	Lead-Time (e.g. overall, manufacturing, delivery)	Yes	Yes	Yes
Granularity	Proximity of company	Yes	Yes	Yes
History	History (Past Relationships)	Yes	No	Yes, with changes

The fourth category, the *Activity* category, reflects the tasks or activities aspect of context information, and is very relevant to dynamic business process formation in B2B collaboration [15]. However, for activities that are less process oriented and where the objective is similar in each case, such as partner selection for example, this is not needed. In such cases, the activities are quite standardised and the objective is always to pre-qualify or identify partners for example. This is evident by the fact that none of the B2B requirements (supplier selection criteria) identified in Section 2.3.2 can be mapped to any of the elements in this category. For this initial version, it was decided that this category will not be included, but be kept-in-view for future versions, where an expanded form of the *B2B Context Model* might be needed for more process-centric B2B collaborations. Examples would include business process formation based on an articulated goal (context of collaboration) and exception management in formed business collaboration for supply chain applications using context-aware adaptation based on newly detected context conditions.

A Context Model to support B2B collaboration

The last category is the *Others* category. The *Social Environment* and *Physical Environment* (referring to context like room temperature for example) elements are not relevant to B2B collaboration. Some of the sub-elements from the *Computing Environment* could potentially be relevant, though not explicitly. For example, the *Service* sub-element could be used to describe the services supported by partner companies as part of the *Operational capability* requirement identified.

From this analysis, it is apparent that the current context information reviewed is inadequate for B2B collaboration, even though the *Physical* context is the most relevant. The context elements from the *Physical* aspect define the basic elements of context-awareness that must be supplemented by the more B2B specific contexts found in the supplier selection criteria. This is discussed next.

3.2 Identifying supplier selection criteria relevant to B2B collaboration

Technically, the supplier selection criteria themed in the mind-map (see Figure 2-4) should underpin a *B2B Context Model*. However, some of the information is not easily processed or modeled; they may be qualitative or aggregate in nature (making it harder to process) and/or not easily obtained (as the sources of information are either not within the control of collaborating parties or inaccessible due to the confidentiality of the information). Also, different types of companies attach different importance to the selection criteria [60]. For example, if a company is extremely cost conscious, such as small companies operating with very low profit margins, the main selection criterion could be just cost. In support of this main criterion, the delivery lead-time could be another consideration. In contrast, for bigger companies, cost is not the sole or key criterion. Factors like timely delivery based on planned schedule and product quality could be key considerations. Product price, though important, could be relegated to

A Context Model to support B2B collaboration

secondary importance. In fact this has been verified in an industry survey conducted, to be discussed in Section 3.6. In addition, companies typically consider the cost aspect in a holistic manner, not just the product price alone [61]. Other related factors like transportation cost and prevailing taxes or tariffs are also included in the total cost calculations of an order.

Thus the selection criteria identified in Figure 2-4 were filtered, to determine which criteria can be included into the *B2B Context Model* as context elements. These criteria were filtered according to 5 measures:

- (1) *Type* of data (quantitative or qualitative)
- (2) *Nature* of the data (simple or aggregate)
- (3) *Potential source(s)* of the data – this provides an indication of the availability or accessibility of data
- (4) *Level of difficulty* in processing the data for incorporation into the model (easy, moderate or difficult) – this is based on the above points (1), (2) and (3).
E.g: If type = “quantitative”, nature = “simple” and the source of documents are multiple business documents, then difficulty = “easy”.
- (5) *Importance* of criterion as a context to support B2B collaboration (low, medium or high) – this is a judgment call, based on the internal reports of research projects conducted with industry partners⁵ accumulated over the years, in developing inter-enterprise integration technologies for the industry. Feedback from industry partners is also continually sought.

The detailed results of this analysis are summarised in Table A2-2 of Appendix 2.

In summary, the criteria in the *Cost* category are easy to process and have either a high or medium level of importance. The criteria in the *Ability-to-Deliver* category range from easy to difficult to process, likewise the level of importance. In contrast, the

⁵ The reports are not cited here due to client confidentiality. These projects are conducted under the purview of Singapore Institute of Manufacturing Technology (SIMTech), Singapore.

A Context Model to support B2B collaboration

Capability category has criteria that are all difficult to process and generally low in importance. The exceptions are *Technical* (medium importance) and *Customer Service* (high importance). The *Quality* category contains criteria that are not easy to process except for *Quality Certification*. Although the importance to B2B collaboration is high for most criteria, the information from this category is typically not easy to model as context information for B2B collaboration, as they have to be accumulated over-time to obtain a relevant track record (e.g. *Reject Rate*, *Product Reliability*).

The *Organisational* category throws up an interesting mix of criteria that cover the ranges for both processing difficulty and importance. In this category, *Financial Status*, *Profitability* and *Conduciveness for Business* (under the sub-category of *Risk*) are easy to process and high in importance. These criteria are critical to business considerations of today. For example, risk exposure considerations are gaining importance when outsourcing to overseas companies, or deciding on alternative manufacturing locations to mitigate supply chain risks [4, 62, 63]. Risks are inherently difficult to quantify and measure, and being a research area on its own, will not be the focus of this work. However, it can be partially measured from the conducive-perspective, for example using “ease of doing business” as a measure. Such information is available at country level [64], and can be incorporated into the model as context information.

As a start, a criterion is identified for incorporation into a *B2B Context Model* if either of the following is fulfilled:

- Easy to process and of high or medium importance, or
- Moderately difficult to process but high in importance.

Beyond these evaluation criteria, there is also a need to consider other information related to collaborating organisations, their locations and their products and/or services offerings. These are provided (where possible) from the context elements in the *Physical* aspect. Together they provide a more holistic foundation for the development of a *B2B Context Model*.

3.3 Proposed B2B Context Model (Version 1.0)

To recap from Section 2.3.1, from a B2B collaboration perspective, *any information that characterises the situation of a participant in an interaction* is defined as *context*. This viewpoint is relevant to enterprise collaboration, where *B2B context* consists of three major facets - *User*, *Location* and *Temporal*. These facets are derived from the *Physical* aspect of context information, as discussed in Section 3.1. A mind-map of the *B2B Context Model* proposed is as shown in Figure 3-1. The underlying elements within each category reflect the context-sensitive information distilled from existing supplier selection criteria discussed in Section 3.2.

The *B2B Context Model* is a hierarchical model with three main context facets; *User*, *Temporal* and *Location*. Each has a context element that stores the direct information of the facet, namely *UserExpression*, *TimeExpression* and *GeographicalExpression*. Each facet is further defined with elements and sub-elements. The *User* facet embodies the organisation and its products or services, the *Temporal* facet embodies the time lapse in fulfilling a B2B transaction or activity (presently for product or services) and the *Location* facet encapsulates information pertaining to the geographical site(s) of a company.

Under the *User* facet, the most important context element is *User::ProductService*. This element contains information regarding the products or services being offered, product category, product specifications and availability (e.g. country or region) which is linked to the *Location* facet. *User::PricingInformation* is another critical element in this facet, being based on the *Cost* category (of selection criteria). Information pertaining to an organisation, *User::Profile*, *User::IndustrySector* and *User::TrackRecord* is also modeled. This information reflects the criteria identified under the *Organisational* category (of selection criteria). The information contained within the *User* facet is used in context-aware decision making, supported by the other two facets. One good

A Context Model to support B2B collaboration

example is *User::LeadTime*. It is linked to *Temporal::LeadTime*, which provides a more granular representation of the lead time through *Temporal::ManufacturingTime* and *Temporal::DeliveryTime*. Either or both depend on *User::ProductService::PricingInformation::SalesBasis*. For instance, if the product is quoted “Ex-Works”, then only the manufacturing lead time is considered. However, if the quotation is “Free-on-Board”, then both sub-elements need to be considered.

Figure 3-1: B2B Context Model (version 1.0)

A Context Model to support B2B collaboration

Another example is the *UserExpression::PostalAddress* sub-element, which is linked to the *Location::GeographicalExpression::PostalAddress* sub-element. This information identifies the geographical locations of potential partners and is used to calculate the total cost of a product or service. Here, multiple locations could be captured, as the billing location and the delivery location could differ for example. During matching, an algorithm to calculate the applicable taxes, available transportation modes (*Location::TransportationMode*) and their frequency and costs are based on this location information. For illustration, assume that the requestor's (customer) location is "USA" and a potential partner is located in "Singapore". In this instance, the product may not be subjected to any import tariffs, as a Free Trade Agreement (FTA) exists between the USA and Singapore. However, if the potential partner is from a country that does not have an FTA with the USA, then import tariffs will apply.

Other context elements like *Location::EaseOfDoingBusiness* may be found in the *Organisational* category (of selection criteria), indicating the risk exposure when conducting business with the identified partner. The *Temporal::Periodicity* models events that recur (e.g. frequency of orders, frequency of price changes, frequency of rejects, etc) and are related to *User::TrackRecord::Quality* and *User::TrackRecord::Pricing*.

3.4 Verifying Model Completeness using RosettaNet

This verification compares the proposed *B2B Context Model* with the Partner-Interface-Processes (PIPs) specification of the RosettaNet standard. The RosettaNet standard is a set of XML-based specifications that define message guidelines, business process interfaces and implementation frameworks that enable businesses to communicate efficiently across multiple platforms, applications and networks. Founded in 1988, RosettaNet is supported by a non-profit consortium of industry leaders. Today,

A Context Model to support B2B collaboration

RosettaNet has become a *de-facto* B2B collaboration standard, in particular for high-technology manufacturing. It is endorsed by more than 500 companies worldwide, with a combined annual revenue of more than US\$1 trillion [65].

3.4.1 RosettaNet Standards Overview

The Partner Interface Processes (PIPs) and Dictionaries [66] specifications define a common set of properties for PIPs®, associated with basic business activities. PIPs specify the structure and format of business documents, activities, actions and roles for each trading partner. PIPs are grouped into 7 distinct clusters, supporting different aspects of the trading network for B2B collaborations [67], as shown in Table 3-4. Each cluster can be decomposed further into segments and then finally into the PIPs themselves. As part of the PIP definition, the payload information defines the type and structure of business information to be exchanged between collaborating parties. This payload information is a good reference against which to benchmark the *B2B Context Model*, as it contains information (including contextual) commonly used and exchanged in B2B collaboration. A sample of a typical PIP payload is shown in Table A3-1 of Appendix 3, for PIP 3A2 (Request Price and Availability).

Table 3-4: Clusters and segments in RosettaNet PIPs

Clusters and Segments	Numbers of PIPs in each segment	Number of selected PIPs
Cluster 0 – RosettaNet Support		
0A – Administrative	1	-
0C – Testing	4	-
Cluster 1 – Partner Product and Service Review		
1A – Partner Review	2	-
Cluster 2 – Product Introduction		
2A – Preparation for Distribution	13	-
2B – Product Change Notification	8	-
2C – Product Design Information	10	-
Cluster 3 – Order Management		
3A – Quote and Order Entry	12	6
3B – Transportation and Distribution	11	6

A Context Model to support B2B collaboration

Clusters and Segments	Numbers of PIPs in each segment	Number of selected PIPs
3C – Returns and Finance	7	6
Cluster 4 – Inventory Management		
4A – Collaborative Forecasting	6	2
4B – Inventory Allocation	2	2
4C – Inventory Reporting	1	1
4D – Inventory Replenishment	1	1
4E – Sales Reporting	2	1
Cluster 5 – Marketing Information Management		
5C – Design Win Management (Electronic Components)	5	-
5D – Ship From Stock and Debit (Electronic Components)	6	-
Cluster 6 – Service and Support		
6A – Provide and Administer Warranties, Service Packages, and Contract Services	2	-
6C – Technical Support and Service Management	4	-
Cluster 7 – Manufacturing		
7B – Manage Manufacturing WO (Work Order) and WIP	4	2
7C – Distribute Manufacturing Information	3	-

Cluster 3 and cluster 4 PIPs were identified as being relevant as they are contextual in nature and common place in typical B2B collaboration in a supply chain. Cluster 3 is related to order management, from soliciting quotations to transportation and distribution to finance matters, whereas cluster 4 is about inventory management, including tasks like forecasting, inventory and sales reports. Several Cluster 7 PIPs that relate to distribution of work orders and work-in-progress information were also relevant to this verification. The other clusters (as shown in Table 3-4), are either not relevant to B2B collaboration, not contextual in nature or have similar elements to the PIPs identified for this verification exercise. Altogether, 27 PIPs from a total of 46 PIPs were selected from the three clusters for this verification (see Table 3-4). Some of the PIPs in the selected clusters were not chosen as they are typically a response to selected PIPs in the form of acknowledgements, updates, changes, cancellation or queries. Such PIPs do not carry payload that has additional contextual information.

A Context Model to support B2B collaboration

3.4.2 Verification Methodology

The high level steps in the verification process are as follows:

- (1) Select and map contextual PIP elements onto the initial *B2B Context Model*
- (2) Identify potential PIP context elements to add to the current *B2B Context Model*
- (3) Repeat step (1) to (2) for all selected PIPs
- (4) Consolidate results by sorting and grouping the identified additions into influencing factors

The methodology is summarised in Figure 3-2. It should be noted that though Step (1) maps contextual PIP elements to the *B2B Context Model*, in essence it is similar to mapping context elements from the model to the PIP elements. This approach in Step (1) is adopted as it is easier to manage the mapping process. The intent remains the same, namely, to identify contextual PIP elements missing from the initial model and to add relevant missing elements into the refined *B2B Context Model*, to ensure completeness from RosettaNet's viewpoint.

In Step (1), only leaf node elements are considered, as the payload is hierarchical by nature, and each non-leaf node element may contain multiple elements, be they simple or complex. In determining whether a given element is contextual or otherwise, the definition, constraints and examples provided by the RosettaNet PIP documentation (Guideline Information) [67] are used. The detailed mapping flow is illustrated in Figure 3-3. Every contextual element identified and represented in the *B2B Context Model* is denoted by a "Y" in the model. Otherwise a "C" is used instead, to indicate that the leaf node element in the PIP is a candidate addition to the model.

A Context Model to support B2B collaboration

Figure 3-2: Schematic representation of the verification methodology

In Step (4), the potential PIP context elements, marked as “C”, are sorted and grouped into 3 types of influencing factors:

- **Primary Influencing Factor**

Factors that are crucial for B2B collaboration, and omitted from the *B2B Context Model*

- **Secondary Influencing Factor**

Factors that are crucial for B2B collaboration, present in the *B2B Context Model* but require refinement.

- **Tertiary Influencing Factor**

Factors that are not crucial for B2B collaboration (nice to have), present in *B2B Context Model* but require refinement.

A Context Model to support B2B collaboration **Figure 3-3: Mapping flow for Step (1)****3.4.3 Mapping Results**

From the verification, 10 PIP context elements were identified, i.e. elements marked with “C”. These elements are non-leaf node elements. Although the mapping was done at leaf node level, the information is only useful and comparable at non-leaf node level, otherwise they are too granular. Appendix 3 (Table A3-2) provides detailed information on the mapping of each of the leaf node elements within each non-leaf group.

These PIP context elements are further grouped into the 3 types of influencing factors defined (see Table A3-3 of Appendix 3):

- 0 Primary Influencing Factors,
- 5 Secondary Influencing Factors and

A Context Model to support B2B collaboration

- 5 Tertiary Influencing Factors

As there were no Primary Influencing Factors, it can be inferred that the current *B2B Context Model* contains all the essential elements needed to support B2B collaboration. However, the model can be improved by inclusion of the Secondary and Tertiary Influencing Factors.

Table 3-5: Influencing Factors' relevance for inclusion into B2B Context Model

Influencing Factor	Description	Include?	Reason	B2B Element Name (new/changed)
Secondary	Delivery Exception	Yes	Allow providers to state the coverage and time of delivery, and price validity period.	- <i>MarketAvailability</i> - <i>Validity</i>
	Step Pricing	Yes	Step pricing is the implementation of different pricing for different periods of time and for different quantity of product ordered. Required in model to allow companies to practice price differentiation in similar products	Restructure the model to allow price variation with quantity (as <i>PricingInformation</i>)
	Interest Information	Yes	RosettaNet adopted this to provide information on interest due to late payment. Late payment penalties can influence purchase decisions.	- <i>PaymentPenalties</i>
	Terms And Conditions Information	No	Most are terms and conditions require manual intervention. Not relevant in supporting context-aware B2B collaboration	- Not applicable
	Handling Charges	No	Such charges are usually included in the price, as declassification creates too much complexity.	- Not applicable
Tertiary	Contact Information	No	RosettaNet's contact information is more complete. However, adding more information does not increase the contextual capability of the model.	- Not applicable
	Storage	No	Related to packaging	- Not applicable

A Context Model to support B2B collaboration

Influencing Factor	Description	Include?	Reason	B2B Element Name (new/changed)
Description	goods or packages being held in storage.		information. Not relevant to context-aware B2B collaboration.	
Mass Physical Dimension	The physical dimension of unit of mass used for measuring the masses of weights, volumes etc.	No	Related to packaging information. Not relevant to context-aware B2B collaboration.	- Not applicable
Proprietary Information	Description of information, relating to a product.	No	RosettaNet uses it as a free-form-text to describe proprietary Information. Not useful for context-aware B2B collaboration.	- Not applicable
Product Identification	Describe proprietary and global identifier information regarding a product.	Yes	RosettaNet provides a unique identifier for products globally. Adopted into model for similar reason.	- <i>Global Product Identifier (GTIN)</i>

The relevance of these PIP context elements for inclusion was further analysed. Table 3-5 provides a detailed listing of the justification for either inclusion or exclusion into the *B2B Context Model*. In summary, four influencing factors (three secondary and one tertiary) were identified, to enhance the model's capability to better reflect real-life B2B scenarios. The PIP context elements are *Delivery Exception*, *Step Pricing*, *Interest Information* and *Product Identification*. These elements are mapped into different B2B elements as indicated in the last column of Table 3-5.

3.5 Refined B2B Context Model (Version 2.0)

The verification exercise has confirmed that the *B2B Context Model* Version 1.0 embodies all critical contextual elements needed for B2B collaboration. Several non-critical elements were also identified, as discussed. Furthermore, several shortcomings were also identified during the verification exercise; in particular the way context elements are structured:

A Context Model to support B2B collaboration

- The initial model is context centric, centered around 3 categories of context, namely *User*, *Location* and *Temporal*. Such a categorisation cannot capture the semantics between context elements. For example, most companies practice price differentiation that is time and quantity sensitive. The current model is unable to encapsulate such complexity.
- Also, association of elements from different context categories is not captured. For example, cost is related to both product price and other factors like transportation.
- Resulting from the context centric focus, some elements are actually meaningless if not associated with each other. For example, the *Temporal::TimeExpression* is meaningless unless linked to other context elements like *Temporal::Leadtime* and *User::ProductService::Leadtime*.

Arising from the verification phase, a new *B2B Context Model* containing two main categories; *OrganisationalProfile* and *ProductService* is proposed (Figure 3-4), embedding the context aspects of *User*, *Location* and *Temporal*. *OrganisationalProfile* embodies all context information related to an organisation (user); *Organisational_Expression* for storing direct organisation information (e.g. name and industry sector), *Geographical_Expression* to capture the location context; both direct and indirect and *Current* to capture a snapshot of the current state of the company in terms of financial, quality, and turnover (which measures the profitability of the company). It also has other location related context, such as *Ease_of_Doing_Business*, based on the country in which the company operates. The *History* branch attempts to capture a track record of past performances of the company through *Years_of_Operation*, *Quality* (measured as percentage of defect free deliveries), *On-time_Delivery*, *Profitability* and *Past_Turnover*.

A Context Model to support B2B collaboration

Figure 3-4: B2B Context Model (version 2.0)

ProductService is a hierarchical structure that captures the semantic relationship of a product or service. In *PricingInformation*, *Costing* is scoped by other elements like

A Context Model to support B2B collaboration

Payment, Validity and *Quantity* (minimum or order) for instance. It is important to note that the generic context elements from *Location* and *Temporal* are still present, except that they are embedded within the B2B context elements. Examples include *PricingInformation::Costing::SalesTerritory::SourceCountry* and *PricingInformation::Validity::TimeScale*. A detailed description of the elements in Version 2.0 is provided in Appendix 4; Table A4-1 for *OrganisationalProfile* and Table A4-2 for *ProductService* respectively.

By moving away from a context centric model, version 2.0 is better able to address the limitations highlighted. However, not all aspects can be addressed, in particular the relationship or linkage between elements. Hence, other than the B2B context elements, the model needs business rules to provide a complete information model. For example, to determine the order lead-time, two context elements are needed; *Manufacturing_Leadtime* and *Delivery_Leadtime*, depending on the *SalesBasis (Incoterms)* of the product. These are expressed as Business Rule- 1 and 2 in Table A4-3 of Appendix 4. Other relevant business rules are captured in the same table also. These business rules are used in particular for partner selection. Although the *B2B Context Model* is designed to support different types of B2B applications (discussed in Section 3.7), such business rules are typically application specific.

3.6 Industry Verification of the Model

To verify that the *B2B Context Model* is able to support real industry needs, a survey of 10 companies were conducted. As context-aware B2B collaboration is non-existent today, this survey had to be conducted differently. Companies were asked instead to identify the criteria for supplier selection, as supplier (or partner) selection is an integral part of B2B collaboration [15]. 6 SMEs (Small and Medium Enterprises) and 4 MNCs (Multi-National Corporations) were identified for this survey, and their senior executives

A Context Model to support B2B collaboration

(e.g. Managing Director, Chief Executive Officer of smaller companies or the Purchasing Manager, Supply Chain Director of bigger companies) interviewed. The industry sectors (or domains) were intentionally varied, in an effort to ensure that the survey does not skew towards any particular sector. The survey had two parts; the first verifies the criteria companies used to select suppliers, which is discussed here. The second part is further detailed in Chapter 6, as part of the exercise to compare the decisions derived from this context-aware approach versus the decisions taken by industry experts.

In the first part, the company executives were presented with a list of potential criteria (or criteria grouping) that their companies might consider in supplier selection. The full list of criteria is shown in Appendix 4 (Table A4-4). The executives were asked to select and rank the criteria according to how their company selects suppliers. The results from this part are detailed in Table A4-5 in Appendix 4.

From the results, unsurprisingly, all 6 SMEs and 3 MNCs identified *Product Order Cost* as the top (or equal) criteria. Only 1 MNC listed *Quality* as the top. The second most important criteria is *Order Lead-time*, being 4 companies' top-3 criteria. Another important criteria appears to be *Track Record* (in particular *Quality*), identified by 6 out of the 10 companies' top-5 selection criteria. Most importantly, all the criteria mentioned figured at least once in the companies' top-5 criteria, except for *Proximity*. However, companies like SME-2 and MNC-3 have expressed the view that if lead-time is a factor, the local supplier is always preferred, implicitly factoring in the *Proximity* criterion.

Several other criteria not included in the *B2B Context Model*, subsequently not listed in Table A4-4 of Appendix 4, surfaced from the survey. They include responsiveness of the supplier (measurable factors like *On-time Delivery* are already in the model) to queries and changes, management's commitment (including past relationship that fosters trust) and environmental considerations (e.g. REACH, RoHS, WEEE) which are beginning to

A Context Model to support B2B collaboration

gain importance. Environmental criteria did not make the cut in the analysis conducted in Section 3.2, whilst the other two factors are hard to capture and process, and hence were not included also. Therefore these items, whilst known to be important, have been omitted for now. This was also discovered in the review of supplier selection criteria, and not selected for inclusion into the model, as they are difficult to process (see Table A2-2 of Appendix 2). In fact, respondents have confirmed these are typically not measurable, and usually evaluated in a “gut-feel” manner from past experiences.

3.7 Potential Applications of the B2B Context Model in B2B Collaboration

The *B2B Context Model* is intended to support different types of B2B collaboration for supply chain applications. There are two major categories of target applications; (1) Formation of new B2B collaboration and (2) Formed B2B collaboration. In the first category, one of the major uses of the *B2B Context Model* is for partner evaluation and selection. This step is an integral part in forming the business process to support B2B collaboration [15]. The partner evaluation and selection could be for identifying suitable suppliers, design partners or even third party logistic providers to support the activities in the business process that is being formed. Examples of useful contexts include *Price*, *Lead-time* (both manufacturing and delivery), *Capacity* and *Location* (to model the proximity of the partner). The *B2B Context Model* could also be used to support the identification of new partners to be added to the Approved Manufacturers’ List (AML) for example. In this case, contexts like *Ease_of_Doing_Business*, *Years_of_Operation*, *Quality*, *Profitability* and *Past_Turnover* of a potential partner could be important.

For the second category, the model could be used for other B2B applications, such as (a) exception handling in supply chain track and trace applications, (b) replenishment of warehouses and distribution centres in the supply chain, and (c) monitoring of order

A Context Model to support B2B collaboration

fulfillment. In exception handling, coupled with sensing technologies like GPS (Graphical Positioning System) and RFID (Radio Frequency Identification), relevant alerts and actions can be initiated, depending on the context of the situation. An example is tracking hazardous cargo movements in the supply chain. When a batch of cargo does not arrive at the expected destination in a given time-slot (context of *lead-time* and *location*), a warning alert can be triggered to the relevant parties (*CompanyName* and/or *ContactInformation* context). When another non-compliance (exception) is detected, other than the alert, an action could also be triggered. Depending on the *Location*, appropriate authorities (e.g. local police) could be dispatched to intercept the movement of the hazardous cargo.

In the second application, based on the *Location* of stores, *Delivery_Leadtime* needed to stores, *Quantity* sold and *Capacity* (holding capacity) of the stores, replenishment deliveries can be activated depending on the situation and importance of the context/criteria under consideration. Where required, threshold or preferred values for the activation of the deliveries could also be set or determined by the requestor. For the third application, the track record of a partner could be monitored based on its fulfillment capabilities, such as *On-time_Delivery* and *Quality* for instance. When the overall performance based on these context drops or exceeds acceptable levels, then the situation can be flagged for further actions. The *B2B Context Model* proposed is expected to be able to meet to the needs of such applications, without major or substantial changes. However, the business rules associated with each application are expected to change.

3.8 Chapter Summary

This chapter analysed the *Physical* context aspect and the supplier selection criteria uncovered in Chapter 2. Arising from the analysis, three main context categories were

A Context Model to support B2B collaboration

identified; namely *User*, *Temporal* and *Location*. These contexts, complemented by the supplier selection criteria that were identified for inclusion, underpin the *B2B Context Model*. Two versions of *B2B Context Model* were proposed. The first version was verified for completeness against the identified RosettaNet PIPs (Partner Interface Processes). Arising from this verification, all the essential elements needed to support B2B collaboration were accounted for in the initial version. However it can be improved, by incorporating four PIP context elements. Several issues were also identified during this verification exercise. These were taken into considerations holistically in the second version of the model.

The *B2B Context Model* version 2.0 moved away from the context-centric approach of the initial version. Version 2.0 has two main hierarchies that attempt to provide meaningful context and capture the relationships between context elements where possible; *OrganisationalProfile* and *ProductService*. These hierarchies are augmented by a set of business rules to provide a complete information model for context-aware B2B collaboration. A survey of 10 companies across different industry sectors confirmed that this model is sufficient and practical, using supplier selection as an example. Examples of the potential application areas in B2B collaboration for supply chains were also discussed, illustrating the context information usage. With the *B2B Context Model* formulation completed, the next step is to investigate into a formalised reasoning methodology to process context information. This is discussed in Chapter 4.

4 Representation and Reasoning of the B2B Context Model

Chapter 3 discussed the formulation of a *B2B Context Model* to support context-aware B2B collaboration. In order to utilise the context information in an effective manner, Description Logic (DL) and the realisation through OWL (Web Ontology Language) DL is investigated as a formal representation and reasoning mechanism. To expand the expressivity of OWL DL so that the defined business rules can be supported, the Semantic Web Rule Language (SWRL) was incorporated. Thereafter, an experimental investigation into the computational performance of ontology described in OWL and SWRL was conducted.

4.1 Using the B2B Context Model

The *B2B Context Model* is expected to be used in a Service Oriented Architecture (SOA) environment, where partners offer services that can be executed in formed business processes, as part of B2B collaboration between partners [15]. In this environment, context information can be formulated into *context-aware profiles* to support context-aware B2B collaboration, in particular the formation of virtual enterprises (see Figure 4-1). These profiles function like the “yellow pages” of these services. In the Web Services environment, the equivalent would be WSDL, and OWL-S (Semantic Markup for Web Services) profiles for the semantic version of Web Services. Here the *context-aware profiles* are oriented towards capturing business information (as embodied in the *B2B Context Model*) that is typically not available in either the WSDL or OWL-S profiles, and is expected to complement such profiles.

Figure 4-1: Realisation of the model as *context-aware profiles*

The lifespan of the context information arising from such profiles are expected to differ, with varying frequency of change and validity periods. For instance, information pertaining to a company, such as *OrganisationalProfile::OrganisationalExpression* and *ProductService::Product_Identifier* are not expected to change very often. Others like *ProductService::PricingInformation* would change fairly often, depending on the products and services. Tariffs for the product/service on the other hand may stay fairly constant, unless there are changes in the tax structure of a particular country for

Representation and Reasoning of the B2B Context Model

example. The information sources for the context elements are also expected to be varied. For example, company related information is expected to be published by the company itself or could be obtained from business documents that are commonly exchanged during B2B transactions. Information on products/services would have to be provided by the company itself, such as product catalogues and quotations. Again, such information is exchanged as business documents too. Other information like the GPS (Global Positioning System) coordinates can be obtained readily from external sources. Websites readily provide such information (e.g. <http://www.gps-data-team.com/map/>). Information on ease of doing business could also be obtained externally, such as from The World Bank Group (<http://www.doing-business.org/economyrankings/>). There are numerous methods for sensing and capturing the relevant information into the context model, such as data mining and auto-updates for example. This, however, is not the focus and scope of this research and so will not be discussed.

Instead, this chapter focuses on the representation and reasoning of context information from the *B2B Context Model*. The context-aware profiles must be represented by a format that is suitable for automatic processing and which supports reasoning as much as possible. The XML Schema is an appropriate representation scheme, but it does not support reasoning. The other is an ontology-based representation that supports reasoning, one example being the Web Ontology Language (OWL) [68]. OWL's syntax is based on XML/RDF and uses Description Logic (DL) based semantics for reasoning. As DL guarantees computational completeness (all conclusions are guaranteed to be computable) and decidability (all computations will finish in finite time), it provides a theoretical basis for reasoning of context information from the profiles. A knowledge base supported by DL is also able to provide several types of reasoning. Such a knowledge base has semantics that makes it equivalent to a set of axioms in first-order predicate logic. In short, the knowledge base contains implicit knowledge that can be made explicit through inferences. These inferences will support reasoning of the context information from the *B2B Context Model*.

4.2 Overview of Relevant Concepts

4.2.1 Description Logic (DL)

DL is rooted in first-order logic (FOL) and is a structured fragment of predicate logic. Its research was motivated by the lack of formal semantics of predecessors such as semantic networks and frames. DL makes use of *concept descriptions* to represent domain notions or objects (e.g. Buyer, Seller and Product) and *roles* to represent binary relationships between concepts (e.g. hasProduct). DL has many flavours or extensions, and naming conventions. One of the more common conventions is using $\mathcal{AL}$ (Attributive concept Language) to denote a basic DL and additional letters for other extensions. For example, the addition of complement operator ($\neg$) is denoted by $\mathcal{ALC}$ (Attributive concept Language with Complements). The general syntax of DL consists of:

- A set of unary predicate symbols to denote *concept names*
- A set of binary relations that are used to denote *role names*
- A recursive definition for defining concept terms from *concept* and *role names* using constructors

The DL that includes just the conjunction ($\sqcap$), disjunction ($\sqcup$), negation ($\neg$), existential restriction ($\exists$) and value restriction ($\forall$) constructors is called $\mathcal{ALC}^6$, the focus of this section.

4.2.1.1 Syntax and Semantics of $\mathcal{ALC}$

This section will discuss the syntax and semantics of DL, in particular $\mathcal{ALC}$ as the basis for the use of DL in the representation and reasoning of context information from the *B2B Context Model*.

⁶ Some literature refers to $\mathcal{ALC}$ and $\mathcal{ALVE}$ inter-changeably. However, most do not distinguish between the complementary (negation) with the universal and existential quantifications, as they are equivalent semantically.

Representation and Reasoning of the B2B Context Model

DEFINITION 4.1: ($\mathcal{ALC}$ syntax)

Let N_C be a set of concept names and N_R be a set of role names. The set of $\mathcal{ALC}$ -concept descriptions is the smallest set such that [69, 70]:

1. An atomic concept is an $\mathcal{ALC}$ -concept
2. $\top$ (top concept), $\perp$ (bottom concept) and every concept name, $A \in N_C$ is an $\mathcal{ALC}$ -concept
3. If C, D are $\mathcal{ALC}$ -concepts and $r \in N_R$, then $C \sqcap D, C \sqcup D, \neg C, \forall r. C$ and $\exists r. C$ are also $\mathcal{ALC}$ -concepts.

DEFINITION 4.2: ($\mathcal{ALC}$ semantics)

An interpretation, $I = (\Delta^I, \cdot^I)$ consists of a non-empty set, Δ^I (domain of I) and a function ($\cdot^I$) that maps [69, 70]:

- Every $\mathcal{ALC}$ -concept to a subset of Δ^I , and
- Every role name to a subset of $\Delta^I \times \Delta^I$

As such, for all $\mathcal{ALC}$ -concepts C, D and all role names r ,

$$\top^I = \Delta^I, \perp^I = \emptyset$$

$$(C \sqcap D)^I = C^I \cap D^I, (C \sqcup D)^I = C^I \cup D^I, \neg C^I = \Delta^I \setminus C^I$$

$$(\exists r. C)^I = \{x \in \Delta^I \mid \text{There is some } y \in \Delta^I \text{ with } \langle x, y \rangle \in r^I \text{ and } y \in C^I\}$$

$$(\forall r. C)^I = \{x \in \Delta^I \mid \text{For all } y \in \Delta^I, \text{ if } \langle x, y \rangle \in r^I, \text{ then } y \in C^I\}$$

This provides the basis for the interpretation of knowledge bases in DL, where there are two parts, a terminological part ($TBox$) and an assertional part ($ABox$). The most general form of $TBox$ is the general concept inclusion, defined next.

DEFINITION 4.3: ($TBox$)

A general concept inclusion (GCI) is of the form $C \sqsubseteq D$ where C, D are $\mathcal{ALC}$ -concepts. A finite set of GCIs is called a $TBox$. Following [69, 70]:

- an interpretation I is a model of a GCI $C \sqsubseteq D$, if $C^I \sqsubseteq D^I$
- I is a model of a $TBox, \mathcal{T}$ if it is a model of every GCI in $\mathcal{T}$

Representation and Reasoning of the B2B Context Model

A *TBox* is expected to be unequivocal, where for every atomic concept, A , there is at most one axiom (definition) in $\mathcal{T}$ for A . A *TBox* is called *definitorial* if it satisfies the following additional conditions of (1) it contains only definitions and (2) is acyclic (i.e. the definition of any concept A in $\mathcal{T}$ does not refer to itself (directly or indirectly)). In a definitorial *TBox*, the left-hand side of a definition (e.g. $\text{Company} \equiv \text{Buyer} \sqcup \text{Seller}$) is called the *defined concept* (e.g. *Company*) and the right-hand side is termed as *primitive concepts* (e.g. *Buyer*, *Seller*)

The second component, *ABox* can be viewed as the world description or specific situations in an application domain.

DEFINITION 4.4: (*ABox*)

An assertional axiom is of the form $x: C$ or $\langle x, y \rangle : r$,⁷ where C is an $\mathcal{ALC}$ -concept, r is a role name and x, y are individual names. A finite set of assertional axioms is called an *ABox*. Following [69, 70]:

- an interpretation I is a model of an assertional axiom $x: C$ if $x \in C^I$
- I is a model of a *ABox*, $\mathcal{A}$, if it is a model of every assertional axiom in $\mathcal{A}$

As defined, two types of axioms can exist in an *ABox*:

- (1) Concept Assertions – asserting that an individual is an instance of a given concept (e.g. $\text{Company}(\text{QUICKLITE})$)
- (2) Role Assertions – asserting that a pair of individuals is an instance of a given role name (e.g. $\text{hasProduct}(\text{QUICKLITE}, \text{MEMORYCARD})$)

The definitions (4.1 to 4.4) introduced can be illustrated diagrammatically (see Figure 4-2). Following on the examples discussed earlier, a *TBox* has concepts that include *Buyer*, *Seller*, and *Product*. The *Company* concept is a union of the *Buyer* and *Seller* concepts. The diagram also illustrates a possibility of $(\text{Buyer} \sqcap \text{Seller})$, where the *Seller* and *Buyer* concepts intersect. It also has a role defined, *hasProduct*. The *ABox* is populated with 4 individuals; *Buyer*(*5KELL*), *Seller*(*INNOTEL*), *Seller*(*QUICKLITE*) and

⁷ Other notations exist for *ABox* axioms. One example is $C(x), R(x, y)$

Representation and Reasoning of the B2B Context Model

Product(MEMORYCARD). The example also illustrates the hasProduct role, which the Company instances to the specific product instances, hasProduct(QUICKLITE, MEMORYCARD). The diagram could also be used to represent a knowledge base, defined in DEFINITION 4.5.

Figure 4-2: A diagrammatic illustration of the semantics in DL ($\mathcal{ALC}$)

DEFINITION 4.5: (Knowledge base)

A knowledge base (KB) consists of a $TBox$ ($\mathcal{T}$) and $ABox$ ($\mathcal{A}$). Following [69-71]:

- an interpretation I is a model of a KB $\mathcal{K} = (\mathcal{T}, \mathcal{A})$

Such a KB is able to support inferences of explicit knowledge from implicit knowledge. These inferences are discussed next.

4.2.1.2 Inferences with Description Logic (DL)

When modeling a domain, a terminology box, $\mathcal{T}$ is constructed by defining a set of concepts. It is important to check that these concepts are not contradictory. To do this, the following four inferences are defined [69, 70, 72].

*Representation and Reasoning of the B2B Context Model***DEFINITION 4.6:** (Satisfiability)

A KB, $\mathcal{K} = (\mathcal{T}, \mathcal{A})$ is consistent if it has a model. A concept C is *satisfiable* with respect to $\mathcal{K}$ if there is a I model of $\mathcal{K}$ with $C^I \neq \emptyset$. C^I is a model of C with respect to $\mathcal{K}$.

DEFINITION 4.7: (Subsumption)

A concept C is *subsumed* by a concept D with respect to $\mathcal{T}$ if $C^I \subseteq D^I$ for every model I of $\mathcal{K}$. This is written as $C \sqsubseteq_{\mathcal{K}} D$ or $\mathcal{K} \models C \sqsubseteq D$.

DEFINITION 4.8: (Equivalence)

Two concepts C, D are *equivalent* with respect to $\mathcal{K}$ if $C^I = D^I$ for every model I of $\mathcal{K}$. This is written as $C \equiv_{\mathcal{K}} D$ or $\mathcal{K} \models C \equiv D$.

DEFINITION 4.9: (Disjointness)

Two concepts C, D are *disjoint* with respect to $\mathcal{K}$ if $C^I \cap D^I = \emptyset$ for every model I of $\mathcal{K}$.

Also, individual concepts and roles in a KB can be defined as instances of a KB.

DEFINITION 4.10: (Instance)

An individual a is an instance of a concept C with respect to $\mathcal{K}$, if $a^I \in C^I$ holds for every model I of $\mathcal{K}$. This is written as $\mathcal{K} \models a : C$.

A pair of individuals (a, b) is an instance of a role r with respect to $\mathcal{K}$, if $\langle a^I, b^I \rangle \in r^I$ holds for every model I of $\mathcal{K}$. This is written as $\mathcal{K} \models (a, b) : r$.

For basic DL systems, most reasoning is to check for *subsumption* (also known as classification) of concepts. This is illustrated through the following [70, 72]:

(1) **Reduction to Subsumption** – For concepts C and D ,

- a) C is unsatisfiable $\Leftrightarrow C$ is subsumed by $\perp$
- b) C and D are equivalent $\Leftrightarrow C$ is subsumed by D and D is subsumed by C
- c) C and D are disjoint $\Leftrightarrow C \sqcap D$ is subsumed by $\perp$

Representation and Reasoning of the B2B Context Model

From here, the state of *subsumption*, *equivalence* and *disjointness* of concepts can be further reduced to (un)satisfiability problem for DL that supports negation, as in $\mathcal{ALC}$. This is illustrated through the following [70]:

(2) **Reduction to Unsatisfiability** – For concepts C and D ,

- a) C is subsumed by $D \Leftrightarrow C \sqcap \neg D$ is unsatisfiable
- b) C and D are equivalent $\Leftrightarrow C \sqcap \neg D$ and $\neg C \sqcap D$ are unsatisfiable
- c) C and D are disjoint $\Leftrightarrow C \sqcap D$ is unsatisfiable

Thus for $\mathcal{ALC}$, all the four inferences can be reduced to a KB consistency check or to check the *satisfiability* of a concept. This *satisfiability* check gives rise to tableau algorithms for reasoning in DL, which is discussed next.

4.2.1.3 Reasoning using Tableau Algorithm

There are many reasoning algorithms that can be used to solve the inference problems highlighted in section 4.2.1.2, including automata-based and structural approaches. However, the most widely used technique is the tableau-based approach [70].

As discussed earlier, a tableau algorithm is used to test (un)satisfiability of a model, as all other inference problems can be reduced to a *satisfiability* problem (reduction to unsatisfiability). The basic steps involved in constructing a tableau algorithm for $\mathcal{ALC}$ for a knowledge base, $\mathcal{K} = (\mathcal{T}, \mathcal{A})$ can be summarised as [69-72]:

- Change all concepts into the **negation normal form** (NNF), using de Morgan's law (e.g. $\neg \exists r. C \equiv \forall r. \neg C$, $\neg \forall r. C \equiv \exists r. \neg C$)
- Break down C syntactically by **inferring constraints** on elements of I
- Build a **tree-like model**, I of input concept C
 - Nodes represent elements of Δ^I (e.g. $\mathcal{L}(x), \mathcal{L}(y)$)
 - Edges represent role-successorships between elements of Δ^I (e.g. $\mathcal{L}(\langle x, y \rangle)$)
- Decompose or expand iteratively using the **tableau rules** (listed in Table 4-1) for the corresponding constructors

Representation and Reasoning of the B2B Context Model

- **Blocking** (cyclic check) to ensure termination of algorithm
- Stop when **clash** (contradiction) occurs or when no rule is applicable

If no more rules are applicable and no clash occurs in the possible branches of the tree-like model, C is *satisfiable*.

Table 4-1: Tableau expansion rules for $\mathcal{ALC}$

Rule Type	Rule
$\sqcap$ -rule	If <ol style="list-style-type: none"> 1. $C_1 \sqcap C_2 \in \mathcal{L}(x)$, x is not blocked, and 2. $\{C_1, C_2\} \not\subseteq \mathcal{L}(x)$ then $\mathcal{L}(x) = \mathcal{L}(x) \cup \{C_1, C_2\}$
$\sqcup$ -rule	If <ol style="list-style-type: none"> 1. $C_1 \sqcup C_2 \in \mathcal{L}(x)$, x is not blocked, and 2. $\{C_1, C_2\} \cap \mathcal{L}(x) = \emptyset$ then $\mathcal{L}(x) = \mathcal{L}(x) \cup \{C\}$ for some $C \in \{C_1, C_2\}$
$\exists$ -rule	If <ol style="list-style-type: none"> 1. $\exists r. C \in \mathcal{L}(x)$, x is not blocked, and 2. x has no r-successor y with $C \in \mathcal{L}(y)$ then $\mathcal{L}(\langle x, y \rangle) = \{r\}$ and $\mathcal{L}(y) = \{C\}$ where $\mathcal{L}(y)$ is a new node
$\forall$ -rule	If <ol style="list-style-type: none"> 1. $\forall r. C \in \mathcal{L}(x)$, x is not blocked, and 2. has no r-successor y with $C \notin \mathcal{L}(y)$ then $\mathcal{L}(y) = \mathcal{L}(y) \cup \{C\}$
$\sqsubseteq$ -rule	If <ol style="list-style-type: none"> 1. $C_1 \sqsubseteq C_2 \in \mathcal{T}$, x is not blocked, and 2. $C_2 \sqcup \neg C_1 \notin \mathcal{L}(x)$ then $\mathcal{L}(x) = \mathcal{L}(x) \cup \{C_2 \sqcup \neg C_1\}$

The $\sqcup$ -rule (in Table 4-1) is non-deterministic, as it can add either C_1 or C_2 to $\mathcal{L}(x)$. There are two non-deterministic types:

- “**Don’t know**” – choice may affect the result of the algorithm

In this case, if the first choice leads to a clash (inconsistency), then the second option must be explored. This could lead to algorithm complexity as all options must be explored.

Representation and Reasoning of the B2B Context Model

- “Don’t care” – choice does not affect the result of the algorithm

In this case, any choice is acceptable, though the choice may affect the efficiency of the algorithm

Blocking refers to a mechanism for stopping the expansion of concepts using the tableau rules when the construction yields repetitive concepts. There are two types of blocks:

- When $\mathcal{L}(x) \subseteq \mathcal{L}(y)$, where y blocks x , and x is *directly blocked*, or
- When there is an ancestor of x , z such that x blocks z , i.e. *indirectly blocked*

To further explain the underlying ideas in the tableau algorithm, an example is used next. Let A, B be two concepts and R be a role name in a KB. Next, we want to check whether $((\exists R.A) \sqcap (\exists R.B)) \sqsubseteq \exists R.(A \sqcap B)$. To do this we need to test whether $C = (\exists R.A) \sqcap (\exists R.B) \sqcap \neg \exists R.(A \sqcap B)$ is unsatisfiable (based on reduction to unsatisfiability). Using the tableau algorithm,

- (1) To **reduce C into NNF**, where

$$C = (\exists R.A) \sqcap (\exists R.B) \sqcap \forall R. \neg(A \sqcap B)$$

$$C = (\exists R.A) \sqcap (\exists R.B) \sqcap \forall R. (\neg A \sqcup \neg B)$$

- (2) Break down C syntactically by **inferring constraints** on elements of I

Take an individual, w and impose the constraint $w \in C^I$. As C is a conjunction of three concepts, this means that w must satisfy the following constraints:

$$w \in (\exists R.A)^I, w \in (\exists R.B)^I \text{ and } w \in \forall R. (\neg A \sqcup \neg B)^I$$

- (3) Build a **tree-like model**, I of input concept C

This is done for all the concepts in C and expanded using the tableau rules. By starting with $\mathcal{L}(w) = \{\exists R.A, \exists R.B, \forall R. (\neg A \sqcup \neg B)\}$, the following concepts will be obtained, in a tree-like model (see Figure 4-3):

$$\begin{aligned} \mathcal{L}(x) &= \{A\}, \quad \mathcal{L}(x) = \{A, (\neg A \sqcup \neg B)\}, & \mathcal{L}(x) &= \{A, (\neg A \sqcup \neg B), \neg A\} & \text{and} \\ \mathcal{L}(x) &= \{A, (\neg A \sqcup \neg B), \neg B\} \\ \mathcal{L}(y) &= \{B\}, \quad \mathcal{L}(y) = \{B, (\neg A \sqcup \neg B)\}, & \mathcal{L}(y) &= \{B, (\neg A \sqcup \neg B), \neg A\} & \text{and} \\ \mathcal{L}(y) &= \{B, (\neg A \sqcup \neg B), \neg B\} \end{aligned}$$

Representation and Reasoning of the B2B Context Model

As the algorithm ends with all constraints satisfiable (both branches have concepts that do not contradict (clash), therefore C is satisfiable. This means that $((\exists R.A) \sqcap \exists R.B) \not\sqsubseteq \exists R.(A \sqcap B)$.

Figure 4-3: Example of using the Tableau Algorithm to create a tree-like model

For the more expressive DL (as discussed in the next section), more tableau rules need to be added to process different constructors. Such constructors might require more sophisticated blocking mechanisms also [71].

4.2.1.4 Important Extensions to $\mathcal{ALC}$ relevant to Ontology-based reasoning

DL was investigated as a formal foundation for reasoning with the context information in the *B2B Context Model*. Ontology provides a foundation for the representation of the context information, and together with DL, provide a formal basis for expressing and reasoning the information in a principled manner. $\mathcal{ALC}$ has been extended to include several features that are important in an ontology language. They include [69, 73, 74]:

Representation and Reasoning of the B2B Context Model

- **Number restrictions ($\mathcal{N}$)** – a restriction on the *number of relationships* of a particular type for individual (instance). E.g. $\geq 1\text{hasProduct}$ indicates that a company has at least one product
- **Qualified number restrictions ($\mathcal{Q}$)** – a further restriction on the *type of individuals* that are counted by a given number restriction. E.g. $\geq 1\text{hasProduct.MemoryCard}$ indicates that a company has at least one product of type MemoryCard.
- **Inverse roles ($\mathcal{I}$), transitive roles and subroles ($\mathcal{H}$)** – this extension *defines roles* in a hierarchical and transitive manner. E.g. the inverse of productOf is hasProduct , and also a subrole of categoryOf . We can also specify these roles to be transitive. For $\mathcal{ALC}$ with transitive roles, the abbreviation $\mathcal{S}$ is often used.
- **Concrete domains ($\mathcal{D}$)** – provides DL with the means to integrate with *concrete sets* like real numbers, integers and strings and concrete predicates like numerical comparison, string comparisons or constant comparisons. However, in their unrestricted forms, concrete domains are very complex and sometimes may not be decidable at all [74]. As such, a more restricted form called *datatypes* is often used [75].
- **Nominal constructors ($\mathcal{O}$)** – allows for the *use of individual names* within a concept description. E.g. if “MC16345” is a product name of type MemoryCard, then $\{\text{MC16345}\}$ is a *nominal* concept, and interpreted as a singleton set. However, they also give rise to very complex reasoning [71].

The DL corresponding to the OWL DL ontology language includes most of the extensions discussed above, and is typically referred to as $\mathcal{SHOIN}(\mathcal{D})$.

4.2.2 Ontology and the Web Ontology Language (OWL)

An ontology models knowledge or concepts about some domain as classes (or sets), attributes (or properties) and relationships [76]. OWL [68], a standard ontology language is a specific formalism for encoding ontologies. OWL, like its predecessors

Representation and Reasoning of the B2B Context Model

(RDF and DAML), is designed for greater machine interpretability through the formalised semantics.

An OWL ontology corresponds to a DL TBox, and together with a role hierarchy, describes the domain as classes and properties. The set of constructors and axioms supported by OWL is detailed in Appendix 5 (Table A5-1 and Table A5-2 respectively) [69, 70]. There are three sub-languages of OWL, with increasing expressiveness; OWL-Lite, OWL-DL and OWL-Full. However, only the first two are based on DL, as OWL-Full is an extension of the RDF model theory [69]. OWL-Lite is a subset of OWL-DL that does not support constructs such as `disjointWith` and `subClassOf`. As these are needed, OWL-DL is the preferred choice for developing the ontology for supporting the *B2B Context Model*.

4.2.2.1 Advantages of Using Ontology

Technically, ontology (through OWL) has several advantages over XML Schema. Each defined XML schema requires a customised system for reasoning. There is no “standard engine” that can use information from XML instances directly. Typically, this information must be parsed and then formatted into some repository or in-memory cache to be used for further processing or reasoning. There is no one size fits all. Furthermore, it is relatively resource intensive to set up an effective and stable reasoning system. For OWL-based ontologies, there are reasoning tools (e.g. Protégé, Racer and KAON2) that provide generic support for different domains of knowledge. These reasoning tools provide powerful “built-in” ability to ensure that an ontology is consistent and decidable.

An XML document has to include empty fields which do not hold any data values as it has to conform to an XML schema (e.g. some providers that do not provide delivery services will not publish any related delivery information) leading to redundancy. In an

OWL ontology, the user can choose to only create individuals for the classes (or concepts) as needed.

However, there are some instances where OWL DL may not be able to provide all the necessary semantics to represent the *B2B Context Model*, in particular the business rules governing the model. For example, in the rule to compute the Total Cost of an order, there is a need to include the cost associated with the price of the product, transportation costs and other associated tariff costs. This is not possible using the constructs provided by OWL DL. The next section discusses the use of Semantic Web Rule Language (SWRL) to complement OWL-DL, whilst trying to maintain decidability.

4.2.3 Semantic Web Rule Language (SWRL)

SWRL is designed to bridge the gap between the lack of expressivity in OWL-DL (including OWL-Lite) and the need to maintain decidability in a knowledge base that includes rules [77]. SWRL is a restricted version of RuleML (Rule Markup Language), where only unary/binary relations are allowed to extend the OWL axioms through Horn-like clauses [78-80]. This enables Horn-like rules to be combined with an OWL knowledge base.

DEFINITION 4.11: (SWRL syntax)

A SWRL rule, r is an expression of the form:

$$a \leftarrow b_1, \dots, b_n$$

where a is the head or consequent (an atom) and $b_1, \dots, b_n$ is the body or antecedent of r .

Arising from the above definition, a SWRL knowledge base ($\mathcal{K}$) can be defined to consist of a *SHOIN(D)* knowledge base ($\mathcal{E}$) and a set of SWRL rules ($\mathcal{P}$). Thus $\mathcal{K} = (\mathcal{E}, \mathcal{P})$. The SWRL atoms in the rules are in the form of $C(x)$, $P(x, y)$, $\text{sameAs}(x, y)$ or $\text{differentFrom}(x, y)$. C is an OWL description (class), P is an OWL property and x, y are either variables, OWL individuals or OWL data values.

The following example creates a SWRL rule which describes a company that sells a product (e.g. memory card). Several concepts must first be defined in OWL. The concepts of company, memory card and product owner can be captured as OWL classes of *Company*, *MemoryCard* and *Seller* respectively. The ownership relationship can be captured as OWL object property *ownsProduct* with a domain of *Company* and range of *Product*. The corresponding SWRL rule would be:

$$Company(?c) \wedge ownsProduct(?c, ?p) \wedge MemoryCard(?p) \rightarrow Seller(?c)$$

4.2.3.1 SWRL Built-ins

SWRL built-ins allow arithmetic operations to be expressed in SWRL rules and bind values to arguments. For example, the SWRL atom `swrlb:add(?x, 10, 3)` uses the core SWRL built-in `add` method for addition of two integer values. If `x` is unbound when the built-in is executed, it will be assigned the value 13 upon return of the built-in. If `x` is already bound when the built-in is executed, it will return true if “`x` is 13” or false otherwise. For a more complex example, to express that total cost is the sum of product cost and transportation cost, the concept of product is captured using the OWL class *Product*. Using OWL data properties *productCost*, *transportCost* and *totalCost* with the domain of *Product* and range of type float, the following SWRL rule can be constructed:

$$Product(?c) \wedge productCost(?p, ?pc) \wedge transportCost(?p, ?tc) \wedge swrlb:add(?total, ?pc, ?tc) \rightarrow totalCost(?p, ?total)$$

4.2.3.2 Features not supported by SWRL

Non-monotonicity is not supported in SWRL (i.e. it only supports monotonic inferences). Thus, knowledge in an ontology cannot be changed using SWRL rules, where rules do not add semantic value [80]. For example, a rule is created to increment the total number of products sold by a *Company* by one:

$$\text{Company}(?c) \wedge \text{noProductsSold}(?c, ?p) \wedge \text{swrlb:add}(?newP, ?p, 1) \rightarrow \\ \text{noProductsSold}(?c, ?newP)$$

Upon successful execution of this rule, there will be two values for the property *noProductsSold* instead of one (whereas the intended result is for the old value to be replaced by the new value). The rule will not modify the knowledge base (ontology). Furthermore, each time this rule is invoked, a new value will be added to the property indefinitely. As a consequent, negation as failure is also not supported.

4.2.3.3 DL-Safe SWRL Rules

Decidability is not supported in the full set of SWRL rules. It is known that when variables are bound to individuals (instances of classes) that are unknown, it will cause undecidability. Restricting such rules to bind with only known rules can ensure decidability, also known as *DL-safe* rules [77]. The use of *DL-safe* rules reduces the expressivity of SWRL. On the other hand, the use of SWRL built-ins that bind their arguments (example shown in section 4.2.3.1) might cause undecidability, due to the monotonicity of DL reasoning, causing the inference to be non-terminating. Consequently, built-ins must be used with care, to ensure decidability in knowledge bases that include both OWL ontology and SWRL rules.

4.3 Modelling the B2B Context Model as an Ontology

In the previous section the underlying formalism for an ontology-based representation and reasoning of context information, arising from the *B2B Context Model*, is discussed, including the potential to incorporate business rules as part of the reasoning process. This section will cover the realisation of the conceptual *B2B Context Model*, including the business rules, discussed in Chapter 3.

4.3.1 Design Considerations

The ontology design should fulfill the following requirements:

(1) Representing B2B context information

- Represent all the elements in the *B2B Context Model* and the relationships between these elements

(2) Realising the business rules

- Incorporate the business rules as OWL-DL language constructs where possible
- Otherwise, express the business rules using DL-safe SWRL rules and extend the ontology with these newly created SWRL rules

(3) Filtering of irrelevant information to improve the performance of reasoning process

- Support the filtering of irrelevant providers, (e.g. Filter off providers that do not sell the requested product)
- Support the filtering of irrelevant product information from relevant providers (e.g. Filter off product information not relevant to requested product)

4.3.2 Ontology Structuring

The *B2B Context Model* is modeled as a main ontology, functioning as a template for every participant (providers and requestor alike). In short, an ontology replica will be created for every provider or requestor, where each ontology will have the same classes, object properties and datatype properties as the main ontology. The main ontology may also contain SWRL rules constructed to express the B2B business rules. These rules are not replicated in the other ontologies as they are not needed for the population of data. The SWRL business rules can still be applied to the providers' or requestor's data through the main ontology and the replicas will be combined to form the knowledge base.

The ontology modeled the *B2B Context elements* as either classes (objects) or datatype properties (data attributes). Datatype properties represent elements storing data values

Representation and Reasoning of the B2B Context Model

(e.g. *Value* or *TimeScale*), the rest being represented as classes. The relationships between elements are represented as object properties (e.g. *hasProductService*). This satisfies requirement (1) discussed earlier.

For requirement (2), the business rules can be partially implemented as OWL concepts, but the full implementation needs the extension provided by SWRL. For example, certain concepts in the antecedent of the business rules (e.g. *Incoterms* is “FOB”) are represented as OWL classes (e.g. *FOB_Products*). With such definitions in the ontology, product instances where the *Incoterms* is “FOB” will be reclassified as instances of *FOB_Products* class, when the reasoner is invoked.

For requirement (3), the filtering mechanism is partially enforced by a sub-class approach:

- Defining separate classes for selected companies (*Provider* being a sub-class of *Organisation*) and selected products (*SelectedProductService* as a sub-class of *ProductService*) respectively.
- During runtime, companies that meet the condition (sells requested product) will be reclassified as instances of *Provider*. Similarly for identified providers, only suitable products are reclassified as instances of *SelectedProductService*.

Thereafter, the business rules (expressed using SWRL, see next section) will only query classes *Provider* and *SelectedProductService* instead.

The complete *B2B Context* ontology model, with the identified classes and object properties, is shown in Figure 4-4. The datatype properties to support this ontology model are detailed in Figure A5-1 of Appendix 5. A sample of an OWL file representing the ontology described, with relevant instantiation is detailed in Appendix 5 (Table A4-3). Requirements (2) and (3) are then extended using SWRL rules, which are discussed next.

Representation and Reasoning of the B2B Context Model

Figure 4-4: Classes and Object Properties in the ontology for B2B Context Model

4.3.3 Extending the Ontology through SWRL

The SWRL rules are needed to extend the ontology for supporting requirements (2) and (3) fully, as the OWL concepts defined in the ontology provided partial support only. For example, some of the business rules require mathematical computation, which is not supported by OWL. This is done through built-ins in SWRL. In essence, the extension of the ontology through SWRL for the business rules can be categorised into 2 types:

- Business rules that are fully represented in SWRL
- Business rules that are represented in SWRL and a programming language

The business rules expressed in Appendix 4 (Table A4-3) can be fully represented in SWRL except for Rule-3. In this rule, the maximum order lead-time for all suitable

providers needs to be determined; this can only be known after the execution of other SWRL rules. As such, the consequent (action) component of business Rule-3 is implemented in Java. Furthermore, business Rule- 4, 5, 6, 8 to 16 require the use of SWRL built-in functions (e.g. to compute the order lead-time from manufacturing and delivery lead-times, the `swrl:add` function is required). As discussed earlier, such functions may cause the knowledge base to be undecidable, if the function causes a binding to an unknown individual. At present, this shortcoming remains unresolved. The full complement of SWRL rules developed to represent the business rules are documented in Appendix 5 (Table A5-4).

4.4 Experimental Investigation and Analysis of Ontology-based Representation

The purpose of this investigation is to determine the performance (in terms of speed) of using a DL-based reasoning process. For this purpose, this section will briefly discuss the deployment of the ontology and SWRL rules developed for this investigation. The full prototype implementation, which is XML-based, including the architecture, ranking modules and others will be discussed separately in Chapter 6. The experimental setup, results and analysis of the performance will also be discussed in this section.

4.4.1 Prototype Development

The ontology model was developed using the Protégé-OWL editor⁸, an extension of Protégé that supports OWL. Version 3x was chosen as it has better support for SWRL rules creation. For the ontology reasoner, there are several OWL-DL reasoners; Pellet⁹ [81] and Ontobroker¹⁰ (a commercial version based on KAON2 infrastructure) being two

⁸ <http://protege.stanford.edu/download/download.html>

⁹ <http://clarkparsia.com/pellet/>

¹⁰ <http://www.ontoprise.de/en/home/products/ontobroker/>

Representation and Reasoning of the B2B Context Model

of possible candidates. At the time of choosing a reasoner, Pellet did not support SWRL built-ins, whilst Ontobroker had a full complement of built-ins. As such, the Ontobroker was chosen as the ontology reasoner for this investigation.

Figure 4-5: A high-level architecture of the Cognitive Advisor

This investigation uses modules from the *Cognitive Advisor*, a prototype developed to investigate the viability of using a context-aware approach for B2B collaboration, with supplier selection as a specific example. The prototype and its system architecture are further detailed in Chapter 6; a high-level architecture is shown in Figure 4-5. The modules within the dash-red lines are to support multi-criteria decision making (MCDM) algorithms, which are further discussed in Chapter 5 and Chapter 6. Here, only the ontology related aspects and their performance will be discussed, including the retrieval of ontologies (from requestor and candidate providers), combining the retrieved ontologies into a knowledge base and querying the knowledge base, which is part of the Context Information Manager (CIM) module. The performance of these major tasks will be investigated.

4.4.2 Experimental Setup

In this investigation, 3 tests were conducted, each with its own objective:

Representation and Reasoning of the B2B Context Model

- **Test-1** – To examine the performance of the DL-based reasoning process (CIM module) as the number of candidate providers increase

Test procedure:

For all the runs, the CIM module is executed with the same requested product, same set of selection criteria and criteria weights. The number of providers is varied from 20 to 70 at an increment of 5, with each set executed 3 times. The average value of the 3 executions will be used for the analysis.

- **Test-2** – To examine the effect of increasing the number of criteria on the performance of the DL-based reasoning process

Test procedure:

For all the runs, the CIM module is executed with the same requested product. The number of providers is varied from 20 to 70 at an increment of 5. Each set of providers is executed 3 times for each of these cases: 3-criterion, 4- criterion and 5-criterion, using the same criteria weights for each criterion set. The average value of the 3 executions will be used for the analysis.

- **Test-3** – To compare the performance of DL-based reasoning against that of a XML-schema based reasoning implementation

Test procedure:

For all the runs, the same set requestor's and providers' data, same requested product, same set of selection criteria and criteria weights are used in both ontology-based and XML schema-based CIM module. The number of providers is varied from 20 to 70 at an increment of 5. There are 3 execution runs for each set of the providers. The average value of the 3 executions will be used for the analysis.

4.4.3 Results and Analysis

Figure 4-6 shows a graphical illustration of the test results from Test-1. It is obvious that the greatest percentage of the total time is spent on evaluating and querying the knowledge base. Furthermore, as the number of providers increase, the percentage of

Representation and Reasoning of the B2B Context Model

total time for query evaluation increases from about 77% to 94%, as shown by the line graph in Figure 4-6. This causes the entire *Total Time* to increase in a non-scalable manner. The other tasks of the CIM module scale well, including the *Ranking* performance. The *Ranking* performance, though not part of the CIM module, was included for comparison purposes. This shows that the ontology-based reasoner does not scale well. Furthermore, even for 20 providers, it takes an average of 11,271 ms (11.3 seconds) to reason and rank, which is unsatisfactory from a user's perspective. This reaches to an unacceptable 79,484 ms (79.5 secs) for just 70 providers. These values were obtained after fine-tuning the query, by just executing the query once for any number of providers. This has improved performance by at least 5 times. This is clearly not acceptable from the performance and scalability viewpoints. The details of the test results are documented in Appendix 5 (Table A5-5).

Figure 4-6: Time taken to perform the different tasks in the CIM module (Test 1)

Representation and Reasoning of the B2B Context Model

For Test-2, the increase in the number of criteria has negligible effect on the performance, as shown by the relatively flat trends in Figure 4-7. This is consistent across the tests, as the number of providers is increased from 20 to 70. The raw data from this test is documented in Appendix 5 (Table A5-6).

Figure 4-7: Total time taken for different criteria (Test 2)

Representation and Reasoning of the B2B Context Model

$$*: \text{Performance Ratio} = \frac{\text{Total Time taken by Ontology KB}}{\text{Total Time taken by XML-based KB}}$$

Figure 4-8: Comparison of total time taken between ontology-based and XML-based implementations (Test 3)

As already seen in Test-1, the results from Test-3, shown by Figure 4-8, confirms that the ontology-based implementation is not scalable and is poor compared to that of using an XML-based implementation. The XML-based implementation outperforms the ontology-based implementation by more than 16 times for a test set of 70 candidate providers, and about 4 times for 20 candidate providers.

4.5 Chapter Summary

From the investigation, several conclusions can be drawn:

- Description Logic (DL) is a good formalism for representing and reasoning context information from the *B2B Context Model*, as it ensures decidability and guarantees computational completeness.
- However, while a DL-based knowledge base provides the necessary formalism and ensures decidability, it has limitations. One such limitation is the inability to model rules using the OWL DL constructs. This is due to the limited expressivity of the OWL DL constructs.
- SWRL rules were needed to extend the ontology, in particular to represent the business rules used in the *B2B Context Model*. Even though the regular SWRL rules can be designed to be DL-safe, the use of built-in functions (e.g. `swrl:add`) in the SWRL expressions to perform mathematical calculations may render the reasoning non-decidable guaranteed.
- Furthermore, from tests conducted, a knowledge base that uses an ontology and SWRL rules does not have scalable performance (speed), and compares poorly with an equivalent XML-based implementation.

Representation and Reasoning of the B2B Context Model

The work in this chapter highlights the importance of using a DL-based knowledge base. However, for practical reasons, the implementation, to be described in Chapter 6, was ultimately XML-based. The next chapter will discuss the various multi-decision making techniques that can be deployed for utilising context information from the *B2B Context Model*.

5 Decision Making Techniques to Support Context-aware B2B Collaboration

Chapter 4 discussed the use of Description Logic (DL) as a formalised foundation for modelling and reasoning of context information from the *B2B Context Model*. To enable context-aware B2B collaboration, pertinent context information from the *B2B Context Model* should be used in appropriate multi-criteria decision making (MCDM) techniques. This chapter introduces the relevant MCDM techniques and proposes an evaluation framework to assess the suitability of these techniques for decision making in context-aware B2B collaboration.

Two classes of MCDM techniques, Multi-Attribute Utility Theory (MAUT) techniques and Outranking techniques are reviewed by the evaluation framework. A new MAUT technique that is designed for B2B collaboration is also formulated. Finally, a hybrid approach for enabling context-aware B2B collaboration is proposed, augmented by fuzzy processing.

5.1 Overview of Multi-Criteria Decision Making (MCDM) Techniques

Decision Making can be viewed as “the study of identifying and choosing alternatives based on the values and preferences of the decision maker”. In decision making, the steps involved can be distilled into the following [82, 83]:

- Step (1): *Define objectives/goals* – A statement of intent or problem statement in the proposed undertaking.
- Step (2): *Formulate decision criteria* – Identify performance measures (standards) to judge and compare alternatives by.
- Step (3): *Identify alternatives* – A set of options or solutions to the defined objective(s) that are feasible for a given context of decision making.
- Step (4): *Evaluate alternatives* – Based on the identified criteria, the alternatives are evaluated using a defined model that accompanies a specific technique. This step is also known as preference elicitation.
- Step (5): *Recommend decision* – A decision is made or recommended, based on the outcome of the evaluation of alternatives. The decision can be accepted or the entire process can be iterated by changing the criteria.

Typically, decision making involves multiple criteria, having several values and preferences, which cannot be simply combined into a single aggregate measure. This class of decision making with finite multiple criteria is referred to as Multiple Criteria Decision Making (MCDM). The three key concepts in the decision making process, namely *alternatives*, *decision criteria* and *decision type* [84] are discussed next.

5.1.1 Alternatives

Alternatives in MCDM are generally considered as *potential actions*. Roy [84] specifically stressed the notion of “potential”, asserting that a particular *action* is either

Decision Making Techniques to Support Context-aware B2B Collaboration

feasible or of considerable interest before it can be considered as an *alternative*. As an example, all potential partners may not be feasible. For instance, some partners may not have the product that is of current interest in the decision making process. Hence these infeasible partners must be filtered accordingly. By convention, the j -th alternative in the set A is denoted as a_j , where A is a finite set of alternatives, $|A| = n$ and $A = \{a_1, a_2, a_3 \dots a_n\}$.

5.1.2 Decision Criteria

Decision criteria discriminates among alternatives based on how well each realises the goals of the decision making process. That is, criteria are objective measures that represent the goals of decision making [82]. In this research, these criteria are also the *context* of the decision making, for example, *cost* and *lead-time*.

MCDM, as the name implies, addresses decision making with multiple criteria. By convention, the i -th criterion in the set G is denoted as g_i . The result of evaluation of an alternative, a by criterion g is denoted as $g(a)$, and is called the *performance* of a according to g , or *performance value* in short. The set of all possible values of $g(a)$ is denoted as X_g , which should have a complete order $<_g$ to allow for comparisons. $(<_g, X_g)$ is called the *scale* of criterion g . The elements, $x \in X_g$ are the *degrees or scores* of the scale [84].

To compare a pair of alternatives based on a criterion, the two *scores* corresponding to the two alternatives are compared. In order to perform a proper comparison, it is important to first clearly specify the order of preference in the scale employed. Roy [84] identified two commonly encountered types of scale:

- (i) *Qualitative (ordinal) scale* is a scale in which the unit difference between two consecutive degrees does not have any explicit meaning in terms of preference.

Decision Making Techniques to Support Context-aware B2B Collaboration

This type of scale can be either a *verbal* or a *non-numerical* scale, such as Hot, Warm or Cold for example.

- (ii) *Quantitative (cardinal) scale* is a scale in which the numerical difference between two degrees is proportional to the preference difference that they represent. This type of scale is always a *numerical* scale. Examples include the numerical values of weight (50 kg), age (25 years old) or price (\$20.00) of a product.

Some criteria, however, are not compared using scales; such criteria are usually referred to as *nominal criteria*. In this class of criteria, a candidate receives a full score if its property matches the specified property; and zero otherwise. For example, if the requestor specifies that one of the criteria is *Source Country*, so if the preferred value is China, then it is either a full match (score of 1) or a no match (0). It is desirable for decision support models to be able to accommodate these three types of criteria in a flexible yet consistent manner.

5.1.3 Decision Type

Decision type refers to the parameters that influence the outcome of the decision. In short, *decision type* dictates whether the intended decision is an outright choice, a classification or a ranking. Traditionally, the expected decision in MCDM is a choice, which is essentially a smaller subset of alternatives. However, this is not always the case. Roy [84] identified the three most commonly encountered *decision types* in MCDM as follows:

- (i) *Choice*: Determine a minimal subset, A_0 of the available alternatives, A , that can justify the elimination of all other alternatives $A \setminus A_0$ [85]. The members of A_0 are considered indifferent.
- (ii) *Classification*: Assign each action of A to the most appropriate predefined category. The categories may be defined based on the expected actions (e.g.

Decision Making Techniques to Support Context-aware B2B Collaboration

Approve, Reject, or KIV), or on the qualitative judgments (e.g. Good, Average, or Bad).

- (iii) *Ranking*: Build a complete or partial pre-order on A based on the degree the decision criteria is satisfied by each alternative.

In B2B collaboration, decision making typically requires choosing the best option, and where the best option is not feasible (e.g. due to extenuating circumstances such as earthquake or tsunami), knowing and choosing the next best option. *Choice* decision type only provides a segregation of the better alternatives. Likewise, *classification* decision type provides a few alternatives that it considered similar according to pre-defined categories. These are not good enough for B2B decision makings, as there is a need to be able to choose the best option or the second best option in most cases. As such, in this research, the main interest is in *ranking*. *Ranking* decision type provides the ability to build pre-orders, thus knowing the standing of each alternative in relation to the others. Having explained the fundamental concepts underlying MCDM, the next section discusses the parameters that should be considered when selecting a suitable MCDM technique for decision making, in particular *ranking decision type*.

5.2 Selecting Suitable MCDM Techniques

Whilst MCDM provides a good basis for decision making, there are many techniques, each designed to solve different types of problems. There are different ways to classify the plethora of MCDM techniques. In this section, the approach adopted by Figueira *et al.* [86] is adopted here, namely Multi-Attribute Utility Theory (MAUT) techniques and Outranking techniques. In order to identify suitable technique(s) for supporting context-aware B2B collaboration, the key considerations and how they can be “measured” must first be established. This is the focus of this section.

5.2.1 Brief Review of Existing Work

Although MCDM techniques have existed for many years, not much work on selecting decision making techniques for a specific domain has been reported. One such work was by Tecle in 1988 [87], who proposed 49 desirable attributes of any technique. This was further refined by Al-Shemmeri [88] into 27 attributes, which can be summarised as follows:

- (1) *Problem Formulation* - includes the types of data it can handle, how objectives are formulated and how the technique compares the different alternatives (preference structuring).
- (2) *Ease of Use for decision maker* – includes the knowledge required to use the technique, the interaction required and ability to handle group decisions
- (3) *Automation* – includes the implementation and computation time
- (4) *Quality of Decision* – includes the completeness or ranking, consistency and robustness of results.

In another work, a three criteria framework was proposed [89]: (1) *Consistency of results* which measures the influence of alternatives on the outcome of the ranking, (2) *Degree of interaction* by the user, including the amount of information the user needs to supply and the extent of interaction needed, and (3) *Ease of understanding*, which translates into time required for the user to understand assumptions, trade-offs and steps in the method. Similarly another four criteria framework [90] was also proposed: (1) *Characteristics describing the analyst* (user friendliness) which encompasses an evaluation of whether thresholds are used and how these thresholds are defined, (2) *Characteristics describing the technique* which translates to how easy it is to understand and use a MCDM technique, (3) *Variation in the solution*, relating to the non-ambiguity (completeness of ranking), variation of solution to changing preferences (weights), variation of solution between different methods and accuracy of solution (though this was not illustrated in the paper, due to a lack of data) and (4) *Ease of Implementation*

Decision Making Techniques to Support Context-aware B2B Collaboration

which includes integration with an existing system (e.g. Geographical Information System) and coding the steps using identified software (e.g. EXCEL spreadsheet).

One common thread emerged when examining these work; most of the considerations are qualitative in nature, are hard to quantify and are subjective. Furthermore, too many considerations [88] also lead to a very tedious and difficult to comprehend evaluation process. There is a distinct lack of quantitative metrics. Hajkowicz [91] attempted to address this through the use of two quantitative metrics; Spearman's rank correlation and Kendall's coefficient of concordance. These two metrics measure the similarity between two sets of rankings, assuming that there are no tied rank positions. However, the strength of a technique cannot be measured by either the qualitative considerations alone or through Spearman's and Kendall's quantitative metrics only. The next sub-section will discuss important considerations from the B2B and context-aware perspectives. These will provide the additional basis for the proposed evaluation framework.

5.2.2 Important Considerations for supporting Context-aware B2B Collaboration

When selecting a MCDM technique, several primary characteristics of B2B collaboration should be taken into account:

- *No known ideal values, only acceptable or preferred values are known*
 - In partner selection for example, the requestor might declare the maximum value for cost as \$5.00 per unit. However, a cheaper option is always "preferred", everything else being equal.
 - Ideal or optimum values are usually unknown
- *The context of collaboration is known*
 - The criteria for a given context are known. For example cost and lead-time to identify a suitable partner.

Decision Making Techniques to Support Context-aware B2B Collaboration

- Typically, the relative importance of the criteria in relation to each other is also known, or can be determined. E.g. cost is more important than lead-time in identifying a suitable partner.
- The relative importance of all the criteria is usually pre-determined or can be determined (e.g. Hewlett Packard's selection metrics [92])
- *Each criterion has a different unit of measure*
 - Typically, criteria have different units of measure (e.g. 4 days for lead time and \$5.00 for cost)
 - As such, in order to support meaningful comparison, the units of measure must first be normalised

In addition, from a context-aware decision making viewpoint, these are also important considerations:

- *Ability to use context information automatically*
 - The *B2B Context Model* consists of contexts that are quantitative, qualitative and nominal in nature
 - A technique should ideally be able to automatically process these types of information
- *Level of interaction between requestor and technique*
 - A requestor (human user or another service) should only need to specify the context of collaboration (e.g. through identifying the collaboration criteria) and the relative importance of these criteria
 - Beyond these, no further interaction or intervention should be needed, as this would impair automatic processing
- *Number of assumptions made*
 - Some techniques require thresholds that are typically assumed or arbitrarily specified
 - These thresholds can potentially skew the final ranking of the techniques
 - Also, some techniques require the mapping of actual data into scales

Decision Making Techniques to Support Context-aware B2B Collaboration

- Where the mappings are not specified in the technique's elicitation process, they are typically not deterministic (usually based on the assumptions of the decision maker or analyst) and can also potentially skew the final ranking

These considerations are particularly important in context-aware decision making as one of the main goals is to automate the B2B collaboration process [15]. The next sub-section will discuss an evaluation framework to address the short-comings in existing frameworks and how they can be improved based on what is discussed in this sub-section.

5.2.3 Proposed Evaluation Framework

This proposed framework evaluates a technique based on how well it formulates a problem (Model Formulation), the ease of automating the technique (Automation Practicality) and Quality of Solution which measures the quality of the decision making process. Thirteen considerations forming the three categories are proposed:

- (a) **Model Formulation** – relates to how the MCDM technique reaches a ranking sequence
 - (1) *Criteria type support* – pertains to a technique's ability to handle quantitative, qualitative and nominal data types
 - (2) *Normalisation of criteria data* – the method adopted to normalise the different measurement units of criteria data and the soundness of the normalisation method
 - (3) *Weights* – ascertains how the relative importance of criteria are determined, if any
 - (4) *Data usage* – relates to how a technique uses the context information; in the actual form, normalised or in other forms for comparisons
 - (5) *Preference elicitation* – the way a technique formulates and uses data
 - (6) *Ranking Robustness* – the interpretation of the final ranking and its adoption

Decision Making Techniques to Support Context-aware B2B Collaboration

(b) **Automation Practicality** – the ease of automating the technique to support context-aware decision making

(7) *Degree of interaction* – measures the degree of interaction and intervention by the requestor

(8) *Assumptions* – identifies the type and number of assumptions required in using the technique

(9) *Data scaling* – determines if data needs to be mapped into a common scale (e.g. AHP)

(c) **Quality of Solution** – measures the quality of the final ranking in terms of completeness, stability and sensitivity to changes using quantitative metrics

(10) *Rank completeness* – quantifies the completeness of the ranking based on the number of unique rankings obtained from possible alternatives:

$$\text{Rank completeness, } \omega = n_u / n_t$$

where n_u = number of unique ranks

n_t = total number of alternatives

(11) *Rank correlation* – measures the stability of the solution when new alternatives are introduced. For this purpose, two ranking sequences are compared using Pearson's rank correlation, ρ , which is based on Pearson's product-moment correlation coefficient that is typically used in statistics [93]:

$$\rho = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}}$$

where x_i = position in original rank sequence X

Y = complete rank sequence with new alternatives

y_i = position in new rank sequence Y'

n = number of alternatives in each sequence (same for both)

$Y' = Y \setminus X$

This measure can also be used to measure the degree of correlation of two ranks obtained from different MCDM techniques.

Decision Making Techniques to Support Context-aware B2B Collaboration

- (12) *Rank reversal, θ* – assesses the robustness of the solution based on the similarity between two sequences. For this, the Spearman's foot-rule distance, d_n which measures the absolute distance (representing the disagreement) between two ranks is adopted [93]:

$$d_n = \sum_{i=1}^n |x_i - y_i|$$

This is similar to the Manhattan distance used for quantitative variables in data mining [94]. To measure the degree of disagreement between two ranks, caused by rank reversal, θ , the following is used:

$$\theta = \frac{d_n}{d_{n-max}}$$

where d_{n-max} = maximum distance between two rankings of n -length
When there is no tied rank, the maximum foot-rule distance can be generalised to:

$$d_{n-max} = 2 \times \left\lfloor \frac{n}{2} \right\rfloor \times \left(\left(re\left(\frac{n}{2}\right) + 1 \right) + \left(\left\lfloor \frac{n}{2} \right\rfloor - 1 \right) \right)$$

When there are tied ranks, the maximum foot-rule distance can be generalised to:

$$d_{n-max} = \frac{(n-1)(n-2)}{2}$$

The derivations of these equations can be found in Section A6.9 of Appendix 6.

- (13) *Sensitivity Analysis* – gauges a technique's sensitivity to changes of the criteria weights (requestor's preference change). This is typically done using graphical means and will be detailed in Chapter 6.

The considerations (1) to (9) are used in the review and analysis of pertinent MCDM techniques, discussed in the next section. Considerations (10) to (13) will be evaluated empirically and further discussed in Chapter 6.

5.3 Multi-Attribute Utility Theory (MAUT) Techniques

Multi-Attribute Utility Theory (MAUT) methods use *utility functions* [95] to transform raw performance values of the alternatives into a common dimensionless scale, typically [0,1] or [0,100]. This section briefly reviews some of the more common MAUT methods such as AHP (Analytic Hierarchy Process), VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Thereafter, an assessment based on the first two categories of the evaluation framework is made. Arising from this, a new method, *Deviation Measure* is proposed, to address some of the shortcomings identified.

5.3.1 AHP

Put simply, the Analytic Hierarchy Process (AHP) [96] makes pair-wise comparisons of criteria to determine their relative weights, and then like-wise scores the alternatives. The *Saaty scale*, ranging from 1 to 9 (9 being the widest disparity of relative importance) is adopted for the comparisons [96]. For example, consider two criteria, *price* and *Lead-time*. If *price* is equally important as *Lead-time*, then the score assigned to this pair-wise comparison is 1. If *price* is only marginally more important than *Lead-time*, then a score of 3 is apt. However, if it is significantly much more important, a score of 7 or 9 could be assigned. On the other hand, when *Lead-time* is compared to *price*, a score of less than 1 is expected (for instance 1/3, 1/7 or 1/9). The generalised steps of the AHP evaluation process can be found in Section A6.2 of Appendix 6.

This technique is useful when evaluating qualitative criteria or criteria that are hierarchical in nature. The criteria are assumed to have a common unit of measure. Otherwise, they must be mapped onto a common scale. During the elicitation process, the decision maker (or requestor) needs to choose a Saaty number at each pair-wise

comparison, making it very interactive in nature. The highest scored alternative is the most preferred alternative.

5.3.2 VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje)

VIKOR, introduced by Opricovic in 1998 [97, 98], ranks alternatives based on the distance of each alternative from the ideal solution. The distance is measured using the Euclidean distance [99]. This method is useful when there are conflicting criteria, as it tries to reach a compromised solution by trying to obtain a maximum group utility and minimising the minority regret of opposing criteria. The details of the elicitation process can be found in Section A6.3 of Appendix 6.

VIKOR is able to handle criteria with different units of measure through a linear normalisation of its performance values (see Step (2) of the elicitation process in Section A6.3). In the elicitation process, this method starts off with a pre-defined weight, v for the group of criteria that belongs to the maximum group utility. The initial state is $v = 0.5$. For the decision to be stable, v must fall within the stability range [81]. In this stability range determination process, each criterion weight stability range must be determined individually. This is computationally intensive and typically cannot be done manually. VIKOR considers the relative importance of the criteria through this stability range check. The highest ranked alternative in this technique is the closest to the ideal solution, i.e. the best compromise solution.

5.3.3 TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

TOPSIS was proposed by Cheng and Hwang [97, 98] for choosing alternatives based on the shortest distance from the ideal solution and farthest distance from the negative-ideal (nadir) solution. The distances are also measured by the Euclidean distance, but using the 2-norm distance form instead, see Step (4) of Section A6.4 in Appendix 6.

TOPSIS normalises the performance values across different units of measure through a vector, see Step (2) of Section A6.4. The resulting normalised value could be different when evaluated using different units of measure, as shown by Opricovic and Tzeng [97]. The preference order in TOPSIS is an indication of the closeness to the ideal solution as well as how far it is from the negative-ideal solution, without considering the relative importance of different criteria. As a result, the highest ranked alternative may not be the best alternative [100].

5.3.4 An assessment of the three MAUT techniques

Table 5-1 summarises the analysis of the three MAUT techniques based on nine considerations discussed in Section 5.2.3. It is clear that AHP is the only method that can determine weights that reflect the relative importance of criteria. However, AHP has many drawbacks, the main ones being:

- (i) The tedious interaction of criteria and alternatives in pair-wise comparison limits the possibility of automation, which is necessary for context-aware enabled B2B collaboration.
- (ii) AHP maps performance values across different criteria into a common scale that is not part of the technique. Consequently, this mapping is arbitrary and is based on the assumptions of the decision maker (or requestor) and is therefore scientifically unsound. This also makes automation difficult.

Furthermore, the use of the Saaty scale has not been rigorously justified [101]. The elicitation process in AHP has also been questioned for its internal consistency [102]. Furthermore, Dyer [103] has shown that AHP's ranking results can be arbitrary, with rank reversal being a symptom of such arbitrary rankings. As such moving forward, AHP was dropped from further evaluation for use in this research as a candidate MCDM technique.

Decision Making Techniques to Support Context-aware B2B Collaboration

Table 5-1: Comparison of relevant MAUT methods using the evaluation framework

#	Consideration	AHP	VIKOR	TOPSIS
1	Criteria Type Support	Non-directly, see #9	Quantitative	Quantitative
2	Normalisation (Method & independence from criteria's units of measure)	<ul style="list-style-type: none"> No direct normalisation, see #9 Independent of criteria's units of measure 	<ul style="list-style-type: none"> Linear normalization Independent of criteria's units of measure 	<ul style="list-style-type: none"> Vector-based normalization Dependent on criteria's units of measure
3	Weights	Yes, embedded into the technique	No, weights of criteria must be known or pre-determined	No, weights of criteria must be known or pre-determined
4	Data usage	Uses a common mapped scale, see #9	Uses the performance values directly	Uses the performance values directly
5	Preference Elicitation	<ul style="list-style-type: none"> Uses rigid scoring system (Saaty scale) Ranking is based on the aggregated scores from pair-wise comparison of alternatives using the Saaty scale 	<ul style="list-style-type: none"> Distance measure from ideal solution using Euclidean distance Ranking is based on aggregation of criteria distance measures 	<ul style="list-style-type: none"> Distance measure from both positive ideal and negative (nadir) ideal using Euclidean distance Relative importance of the two distances are not considered Ranking is based on the index created from the two distance measures
6	Ranking Robustness	<ul style="list-style-type: none"> Highest ranked alternative is most preferred 	<ul style="list-style-type: none"> Highest ranked alternative is the closest to ideal solution 	<ul style="list-style-type: none"> Highest ranked alternative is the best in terms of ranking index only No indication of closeness to positive ideal solution
7	Amount of interaction	<ul style="list-style-type: none"> High - requires interactions at criteria and alternatives pair-wise comparisons 	<ul style="list-style-type: none"> None – after request is made. This is a computationally intensive method 	<ul style="list-style-type: none"> Medium - requires identification of positive and negative ideal solutions
8	Assumptions	<ul style="list-style-type: none"> Availability of performance matrix Performance matrix can be mapped into a scale, see #9 	<ul style="list-style-type: none"> Availability of performance matrix Able to determine or know the ideal solution 	<ul style="list-style-type: none"> Availability of performance matrix Able to determine or know the ideal and negative-ideal (nadir) solutions

*Decision Making Techniques to Support Context-aware B2B Collaboration***Continuation of Table 5-1: Comparison of relevant MAUT methods using the evaluation framework**

#	Consideration	AHP	VIKOR	TOPSIS
9	Data scaling	Yes, consequently provide pseudo values and normalising the performance values	No, direct performance values used	No, direct performance values used

VIKOR's strengths lie in the method's ability to rank alternatives according to their closeness to the ideal solution in the presence of conflicting criteria. The drawback is that, VIKOR needs to know the ideal solution for a given problem. As discussed in Section 5.2.2, the ideal values and consequently, the ideal solution are both unknown in B2B collaboration. Also, VIKOR tries to achieve a compromise solution by adjusting the strategy weight of the majority of criteria. Thus for a solution to be robust, the individual criterion weight must fall within a determined stability range. This may not be possible all the time in B2B collaboration, as a specific criterion (such as *Cost*) could be considered as being far more important than another (such as *Lead-time*) and consequently does not fall within the stability range. As such VIKOR is ill suited to handle decision making in B2B collaboration.

TOPSIS's biggest drawback is the elicitation process. The ideal (positive) and negative-ideal (nadir) solutions need to be ascertained, before an alternative is selected based on the Euclidean distances between these two points. As already mentioned, positive and negative ideal values are unknown in B2B collaboration. Without these values, the TOPSIS method simply cannot work. Thus, it is also not suited for B2B collaboration decision making.

Arising from the outcome of this analysis, another technique is proposed. This method is inspired by the three MAUT methods reviewed, but tailored to the specific needs of context-aware and B2B collaboration decision making discussed in Section 5.2.2.

5.3.5 Proposed Deviation Measure

From a context-aware B2B collaboration viewpoint, the criteria specified by a requestor (e.g. *price* and *Lead-time*) are termed *preferred values*. Any deviation from these values can be positive (e.g. lower *price*) or negative (e.g. longer *Lead-time*), as illustrated in Figure 5-1.

Figure 5-1: A deviation measure from the preferred values

This *deviation measure* and the subsequent elicitation steps can be easily automated, and the performance values from the *B2B Context Model* can be used directly. This confines user intervention to the selection of criteria (collaboration context) and weights determination only. This *deviation measure* concept is structured into a series of elicitation steps, where the different units of measure are normalised linearly so that the performance values of different criteria can be aggregated, to obtain the Overall Suitability Score (OSS). The weight of each criterion is incorporated in the calculation of the Individual Criterion Score (ICS), see Step (3) below. The AHP pair-wise comparison is adopted to determine the weights of the criteria, as it provides a good intuitive way to compare the relative importance of pairs of criteria, instead of all simultaneously. This mimics industry practice well. The highest ranked alternative based on the OSS values is the best alternative.

The elicitation steps of the *Deviation Measure* technique are:

- (1) Determine the weights of the criteria, w_i ascertained by AHP pair-wise comparison, where for n criteria

Decision Making Techniques to Support Context-aware B2B Collaboration

$$\sum_{i=1}^n w_i = 1$$

(2) Calculate the normalised performance matrix

By applying the *deviation measure*, the normalised performance value of the i -th criterion in the j -th alternative, $p_i(a_j)$ can be computed depending on whether the objective is to minimise or maximise a particular criterion.

For a criterion where the objective is to minimise its value,

$$p_i(a_j) = \left(\frac{g_i^* - g_i(a_j)}{g_i^*} \right)$$

For a criterion where the objective is to maximise its value,

$$p_i(a_j) = \left(\frac{g_i(a_j) - g_i^*}{g_i^*} \right)$$

where

g_i^* = preferred value associated with criterion g_i

$g_i(a_j)$ = non-normalised alternative's performance value

(3) Calculate the weighted normalised performance matrix

The weighted normalised individual criterion score, ICS_{ij}

$$ICS_{ij} = w_i p_i(a_j)$$

where w_i = weight of i -th criterion and

$$\sum_{i=1}^n w_i = 1$$

(4) Calculate the overall suitability score OSS_j for **all** n criteria for each j -th alternative

$$OSS_j = \sum_{i=1}^n ICS_{ij}$$

A positive score indicates that the alternative is a viable alternative, whereas a negative score indicates that it is not viable, when compared to the *preferred* values.

(5) Rank all alternatives by their overall suitability scores in descending order. The highest ranked alternative is the best alternative.

A worked example of this proposed method is detailed in Section A9.1 of Appendix 9.

From the viewpoint of the evaluation framework, the proposed *Deviation Measure* rates well for considerations (1) to (9), except for (1) as it only handles quantitative criteria. However, the other three MAUT techniques reviewed are likewise limited. This short-coming will be addressed separately in Section 5.5.2 as part of the hybrid approach proposed. For consideration (2), it provides a linear normalisation method via Step (2) of the elicitation process. This results in independence from the criteria's units of measure. This technique will be empirically evaluated for its **Quality of Solution**, against another class of methods, namely the Outranking methods. These investigations are discussed in Chapter 6.

The next section will briefly review pertinent Outranking techniques as alternative MCDM techniques to support context-aware B2B collaboration. Outranking techniques use binary relationships to compare and determine whether one alternative outranks the other. Some of the outranking techniques fit the *ranking* decision type, which is the focus of this research. The purpose is to identify additional possible techniques and compare the empirical results obtained to determine the best technique to support decision making in supply chain applications.

5.4 Outranking Techniques

The basic building block of outranking methods is the binary outranking relation, S for a set of alternatives A and a set of criteria G . aSb asserts that alternative a is at least as good as alternative b . In other words, there are enough $g(a) \in G$ to support the claim that a is at least as good as b and there is no $g(b) \in G$ which credibly rebuts such an assertion. Different outranking methods are designed to deal with different decision types (namely, choice, classification and ranking) [104]. This section briefly reviews the

ELECTRE (**EL**imination **Et** **Choix** Traduisant la **RE**alité or Elimination and Choice Expressing Reality) [82, 85] and PROMETHEE (**P**reference **R**anking **O**rganization **M**ETHOD for **E**nrichment **E**valuation) [105] methods, which are the two well-known and widely used families of outranking methods. For simplicity, it is assumed that the criteria are in ascending order of preference (i.e. higher values are better), unless otherwise indicated. Thereafter, the suitability of these techniques to support context-aware B2B collaboration will be assessed.

5.4.1 ELECTRE Methods

All methods in the ELECTRE family use the binary outranking relation S described earlier. The methods in this class are differentiated by the type of outranking relations they construct (crisp, fuzzy, or embedded) and their preference elicitation procedure. Figure 5-2 shows the family of different ELECTRE methods. Each of the methods will be briefly reviewed in the next sub-sections.

Figure 5-2: Family of ELECTRE methods

5.4.1.1 ELECTRE I, Iv, and IS

The first method, ELECTRE I was designed to select a choice out of a finite set of alternatives, i.e. *choice* decision type. This method constructs the binary outranking relations through two indices, concordance and non-discordance. Some literature refers to the non-discordance index as discordance index [82]. The details are captured in Section A6.5 of Appendix 6. The score for each alternative is based on the weighted sum of criteria that satisfy the concordance threshold and does not violate the discordance threshold.

Both these threshold values are set arbitrarily, without any scientific means. Another major drawback of ELECTRE I is that it does not consider the fact that different criteria have different ranges, and thus, there cannot be a unique non-discordance threshold defined for all criteria. This is important to B2B collaboration as different criteria are likely to have different units of measure, and hence different ranges. This is addressed in ELECTRE Iv, where the non-discordance requirement is replaced by a *no-veto condition*.

However, both ELECTRE I and Iv suffer from another limitation, namely the use of the *true-criteria*. A true-criteria procedure assigns the whole weight associated with a particular criterion to the alternative that performs better, regardless of the degree (how much better). ELECTRE IS, proposed to address this limitation, uses the concept of *preference and indifference thresholds*. ELECTRE I, Iv, and IS, however, are designed to address the *choice* decision type only. As this research requires the construction of ranking sequences (*ranking* decision type), these methods are not suitable for use. However, they form the basis for other ELECTRE techniques.

5.4.1.2 ELECTRE II

ELECTRE II [85] was developed to address the *ranking* problem, as shown in Figure 5-2. As a result, a sequential pre-order or ordered list of alternatives can be formed, given a

set of criteria and known relative weights to each criterion. It is also a true-criteria procedure that constructs *embedded outranking relations* based on two concordance cut-off levels and a no-veto condition; see Section A6.6 of Appendix 6 for details.

Like ELECTRE I and ELECTRE IV, it suffers from the same drawback of a true-criteria procedure where the whole weight of a criterion is assigned to the alternative that has a better performance value, regardless of degree. This can lead to several consequences; (1) the final ranking pre-order can be skewed unjustly and (2) many incomparable alternatives when constructing the final pre-order. This leads to incomplete (or partial) pre-orders.

5.4.1.3 ELECTRE III

ELECTRE III [104] was introduced to deal with the drawbacks of ELECTRE II by adopting the preference and indifference thresholds of ELECTRE IS (see the development in Figure 5-2). It introduced the concept of pseudo-criteria to define the degree “ a outranks b ”, thereby adding better discriminating capability in the elicitation process. The details are captured in Section A6.7 of Appendix 6.

Unfortunately, ELECTRE III also suffers from other drawbacks. A major one is the arbitrary determination of threshold values. This exposes the decision making process to ill-determined threshold values, leading to results that are inadmissible. A few guidelines, including those in [106], have been proposed. However, they still rely on the use of arbitrary values in threshold determination. Furthermore, there is no standardised distillation of the pre-orders in ELECTRE III; the one documented in Section A6.7 of Appendix 6 is one of the more common procedures, but there are others.

5.4.1.4 Summary on ELECTRE methods

In this research, requestors of services in B2B collaboration are assumed to be able to specify weights or relative importance of each criterion. As such, though ELECTRE IV can rank alternatives, it is not considered because it does not use weights (see Figure 5-2). ELECTRE TRI is for *classification* decision type, again not within the focus of this research, and hence not considered. Moving forward, ELECTRE II and ELECTRE III are possible candidate MCDM techniques to support context-aware B2B collaboration. The possibility of adopting either or both them is further discussed in Section 5.4.3.

5.4.2 PROMETHEE Methods

PROMETHEE methods [105] belong to the class of outranking methods which have a canonical structure of outranking relations, followed by an exploitation method. However, they do not follow the definition of outranking relation based on concordance and non-discordance. Instead, PROMETHEE uses the concept of *preference intensity functions* for *valued outranking*. This preference intensity is a function of the performance advantage of *a* over *b*. PROMETHEE allows each criterion to have different preference functions. This allows the criteria to be treated according to their units of measure or scale. The detailed treatment is documented in Section A6.8 of Appendix 6.

There are two standard methods in PROMETHEE that address the *ranking* decision type, PROMETHEE I and II. PROMETHEE I constructs *partial pre-orders*, while PROMETHEE II constructs *complete pre-orders*.

PROMETHEE I's elicitation process results in partial pre-orders that are determined from the leaving and entering flows. The binary relations between pairs of alternatives is one of the three possibilities; preference, indifference or incomparable (see Section A6.8 of Appendix 6 for details). When the relation between a pair of alternatives is incomparable, it asserts that the leaving and entering flows information is inconsistent.

Decision Making Techniques to Support Context-aware B2B Collaboration

While this form of consistency check is useful, partial pre-orders leave the decision maker with the task of choosing among a few alternatives that are considered indifferent from one another. This becomes a *choice* decision type rather than a *ranking* decision type.

PROMETHEE II provides a complete pre-order that is determined from the calculated net flows. Alternatives with positive net flows relatively outrank the others based on all decision criteria, while those with negative net flows are relatively outranked. Using PROMETHEE II, all pairs of alternatives are considered comparable. The advantage of this assumption is that the constructed pre-order is usually complete, unless there are identical alternatives. However, this complete pre-order comes at the cost of being unable to detect inconsistency of information provided by the flows, unlike PROMETHEE I. This has been criticised as a major disadvantage of PROMETHEE II [107]. However, as this method provides a complete pre-order that suits the *ranking* decision type problem, it is short-listed as a potential MCDM technique for context-aware B2B collaboration.

5.4.3 Assessing the suitability of the Outranking techniques

For this assessment, only ELECTRE II, ELECTRE III and PROMETHEE II are compared. The other methods have been deemed to be unsuitable (e.g. PROMETHEE I does not provide a complete ranking and ELECTRE I yields choices only). Table 5-2 summarises the results of the analysis using considerations (1) to (9) of the evaluation framework.

Table 5-2: Comparison of relevant Outranking methods using the evaluation framework

#	Consideration	ELECTRE II	ELECTRE III	PROMETHEE II
1	Criteria Type Support	Quantitative in general, see #9	Quantitative in general, see #9	Quantitative
2	Normalisation (Method and independence from criteria's	<ul style="list-style-type: none"> • No direct normalisation • Only weights are used 	<ul style="list-style-type: none"> • No direct normalisation • Only weights are used 	<ul style="list-style-type: none"> • Normalisation through mapping of performance values

Decision Making Techniques to Support Context-aware B2B Collaboration

#	Consideration	ELECTRE II	ELECTRE III	PROMETHEE II
	units of measure)	in preference elicitation, see #5	in preference elicitation, see #5	onto a scale, see #9
4	Data usage	Uses the performance values for alternatives pair-wise comparisons only, see #5	Uses the performance values for alternatives pair-wise comparisons only, see #5	Uses a common mapped scale for each criterion, see #9
5	Preference Elicitation	<ul style="list-style-type: none"> • Assigns criterion weight to alternative that has better performance value in pair-wise comparisons • Ranking is based on alternatives' aggregate scores satisfying concordance & non-discordance thresholds 	<ul style="list-style-type: none"> • Assigns criterion weight to alternative that has better performance value in a pair-wise comparisons • Ranking is based on alternatives' aggregate scores satisfying concordance & non-discordance thresholds • No commonly agreed method on the exact elicitation steps for credibility index 	<ul style="list-style-type: none"> • Assign value based on preference intensity function • Calculate aggregate score based on the net flow of each alternative • Ranking is based on aggregate score
9	Data scaling	<ul style="list-style-type: none"> • No, direct performance values used. • For automation purposes, quantitative values are needed. 	<ul style="list-style-type: none"> • No, direct performance values used. • For automation purposes, quantitative values are needed. 	Yes, uses a selected preference intensity function to map the performance values to a scale of between 0 and 1

The three candidate techniques are similar in terms of consideration (3)(where weights must be pre-determined) and consideration (6)(where the highest ranked alternative is the most preferred alternative). They are also similar in terms of the level of interaction, consideration (7), in which the threshold values must always be pre-determined by the decision maker. The only exception is when the Gaussian mapping function is selected in PROMETHEE II, then no threshold values are needed. This is a major advantage. Under consideration (8), the assumptions needed are also similar; availability of performance values of each criterion in all alternatives and the threshold values needed must be pre-determined. These considerations (3,6,7 and 8) are omitted from the table.

ELECTRE II and ELECTRE III share a common set of preference elicitation steps, whereas ELECTRE III has additional steps in calculating the credibility index. This also gives rise to

Decision Making Techniques to Support Context-aware B2B Collaboration

additional thresholds and assumptions that can significantly influence the outcome of the decision making process. Furthermore, ELECTRE III does not have a commonly agreed elicitation process for the computation of the credibility index. As such, although ELECTRE III is expected to be able to provide complete rankings through the adoption of pseudo-criteria in its elicitation process, it is dropped from further consideration.

PROMETHEE II's strength lies in the relatively simple elicitation process. In addition, the mapping of performance values to a scale of [0, 1], combined with the use of Gaussian preference intensity mapping function (see Table A6-2 of Section A6.8) eliminates the need to identify thresholds, which are arbitrary and lack scientific basis. The standard deviation required in the Gaussian function can be determined statistically in an automatic manner [105]. Therefore, ELECTRE II and PROMETHEE II are chosen for further investigations. They will be evaluated empirically for their **Quality of Solutions**, using considerations (10) to (13). These will be discussed in Chapter 6.

5.5 Proposed MCDM Approach

From the assessment of the MAUT and Outranking methods, Deviation Measure, ELECTRE II and PROMETHEE II are chosen for further empirical analysis using considerations (10) to (13) of the proposed evaluation framework. However, all three methods do not fully satisfy the following three considerations of context-aware B2B collaboration:

- *Weights determination* – all the methods are unable to determine their own weights. Deviation Measure circumvents this by adopting the pair-wise comparison method from AHP for its weight determination. Therefore, a common method to determine weights for the different MCDM techniques short-listed must be defined.

Decision Making Techniques to Support Context-aware B2B Collaboration

- *Criteria type support* – all three methods support only quantitative values. As the *B2B Context Model* has qualitative and nominal data types, other adaptations must be designed.
- *Normalisation of criteria data* – Deviation Measure uses a linear method, PROMETHEE II uses a preference intensity function, whereas the ELECTRE methods do not need to normalise criteria data. The soundness of these normalisation methods needs to be established.

This section addresses these issues.

5.5.1 Weights Determination

The assignment of weights which measure the relative importance of each criterion is a crucial step in the selected MCDM techniques (namely ELECTRE II, PROMETHEE II and Deviation Measure). Many methods have been proposed to ascertain the weights used in MCDM techniques, including Direct Weighting, Mousseau System, 'Pack of Cards' and 'Resistance to Change' Grid [82]. The end result of these methods is a set of normalised weights to elicit preferences. A study of five different weighting methods [108] revealed that the weights obtained by disparate weighting methods are essentially the same. These researchers went on to conclude that a method can be chosen based on personal preferences. AHP was one of the methods investigated in this research.

In this research, the AHP method and Saaty scale (1 to 9) was chosen as the common weighting method for all the MCDM techniques. One of the main reasons for this choice is that the Saaty scale provides an intuitive yet easy to understand way for users (or requestors) to perform pair-wise comparisons, without the need to consider too many criteria at any one time. One of the major short-comings of AHP is the inconsistency that could potentially arise out of such pair-wise comparisons [101], best illustrated through the following example:

$$N_s(c_1, c_2) = 9 \text{ and } N_s(c_1, c_3) = 7$$

where N_s = Saaty number and c_i = criterion under consideration

Thus $N_s(c_2, c_3) \leq (9-7)$ for the criteria weighting to be consistent.

If a user or requestor provides any number greater than 2 for $N_s(c_2, c_3)$, then an inconsistency in the weighting of the criteria is said to exist. This can be addressed during implementation by using similar constraints. This is handled in the prototype implementation of Cognitive Advisor, see Section 6.2 in Chapter 6.

5.5.2 Fuzzification of Qualitative Criteria

In the *B2B Context Model*, there are qualitative criteria (e.g. *OrganisationalProfile::Current::Ease_of_Doing_Business*). These criteria are different from the quantitative criteria, which have performance values that can be used directly by the various MCDM techniques. A separate algorithm, based on Fuzzy Set Theory [109], is therefore needed to determine the crisp values representing the qualitative criteria that can be used in the elicitation process of the MCDM techniques.

Figure 5-3: Triangular interval of Type-2 Membership Function

A *fuzzy set* is a set without a crisp boundary, where the transition of “belong to a set” to “not belong to a set” is gradual. This gradual transition is characterized by *membership functions* by which fuzzy sets can flexibly model commonly used linguistic expressions. *Fuzzy logic*, based on fuzzy set theory, emulates the ability to reason and use approximate data to find solutions. In fuzzy logic, there are two types of fuzzy sets;

type-1 and type-2. In type-1, the membership spaces are assumed to be operating in the space of real numbers, leading to membership functions of *crisp values*. In type-2 fuzzy sets, the starting point is a type-1 membership function, and then generalised to handle uncertainty that may exist in the definition of the membership function. This generalization is also known as “blurring”, and is referred to as the Footprint of Uncertainty (FOU), bounded by upper and lower membership functions. An illustration on both types of membership function is shown in Figure 5-3 [110]. The FOU provides an additional mathematical dimension, to represent the uncertainties in the shape and position of type-1 fuzzy sets. For the fuzzification of the qualitative criteria, only type-1 is considered as uncertainty in data accuracy and impreciseness is not within the scope of this research.

5.5.2.1 Membership Functions Design

In fuzzy logic, the membership function represents the *degree-of-truth* of a statement such as “The turnover of a company is high”. A membership function can have many forms such as triangular, trapezoidal and Gaussian. In this work, after some initial experimentation, the basic trapezoidal form was found to be the most suitable to model qualitative criteria. From the *B2B Context Model*, 10 criteria were identified to be of ordinal type. 9 of them are under the *OrganisationalProfile* hierarchy, namely:

- *Current::Ease_of_Doing_Business*
- *Current::Quality_Certification*
- *Current::Financial_Rating*
- *Current::Turnover*
- *Current::Years_of_Operation*
- *History::Quality*
- *History::TrackRecord::On-Time_Delivery*
- *History::TrackRecord::Profitability*
- *History::TrackRecord::Past_Turnover*

Decision Making Techniques to Support Context-aware B2B Collaboration

The *Current::Years_of_Operation* criterion is modeled as fuzzy though its values are quantitative in nature because requestors do not typically explicitly state the preferred value. For example, instead of indicating 10 or 13 years, values like short, medium or long will be used instead. The 10th criterion belongs to the *ProductService* hierarchy, namely *Payment::PaymentTerm*.

The membership functions for each criterion are designed to cater for either 3 or 5 categories, as most qualitative values are typically stated in such categories. For example, the membership functions for *On-Time Delivery* (Very Low, Low, Average, High and Very High) are shown in Figure 5-4. The x-axis shows the percentage of on-time delivery by a company. As a high percentage of on-time delivery is expected of any partner of choice, the membership function has been designed to reflect this. The peak of Very High was designed at 100% so that a partner will only score a degree-of-truth value of 1.0 at this point. The peaks of the other membership functions are then spaced out across the entire x-axis, as shown in Figure 5-4. A similar 3-category membership functions for *Quality_Certification* is shown in Figure 5-5. The details on the design of the fuzzy models for other selected qualitative criteria are documented in Appendix 7.

*: The vertical line is used to show the mapped fuzzy conditions in the example used in Section 5.5.2.2

Figure 5-4: Fuzzy Model of *On-Time_Delivery*

Decision Making Techniques to Support Context-aware B2B Collaboration

Figure 5-5: Fuzzy Model of *Quality_Certification*

5.5.2.2 Fuzzy Processing using a Fuzzy Controller

Using the Fuzzy Controller that is based on the Mamdani concept [111], the stages involved in handling fuzzy criteria can be decomposed into [112]:

- (1) **Input Stage** - Mapping of performance values of each criterion to appropriate membership functions (based on pre-designed membership models)

Using the example of a *On-Time_Delivery* of 95% and the fuzzy model in Figure 5-4, the related fuzzy conditions are $(On-Time_Delivery = High)_{0.25}$ and $(On-Time_Delivery = Very High)_{0.75}$. 0.25 and 0.75 represent the membership values or *degree-of-truth* for each of the linguistic statement. In order to automatically generate fuzzy rules, a *rank value* is defined in this research. *Rank value* is a real number between a 0 and 1 that is assigned to a linguistic value like high, average or low. The rank values for 3- or 5-category models are shown in Table 5-3.

Table 5-3: Rank values used

Linguistic Value	Rank Values	
	5-category	3-category
Very High	1.0	1.0
High	0.8	-
Average	0.6	0.6
Low	0.4	0.3
Very Low	0.2	-

Decision Making Techniques to Support Context-aware B2B Collaboration

(2) **Processing Stage** - Invocation of relevant fuzzy rules and generating the result for each rule, including aggregating the results into a single output

A fuzzy rule typically has the form of **IF-THEN** statements, where the IF part is the *antecedent* and the THEN part is the *consequent*. *Antecedents* are combined using fuzzy operators (similar to Boolean operators) such as AND, OR and NOT. The AND operator usually uses the minimum weight of all operators, while OR uses the maximum weight. The NOT operator results in a complementary function to the *antecedents*. For the qualitative criteria, the *consequent* of the rules (the THEN part) is aggregated into a single outcome (or output) known as *Business_Profile* (see Figure 5-6).

Figure 5-6: Fuzzy Model of *Business_Profile*

Figure 5-7: Fuzzy Model of *Quality*

Decision Making Techniques to Support Context-aware B2B Collaboration

Instead of pre-defining the fuzzy rules, an algorithm to automatically generate the relevant fuzzy rules was designed. The algorithm is based on the following steps:

- Determine the *rank value*, RV_i of each input fuzzy condition arising out of i th-criterion, using Table 5-3
- Calculate the *average rank value* from all the fuzzy input criteria for each possible combination, $\overline{RV}_n$ for the n th-combination. n represents the number of possible combinations from the individual input fuzzy criteria under consideration. For example, if there are two input criteria, then $n = 4$.
- Determine the outcome, LV_n of all the input conditions (*consequent* portion of each rule), based on the following:
 - If $\overline{RV}_n > 0.83$ then $LV_n = \text{Very High}$
 - If $\overline{RV}_n < 0.83$ and $\overline{RV}_n > 0.65$ then $LV_n = \text{High}$
 - If $\overline{RV}_n < 0.65$ and $\overline{RV}_n > 0.50$ then $LV_n = \text{Average}$
 - If $\overline{RV}_n < 0.50$ and $\overline{RV}_n > 0.30$ then $LV_n = \text{Low}$
 - If $\overline{RV}_n < 0.30$ then $LV_n = \text{Very Low}$

In other words, these are the conditions for generating the rules. Using an example of the two fuzzy criteria *On-Time_Delivery* (input value 95%, refer to Figure 5-4) and *Quality* (input value 0.12%, refer to Figure 5-7, the following fuzzy conditions apply:

- $(\text{On-Time_Delivery} = \text{High})_{0.25}$ and $(\text{On-Time_Delivery} = \text{Very High})_{0.75}$
- $(\text{Quality} = \text{High})_{0.10}$ and $(\text{Quality} = \text{Very High})_{0.40}$

The 4 possible combinations, and their respective LV_n are:

- (i) $(\text{On-Time_Delivery} = \text{High})_{0.25}$ and $(\text{Quality} = \text{High})_{0.10}$,
then $\overline{RV}_1 = \frac{0.8+0.8}{2} = 0.8$, resulting in $LV_1 = \text{High}$
- (ii) $(\text{On-Time_Delivery} = \text{High})_{0.25}$ and $(\text{Quality} = \text{Very High})_{0.40}$,
then $\overline{RV}_2 = \frac{0.8+1.0}{2} = 0.9$, resulting in $LV_2 = \text{Very High}$
- (iii) $(\text{On-Time_Delivery} = \text{Very High})_{0.75}$ and $(\text{Quality} = \text{High})_{0.10}$,

Decision Making Techniques to Support Context-aware B2B Collaboration

then $\overline{RV}_3 = \frac{1.0+0.8}{2} = 0.9$, resulting in $LV_3 = \text{Very High}$

(iv) $(\text{On-Time_Delivery} = \text{Very High})_{0.75}$ and $(\text{Quality} = \text{Very High})_{0.40}$,

then $\overline{RV}_4 = \frac{1.0+1.0}{2} = 1.0$, resulting in $LV_4 = \text{Very High}$

(3) **Output Stage (De-fuzzification)** - Conversion of the output into a specific control output value (crisp value).

Here the centroid method of de-fuzzification is adopted. In determining the areas to calculate a centroid, the typical treatment of AND or OR operators is adopted to determine the relevant membership values. Using the same example:

(i) For $LV_1 = \text{High}$, membership value, $mv_1 = \min(0.25, 0.10) = 0.10$

(ii) For $LV_2 = \text{Very High}$, membership value, $mv_2 = \min(0.25, 0.40) = 0.25$

(iii) For $LV_3 = \text{Very High}$, membership value, $mv_3 = \min(0.75, 0.10) = 0.10$

(iv) For $LV_4 = \text{Very High}$, membership value, $mv_4 = \min(0.75, 0.40) = 0.40$

Using the centroid calculation method for de-fuzzification, $C = \frac{\int x f(x) dx}{\int f(x) dx}$, the crisp value obtained for the example shown is 85.26, as illustrated in Figure 5-8.

Figure 5-8: Calculation of crisp value based on the *Business Profile* fuzzy model

This sub-section detailed the fuzzy approach for supporting qualitative criteria in the *B2B Context Model*. The output value(s) obtained can be used as inputs into any MCDM technique, treating such inputs as quantitative in nature. The implementation and role

of this fuzzification process in the overall flow of the prototype, Cognitive Advisor, is discussed further in Chapter 6 under Section 6.2.

5.5.3 Processing Nominal Criteria

The short-listed MCDM Techniques also cannot process nominal data directly. An example of this nominal data is *ProductService::ProductIdentifier::GTIN*. As discussed in section 5.1.2, an alternative is assigned a full score if there is a complete match; zero otherwise. Such a characteristic has a filtering effect and should not be included in the preference elicitation. One possible approach is to filter off alternatives that do not match a given criterion of nominal nature. For example, in the case of *ProductService::ProductIdentifier::GTIN*, if a product does not meet the *GTIN* number specification, it is basically not suitable. As such, any alternative that does not meet such a criterion should not be considered. Such a filtering mechanism can be enforced implementation wise. It does not require any specialized treatment within the MCDM considerations. The implementation is further discussed in Section 6.2 of Chapter 6.

5.5.4 Soundness of the Normalisation Methods Adopted

Typically, quantitative criteria have different units of measure and operate over a range of scales. Consider *price*, *Lead-time* and *production capacity* for example. Each of them has a totally different unit of measure. These different measures must be normalised, before weights can be assigned, otherwise the influence of each criterion is distorted thereby affecting the robustness and correctness of the decision.

Most methods normalise the criteria values into a range, some onto a pre-defined common range, such as the PROMETHEE methods. If the exact range of values in a criterion's scale is known, ideal range normalisation can be carried out, and the problem becomes trivial. For example, suppose there are three criteria g_1 , g_2 , and g_3 of ascending preference, with ranges $[0, 100]$, $[0.04, 0.18]$, and $[2000, 5000]$ respectively. These

Decision Making Techniques to Support Context-aware B2B Collaboration

disparate ranges can be normalised into $[0, 1]$, a commonly used scale, using a linear function such as:

$$\text{norm}(g_i) = \alpha(g_i + \beta)$$

where

$$\alpha = \frac{1}{\max_i g_i - \min_i g_i}$$

$$\beta = -(\min_i g_i)$$

$\max g_i$ and $\min g_i$ are the upper and lower bounds of the scale of g_i , respectively. The normalising functions for g_1 , g_2 , and g_3 are thus $0.01g_1$, $7.143(g_2 - 0.04)$ and $0.00033(g_3 - 2000)$ for the examples.

However, in real life, these upper and lower bound ranges are seldom known. Consider the three criteria of *price*, *Lead-time* and *production capacity* used earlier. There is no practical upper bound for these criteria, although their lower bounds can be assumed to be zero. The subsequent sections deal with the normalisation issue arising from this consideration.

5.5.4.1 Normalisation in PROMETHEE methods

A particularly well-accepted preference intensity function in PROMETHEE is the Gaussian preference function [113]. This preference intensity function is a range normalisation method in the form of:

$$P_i(a, b) = \begin{cases} 0 & , g_i(a) - g_i(b) \leq 0 \\ 1 - e^{-\frac{d^2}{2\sigma^2}} & , g_i(a) - g_i(b) > 0 \end{cases}$$

This method is illustrated in the last figure of Table A6-2 of Appendix 6. The only parameter required by this function, namely the standard deviation for the Gaussian curve (σ), can be statistically determined from the performance data of the alternatives [105]. The parameters are objectively determined, unlike in ELECTRE III where the threshold values are arbitrarily determined.

5.5.4.2 Normalisation in Deviation Measure

The Deviation Measure is by itself a normalisation method in the form of:

$$p_i(a_j) = \left(\frac{g_i(a_j) - g_i^*}{g_i^*} \right)$$

where g_i^* denotes the preferred value associated with a criterion g_i ; the higher the value the better. This normalisation method does not have a consistent range. With a constant g_i^* and an unbounded $g_i(a_j)$, $p_i(a_j)$ can take any value. Practically, this method does not normalise the performance values into any range, making the criterion weights ineffective for $g_i(a)$ values that are beyond the assumed range of $0 \leq g_j(a_i) \leq 2g_i^*$ for all i -criterion and j -alternative. If this assumption is true, then $p_i(a_j)$ can be correctly normalised to $[-1, 1]$. However, as this is not always the case, the simplest correction is to redefine $p_i(a_j)$ as:

$$p_i(a_j) = \begin{cases} -1, & g_i(a) < 0 \\ 1, & g_i(a) > 2g_i^* \\ \frac{g_i(a) - g_i^*}{g_i^*}, & \text{otherwise} \end{cases}$$

By so doing, the Deviation Measure is rendered a valid normalisation technique with the $[-1, 1]$ range. However, it relies on arbitrarily specified *preferred values*, and based on several initial empirical tests, the constructed pre-order was found to be pre-disposed to non-negligible rank reversal if these *preferred values* are changed. Another issue is the usage of *preferred values* to represent the range of values. As mentioned earlier, the range of values is assumed to be $[0, 2g_i^*]$ with everything else being outliers. This is not always a good assumption. For instance, if a requestor who does not fully understand the mechanics of the method naively asks for a very low preferred price of \$1, then any candidate with price >\$2 is assigned the lowest possible score of -1. If the real market price range is between \$5 and \$20, the difference of prices cannot be captured by this range normalisation method. Ironically, the original proposed Deviation Measure method is able to capture such differences. However, as discussed, it is not a good normalisation method. The next sub-section proposes a normalisation method that addresses this issue.

5.5.4.3 Proposed modification to the Deviation Measure

Although the use of *preferred values* as normalisation constants has major drawbacks, these values can nonetheless ascertain if an alternative is better or worse than expected. In light of this, a statistical method is proposed to improve the current normalisation method of the original Deviation Measure.

According to Chauvenet's criterion [114], a sample is an outlier if its value is not within the Gaussian distribution: that is, its statistical value (probability multiplied by sample count) is less than 0.5. Based on this criterion, the range of a cardinal (quantitative) scale can be estimated as follows:

- (1) Calculate the mean, $\bar{g}$ and the population standard deviation, s of the available performance values.
- (2) Using the three sigma rule of Gaussian distribution, find the closest region to the mean with statistical value < 0.5 . The statistical value is calculated by multiplying the sample count with the probability associated with the four regions separated by s , which are pre-computed as 0.341, 0.136, 0.021, and 0.001 respectively [93]. If the statistical value is still ≥ 0.5 in the 4th region, assume that the selected region is region 5.
- (3) For the n th region identified in Step (2), the upper bound of the range can be calculated as $\bar{g} + (n - 1)s$, and the lower bound as $\bar{g} - (n - 1)s$. Thus, the breadth of the range is $2(n - 1)s$.

To illustrate this method, consider a quantitative criterion for which the performance values of 40 alternatives are known. The mean is $\bar{g}=1000$, and the population standard deviation is $s=200$. With 40 samples, the statistic values of the four regions are 13.64, 5.44, 0.84, and 0.04 respectively. So, the nearest region with statistic value < 0.5 is the 4th region. The range can therefore be calculated as $2 \times 3 \times 200 = 1200$, with an upper bound of 1600 and a lower bound of 400.

Decision Making Techniques to Support Context-aware B2B Collaboration

Thus, the normalised performance value, $p_i(a_j)$ calculated in Step (2) of Deviation Measure can be modified accordingly.

For a criterion where the objective is to maximise the value,

$$p_i(a_j) = \begin{cases} -1, & g_i(a) < \min_i g_i \\ 1, & g_i(a) > \max_i g_i \\ \frac{g_i(a) - g_i^*}{\max_i g_i - \min_i g_i}, & \text{otherwise} \end{cases}$$

where

$\min_i g_i$ = statistical lower bound

$\max_i g_i$ = statistical upper bound, and

g_i^* = specified preferred value

This range is calculated automatically from the pool of available or considered alternatives.

For a criterion where the objective is to minimise the value,

$$p_i(a_j) = \begin{cases} -1, & g_i(a) > \max_i g_i \\ 1, & g_i(a) < \min_i g_i \\ \frac{g_i^* - g_i(a)}{\max_i g_i - \min_i g_i}, & \text{otherwise} \end{cases}$$

This modified range normalisation method has two favourable implications. First, the outlier thresholds and range are estimated using a statistically model that is sound. Second, the *preferred values* are still used to measure the deviation of each alternative's performance from expectations. Hence, it is still possible to see which alternatives generally exceed expectations, and which ones are not as good as expected. This maintains the original intent of the technique.

However, with the use of the alternatives' performance values to determine the statistical lower and upper bounds, it is expected that the inclusion or exclusion of

alternatives will have an effect on the quality of solutions, in particular the rank correlation and rank reversal metrics. This needs further empirical investigation. Both the Deviation Measure (Original) and this newly proposed modification, Deviation Measure (Modified) will be further investigated in Chapter 6.

5.6 Chapter Summary

The main purpose of this chapter is to identify MCDM techniques that can be applied to support context-aware B2B collaboration. Towards this end, an evaluation framework is designed. This framework encompasses three categories of considerations; **Model Formulation**, **Automation Practicality** and **Quality of Solution**, with 13 considerations altogether. The first two categories' considerations are used to assess the short-listed MCDM techniques in this chapter whilst the third category needs empirical analysis.

This framework was used to evaluate two main classes of MCDM techniques; Multi-Attribute Utility Theory (MAUT) and Outranking. Three MAUT techniques were reviewed and analysed, namely AHP, VIKOR and TOPSIS. Based on the first two categories' considerations, none of these three MAUT techniques was deemed suitable. These three techniques either require too much user interaction (such as in AHP) that renders automation impractical or make use of assumptions that are not possible in context-aware B2B collaboration (such the need to identify ideal solutions in TOPSIS and VIKOR). To address the limitations of these MAUT techniques, a new *Deviation Measure* technique, specially tailored for context-aware B2B collaboration, is proposed. For the Outranking methods, the ELECTRE and PROMETHEE family of methods were reviewed and analysed. Based on the evaluation framework's first two categories of considerations, ELECTRE II and PROMETHEE II were found to be potential candidate Outranking methods to support context-aware B2B collaboration.

Decision Making Techniques to Support Context-aware B2B Collaboration

However, all three techniques identified (including Deviation Measure) have limitations that need further considerations and adaptation. In the proposed MCDM approach for this research, the following are adopted:

- Weights are to be ascertained by the AHP pair-wise comparison,
- Qualitative values will be fuzzified into crisp (quantitative) values that can be used directly and automatically by the techniques,
- Implementing a filtering mechanism to address nominal criteria in the *B2B Context Model*, and
- To ensure the normalisation of criteria is sound, the Deviation Measure-Original was modified into a Deviation Measure-Modified

Moving forward, the four techniques; Deviation Measure-Original, Deviation Measure-Modified, ELECTRE II and PROMETHEE II will be implemented into a Cognitive Advisor prototype. This will enable empirical analysis of the third category for the evaluation framework, **Quality of Solution**.

6 Realisation of Context-aware Hybrid Decision Making Approach

An evaluation framework was proposed in Chapter 5 to assess the suitability of candidate MCDM techniques. This chapter continues the assessment, using the four metrics defined in the **Quality of Solution** category. The empirical assessment to determine the most suitable MCDM technique is done using a case study based on real industry data. The viability of the hybrid approach, specifically the fuzzification process was also tested. To support the tests, a prototype implementation of the hybrid approach was developed, called Cognitive Advisor. This prototype provides the platform to conduct all the tests discussed. Finally, an industry study was conducted, to compare the results obtained by current industry practices versus using this context-aware approach.

6.1 Overview

This chapter discusses the implementation and evaluation of the four short-listed MCDM techniques, namely Deviation Measure-Original (DMO), Deviation Measure-Modified (DMM), ELECTRE II and PROMETHEE II. The objectives are:

- (1) To empirically ascertain the most suitable MCDM technique based on the considerations from the third category of the evaluation framework proposed in Chapter 5; **Quality of Solution**, and
- (2) To establish the viability of the fuzzy implementation for the qualitative criteria.

In order to carry out the empirical assessment, a particular application or usage of the *B2B Context Model* and the MCDM techniques needs to be identified. For the purpose of this investigation, the target application is partner evaluation and selection, as it is a key step towards dynamic B2B collaboration (as discussed in Chapter 1). Furthermore, the relevant data for the experiments are readily available. Hence, though the previous chapters discussed the *B2B Context Model* and MCDM techniques for B2B collaboration in general, the investigations in this chapter are specific to partner evaluation and selection. In essence, it can be treated as a specific example of how this research can be realised and applied. Each of the objectives discussed above would be based on a case study, discussed in section 6.3.

To conclude this chapter, the results from an industry survey are discussed. The purpose of this survey was to seek out differences and/or similarities between this context-aware approach and the decision making approach in industry.

6.2 Prototype Implementation of Cognitive Advisor

The tests were conducted on a prototype implementation called *Cognitive Advisor*. This section will briefly discuss the architecture and usage flow of this prototype. As mentioned in Chapter 4, the *B2B Context Model* was implemented using XML Schema for performance and scalability reasons.

6.2.1 Architecture

The *Cognitive Advisor* is implemented as a web-based application using Java. Figure 6-1 shows a high-level system architecture of the implementation. It was developed based on a component concept with a layered architecture. It has a web-based graphical user interface (GUI) supported by Java Server Pages and servlets in the front-end, with back-end modules that are implemented as components. There are separate GUIs for the User and Administrator functionalities, to differentiate between administrative and typical usage functions. The backend components consist of the following modules:

- *Main Facade* – This provides a centralised access to the back-end modules from the front-end servlets.
- *Java Source Generator/Compiler* – This module generates Java source classes based on a loaded *B2B Context Model*, and compiles these classes. The compilation is done using Apache ANT.
- *Instance Binder* – The Java classes generated are used to instantiate in-memory *B2BContext* Instances. The binding of values to these created instances are done by this module.
- *Filtering* – This module implements the filtering for nominal criteria (discussed in Section 5.5.3). The candidate providers are filtered to eradicate unsuitable candidates. This filtering makes use of the JBoss Rule Engine version 4.0.1, with rules codified using the rule engine's native language. The rules are based on the business rules in Table A4-3 of Appendix 4.

Realisation of Context-aware Hybrid Decision Making Approach

- *Ranking Module* – This module ranks the candidate partners (providers) based on a chosen ranking method. The implemented ranking algorithms are DMO, DMM, PROMETHEE II and ELECTRE II.
- *Data Objects* – Information that is exchanged between the different components are handled by JavaBeans defined in this module.
- *Fuzzy Controller* – This module uses the fuzzy membership functions to compute a quantitative value that can be used by the ranking methods for qualitative criteria. It implements the process described in Section 5.5.2.
- *Data Handler* – This is the interface that manages the information exchanges between the external components (e.g. MySQL database) and the *Cognitive Advisor*.

Figure 6-1: High-level architecture of Cognitive Advisor

The layer segregation and componentisation allow each module to be implemented independently, and allow for easy replacement or additions to the system. This is especially important as the *Cognitive Advisor* is a prototype implementation that is expected to handle different representations and decision making techniques. The prototype was deployed on a Tomcat 6 server for the tests discussed in this thesis.

Realisation of Context-aware Hybrid Decision Making Approach

6.2.2 Usage Flow

Figure 6-2 shows two phases of usage flow: the configuration and runtime phases. The configuration (and loading) phase is only executed when a new *B2B Context Model* needs to be loaded, whereas the runtime phase is executed for every request made.

Figure 6-2: Usage flow of Cognitive Advisor

During configuration, a *B2B Context Model* schema is loaded using the Administrator GUI, where a criteria list is generated. The user picks the relevant criteria from this list when initiating a request. At this time, the business rules that govern the model are also loaded into the Rules Database that filters candidates during a runtime request. The Profile Repository contains the candidates' information, stored as Partners B2BContext Instances, which is typically uploaded during configuration too.

A request is initiated after the selection criteria have been selected via the User GUI and the associated requestor profile uploaded. This requestor profile is instantiated as the Requestor B2BContext Instance, and is termed the *preferred* profile, against which

Realisation of Context-aware Hybrid Decision Making Approach

all other profiles are compared. It is used to match against a pool of pre-qualified providers (candidate partners), represented as Partners B2BContext Instances.

The selection criteria are then weighted using the AHP pair-wise comparison technique. The consistency check in using Saaty scale (discussed in Section 5.5.1) is built into this step. Thereafter, the system filters off incompatible candidates (B2BContext instances) using pre-defined business rules that has been loaded in the JBoss Rule Engine and activates the fuzzy controller for qualitative criteria. Finally, the short-listed candidates are ranked using the chosen ranking method.

6.3 Multi-criteria Partner Evaluation and Selection – A Case Study

6.3.1 Motivating Scenario

QuickLite Manufacturer is a Singapore based OEM (Original Equipment Manufacturing) company manufacturing other companies' labels. They make a wide range of electronic products, ranging from memory cards to MP3 players. As in any typical manufacturing company in Singapore, most of the actual manufacturing activities are done elsewhere in the region. In QuickLite's case, they have manufacturing plants in Malaysia and China. They also have a series of outsourced partners in the region, including partners in Thailand, Taiwan, China, Malaysia and Indonesia. Their customers are typically MNCs whose own end-customers are in usually in North America or Europe.

There are two common types of purchase orders (POs); standalone and blanket [115]. A standalone PO is where a customer is only invoiced (or billed) when all the items in the PO have been delivered to the customer. In blanket POs, a customer is invoiced for each delivery. It is typically used when multiple purchases (with deliveries) and payments are anticipated.

Realisation of Context-aware Hybrid Decision Making Approach

QuickLite has just received a blanket PO from one of its MNC customers, 5Kell, that is valid for the next 12 months. 5Kell is an international MNC that has an Operational Headquarters (OHQ) in Singapore. The office here coordinates the supply chain activities for its parent office in the United States. This blanket PO's applicable product range, prices and guaranteed minimum and/or maximum are as shown in Table 6-1.

Table 6-1: 5Kell's Blanket PO Scope of Product and Pricing

Category	Model	Quantity (week)*		Price (USD)**	
		Minimum	Maximum	Guaranteed	Alternate
MP3 Player	MP-8GB	200	-	40.00	38.00
	MP-16GB	100	1000	50.00	45.00
	MP-32GB	-	500	60.00	N.A.
	MP-64GB	-	300	80.00	N.A.
Digital Photo Frames	DP-3R	1000	-	50.00	48.00
	DP-4R	2000	-	70.00	65.00
	DP-8R	500	-	150.00	130.00
Memory Cards	MC-8GB	1000	-	10.00	8.00
	MC-16GB	1000	-	15.00	14.00
	MC-32GB	-	-	20.00	N.A.
	MC-64GB	-	-	30.00	N.A.
	MC-132GB	-	-	50.00	N.A.

* Indicates the minimum and/or maximum quantity expected from 5Kell each week. A '-' indicates no specification in the PO.

** Indicates the chargeable price. A "Guaranteed" price is applicable if 5Kell orders above the minimum quantity, whereas the "Alternate" price is applicable if 5Kell orders below the minimum quantity. A 'N.A.' means not applicable.

As part of this PO, QuickLite has also received a forecast of expected deliveries for the coming months from 5Kell:

- QuickLite to deliver 1,000 units of MP3 players (model MP-16GB) each week for the next 8 weeks to 5Kell's office in New York, USA. This is to start immediately.

Realisation of Context-aware Hybrid Decision Making Approach

- QuickLite to deliver 5,500 units of digital photo frames (3,000 units of model DP-3R, 2,000 units of model DP-4R and 500 units of model DP-8R) each week to San Diego, USA for 3 weeks, starting in 3 weeks time.
- QuickLite to deliver 1,000 units of 32 GB memory cards (model MC-32GB) and 500 units of 64 GB memory cards (MC-64GB) each week for 4 weeks, starting in 2 weeks time, to Sydney, Australia.

6.3.2 Evaluation Considerations and Options Available

After looking at its capacity and current confirmed orders, QuickLite summed up its business situation as follows:

- (S1) It can fulfill the forecast for MP-16GB. However, it needs to order the necessary memory cards for the MP3 units (**1000 units of MC-16GB**) from a suitable supplier. It has the option of assembling the MP-16GB in Singapore or in Shah Alam, Malaysia.
- (S2) It cannot fulfill the forecast for the digital photo frames, in particular **3000 units of DP-3R**. It needs to find a suitable partner (outsource). It is also considering direct delivery to San Diego, USA.
- (S3) It has the ability to fulfill the forecast for the MC-32GB memory cards in-house, but needs to outsource the forecasted **500 units of MC-64GB**. It is considering direct delivery to Sydney, Australia too.

These items are highlighted in bold in Table 6-1.

In its evaluation of potential partners, QuickLite has many considerations. If a partner has no prior history (or is unknown to QuickLite), then factors such as ability to deliver on-time, the capacity of the partner's production facility, quality infrastructure and also business risks associated with the potential partner are important. However, if a partner is already pre-qualified, these factors are no longer important. As QuickLite needs to quickly identify the most suitable partner(s) due to the urgency mandated by

Realisation of Context-aware Hybrid Decision Making Approach

the forecasted deliveries, it has decided that it will consider only pre-qualified partners from its Approved Manufacturers List. However, it would like to study the options available for each situation based on the following criteria preferences:

- Cost, lead-time and location (proximity of partner to delivery location)
- Cost, lead-time, location and payment (duration)
- Cost, lead-time, location and payment (payment penalty)
- Cost, lead-time, location and payment (overall)
- Cost, lead-time and production capacity (of partner)
- Cost, lead-time, overall payment and production capacity

These considerations are relevant to the evaluation of the suitability of the four short-listed MCDM techniques.

On the other hand, QuickLite would also like to assess the performance of its partners over the past years, not only based on the criteria listed earlier, but also using other criteria such as on-time delivery and quality performance for example. As these criteria include the qualitative type, the fuzzy implementation can also be tested. The details of the experimental setups are discussed next.

6.4 Suitability of Candidate MCDM techniques

6.4.1 Overall Experimental setup

QuickLite identified several scenarios for testing the different situations, (S1 to S3) discussed in section 6.3.2, to evaluate the viability of the options. For each of the situations, there is a need to consider the criteria and decision options of interest. For S1 and S3 there are four decision options whereas for S2 there are only two decision options. There are 6 criteria preferences for each of the situations discussed, as listed in section 6.3.2. This results in a hierarchical experimental setup, as illustrated in Figure 6-3. The details of the test sets, including the criteria adopted and the preferred values of QuickLite are documented in Section A8.1 to Section A8.3 of Appendix 8. Finally, each

Realisation of Context-aware Hybrid Decision Making Approach

test set is tested using the 6 different criteria weights. Depending on the number of criteria used in each set, the relevant weight ratios are used, as documented in Figure A8-1, Figure A8-1 and Figure A8-3 of Appendix 8. Altogether, this experimental setup will yield $(2*6*4*6 + 1*6*2*6=)$ 360 tests, providing enough test data to empirically ascertain the suitability of the techniques based on the 4 metrics defined under the **Quality of Solution** category; namely *rank completeness*, *rank correlation*, *rank reversal* and *sensitivity analysis*.

Figure 6-3: Hierarchical Structure of the Experimental Setup

The data set includes 20 candidate providers, each providing products that may meet some or all the requirements of QuickLite. Table A8-1 of Appendix 8 contains the providers' test data. For each of the metrics, additional test setups or test steps may be needed. For ease of understanding, this is discussed individually before the results are presented in the next section.

6.4.2 Rank Completeness

As discussed in Chapter 5, *rank completeness*, $\omega = n_u/n_t$

where n_u = number of unique ranks

n_t = total number of alternatives

For example, Table 6-2 shows a sample calculation from Set 1-3-4 (W4), where there are 11 suitable companies but only 10 unique ranks, yielding a $\omega = 10/11 = 0.909$ score. This shows that the ranking in this example is only 91% complete. For this measure, the following steps were undertaken:

- 360 tests were conducted for each of the four candidate techniques
- Calculate the *rank completeness* for each sequence (ranking result)

The tabulated rank completeness scores for all 4 candidate techniques are documented in Appendix 8 (Table A8-2 to TableA8-5).

- Calculate the mean and standard deviation from the individual scores, for each candidate technique

The values of each candidate technique are summarised in Table 6-3.

Table 6-2: Sample result from Set 1-3-4 (W4) used to calculate rank completeness for DMO

S/No.	Company	Score	Rank
1	ChingTsing	-0.026	1
2	M-Selangor	-0.049	2
3	MatSalleh	-0.049	2
4	CaiHan	-0.060	3
5	Mangellan	-0.144	4
6	Herote	-0.363	5
7	IndisarPuri	-0.419	6
8	ChenZu	-0.465	7
9	TechJohn	-0.526	8
10	Matreng	-0.873	9
11	ChenPo	-2.294	10
Rank Completeness =		10/11	0.909

Realisation of Context-aware Hybrid Decision Making Approach

From the values shown based on a sample size of 360, DMO, DMM and PROMETHEE II yield the best mean score for rank completeness (about 0.99) and have relative low deviations too (see Table 6-3). However, ELECTRE II had a mean score of only 0.60 and also a relatively much higher deviation. In short, ELECTRE II's ranking is about 60% complete whereas the other three methods' rankings are at least 99% complete. From this *rank completeness* perspective, ELECTRE II is definitely inferior when compared to the other three methods; DMO, DMM and PROMETHEE II.

Table 6-3: Summary of rank completeness scores for the 4 candidate techniques

Technique	Mean Score	Standard Deviation
Deviation Measure–Original (DMO)	0.997	0.016
Deviation Measure–Modified (DMM)	0.987	0.032
PROMETHEE II	0.995	0.021
ELECTRE II	0.604	0.122

6.4.3 Rank Correlation

As discussed in Chapter 5, *rank correlation* measures the stability of the solution based on the correlation between two sequences of ranking when new alternatives are added.

Pearson's rank correlation, ρ is adopted:

$$\rho = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}}$$

where x_i = position in original rank sequence X

y_i = position in new rank sequence Y'

n = number of alternatives in each sequence (same for both)

$Y' = Y \setminus X$

Y = complete rank sequence with new alternatives

To compute ρ , additional test steps are required. There is a need to add different candidate providers to measure the changes (if any) between two rankings caused by the addition.

Realisation of Context-aware Hybrid Decision Making Approach

For this test setup, only S2 and S3 test cases are used as they have more candidate providers offering the product that QuickLite is looking for. This will provide a total of $(6*4*6 + 6*2*6=)$ 216 test cases. For each of the test cases, the following test procedure was followed:

- (a) Test a particular test case using an initial list of 5 candidate providers (alternatives)
- (b) Add in another 3 candidate providers, and repeat the test
- (c) Add in the rest of relevant candidate providers, 5 for S2 and 4 for S3, and repeat the test

The candidate providers used in each test step for both situations are listed in Table 6-4 and Table 6-5 respectively.

Table 6-4: Summary of providers used in each test step - S2

Test Step \ No. of Providers	(a)	(b)	(c)
Initial 5 candidate providers	MatSalleh Indung TangZhang ChingTsing CaiHan	MatSalleh Indung TangZhang ChingTsing CaiHan	MatSalleh Indung TangZhang ChingTsing CaiHan
Add 3 more candidate providers	-	MakeShift ChenZu Matreng	MakeShift ChenZu Matreng
Add 5 more candidate providers	-	-	Hamind Tomoto TangTang Deltazer PerfectMake

After the tests were conducted, the *rank correlation* mean score and standard deviation for each test were computed based on the following:

- Obtain Y' for 5-alternatives of the ranking sequence obtained in Step (b) and Step (c)
 - Calculate the *rank correlation* score ρ between sequences from Step (a) and Step (b)
 - Calculate the *rank correlation* score ρ between sequences from Step (a) and Step (c)

Realisation of Context-aware Hybrid Decision Making Approach

- Obtain Y' for 8-alternatives of the ranking sequence obtained in Step (c)
 - Calculate the *rank correlation* score ρ between sequences from Step (b) and Step (c)

These will yield a sample size of $(216 \times 2 =) 512$ rank correlation scores for 5-alternatives comparison and 216 rank correlation scores for 8-alternatives comparison. Table 6-6 shows a sample calculation of the *rank correlation* score between sequences obtained from Step (a) and Step (b) of the test.

Table 6-5: Summary of providers used in each test step - S3

Test Step \ No. of Providers	(a)	(b)	(c)
Initial 5 candidate providers	MatSalleh IndisarPuri ChingTsing Matreng CaiHan	MatSalleh Indung TangZhang ChingTsing CaiHan	MatSalleh Indung TangZhang ChingTsing CaiHan
Add 3 more candidate providers	-	ChenZu Mangellan ChenPo	MakeShift ChenZu Matreng
Add 4 more candidate providers	-	-	M-Selangor Herote TechJohn DataCon

Table 6-6: Sample calculation for *rank correlation* score - using Set 2-1-2 (W1) data for DMM

Step (a)			Step (b)			Y' of Step (b)		
Candidate Company	Score	Rank X	Candidate Company	Score	Rank Y	Candidate Company	Score	Rank Y'
TangZhang	-0.403	1	MakeShift*	-0.326	1	TangZhang	-0.326	1
MatSalleh	-0.406	2	TangZhang	-0.326	2	MatSalleh	-0.329	2
Indung	-0.412	3	MatSalleh	-0.329	3	ChingTsing	-0.353	3
ChingTsing	-0.428	4	ChingTsing	-0.353	4	Indung	-0.353	3
CaiHan	-0.494	5	Indung	-0.353	4	CaiHan	-0.497	5
* Candidate companies added			CaiHan	-0.497	6			
			ChenZu*	-0.541	7			
			Matreng*	-0.697	8			
Rank correlation (between X and Y') = 0.959								

Realisation of Context-aware Hybrid Decision Making Approach

Table 6-7 summarises the *rank correlation* scores obtained. The *rank correlation* scores for DMO are all 1.000. As the 5-alternatives have shown that DMO is not prone to rank changes, no further analysis was conducted for 8-alternatives. This is expected, as the DMO technique ranking scores are not obtained from or dependent on the values of other candidate providers (alternatives). Thus, the addition of alternatives does not vary the scores of each candidate provider. The other three techniques are dependent on other alternatives in their ranking sequence (or score). Consequently, the *rank correlation* scores show that the addition of alternatives does affect the ranking sequence. The details of the tabulation can be found in Appendix 8. Table A8-6 to Table A8-8 detail the scores for DMM, Table A8-9 to Table A8-11 document the scores for PROMETHEE II and Table A8-12 to Table A8-14 for ELECTRE II. The DMO's individual scores are not documented, as all the rank correlation scores are all 1.000.

Table 6-7: Summary of rank correlation scores

Technique	5-alternatives				8-alternatives		Overall	
	Step (a)-Step (b)		Step (a)-Step (c)		Step (b)-Step (c)			
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
DMO	1.000	0.000	1.000	0.000	-	-	1.000	0.000
DMM	0.927	0.109	0.894	0.162	0.929	0.074	0.917	0.122
PROMETHEE II	0.936	0.118	0.896	0.162	0.918	0.093	0.917	0.129
ELECTRE II	0.880	0.144	0.860	0.163	0.915	0.091	0.885	0.138

Of the three techniques, the rank correlation scores of DMM and PROMETHEE II are very close for both 5-alternatives and 8-alternatives. Coincidentally, the overall mean score for both are the same, 0.917. The deviation of the scores for both techniques is also very close (0.122 for DMM versus 0.129 for PROMETHEE II). The overall mean score for ELECTRE II is 0.885. This indicates that ELECTRE II is more sensitive to the influence of other candidate providers (alternatives) as compared to DMM and PROMETHEE II, whereas DMO is completely immune. It is interesting to note that the *rank correlation* scores are much higher for 8-alternatives' sequences, and the lowest

Realisation of Context-aware Hybrid Decision Making Approach

for 5-alternatives when more alternatives are added. This is intuitive; when more candidate providers are added, the probability of them influencing the scores or sequence is naturally higher. This leads to more rank changes, resulting in a reduction in *rank correlation* scores. In summary, DMO is the best in terms of rank stability, followed by DMM and PROMETHEE II. ELECTRE II is the least stable.

6.4.4 Rank Reversal

Rank reversal assesses the stability of the solution based on the concept of similarity between two sequences. Instead of measuring the correlation, it measures the degree of disagreement caused by rank reversal, θ :

$$\theta = \frac{d_n}{d_{n-max}}$$

where d_n = absolute distance between two ranks using the Spearman's footrule distance

d_{n-max} = maximum distance between two rankings of n -length (calculated differently for sequence with and without tied ranks)

Table 6-8: Sample calculation for rank reversal score - using Set 2-1-2 (W1) data

Candidate Company	Score	Rank X	Candidate Company	Score	Step (b) - Rank Y'	Candidate Company	Score	Step (c) - Rank Y'
TangZhang	-0.139	1	TangZhang	-0.326	1	TangZhang	-0.403	1
MatSalleh	-0.142	2	MatSalleh	-0.329	2	MatSalleh	-0.406	2
ChingTsing	-0.167	3	ChingTsing	-0.353	3	ChingTsing	-0.428	4
Indung	-0.213	4	Indung	-0.353	3	Indung	-0.412	3
CaiHan	-0.497	5	CaiHan	-0.497	5	CaiHan	-0.494	5
θ between X and Y' of Step (b) = $2/14 = 0.071$ where $d_{n-max} = 14$ (as Y' has tied ranks*)								
θ between X and Y' of Step (c) = $2/12 = 0.167$ where $d_{n-max} = 12$ (both have no tied ranks*)								

* Please refer to Section A6.9 on how to determine d_{n-max}

The same test setup, procedure and Y' elicitation as in rank correlation score calculation are applicable to rank reversal. Table 6-8 shows a sample calculation of the individual θ values. As in the earlier test, there will be $(216 \times 2 = 512)$ rank reversal scores for 5-

Realisation of Context-aware Hybrid Decision Making Approach

alternatives and 216 rank correlation scores for 8-alternatives. These are documented in Appendix 8, from Table A8-15 to Table A8-23. The results from DMO are not documented, as the rank reversal scores are all 0.000 due to no change in the rank sequences (as in rank correlation).

The susceptibility of a candidate technique to *rank reversal* is indicated by the degree of disagreement ratios; the larger the ratio, the higher the susceptibility. Table 6-9 summarises these values. Like rank correlation calculations, the degree of disagreement is only calculated for 5-alternatives comparison, and stopped when it was confirmed that DMO is not susceptible to *rank reversal* due to addition of alternatives. The degree of disagreement results for the other three techniques correlate with those for rank correlation measure. Again, DMM and PROMETHEE II perform better, showing a lower susceptibility to *rank reversal* as compared to ELECTRE II.

Table 6-9: Summary of rank reversal (degree of disagreement) scores

	5-alternatives				8-alternatives		Overall	
	Step (a)-Step (b)		Step (a)-Step (c)		Step (b)-Step (c)			
Technique	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
DMO	0.000	0.000	0.000	0.000	-	-	0.000	0.000
DMM	0.103	0.120	0.119	0.151	0.121	0.085	0.115	0.122
PROMETHEE II	0.082	0.119	0.129	0.151	0.133	0.097	0.115	0.126
ELECTRE II	0.154	0.119	0.173	0.120	0.126	0.088	0.151	0.111

In summary, both the *rank correlation* and *rank reversal* measures have confirmed that DMO is immune to influences caused by the addition of alternatives. DMM and PROMETHEE II are influenced by the addition of alternatives, but not as much as ELECTRE II. Although DMM's range normalisation has a more sound foundation compared to DMO's (discussed in Section 5.5.4), it is susceptible to the addition of alternatives. This is largely due to the dependence on the alternatives' values when determining the normalised performance values of individual criterion in DMM.

6.4.5 Sensitivity Analyses

Three methods of sensitivity analyses can be performed on MCDM techniques [116]. The first two methods are used when uncertainties are present either in the data or how the individual criterion score is obtained. The third is based on the sensitivity of the weight for a given technique. This method provides an indication of the stability of the ranking when weights of the criteria of interest are changed. For this empirical study, only the weight-based sensitivity analysis is considered as the issues of uncertainties are not within the scope of this research. For this experimental setup, only 8 test cases employing the 3-criteria options from Situation (1) were chosen; Set1-1-1, Set1-1-2, Set1-1-3, Set1-1-4, Set1-5-1, Set1-5-2, Set1-5-3 and Set1-5-4. The 3-criteria test cases were chosen as they contain two of the most important criteria used in partner selection, *Cost* and *Lead-time* (as borne out by the industry survey discussed in Section 3.6). Also, it was easier to analyse the impact of changing weights with fewer criteria, as the analysis will be graph-based. Too many criteria unnecessarily complicate the analysis.

Figure 6-4: Weights for each criterion used for the sensitivity analysis tests

Realisation of Context-aware Hybrid Decision Making Approach

Figure 6-4 shows the 6 weight combinations used, where $\sum w_i = 1$ for each combination of weight w and i -th criterion. As can be seen, the weights are designed to be biased towards *Cost*, increasing through w_1 to w_6 . For tests in the Series 1-1, the criteria used are *Cost*, *Lead-time* and *Location*. For the tests in the Series 1-5, the criterion *Location* is replaced by *Capacity*. This is to investigate the impact of a criterion that has a large degree of variation between different candidate providers (alternatives). The results are documented in Appendix 8, Figure A8-4 to Figure A8-11, each representing one test case, compared across the four short-listed MCDM techniques.

From the graphs, the following observations and inferences can be drawn:

- From the test results for **Series 1-1**,
 - DMO seems the least affected by the different weights used. Changes in a candidate partner's ranking position are not severe and are only evident in some candidate partners (e.g. Herote and ChenZu). In ChenZu's case, after w_2 , its ranking position dropped significantly. Others like IndisarPuri hardly have any ranking positional change.
 - For DMM and PROMETHEE II, more changes in ranking positions can be observed, especially for the lower ranked candidate partners. The increase of the weight of the *Cost* criterion from w_1 to w_2 seems to cause many ranking positional changes amongst the candidate partners, across all test sets. This was not observed in DMO.
 - ELECTRE II is the most sensitive to weight changes, with significant ranking positional changes across the board, and as previously observed in the earlier measures' calculations, many tied ranks. Tied ranks indicate incomplete ranking.
 - For each test case, say Set1-1-1, it is also obvious that DMO is the least affected by the weight changes, in particular when the *Cost* criterion weight changes from very low (0.053 for w_1) to very high (0.818 for w_6).

Realisation of Context-aware Hybrid Decision Making Approach

- The rank positional changes throughout the test cases for DMM and PROMETHEE are very similar.
- There are no clear trends for ELECTRE II, except that the rank positions fluctuate significantly. For example, in Set1-1-1 MatSalleh changed from 1st position (W1) to 6th position (in W5). Similarly, in Set 1-1-3, MatSalleh again dropped from 1st position (in W1, W2) to 7th position (in W6). Both trends were not observed in the other three techniques.
- From the test results for **Series 1-5**,
 - Overall, the swapping of the *Location* criterion with the *Capacity* criterion caused all the techniques to be more sensitive to the weight changes from W1 to W6. This is expected, as the *Capacity* values from the candidate providers vary greatly; some of them can be considered as outlier values. For example, ChenZu drops from being 1st ranked to 11th ranked (last) when the weight for *Capacity* decreased. This is observed for all test cases across all techniques except for ELECTRE II. Again, ELECTRE II has no discernible pattern or trend, and the results from ELECTRE II do not correlate well with the other three techniques.
 - As with the earlier test cases, DMO is still the least insensitive to weight changes, despite showing a much higher degree of rank positional changes.
 - Again, DMM and PROMETHEE showed a close correlation in their rank positional changes.
 - ELECTRE II, as mentioned earlier, has erratic positional changes that are inexplicable and deviates greatly from the trends shown by the other three techniques.
 - As with the earlier Series 1-1 tests, W2 seems to be a significant weight combination, where many rank changes are observed. This is caused by the sudden drop in the weight for *Lead-time* and a proportional increase in *Location* for Series 1-1 tests and *Capacity* for Series 1-5 tests (see Figure 6-4). In this case the fluctuations for DMO are similar to those of DMM

Realisation of Context-aware Hybrid Decision Making Approach

and PROMETHEE. This can be explained by the high variations in *Capacity* values across the candidate providers.

In summary, DMO is the least sensitive to weight changes, but if the variations in the candidate providers' values are significant (as in Series 1-5 test cases) the weight changes can have a significant impact (e.g. Matreng in Set1-5-1 and Set1-5-3). DMM and PROMETHEE II exhibit very similar fluctuations and are more volatile compared to DMO. ELECTRE II is the least stable of the four techniques, with no observed trends. The fluctuations for both test series are unpredictable (e.g. MatSalleh dropping from 1st rank in W5 to 10th ranked in W6 for Set1-5-2 and Set1-5-4). Furthermore, the rankings have many tied ranks, indicating many occurrences of incomplete rankings. This corroborates with the *rank completeness* score obtained for ELECTRE II.

Although it is not evident which technique is superior, DMO, DMM and PROMETHEE II are all comparable, whereas ELECTRE II is unstable and hence is unpredictable where correctness of results is concerned. The conclusion drawn from the sensitivity analyses is that ELECTRE II is inferior compared to the other three techniques.

6.4.6 Summary of Empirical Analyses

Four measures namely rank completeness, rank correlation, rank reversal and sensitivity analysis were used to gauge the quality of the four short-listed MCDM techniques (namely DMO, DMM, PROMETHEE II and ELECTRE II) to support a context-aware approach for B2B collaboration. This is to fulfill the first objective highlighted in section 6.1; to empirically ascertain the most suitable MCDM technique. In this section, the case study used is a multi-criteria partner evaluation and selection with a set of defined scenarios.

From the test results and analyses, the following conclusions can be drawn:

Realisation of Context-aware Hybrid Decision Making Approach

- From a *rank completeness* viewpoint, ELECTRE II is clearly inferior. DMO, DMM and PROMETHEE are comparable.
- From a *rank correlation* perspective, DMO is the best, followed by DMM and PROMETHEE II as equals. ELECTRE II fairs poorly again, being the least stable.
- From a *rank reversal* standpoint, DMO is immune. DMM and PROMETHEE II are the next best techniques, with ELECTRE II performing the worst.
- From the *sensitivity analysis* stance, DMO, DMM and PROMETHEE are comparable. ELECTRE II is totally unpredictable.

Table 6-10 translates the results into a quantitative score, where the best performer is given a rating of 1, and the worst performer is given a rating of 4. **DMO** emerged as the best candidate MCDM technique for supporting B2B collaboration (with supplier selection as a specific application example), followed by DMM and PROMETHEE II. In instances where the alternatives' criterion values are known to have **outlier** values, **DMM** and **PROMETHEE II** could be used instead of DMO, as these techniques have a better range normalisation method. Furthermore, selected large-scale experiments using 100 alternatives tested for **DMO** and **PROMETHEE II** re-affirmed the empirical proofs provided in this investigation. The details are documented in Appendix 10.

Table 6-10: Summary of the empirical evaluation of candidate MCDM techniques

Technique\Measure*	DMO	DMM	PROMETHEE II	ELECTRE II
Rank completeness	1	1	1	4
Rank stability	1	2	2	4
Rank reversal	1	2	2	4
Sensitivity analysis	1	1	1	4
Overall Score	4	6	6	16

* 1=best performance, 4=worst performance

With the first objective achieved, the next section will attempt to verify the viability of the proposed hybrid approach, in particular the fuzzification of the qualitative criteria.

6.5 Fuzzy Verification

This section attempts to establish the viability of the fuzzy implementation for the qualitative criteria. Similarly, this section will first discuss the experimental setup for this fuzzy verification, followed by the test results and relevant analysis.

6.5.1 Experimental setup

For this verification, tests were conducted using the DMO technique only, as the focus is on the effectiveness of the fuzzy approach in dealing with qualitative criteria, not the MCDM techniques. Tests that encompassed both qualitative and quantitative criteria were employed. A sample of the data of six candidate providers with the preferred requestor's values is shown in Table 6-11. The values here would be mapped onto the respective fuzzy models designed for each of the criterion. For example, *On-time Delivery* would be mapped to the fuzzy model shown in Figure 5-4 in Section 5.5.2.

Table 6-11: Sample Data for Fuzzy Verification

Criterion\Candidate	Requestor	Tomoto	Matreng	Hamind	Indisar Puri	Deltazer	ChenPo
Quality (%)	0.5	0.01	0.03	0.1	0.08	0.15	0.12
On-time Delivery (%)	80	99	98	99	96	99	95
Past Turnover ¹ (\$ mil)	20	183	230	148	122	151	125

¹: Determined on a per annum basis

Table 6-12: The Weights for each Criterion

Test Criteria	Criterion Type*	FTest-1	FTest-2	FTest-3
Price (cost)	T	-	0.60	-
Lead-time	T	-	-	0.50
Capacity	T	0.50	-	-
Past Turnover	L	0.17	-	0.17
Quality	L	0.17	0.20	0.17
On-Time Delivery	L	0.17	0.20	0.17

* T=quantitative criterion, L=qualitative criterion

Realisation of Context-aware Hybrid Decision Making Approach

Like the empirical analysis, the same 20 candidate providers were assessed. Table 6-12 shows the criteria and corresponding weights used in the three tests. The tests (FTest-1, FTest-2 and FTest-3) were designed to understand the effect of fuzzification on the Overall Suitability Score (*OSS*) of the DMO technique, by using a dominant quantitative criterion (*Capacity*, *Price* and *Lead-time*) that has a weight of at least 0.5, and several qualitative criteria.

6.5.2 Discussion of Test Results

Figure 6-5: Effects of Fuzzification (FTest-1)

Figure 6-5 shows the effect of fuzzification on the *OSS* values of candidate providers, as compared to when no fuzzy implementation for the qualitative criteria was available for FTest-1. For no-fuzzy implementation, the performance values of the qualitative criteria are base-lined at -1.0. Thus the change in *OSS* value is benchmarked against this baseline, factoring in the respective criterion weight. Through fuzzification, a more precise *OSS* of candidate providers is achieved. Similar improvements are observed for

Realisation of Context-aware Hybrid Decision Making Approach

FTest-2 and FTest-3. Figure 6-6 illustrates the difference in *OSS* values for all the three tests. The average difference recorded are 0.54, 0.45 and 0.54 for FTest-1, FTest-2 and FTest-3 respectively. The standard deviations for the tests are also at an acceptable range of between 0.08 to 0.14. It is important to note that since the qualitative criteria in FTest-1 and FTest-3 are the same and have the same weights, the *OSS* difference for all candidate providers should be same, regardless of the quantitative criterion. This is confirmed, as shown in the graph of Figure 6-6, with the same mean and standard deviation values.

Figure 6-6 also shows that the *OSS* difference is significantly higher for some companies (e.g. Tomoto) as compared to others (e.g. ChenPo), for all tests. This provides an indication that the fuzzification process is providing the expected differences in the scores; as ChenPo has significantly lower qualitative performance values (see Table 6-11).

Figure 6-6: Effects of Fuzzification on the OSS

6.6 Industry Study

6.6.1 Experimental setup

The goal of this industry study is to understand the differences and/or similarities between this context-aware approach and the decision making process in industry. The first part of this study, to determine the practicality of the *B2B Context Model* formulated, was discussed in Section 3.6 of Chapter 3.

In this second part, the same senior executives (e.g. Managing Director, Chief Executive Officer of smaller companies or the Purchasing Manager, Supply Chain Director of bigger companies) from the same 6 SMEs and 4 MNCs were provided with a mini case study based on Set1-1-2 of the experimental setup discussed in section 6.4.1, but with only 5 candidate partners. The details of the 5 candidate partners are as shown in Table 6-13, whereas the preferred values of the requestor, QuickLite, are shown in Table 6-14.

Table 6-13: The five candidate partners' pertinent values

Item	ChenPo	CaiHan	Mangellan	Tech John	Mat Salleh
Unit Price (\$)	9.50	12.00	12.00	13.00	13.50
Minimum Order Quantity (Units)	10000	1000	1000	1000	1000
Sales Basis	FOB	CIF	FOB	FOB	DDP
Tariff Value / Type	3% / Any sales	3% / All overseas exports	2% / All overseas exports	1% / Any Sales	2% / Any Sales
Lead Time (day)					
Manufacturing	2	0	5	5	0
Delivery	7	5	2	3	1
Location	SuZhou / China	Tianjing / China	Taiping / Malaysia	Tainan / Taiwan	Johor / Malaysia

Table 6-14: Preferred Values of QuickLite

Description	Preferred Value
Unit Price	\$9.50
Order Lead Time	5 days
Location	Singapore
Required Quantity	3000 units

Realisation of Context-aware Hybrid Decision Making Approach

In this study, three criteria; *Cost*, *Lead-time* and *Location* are considered. One of the main reasons is that *Cost* is known to be a major influence in any supplier selection. A 3-criteria test case was intentionally chosen with only 5 candidate partners. This is to minimise the complexity arising from too many criteria or candidate partners. It was hoped that with fewer candidate providers, the decision makers can articulate their decision making process better. In part, this study also attempted to understand whether the decision making process of these experts are overly biased towards a particular criterion, based on gut feel or actual values of the criteria. In this way, it can then be ascertained if the context-aware approach adopted in this research can lead to more transparent and better decisions. To facilitate this decision making, a set of calculated values, Table 6-15, were provided to the respondents during the interviews also (based on the rules defined in Table A4-3 of Appendix 4).

Table 6-15: Calculated Values

Item	ChenPo	CaiHan	Mangellan	Tech John	Mat Salleh
Product Cost (\$)	95000	36000	36000	39000	40500
Tariff charges (\$)	2850	1080	720	390	810
Transportation Cost per Order (\$)	1000	0	300	500	0
Total Order Cost(\$)	98850	37080	37020	39890	41310
Per Unit Order Cost (\$)	9.90	12.36	12.34	13.30	13.77
Total Lead Time (day)	9	5	7	8	1

It is important to note that in study, *Cost* refers to *total cost*, namely includes other associated costs like tariff and transportation charges. The total cost was used as it impacts the cash flow of many companies. However, during the course of this survey, some companies interestingly ignored this aspect, preferring instead the per-unit cost (derived by dividing the total cost with the number of units purchased).

6.6.2 Results and Discussion

From the study, several observations can be drawn about industry's decision making process in supplier selection:

- Although 3 criteria were presented to each of the companies, the decision maker reverted to the criterion that is most important to the company. It was very difficult to get them to consider the 3-criteria concurrently and also to quantify the relative importance between the criteria.
- Each criterion was considered sequentially instead of concurrently. A few decision makers attempted to blend into their decision-making a second criterion (e.g. *Lead-time* after *Cost*). None went beyond the second criterion. This method associates more importance to the first criterion (*Cost*), thus indirectly providing a higher weight (importance) to the criterion.
- *Cost* is the dominant criterion in most companies, and in many instances the only criterion considered.
- No company has a systematic and quantitative supplier evaluation system, although the bigger companies may have a formalised supplier evaluation criteria. However, the decision making process is still very much based on one criterion or at most two criteria, with the rest of the criteria taken into consideration in a qualitative and subjective manner.

Of the companies surveyed, only three companies ranked the candidate partners completely; SME-3, MNC-1 and MNC-3 (see Figure 6-7). From the perspective of the 1st ranked, the following were observed:

- ChenPo was selected by SME-1, SME-2 and SME-3. This decision was based solely on the lowest per unit cost (\$9.90), as shown in Table 6-15.
- Mangellian was preferred by SME-6 as it offered the lowest total *Cost* (as the sole criterion).
- CaiHan was chosen by SME-4, SME-5 and MNC-1. This was based on two criteria; *Cost* and *Lead-time* in a sequential manner, with *Cost* being the dominant criterion.

Realisation of Context-aware Hybrid Decision Making Approach

The *Cost* consideration here is based on either the total cost or per-unit cost. Here, CaiHan was chosen over Mangellan as the *Cost* is comparable, but CaiHan has a shorter lead-time of 5 days for SME-4 and SME-5. MNC-1 chose CaiHan over Mangellan as CaiHan has a longer payment duration (although this was not listed as a criterion).

- MNC-4 chose CaiHan too, but the second ranked is ChenPo instead. It figured that the additional transportation cost (per-order basis) of Mangellan could eventually make Mangellan's product more expensive than ChenPo's.
- MatSalleh was chosen by MNC-3. It considered *Lead-time* as the most important criterion. For the same reason, CaiHan was ranked second, as its lead-time is shorter than Mangellan's (although Mangellan's cost is slightly lower).

The details of each company's ranking and decision making rationale are documented in Appendix 8, Table A8-24.

* MNC-2 did not take part in the ranking portion of the study

Figure 6-7: Ranking of candidate partners by companies in industry study

When the 1st ranked choices from the companies are compared to the sub-set of results from Set1-1-2, it is obvious that there is little correlation, as shown in Figure 6-8. All the MCDM techniques ranked MatSalleh first, across all weights. CaiHan was ranked second across all weights by DMO, whereas Mangellan is ranked second by DMM and

Realisation of Context-aware Hybrid Decision Making Approach

PROMETHEE II. The only exception is in W2 for DMM and PROMETHEE, which ranked CaiHan second instead. ChenPo was ranked last by all the three techniques. Of the 3 complete rankings by SME-3, MNC-1 and MNC-3, only the one provided by MNC-3 compares well with the test results from the MCDM techniques. In fact there is 100% correlation with DMO, and DMM and PROMETHEE II for W2 for the ranking provided by MNC-3.

Figure 6-8: MCDM techniques ranking results (sub-set of Set1-1-2)

Why then the big discrepancy, in particular with the companies that ranked ChenPo first?

The answer lies in the decision making process itself. For example, companies that chose ChenPo as the best candidate supplier used only *Cost* as the criterion, typically without considering the other factors like *Lead-time* for example. Furthermore, the company did not consider the impact of total cost on their cash flow, which is important to some companies like SME-6 for example. When total cost is important, ChenPo is typically eliminated. In the MCDM techniques, all the three criteria are considered holistically, based on the weights for each criterion. Furthermore, the *Cost* criterion refers to the total cost, not per-unit cost. That is the reason ChenPo was ranked last for all the MCDM techniques. MatSalleh, being ranked 1st, shows the best overall package when the 3-criteria are considered together. MNC-3 is the only company that attempted to consider the criteria holistically, and the results correlate well.

Realisation of Context-aware Hybrid Decision Making Approach

Several aspects of real-life decision making in industry were gleaned from this study:

- Decision makers fall back on the norms of their companies' environment. This is shown by the decisions being made based more on the companies' own environment rather than what was set out in this study.
- Decisions are made on a quantitative basis, mostly governed by cost, but augmented by a large dose of experience and gut feel.
- Decisions are made based on very few criteria; in this survey, only two mostly.
- Very few companies have a systematic and quantitative supplier evaluation system, and in this survey none, even for the MNCs. The only known and published quantitative decision making system was introduced by Hewlett Packard [92].

As such, this research could provide a very useful quantifiable approach to help decision makers in companies based their decisions on "actual data". In fact, as part of the survey, most of the respondents agreed that such a system would definitely prove helpful. It will also provide them with a sound basis to choose a certain partner.

6.7 Chapter Summary

The proposed Deviation Measure-Original (DMO) has been empirically identified as the best MCDM technique compared to DMM, PROMETHEE II and ELECTRE II. DMM and PROMETHEE II are good alternatives, in particular when the candidate partners' performance values have large differences (indicating a high potential of outlier values). Also, tests results show that the fuzzification of qualitative criteria definitely provided better sensitivity to the scores obtained in the ranking technique, DMO in this case. In short, the fuzzy approach for the qualitative criteria is viable. Thus, the two objectives set out in this chapter have been achieved; (1) to ascertain the best MCDM technique to support context-aware B2B collaboration, and (2) to establish the viability of the fuzzification process for qualitative criteria.

Realisation of Context-aware Hybrid Decision Making Approach

Finally, a comparative study with current industry practices indicated that this context-aware approach for partner selection can provide companies with a better decision making tool where decisions are not clouded by subjective judgment calls. In this context-aware approach, both quantitative and qualitative criteria are considered based on its importance in a holistic manner.

7 Conclusion

This research has proposed a context-aware B2B collaboration approach, supported by relevant multi-criteria decision techniques. A *B2B Context Model* was developed, augmented by a newly formulated multi-criteria decision technique, *Deviation Measure* to provide a hybrid approach for achieving context-aware B2B collaboration.

7.1 Research Contributions

This research has identified and proven the viability of using the context-aware approach to support B2B collaboration. In realising this, the following contributions were made:

- ***Formulation of a B2B Context Model***

To support the context-aware approach, a generic *B2B Context Model* was formulated. It has two main categories, *Organisational* and *ProductService*, encapsulating the three major aspects of context, namely *User*, *Temporal* and *Location*, embodying business rules which are specific to an application or application type. The *B2B Context Model* was verified against RosettaNet PIPs® (Partner Interface Specifications), an industry *de-facto* B2B collaboration standard. The model was then validated by a survey of industry practice vis-à-vis supplier selection.

- ***Formal representation and reasoning of context information in the B2B Context Model***

To ensure decidability and completeness of reasoning, Description Logic (DL) was adopted to formally represent the context information. Using DL as the foundation, the model was realised using OWL (Web Ontology Language), with a DL-safe subset, *SHOIN(D)*. The business rules were represented using the Semantic Web Rule

Conclusion

Language (SWRL), as DL-safe OWL does not have the necessary expressivity. The performance of an OWL-based knowledge base for representation and reasoning of the context information was investigated. Results showed that an OWL knowledge base is not scalable, and performed poorly compared with the XML schema counterpart. As such, further investigations in this research used the XML schema based representation.

- **Development of *Deviation Measure* to support better decision making in B2B collaboration**

Based on the two aspects of Model Formulation and Automation Practicality in the proposed evaluation framework, existing Multi-Attribute Utility Theory (MAUT) techniques in MCDM were found to be unsuitable. A new MAUT technique, *Deviation Measure*, was therefore proposed. This method addresses the specific nature of B2B collaboration, such as (1) unknown ideal values and solution, (2) known collaboration context, with the relative importance between different criteria in the context determinable, and (3) collaboration criteria of different units of measure, and typically, preferred values are specified. Using the evaluation metrics proposed in the Quality of Solution category for assessment, this *Deviation Method* has been empirically identified as the best MCDM technique.

- **Proving the viability of the proposed hybrid approach in supporting context-aware B2B collaboration**

A hybrid approach, incorporating fuzzification of qualitative criteria, was proposed to address the limitations of short-listed MCDM techniques, which typically deal with quantitative criteria only. This approach has been proven viable through empirical investigations. Results showed that the fuzzification of qualitative criteria definitely added sensitivity to the results, confirming the viability of the hybrid approach. An industry survey, comparing the results from this context-aware approach with that practiced by industry currently, confirmed that this context-aware approach in B2B collaboration can improve the robustness of decision making.

Conclusion

In short, this research has shown the viability of using a context-aware approach for B2B collaboration, including practical considerations for industry use. An integrated context-aware and multi-criteria decision support system for B2B collaboration has been achieved.

7.2 Future Work

As in any research work, this context-aware approach can be further improved. Some areas that could benefit from further research include:

- *Robustness in the fuzzification of qualitative criteria*

The robustness of the fuzzification process on the qualitative criteria is highly dependent on two aspects, fuzzy models and the processing of the input values to automatically generate fuzzy rules (during the Processing Stage in Section 5.5.2.2). The fuzzy models affect the sensitivity of degree-of-truth values obtained for automatically generating the fuzzy rules. As such, further investigations, including industry feedback and verification are needed to ensure that the fuzzy models represent industry practices. This will include further investigations into the best type of form (e.g. trapezoidal, triangle or Gaussian) for the membership functions. Secondly, the conditions used to determine and then generate the fuzzy rules during the Processing Stage could be further improved. Presently, the categories are arbitrarily assumed. A finer grained categorisation with a set of metrics for this categorisation can be formulated to improve this aspect.

- *Extending the B2B Context Model to support context-aware business process formation*

During the analysis of pertinent contexts for inclusion into the model, one aspect was intentionally left out, *Activity*. As acknowledged, this category of context is important for enabling context-aware business process formation. When included

Conclusion

into the *B2B Context Model*, *Activity* contexts will enable the sequencing and capturing of context information based on activities. Such information is needed for the formation of a business process, based on the *context* (or goal) of collaboration. Further investigations into how to define a high-level abstract business process and then expand each of the high-level concepts with realisable activities (that is ready for services discovery and matching) must also be done. This can be supported by the other contexts from the current *B2B Context Model* (e.g. *SalesBasis* element under the *ProductService::PricingInformation* hierarchy to determine whether a delivery activity in a business process needs to be further broken down to include transportation provider).

References

References

- [1] "Mastering complexity in global manufacturing - Powering Profits and Growth Through Value Chain Synchronization," in *A Deloitte Research Global Manufacturing Study*, 2003, accessed on Sep 2007 from <http://www.deloitte.com/dtt/research/0,1015,sid%253D19675%2526cid%253D36776,00.html>.
- [2] G. Samtani and D. Sadhwani, "B2Bi and Web Services: An Intimidating Task?," in *Web Services Business Strategies and Architectures*, P. F. a. M. Waterhouse, Ed.: Wrox Press, 2002, pp. 57-59.
- [3] R. Muthukrishnan and J. A. Shulman, "Understanding supply chain risk: A McKinsey Global Survey," Sep 2006.
- [4] N. Viswanathan, "On-Demand Applications in Supply Chain: Enable Flexible Business Processes," Aberdeen Group, 2007, p. 31, accessed on Sep 2007 from <http://www.aberdeen.com/summary/report/benchmark/4142-RA-supply-chain-demand.asp>.
- [5] L. M. Camarinha-Matos, "Virtual Organizations in Manufacturing: Trends and Challenges," in *12th Int. Conf. On Flexible Automation and Intelligent Manufacturing* Dresden, Germany, 2002.
- [6] C. M. Goh, P. S. Tan, S. G. Lee, and S. P. Lee, "Key issues in manufacturing enterprise integration - the Singapore perspective," in *3rd IEEE International Conference on Industrial Informatics, 2005 (INDIN '05)*, Perth, WA, Australia, 2005, pp. 390-5.
- [7] S. P. Lee, H. B. Lee, and E. W. Lee, "Web Services – An Enabling Technology for Trading Partners Community Virtual Integration," in *Proceedings of the Fourth International Conference on Electronic Business (ICEB2004)*, Beijing, China, 2004.
- [8] G. G. Samtani and D. Sadhwani, "B2Bi and Web Services: An Intimidating Task?," in *Web Services Business Strategies and Architectures*, P. F. a. M. Waterhouse, Ed.: Wrox Press, 2002, pp. 57-59.
- [9] C. R. Thompson and S. H. Teo, "Adopters and non-adopters of business-to-business electronic commerce in Singapore," *Information & Management*, pp. 89-102, 2004.
- [10] M. Littlefield, "Demand Driven Manufacturing: Synchronizing Demand with Production," Aberdeen Group 2007.
- [11] N. Viswanathan, "Supply Chain Innovator's Technology Footprint 2008: Technology Enablers for Driving Supply Chain Transformation," Aberdeen Group 2008.
- [12] N. Viswanathan, "Demand Management in Discrete Industries: Order to Delivery Excellence," Aberdeen Group, 2007, p. 27, accessed on from

References

- http://www.aberdeen.com/summary/report/research_previews/4543-RP-demand-discrete-industries.asp.
- [13] K. Jacobs, P. Jordan, R. v. d. Pluijm, A. J. Vethman, and S. Ritter, "2016: The Future Value Chain," *Executive Outlook*, vol. 6, pp. 46-63, 2006.
 - [14] R. Shecterle, N. Viswanathan, and M. Spinks, "The Supply Chain Executive's Strategic Agenda 2008: Managing Global Supply Chain Transformation," Aberdeen Group 2008.
 - [15] P. S. Tan, A. E. S. Goh, S. S. G. Lee, and E. W. Lee, "Issues and Approaches to Dynamic, Service-oriented Multi-enterprise Collaboration," in *Industrial Informatics, 2006 IEEE International Conference on*, 2006, pp. 399-404.
 - [16] L. D. Ngan, A. Goh, and C. H. Tru, "A Survey of Web Service Discovery Systems," *Int. J. of Information Technology and Web Engineering*, vol. 2, pp. 65-80, 2007.
 - [17] Cambridge, "Cambridge Advanced Learner's Dictionary," in *Cambridge Dictionaries Online*: Cambridge, accessed on 17 November 2007 from <http://dictionary.cambridge.org/define.asp?key=16650&dict=CALD>
 - [18] M. Bazire and P. Brézillon, "Understanding Context Before Using It," in *CONTEXT 2005*, Paris, France, 2005, pp. 29 – 40.
 - [19] C. K. Hess and R. H. Campbell, "An application of a context-aware file system," *Personal and Ubiquitous Computing*, vol. 7, pp. 339-52, 2003.
 - [20] C. K. Hess and R. H. Campbell, "A context-aware data management system for ubiquitous computing applications," in *Proceedings 23rd International Conference on Distributed Computing Systems*, Providence, RI, USA, 2002, pp. 294-301.
 - [21] J. L. Crowley, P. Reignier, J. Coutaz, and G. Rey, "Perceptual components for context aware computing," in *Proceedings of 4th International Conference on Ubiquitous Computing (UbiComp 2002), Lecture Notes in Computer Science*, Goteborg, Sweden, 2002, pp. 117-34.
 - [22] S. S. Yau, Y. Wang, and F. Karim, "Development of situation-aware application software for ubiquitous computing environments," Oxford, United Kingdom, 2002, pp. 233-238.
 - [23] C. Lueg, "Operationalizing context in context-aware artifacts: benefits and pitfalls," *Informing Science*, vol. 5, pp. 43-7, 2002.
 - [24] J. Coutaz, J. L. Crowley, S. Dobson, and D. Garlan, "Context is key [large-scale ubiquitous computing]," *Communications of the ACM*, vol. 48, pp. 49-53, 2005.
 - [25] B. N. Schilit and M. M. Theimer, "Disseminating active map information to mobile hosts," *Network, IEEE*, vol. 8, pp. 22-32, 1994.
 - [26] B. N. Schilit, N. Adams, and R. Want, "Context-Aware Computing Applications," in *IEEE Workshop on Mobile Computing Systems and Applications*, Santa Cruz, California, 1994, pp. 85-90.
 - [27] N. Ryan, J. Pascoe, and D. Morse, "Enhanced Reality Fieldwork: the Context-Aware Archaeological Assistant," in *Computer Applications in Archaeology 1997*, V. Gaffney, M. v. Leusen, and S. Exxon, Eds., 1998.

References

- [28] P.J. Brown, J.D. Bovey, and X. Chen, "Context-Aware Applications: From the Laboratory to the Marketplace," *IEEE Personal Communications*, vol. 4(5), pp. 58-64, 1997.
- [29] A. K. Dey, "Context-Aware Computing: The CyberDesk Project," in *AAAI 1998 Spring Symposium on Intelligent Environments*, 1998 pp. 51-54.
- [30] A. K. Dey and G. D. Abowd, "Towards a Better Understanding of Context and Context-Awareness," in *2000 Conference on Human Factors in Computing Systems (CHI 2000)*, The Hague, The Netherlands, 2000.
- [31] T. Zimmer, "Towards a Better Understanding of Context Attributes," in *Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications Workshops (PERCOMW'04)*, 2004, pp. 23 - 27
- [32] S. K. Mostefaoui and B. Hirsbrunner, "Context aware service provisioning," in *Proceedings. of The IEEE/ACS International Conference on Pervasive Services, 2004. ICPS 2004.*, Beirut, Lebanon, 2004, pp. 71-80.
- [33] Y.-K. Wang, "Context awareness and adaptation in mobile learning," in *Proceedings. 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education*, JungLi, Taiwan, 2004, pp. 154-8.
- [34] R. Klemke, "Context Framework - an Open Approach to Enhance Organisational Memory Systems with Context Modelling Techniques," in *Proceedings of the Third International Conference on Practical Aspects of Knowledge Management (PAKM 2000)*, Basel, Switzerland, 2000.
- [35] W. Huang and T. Tao, "Adding context-awareness to knowledge management in modern enterprises," in *Proceedings of the 2nd International IEEE Conference 'Intelligent Systems'*, Varna, Bulgaria, 2004, pp. 393-398.
- [36] A. John, R. Klemm, A. Mani, and D. Seligmann, "Hermes: a platform for context-aware enterprise communication," in *Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops, 2006 (PerCom Workshops 2006)*, 2006, p. 6 pp.
- [37] R. Rupnik and M. Krisper, "Context-aware mobile application model," *Elektrotehniski Vestnik*, vol. 71, pp. 215-19, 2004.
- [38] R. Beale and P. Lonsdale, "Mobile Context Aware Systems: The Intelligence to Support Tasks and Effectively Utilise Resources," in *Mobile Human-Computer Interaction - Mobile HCI 2004, 6th International Symposium, Glasgow, UK, September 13-16, 2004, Proceedings*, Glasgow, UK, 2004, pp. 240-251.
- [39] P. Brézillon, "Context in Problem Solving: A Survey," *The Knowledge Engineering Review*, vol. 14, pp. 1-34, 1999.
- [40] P. Prekop and M. Burnett, "Activities, context and ubiquitous computing," *Computer Communications*, vol. 26, pp. 1168-1176, 2003.
- [41] P. Kumar, S. Gopalan, and V. Sridhar, "Context enabled multi-CBR based recommendation engine for e-commerce," in *IEEE International Conference on e-Business Engineering*, Beijing, China, 2005, pp. 237-44.

References

- [42] N. A. Bradley and M. D. Dunlop, "Toward a multidisciplinary model of context to support context-aware computing," *Human-Computer Interaction*, vol. 20, pp. 403-46, 2005.
- [43] O. Conlan, Ruaidhr Power, S. Higel, D. O'Sullivan, and K. Barrett, "Next generation context aware adaptive services," in *Proceedings of the 1st international symposium on Information and communication technologies* Dublin, Ireland: Trinity College Dublin, 2003, pp. 205-212.
- [44] H. Harroud, M. Khedr, and A. Karmouch, "Building policy-based context aware applications for mobile environments," in *Mobility Aware Technologies and Applications. First International Workshop, MATA 2004. Proceedings (Lecture Notes in Computer Science)*, Florianopolis, Brazil, 2004, pp. 48-61.
- [45] H. Harroud and A. Karmouch, "Implicit context-sensitive mobile computing using semantic policies," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Paris, France, 2006, pp. 188-200.
- [46] M. Samulowitz, "Towards context-aware user modeling," in *Proceedings of the Third International IFIP/GI Working Conference on Trends in Distributed Systems: Towards a Universal Service Market* Munich, Germany, 2000, pp. 272-7.
- [47] X. Tang, Q. Shen, and P. Zhang, "A distributed context aware model for pervasive service environment," in *International Symposium on Wireless Pervasive Computing 2006*, Phuket, Thailand, 2005, p. 5 pp.
- [48] P. Korpipaa, J. Mantyjarvi, J. Kela, H. Keranen, and E. J. Malm, "Managing context information in mobile devices," *IEEE Pervasive Computing*, vol. 2, pp. 42-51, 2003.
- [49] F. Ling, P. M. G. Apers, and W. Jonker, "Towards context-aware data management for ambient intelligence," in *Database and Expert Systems Applications. 15th International Conference, DEXA 2004. Proceedings (Lecture Notes in Comput. Sci.)*, Zaragoza, Spain, 2004, pp. 422-31.
- [50] S. Jang and W. Woo, "Ubi-UCAM: A unified context-aware application model," in *Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science)*, Stanford, CA, United States, 2003, pp. 178-189.
- [51] O. Bucur, P. Beaune, and O. Boissier, "Steps towards making contextualized decisions: how to do what you can, with what you have, where you are," in *Modeling and Retrieval of Context Second International Workshop, MRC 2005. Revised Selected Papers (Lecture Notes in Artificial Intelligence Vol. 3946)*, Edinburgh, UK, 2005, pp. 62-85.
- [52] T. Flury, G. Privat, and F. Ramparany, "OWL-based location ontology for context-aware services," in *Artificial Intelligence in Mobile Systems 2004*, 2004.
- [53] X. Wang, J. S. Dong, C. Chin, H. SankaRavipriya, and D. Zhang, "Semantic Space: An Infrastructure for Smart Spaces," *Pervasive Computing, IEEE*, vol. 3, pp. 32-39, 2004.
- [54] D. R. de Almeida, C. de Souza Baptista, E. R. da Silva, C. E. C. Campelo, H. F. de Figueiredo, and Y. A. Lacerda, "A context-aware system based on service-

References

- oriented architecture," in *20th International Conference on Advanced Information Networking and Applications, 2006. AINA 2006*, 2006, p. 6 pp.
- [55] J. Anhalt, A. Smailagic, D. P. Siewiorek, F. Gemperle, D. Salber, S. Weber, J. Beck, and J. Jennings, "Toward context-aware computing: Experiences and lessons," *IEEE Intelligent Systems and Their Applications*, vol. 16, pp. 38-46, 2001.
- [56] A. Jameson, "Modelling both the context and the user," *Personal and Ubiquitous Computing*, vol. 5, pp. 29-33, 2001.
- [57] N. A. Bradley and M. D. Dunlop, "Towards a User-centric and Multidisciplinary Framework for Designing Context-aware Applications," in *Proceedings of the International Conference on Ubiquitous Computing (UbiComp 2004)*. Springer, Berlin, Germany. , 2004.
- [58] M. Kaenampornpan and E. O. Neill, "Modelling Context: an Activity Theory Approach," in *Ambient Intelligence: Second European Symposium, EUSAI 2004*, Eindhoven, The Netherlands, 2004.
- [59] D. Preuveneers, J. Van den Bergh, D. Wagelaar, A. Georges, P. Rigole, T. Clerckx, Y. Berbers, K. Coninx, V. Jonckers, and K. De Bosschere, "Towards an extensible context ontology for ambient intelligence," in *Ambient Intelligence. Second European Symposium, EUSAI 2004. Proceedings (Lecture Notes in Computer Science Vol.3295)*, Eindhoven, Netherlands, 2004, pp. 148-59.
- [60] U. Akinc, "Selecting a set of vendors in a manufacturing environment," *Journal of Operations Management*, vol. 11, pp. 107-122, 1993.
- [61] L. de Boer, E. Labro, and P. Morlacchi, "A review of methods supporting supplier selection," *European Journal of Purchasing & Supply Management*, vol. 7, pp. 75-89, 2001.
- [62] Y. Sheffi, "Supply Chain Management under the Threat of International Terrorism," *The International Journal of Logistics Management*, vol. 12, pp. 1-11, 2001.
- [63] M. L. Christopher, Hau, "Mitigating supply chain risk through improved confidence " *International Journal of Physical Distribution & Logistics Management*, vol. 34, pp. 388-396, 2004.
- [64] T. Saaty, "Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP)," *Journal of Systems Science and Systems Engineering*, vol. 13, pp. 1-35, 2004.
- [65] "Value of the RosettaNet Community," accessed on Sep 2007 from <http://www.rosettanet.org/cms/sites/RosettaNet/Community/Value/index.html>
- [66] "RosettaNet Standards," accessed on 10 August from <http://www.rosettanet.org/cms/sites/RosettaNet/Standards/RStandards/index.html>.
- [67] R. P. Office, "Overview Clusters, Segments, And PIPs - Version 02.06.00," RosettaNet Program Office, 2009, accessed on 21 Jan 2009 from <http://portal.rosettanet.org/cms/sites/RosettaNet/Standards/RStandards/index.html>.

References

- [68] D. L. McGuinness and F. v. Harmelen, "OWL Web Ontology Language Overview ", 2004, accessed on 28 July 2008 from <http://www.w3.org/TR/owl-features/>.
- [69] F. Baader, I. Horrocks, and U. Sattler, "Description Logics," in *HANDBOOK OF KNOWLEDGE REPRESENTATION*, 1st ed, F. v. Harmelen, V. Lifschitz, and B. Porter, Eds. Oxford, United Kingdom: Elsevier Science, 2008, pp. 135-179.
- [70] F. Baader and W. Nutt, "Basic Description Logics," in *The Description Logic Handbook: Theory, Implementation, and Applications*, 2nd ed, F. Baader, D. Calvanese, D. L. McGuinness, D. Nardi, and P. F. Patel-Schneider, Eds.: Cambridge University Press, 2007, pp. 47-104.
- [71] S. Tobies, "Complexity Results and Practical Algorithms for Logics in Knowledge Representation," in *LuFG Theoretical Computer Science*. PhD thesis Aachen, North Rhine-Westphalia, Germany: RWTH-RWTH Aachen University, 2001, p. 182.
- [72] A. Borgida, E. Franconi, and I. Horrocks, "Explaining ALC subsumption," in *14th European Conference on Artificial Intelligence (ECAI 2000)*, Amsterdam, Netherlands, 2000, pp. 209-213.
- [73] I. Horrocks, P. F. Patel-Schneider, and F. van Harmelen, "From SHIQ and RDF to OWL: The Making of a Web Ontology Language," *Journal of Web Semantics*, vol. 1, p. 31 pages, 2003.
- [74] C. Lutz, "Reasoning with concrete domains," San Francisco, CA, USA, 1999, pp. 90-5.
- [75] I. Horrocks and U. Sattler, "Ontology Reasoning in the SHOQ (D) Description Logic," in *Proc. of the 17th Int. Joint Conf. on Artificial Intelligence (IJCAI 2001)*, Seattle, Washington, USA, 2001, pp. 199-204.
- [76] T. Gruber, "Ontology," in *Encyclopedia of Database Systems (to appear)*: Springer-Verlag, 2009, accessed on 01 February 2009 from <http://tomgruber.org/writing/ontology-definition-2007.htm>.
- [77] B. Motik, U. Sattler, and R. Studer, "Query answering for OWL-DL with rules," *Web Semantics*, vol. 3, pp. 41-60, 2005.
- [78] I. Horrocks, P. F. Patel-Schneider, H. Boley, S. Tabet, B. Grosz, and M. Dean, "SWRL: A Semantic Web Rule Language Combining OWL and RuleML," 2004, accessed on 28 August 2008 from <http://www.w3.org/Submission/SWRL/>.
- [79] I. Horrocks and P. F. Patel-Schneider, "A proposal for an OWL rules language," New York, NY, United states, 2004, pp. 723-731.
- [80] I. Horrocks, P. F. Patel-Schneider, S. Bechhofer, and D. Tsarkov, "OWL rules: A proposal and prototype implementation," *Web Semantics: Science, Services and Agents on the World Wide Web*, vol. 3, pp. 23-40, 2005.
- [81] S. Opricovic, "Multicriteria Optimization of Civil Engineering Systems," *Faculty of Civil Engineering, Belgrade*, 1998.
- [82] M. Rogers, M. Bruen, and L.-Y. Maystre, *ELECTRE and Decision Support - Methods and Applications in Engineering and Infrastructure Investment*: Kluwer Academic Publishers, 2000.

References

- [83] K. R. Apaiah, "Chapter 5: An Overview of Multi Criteria Decision Making (MCDM) of Designing Food Supply Chains - A structured methodology: A case on Novel Protein Foods." PhD Thesis Wageningen: Wageningen University, The Netherlands, 2006.
- [84] B. Roy, "Chapter 1: Paradigms and Challenges," in *Multiple Criteria Decision Analysis: State of the Art Surveys*, J. Figueira, S. Greco, and S. Ehrgott, Eds. Boston, USA: Springer, 2005, pp. 3-24.
- [85] B. Roy, "The outranking approach and the foundations of electre methods," *Theory and Decision*, vol. 31, pp. 49-73, 1991.
- [86] J. Figueira, S. Greco, and M. Ehrgott, *Multiple Criteria Decision Analysis: State Of The Art Surveys*. Boston, USA: Springer Science + Business Media, Inc., 2005.
- [87] A. Tecle, M. Fogel, and L. Duckstein, "Multicriterion selection of wastewater management alternatives," *Journal of Wastewater Resources Planning and Management* vol. 114, pp. 383-398, 1988.
- [88] T. Al-Shemmeri, B. Al-Kloub, and A. Pearman, "Model choice in multicriteria decision aid," *European Journal of Operational Research*, vol. 97, pp. 550-560, 1997.
- [89] M. R. Mahmoud and L. A. Garcia, "Comparison of different multicriteria evaluation methods for the Red Bluff diversion dam," *Environmental Modelling and Software*, vol. 15, pp. 471-478, 2000.
- [90] S. Gilliams, D. Raymaekers, B. Muys, and J. V. Orshoven, "Comparing multiple criteria decision methods to extend a geographical information system on afforestation," *Computers and Electronics in Agriculture*, vol. 49, pp. 142-158, 2005.
- [91] S. Hajkowicz and A. Higgins, "A comparison of multiple criteria analysis techniques for water resource management," *European Journal of Operational Research*, vol. 184, pp. 255-265, 2008.
- [92] P. G. Russell and W. C. Kropf, "Hewlett-Packard's Packaging Supplier Evaluation Process and Criteria," in *IoPP 16th Educational Symposium on Transport Packaging proceedings*, 1999.
- [93] F. Coolidge, "An Introduction to Correlation and Regression," in *Statistics - A Gentle Introduction* Second Edition ed: SAGE Publications, Inc, 2006, pp. 153-196.
- [94] J. Han and M. Kamber, "Types of Data in Cluster Analysis," in *Data Mining: Concepts and Techniques*, 2 ed, 2006, pp. 386-398.
- [95] J. Wallenius, J. S. Dyer, P. C. Fishburn, R. E. Steuer, S. Zionts, and K. Deb, "Multiple criteria decision making, multiattribute utility theory: Recent accomplishments and what lies ahead," *Management Science*, vol. 54, pp. 1336-1349, 2008.
- [96] T. L. Saaty and L. Vargas, *Fundamentals of Decision Making and Priority Theory With the Analytic Hierarchy Process* vol. Vol. 6: RWS Publications, 2000.
- [97] S. Opricovic and G.-H. Tzeng, "Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS," *European Journal of Operational Research*, vol. 156, pp. 445-455, 2004.

References

- [98] M.-T. Chu, J. Shyu, G.-H. Tzeng, and R. Khosla, "Comparison among three analytical methods for knowledge communities group-decision analysis," *Expert Systems With Applications*, vol. 33, pp. 1011-1024, 2007.
- [99] M. J. d. Smith, M. F. Goodchild, and P. A. Longley, "Building Blocks of Spatial Analysis," in *Geospatial Analysis - A Comprehensive Guide to Principles, Techniques and Software Tools*, Second ed UK: Troubador Publishing Ltd, 2007, pp. 69-172.
- [100] S. Opricovic and G.-H. Tzeng, "Extended VIKOR method in comparison with outranking methods," *European Journal of Operational Research*, vol. 178, pp. 514-529, 2007.
- [101] C. Macharis, J. Springael, K. de Brucker, and A. Verbeke, "PROMETHEE and AHP: The design of operational synergies in multicriteria analysis," *European Journal of Operational Research*, vol. 153, pp. 307-317, 2004.
- [102] E. Triantaphyllou, *Multi-Criteria Decision Making Methods: A Comparative Study*: Dordrecht: Kluwer Academic Publishers, 2000.
- [103] J. S. Dyer, "Remarks on the Analytic Hierarchy Process " *Management Science*, vol. 36, pp. 249-258 1990.
- [104] J. Figueira, V. Mousseau, and B. Roy, "ELECTRE Methods," in *Multiple Criteria Decision Analysis: State of the Art Surveys*, J. Figueira, S. Greco, and S. Ehrgott, Eds. Boston: Springer, 2005, pp. 133-153.
- [105] J. P. Brans, P. Vincke, and B. Mareschal, "How to select and how to rank projects: The method," *European Journal of Operational Research*, vol. 24, pp. 228-238, 1986.
- [106] M. Rogers and M. Bruen, "Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE," *European Journal of Operational Research*, vol. 107, pp. 542-551, 1998.
- [107] C. Macharis, J. Springael, K. De Brucker, and A. Verbeke, "PROMETHEE and AHP: The design of operational synergies in multicriteria analysis.: Strengthening PROMETHEE with ideas of AHP," *European Journal of Operational Research*, vol. 153, pp. 307-317, 2004.
- [108] M. Pöyhönen and R. P. Hämäläinen, "On the convergence of multiattribute weighting methods," *European Journal of Operational Research*, vol. 129, pp. 569-585, 2001.
- [109] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, pp. 338–353, 1965.
- [110] A. Martinez, O. Castillo, and M. Garcia, "Comparative Study of Type-1 and Type-2 Fuzzy Systems Optimized by Hierarchical Genetic Algorithms," in *Soft Computing for Hybrid Intelligent Systems*, 2008, pp. 53-70.
- [111] E. H. Mamdani, "Application of Fuzzy Logic to Approximate Reasoning Using Linguistic Synthesis," *Computers, IEEE Transactions on*, vol. C-26, pp. 1182-1191, 1977.
- [112] J. Jantzen, "Tutorial On Fuzzy Logic," Lyngby: Technical University of Denmark, Department of Automation, DENMARK, 1998.

References

- [113] J. P. Brans and B. Mareschal, "Chapter 5: PROMETHEE Methods," in *Multiple Criteria Decision Analysis: State of the Art Surveys*, J. Figueira, S. Greco, and S. Ehrgott, Eds. Boston: Springer, 2005, pp. 164-189.
- [114] J. R. Taylor, *An Introduction to Error Analysis* (2nd edition) ed. Sausalito, CA: University Science Books, 1997.
- [115] "Order Business Models," Texas Instruments, 1996, accessed on Jun 2008 from <http://www.ti.com/sc/docs/scedi/ordmodel.pdf>.
- [116] W. T. M. Wolters and B. Mareschal, "Novel types of sensitivity analysis for additive MCDM methods," *European Journal of Operational Research*, vol. 81, pp. 281-90, 1995.
- [117] G. K. Mostefaoui, J. Pasquier-Rocha, and P. Brezillon, "Context-aware computing: a guide for the pervasive computing community," Beirut, Lebanon, 2004, pp. 39-48.
- [118] X. Tang, Q. Shen, and P. Zhang, "A distributed context aware model for pervasive service environment," in *International Symposium on Wireless Pervasive Computing 2006*, Phuket, Thailand, 2005, pp. 1-5.
- [119] O. Thiele, H. Knapp, M. Schader, and N. Prat, "A context-aware architecture for mobile knowledge management," in *WINSYS 2006. International Conference on Wireless Information Networks and Systems*, Setubal, Portugal, 2006, pp. 1050-7.
- [120] T. Strang and C. Linnhoff-Popien, "Service interoperability on Context Level in Ubiquitous Computing Environments," in *Advances in Infrastructure for Electronic Business, Education, Science, Medicine, and Mobile Technologies on the Internet (SSGRR2003)*, L'Aquila, Italy, 2003.
- [121] M. H. Van-Tuan Do, Detlef Neumann, "A contextbased approach to support virtual enterprises," in *Hawaii International Conference on System Sciences Hawaii*: IEEE, 2000.
- [122] K. Gunhee, S. Dongkyoo, and S. Dongil, "Design of a middleware and HIML (human interaction markup language) for context aware services in a ubiquitous computing environment," in *Embedded and Ubiquitous Computing. International Conference, EUC 2004. Proceedings (Lecture Notes in Comput. Sci. Vol.3207)*, Aizu-Wakamatsu City, Japan, 2004, pp. 682-91.
- [123] A. Zimmermann, A. Lorenz, and R. Oppermann, "An Operational Definition of Context," in *6th International and Interdisciplinary Conference on Modeling and Using Context, CONTEXT 2007*, Roskilde, Denmark, 2007, pp. 558-571.
- [124] A. Schmidt, M. Beigl, and H.-W. Gellersen, "There is more to Context than Location," in *Proceedings of the International Workshop on Interactive Applications of Mobile Computing (IMC98)*, Rostock, Germany, 1998.
- [125] A. K. Dey, G. D. Abowd, and D. Salber, "A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications," *Human-Computer Interaction*, vol. 16, pp. 97-166, 2001.
- [126] M. Grimm, M. R. Tazari, and D. Balfanz, "Towards a framework for mobile knowledge management," in *Practical Aspects of Knowledge Management. 4th*

References

- International Conference, PAKM 2002. Proceedings (Lecture Notes in Artificial Intelligence Vol.2569)*, Vienna, Austria, 2002, pp. 326-38.
- [127] G. Kappel, B. Proll, W. Retschitzegger, and W. Schwinger, "Modelling ubiquitous Web applications the WUML approach," in *Conceptual Modeling for New Information Systems Technologies. ER 2001 Workshops. HUMACS, DASWIS, ECOMO, and DAMA. Revised Papers (Lecture Notes in Computer Science Vol.2465)*, Yokohama, Japan, 2002, pp. 183-97.
 - [128] H. Chen, T. Finin, and A. Joshi, "An ontology for context-aware pervasive computing environments," *Knowledge Engineering Review*, vol. 18, pp. 197-207, 2003.
 - [129] A. Dogac, G. Laleci, and Y. Kabak, "A Context Framework for Ambient Intelligence," in *In Proceedings of eChallenges Conference*, Bologna, Italy, 2003.
 - [130] H. Q. Ngo, A. Shehzad, S. Liaquat, M. Riaz, and L. Sungyoung, "Developing context-aware ubiquitous computing systems with a unified middleware framework," in *Embedded and Ubiquitous Computing. International Conference, EUC 2004. Proceedings (Lecture Notes in Comput. Sci. Vol.3207)*, Aizu-Wakamatsu City, Japan, 2004, pp. 672-81.
 - [131] R. F. B. De Neto and M. G. C. Da Pimentel, "Toward a domain-independent semantic model for context-aware computing," in *Proceedings - Third Latin American Web Congress, LA-WEB 2005*, Buenos Aires, Argentina, 2005, pp. 61-70.
 - [132] G. Castelli, A. Rosi, M. Mamei, and F. Zambonelli, "A simple model and infrastructure for context-aware browsing of the world," in *2007 IEEE International Conference on Pervasive Computing and Communications*, White Plains, NY, USA, 2007, p. 10 pp.
 - [133] H. J. Lee, J. Y. Choi, and S. J. Park, "Context-aware recommendations on the mobile Web," in *On the Move to Meaningful Internet Systems 2005: OTM 2005 Workshop, OTM Confederated International Workshops and Posters AMeSOME, CAMS, GADA, MIOS+INTEROP, ORM, PhDS, SeBGIS, SWWS, and WOSE 2005. Proceedings (Lecture Notes in Computer Science Vol.3762)*, Agia Napa, Cyprus, 2005, pp. 142-51.
 - [134] S. K. Mostéfaoui and B. Hirsbrunner, "Towards a Context-Based Service Composition Framework," in *International Conference on Web Services*, Fribourg, Switzerland, 2003, pp. 42-45.
 - [135] M. Riaz, K. Saad Liaquat, L. Sungyoung, and L. Young-Koo, "Incorporating semantics-based search and policy-based access control mechanism in context service delivery," in *Proceedings. Fourth Annual ACIS International Conference on Computer and Information Science*, Jeju Island, South Korea, 2005, pp. 175-80.
 - [136] O. Kwon, S. Choi, and G. Park, "NAMA: A context-aware multi-agent based web service approach to proactive need identification for personalized reminder systems," *Expert Systems with Applications*, vol. 29, pp. 17-32, 2005.
 - [137] M. Lundqvist, K. Sandkuhl, T. Levashova, and A. Smirnov, "Context-driven information demand analysis in information logistics and decision support

References

- practices," American Association for Artificial Intelligence, Menlo Park, CA 94025-3496, United States, Pittsburgh, PA, United States 2005.
- [138] I. Roussaki, M. Strimpakou, C. Pils, N. Kalatzis, and M. Anagnostou, "Hybrid context modeling: A location-based scheme using ontologies," Pisa, Italy, 2006, pp. 2-7.
- [139] D. R. de Almeida, C. de Souza Baptista, E. R. da Silva, C. E. C. Campelo, H. F. de Figueiredo, and Y. A. Lacerda, "A context-aware system based on service-oriented architecture," in *20th International Conference on Advanced Information Networking and Applications, 2006. AINA 2006*, Vienna, Austria, 2006, pp. 205-210.
- [140] A. Henrich and K. Morgenroth, "Supporting collaborative software development by context-aware information retrieval facilities," in *Proceedings. 14th International Workshop on Database and Expert Systems Applications*, Prague, Czech Republic, 2003, pp. 249-53.
- [141] J. W. Kaltz, J. Ziegler, and S. Lohmann, "Context-aware web engineering: Modeling and applications," *Revue d'Intelligence Artificielle*, vol. 19, pp. 439-458, 2005.
- [142] L. Baresi, D. Bianchini, V. D. Antonellis, M. G. Fugini, B. Pernici, and P. Plebani, "Context-Aware Composition of E-services," in *Technologies for E-Services*, 2003, pp. 28-41.
- [143] H. Kammanahalli, S. Gopalan, V. Sridhar, and K. Ramamritham, "Context aware retrieval in web-based collaborations," in *Proceedings - Second IEEE Annual Conference on Pervasive Computing and Communications, Workshops, PerCom*, Orlando, FL, United States, 2004, pp. 8-12.
- [144] R. Bierig and A. Göker, "Time, Location and Interest: An Empirical and User-Centred Study," in *Information Interaction in Context* Copenhagen Denmark: ACM, 2006.
- [145] H. Lieberman and T. Selker, "Out of Context: Computer Systems That Adapt To, and Learn From, Context," *IBM Systems Journal*, vol. 39, pp. 617-632, 2000.
- [146] P. Lucas, "Mobile devices and mobile data-issues of identity and reference," *Human-Computer Interaction*, vol. 16, pp. 323-36, 2001.
- [147] K. Van Laerhoven and K. Aidoo, "Teaching context to applications," *Personal and Ubiquitous Computing*, vol. 5, pp. 46-9, 2001.
- [148] B. N. Schilit, A. LaMarca, G. Borriello, W. G. Griswold, D. McDonald, E. Lazowska, A. Balachandran, J. Hong, and V. Iverson, "Challenge: Ubiquitous Location-Aware Computing and the "Place Lab" Initiative," in *Proceedings of the first ACM International Workshop on Wireless Mobile Applications and Services on WLAN Hotspots*, San Diego, CA, United States, 2003, pp. 29-35.
- [149] S. Pokraev, J. Koolwaaij, and M. Wibbels, "Extending UDDI with context-aware features based on semantic service descriptions," in *Proceedings of the International Conference on Web Services*, Las Vegas, NV, United States, 2003, pp. 184-190.

References

- [150] R. Want, A. Hopper, V. Falc, and J. Gibbons, "The active badge location system," *ACM Trans. Inf. Syst.*, vol. 10, pp. 91-102, 1992.
- [151] S. K. Mostefaoui, "Towards a Context-Oriented Services Discovery and Composition Framework," in *18th International Joint Conference on Artificial Intelligence*, 2003.
- [152] D. Shipley and S. Prinja, "HOW DISTRIBUTORS OF ENGINEERING PRODUCTS SELECT SUPPLIERS," *Engineering Management International*, vol. 4, pp. 227-237, 1987.
- [153] R. B. Handfield, "US global sourcing: patterns of development," *International Journal of Operations & Production Management*, vol. 14, pp. 40-51, 1994.
- [154] R. J. Vokurka, J. Choobineh, and L. Vadi, "A prototype expert system for the evaluation and selection of potential suppliers," *International Journal of Operations and Production Management*, vol. 16, pp. 106-27, 1996.
- [155] A. De Toni and G. Nassimbeni, "Buyer-supplier operational practices, sourcing policies and plant performances: results of an empirical research," *International Journal of Production Research*, vol. 37, pp. 597-619, 1999.
- [156] C. Masella and A. Rangone, "A contingent approach to the design of vendor selection systems for different types of cooperative customer/supplier relationships," *International Journal of Operations & Production Management*, vol. 20, pp. 70-84, 2000.
- [157] S. H. Ghodsypour and C. O'Brien, "The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint," *International Journal of Production Economics*, vol. 73, pp. 15-27, 2001.
- [158] B. M. Altuntas, D. Bayraktar, and F. Cebi, "An Application of Expert System Approach for Supplier Evaluation and Selection," in *Technology Management for the Global Future, 2006. PICMET 2006*, 2006, pp. 2755-2758.
- [159] R. M. Garfamy, "A data envelopment analysis approach based on total cost of ownership for supplier selection," *Journal of Enterprise Information Management*, vol. 19, pp. 662-78, 2006.
- [160] L. Dianting, Z. Dejian, and T. Xiaomei, "A Method of Components and Parts Suppliers Selection for SMMEs Based on Uncertainly Voting AHP Group Decision Making," in *Pervasive Computing and Applications, 2006 1st International Symposium on*, 2006, pp. 17-22.
- [161] W.-j. Hao and X.-f. Ju, "The Construction and Implementation of Assessment Indicator System of Suppliers Based on Fuzzy Integral," in *Management Science and Engineering, 2006. ICMSE '06. 2006 International Conference on*, 2006, pp. 618-622.
- [162] S. H. Huang and H. Keskar, "Comprehensive and configurable metrics for supplier selection," *International Journal of Production Economics*, vol. 105, pp. 510-23, 2007.
- [163] V. N. Karthik, "An Integrated Supplier Selection Methodology for Designing Robust Supply Chains," in *Management of Innovation and Technology, 2006 IEEE International Conference on*, 2006, pp. 906-910.

References

- [164] R. Narasimhan, S. Talluri, and S. K. Mahapatra, "Multiproduct, multicriteria model for supplier selection with product life-cycle considerations," *Decision Sciences*, vol. 37, pp. 577-603, 2006.
- [165] I.-L. Wu and Y.-C. Shen, "A model for exploring the impact of purchasing strategies on user requirements determination of e-SRM," *Information and Management*, vol. 43, pp. 411-422, 2006.
- [166] B. Wu, W. Shanshan, and H. Jun, "An analysis of Supplier Selection in Manufacturing Supply Chain Management," in *Service Systems and Service Management, 2006 International Conference on*, 2006, pp. 1439-1444.
- [167] L. Xiaoli and S. Purchase, "Investigating supplier selection using repertory grid technique," Shanghai, China, 2006, pp. 432-435.
- [168] C.-C. Yang and B.-S. Chen, "Supplier selection using combined analytical hierarchy process and grey relational analysis," *Journal of Manufacturing Technology Management*, vol. 17, pp. 926-941, 2006.
- [169] A. Aguezoul and P. Ladet, "A nonlinear multiobjective approach for the supplier selection, integrating transportation policies," *Journal of Modelling in Management*, vol. 2, pp. 157-69, 2007.
- [170] F. T. S. Chan, H. K. Chan, R. W. L. Ip, and H. C. W. Lau, "A decision support system for supplier selection in the airline industry," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 221, pp. 741-758, 2007.
- [171] F. T. S. Chan and N. Kumar, "Global supplier development considering risk factors using fuzzy extended AHP-based approach," *Omega*, vol. 35, pp. 417-31, 2007.
- [172] V. Jain, S. Wadhwa, and S. G. Deshmukh, "Supplier selection using fuzzy association rules mining approach," *International Journal of Production Research*, vol. 45, pp. 1323-1353, 2007.
- [173] P. Liu, "Research on the Supplier Selection of Supply Chain Based on the Improved ELECTRE-II Method," in *Intelligent Information Technology Application, Workshop on*, 2007, pp. 18-21.
- [174] M. Sevkli, S. C. L. Koh, S. Zaim, M. Demirbag, and E. Tatoglu, "An application of data envelopment analytic hierarchy process for supplier selection: A case study of BEKO in Turkey," *International Journal of Production Research*, vol. 45, pp. 1973-2003, 2007.
- [175] Y. Tan, Z.-V. Cai, and W.-X. Mei, "A manager framework of supply chain operational reference model," Shanghai, China, 2007, pp. 4762-4766.
- [176] H. S. Wang, "Configuration change assessment: Genetic optimization approach with fuzzy multiple criteria for part supplier selection decisions," *Expert Systems with Applications*, vol. 34, pp. 1541-1555, 2008.
- [177] C. Yee Ming and H. Pei-Ni, "Bi-negotiation integrated AHP in suppliers selection," *International Journal of Operations & Production Management*, vol. 27, pp. 1254-74, 2007.
- [178] I. H. Yigin, H. Taskin, I. H. Cedimoglu, and B. Topal, "Supplier selection: an expert system approach," *Production Planning and Control*, vol. 18, pp. 16-24, 2007.

References

- [179] G.-H. Zheng, Y. Li, and S.-M. Guo, "Supplier selection based on the combination of entropy weight and TOPSIS," Chengdu, China, 2007, pp. 2942-2947.
- [180] H.-M. Zhu, "Supplier Selection Using Process Capability and Price Information Chart," in *Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007. International Conference on*, 2007, pp. 4850-4853.
- [181] F. T. S. Chan, N. Kumar, M. K. Tiwari, H. C. W. Lau, and K. L. Choy, "Global supplier selection: A fuzzy-AHP approach," *International Journal of Production Research*, vol. 46, pp. 3825-3857, 2008.
- [182] Z. H. Che and H. S. Wang, "Supplier selection and supply quantity allocation of common and non-common parts with multiple criteria under multiple products," *Computers and Industrial Engineering*, vol. 55, pp. 110-133, 2008.
- [183] S.-Y. Chou and Y.-H. Chang, "A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach," *Expert Systems with Applications*, vol. 34, pp. 2241-2253, 2008.
- [184] E. A. Demirtas and O. Ustun, "An integrated multiobjective decision making process for supplier selection and order allocation," *Omega*, vol. 36, pp. 76-90, 2008.
- [185] T. J. Kull and S. Talluri, "A supply risk reduction model using integrated multicriteria decision making," *IEEE Transactions on Engineering Management*, vol. 55, pp. 409-419, 2008.
- [186] W. Li, Y. Chen, and Y. Fu, "Combination of TOPSIS and 0-1 programming for supplier selection in supply chain management," Sanya, China, 2008, pp. 1531-1535.
- [187] T. Shin-Chan and D. I. Cho, "An integrated approach for supplier selection and purchasing decisions," *Supply Chain Management*, vol. 13, pp. 116-27, 2008.
- [188] S. Sen, H. Basligil, C. G. Sen, and H. Barali, "A framework for defining both qualitative and quantitative supplier selection criteria considering the buyer-supplier integration strategies," *International Journal of Production Research*, vol. 46, pp. 1825-1845, 2008.
- [189] M. Sevkli, S. C. L. Koh, S. Zaim, M. Demirbag, and E. Tatoglu, "Hybrid analytical hierarchy process model for supplier selection," *Industrial Management & Data Systems*, vol. 108, pp. 122-42, 2008.
- [190] W. Dan, T. Yezhuang, and H. Yunquan, "Empirical study of supplier selection strategies across the supply chain management in manufacturing companies," in *Engineering Management Conference, 2004. Proceedings. 2004 IEEE International*, 2004, pp. 85-89 Vol.1.
- [191] G. Wang, S. H. Huang, and J. P. Dismukes, "Product-driven supply chain selection using integrated multi-criteria decision-making methodology," *International Journal of Production Economics*, vol. 91, pp. 1-15, 2004.
- [192] F.-j. Zhang, Y.-z. Tian, and X.-l. Sun, "Empirical Analysis of the Effects of Supplier Selection and Integration on Customer Satisfaction and Business Performance," in *Management of Innovation and Technology, 2006 IEEE International Conference on*, 2006, pp. 931-935.

References

- [193] X. Tan, K. Ma, W. Guo, and T. Huang, "An Application of ANP with Benefits, Opportunities, Costs and Risks in Supplier Selection: A Case Study in a Diesel Engine Manufacturing Firm," in *Automation and Logistics, 2007 IEEE International Conference on*, 2007, pp. 1446-1451.
- [194] L. Eon-Kyung, H. Sungdo, and K. Sheung-Kown, "Supplier selection and management system considering relationships in supply chain management," *Engineering Management, IEEE Transactions on*, vol. 48, pp. 307-318, 2001.
- [195] S. Nukala and S. M. Gupta, "Supplier selection in a closed-loop supply chain network: An ANP-goal programming methodology," Boston, MA, United States, 2006, p. 63850.
- [196] Y. Song, Q. Zhang, and X. Zhou, "Supplier Selection model based on distance measure between intuitionistic fuzzy sets," in *Systems, Man and Cybernetics, 2006. ICSMC '06. IEEE International Conference on*, 2006, pp. 3795-3799.
- [197] G. Kannan and A. N. Haq, "Analysis of interactions of criteria and sub-criteria for the selection of supplier in the built-in-order supply chain environment," *International Journal of Production Research*, vol. 45, pp. 3831-3852, 2007.
- [198] V. R. Kannan and K. C. Tan, "Attitudes of US and European managers to supplier selection and assessment and implications for business performance," *Benchmarking*, vol. 10, pp. 472-489, 2003.
- [199] C. Gencer and D. Gurpinar, "Analytic network process in supplier selection: a case study in an electronic firm," *Applied Mathematical Modelling*, vol. 31, pp. 2475-86, 2007.
- [200] D. Ozgen, S. Onut, B. Gulsun, U. R. Tuzkaya, and G. Tuzkaya, "A two-phase possibilistic linear programming methodology for multi-objective supplier evaluation and order allocation problems," *Information Sciences*, vol. 178, pp. 485-500, 2008.
- [201] P. Pal and B. Kumar, "'16T': toward a dynamic vendor evaluation model in integrated SCM processes," *Supply Chain Management: An International Journal*, vol. 13, pp. 391-397, 2008.
- [202] O. Ustun and E. A. Demirtas, "Multi-period lot-sizing with supplier selection using achievement scalarizing functions," *Computers and Industrial Engineering*, vol. 54, pp. 918-931, 2008.
- [203] F. Cebi and D. Bayraktar, "An integrated approach for supplier selection," *Logistics Information Management*, vol. 16, pp. 395-400, 2003.
- [204] C.-T. Chen, C.-T. Lin, and S.-F. Huang, "A fuzzy approach for supplier evaluation and selection in supply chain management," *International Journal of Production Economics*, vol. 102, pp. 289-301, 2006.
- [205] J. R. Carter, A. Maltz, and Y. Tingting, "How procurement managers view low cost countries and geographies: a perceptual mapping approach," *International Journal of Physical Distribution & Logistics Management*, vol. 38, pp. 224-43, 2008.
- [206] C.-Y. Kung, "Using Fuzzy Sets and Grey Decision-Making to Construct the Performance Evaluation Model of Firm's Outsourcing Management – A Case

References

- Study of Avionics Manufacturer in Taiwan," *Quality and Quantity*, vol. 40, pp. 577-593, 2006.
- [207] M. Jackson, A. Mathur, M. Pecht, and R. Kendall, "Part manufacturer assessment process," *Quality and Reliability Engineering International*, vol. 15, pp. 457-68, 1999.
- [208] R. C. Oliveira and J. C. Lourenco, "A multicriteria model for assigning new orders to service suppliers," *European Journal of Operational Research*, vol. 139, pp. 390-399, 2002.
- [209] E. Bottani and A. Rizzi, "An adapted multi-criteria approach to suppliers and products selection-An application oriented to lead-time reduction," *International Journal of Production Economics*, vol. 111, pp. 763-781, 2008.
- [210] C. Sheu Hua and L. Hong Tau, "Analytic network approach for selecting suppliers considering different cooperation patterns," *International Transactions in Operational Research*, vol. 13, pp. 549-60, 2006.
- [211] A. M. Polansky, "Supplier selection based on bootstrap confidence regions of process capability indices," *International Journal of Reliability, Quality and Safety Engineering*, vol. 10, pp. 1-14, 2003.
- [212] C. A. Weber, J. R. Current, and W. C. Benton, "Vendor selection criteria and methods," *European Journal of Operational Research*, vol. 50, pp. 2-18, 1991.
- [213] K. S. Chen and K. L. Chen, "Supplier selection by testing the process incapability index," *International Journal of Production Research*, vol. 44, pp. 589-600, 2006.
- [214] M. Ni, X. Xu, and S. Deng, "Extended QFD and data-mining-based methods for supplier selection in mass customization," *International Journal of Computer Integrated Manufacturing*, vol. 20, pp. 280-91, 2007.
- [215] R. Carvalho Oliveira and J. C. Lourenco, "A multicriteria model for assigning new orders to service suppliers," *European Journal of Operational Research*, vol. 139, pp. 390-9, 2002.
- [216] C.-W. Hsu and A. H. Hu, "Application of analytic network process on supplier selection to hazardous substance management in green supply chain management," Singapore, 2007, pp. 1362-1368.
- [217] R. R. Levary, "Ranking foreign suppliers based on supply risk," *Supply Chain Management*, vol. 12, pp. 392-4, 2007.
- [218] P. K. Humphreys, Y. K. Wong, and F. T. S. Chan, "Integrating environmental criteria into the supplier selection process," *Journal of Materials Processing Technology*, vol. 138, pp. 349-356, 2003.
- [219] W. L. Tate, L. M. Ellram, and C. R. Carter, "The impact of supply management on environmental performance outcomes," Philadelphia, PA, United States, 2004, pp. 94-105.
- [220] M. J. d. Smith, M. F. Goodchild, and P. A. Longley, "Extended Euclidean and Lp-metric distances," in *Geospatial Analysis - A Comprehensive Guide to Principles, Techniques and Software Tools*, Second ed: Matador, accessed on 26 March 2009 from

References

- <http://www.spatialanalysisonline.com/output/html/ExtendedEuclideanandLp-metricdistances.html>.
- [221] J. Figueira, V. Mousseau, and B. Roy, "Chapter 4 - ELECTRE Methods," in *Multiple Criteria Decision Analysis: State of the Art Surveys*, J. Figueira, S. Greco, and S. Ehrgott, Eds. Boston: Springer, 2005, pp. 133-153.
- [222] J. Buchanan, P. Sheppard, and D. Vanderpooten, "PROJECT RANKING USING ELECTRE III," University of Waikato, Dept of Management Systems, New-Zealand 1999.
- [223] P. Zielniewicz, "ELECTRE III-IV," LAMSADE, 1994, accessed on 29 August 2008 from <http://www.lamsade.dauphine.fr/english/software.html#el34>.

Publications Derived From This Research

Journals

1. P.S. Tan, A.E.S. Goh and S.S.G. Lee, "Context information support for B2B collaboration", International Journal of Web Engineering and Technology 2009, Vol. 5, No.2, pp. 214 – 245, 2009.
2. P.S. Tan, A.E.S. Goh, S.S.G. Lee, K. Mous, "A context-aware approach for supplier selection in B2B collaborations", International Journal of Information Technology and Decision Making (IJITDM) [submitted in 2009]
3. P.S. Tan, A.E.S. Goh and S.S.G. Lee, "Multi-criteria decision techniques for context-aware B2B collaboration in supply chain applications", Decision Support Systems [submitted in 2010]

Book Chapters

4. P.S. Tan A.E.S. Goh and S.S.G. Lee, "Chapter 9: A Context Model to support Business-to-Business (B2B) collaboration" in Enabling Context-Aware Web Services: Methods, Architectures, and Technologies, pp. 241 – 269. [To publish in 2010]

Conferences

5. P.S. Tan, A.E.S. Goh, S.S.G. Lee, E.W. Lee, "Issues and Approaches to Dynamic, Service-oriented Multi-enterprise Collaboration", 4th IEEE Industrial Informatics Conference (INDIN 2006), Singapore, 2006, pp. 399-404.
6. P.S. Tan, S.S.G. Lee, A.E.S. Goh, E.W. Lee "Context-enabled B2B Collaborations" 2007 IEEE International Conference on Services Computing (SCC 2007), Salt Lake City, Utah, USA, 2007, pp. 240-243. [Acceptance Rate: 15-18 %]

Publications Derived From This Research

7. P.S. Tan, A.E.S. Goh, S.S.G. Lee, "A Context Model for B2B Collaborations" 2008 IEEE International Conference on Services Computing (SCC 2008), Honolulu, Hawaii, USA, 2008, pp. 108-115. [Acceptance Rate: 15-18 %]
8. P.S. Tan, E.W. Lee, K. Mous, S.S.G. Lee, A.E.S. Goh, "An Implementation of Context-aware Partner Selection to Support Supply Chain Collaborations" 6th IEEE Conference on Industrial Informatics (INDIN 2008), Daejeon, South Korea, 2008, vol. 1, pp. 812 -818.
9. P.S. Tan, K. Mous, S.S.G. Lee, A.E.S. Goh, E.W. Lee "Multi-criteria, context-enabled B2B partner selection" 2008 IEEE International Conference on Systems, Man and Cybernetics (SMC 2008), Singapore, 2008, pp. 1699-1706. [Acceptance Rate: 35 %]
10. P.S. Tan, A.E.S. Goh, S.S.G. Lee, "An Ontology to support context-aware B2B services" 2010 IEEE International Conference on Services Computing (SCC 2010), Miami, Florida, USA, 2010, pp. 586 – 593. [Acceptance Rate: 15-18 %]
11. P.S.Tan, S.S.G. Lee, A.E.S. Goh, E.W. Lee "An evaluation framework to identify suitable MCDM techniques for B2B collaboration" 2010 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI 2010), Qingdao, China, 2010, pp. 446-451.

Appendices

The appendices in this section provide detailed information that will distract from the main flow in the main chapters. Each appendix follows a sequential numbering scheme, according to the referenced precedence of the referencing chapters.

Table of Contents

Appendices.....	1
Table of Contents.....	2
Appendix 1: Classification of Context Elements	3
Appendix 2: Supplier Selection Criteria – Categorisation and Analysis.....	9
Appendix 3: Details on RosettaNet Mapping	18
Appendix 4: Detailed Description of B2B Context Model Version 2.0	24
Appendix 5: An OWL-based Ontology for B2B Context Model	29
Appendix 6: Formula and Elicitations Steps of MCDM Techniques	37
Appendix 7: Fuzzy Models of the Qualitative Criteria in B2B Context Model.....	54
Appendix 8: Empirical Testing of Candidate MCDM Techniques	58
Appendix 9: Worked Examples	99
Appendix 10: Large-scale Empirical Testing of DMO and PROMETHEE II	105

Appendix 1: Classification of Context Elements

Table A1-1: Abstract Elements of Contextual Information

Contextual Pair		Description	References
Physical	Virtual	Describes whether the information is related to a physical aspect (eg: user, location) or a virtual aspect (eg: computing environment)	Conlan [43], Harroud et al. [44], Harroud and Karmouch [45]
<ul style="list-style-type: none"> • Primary • Preliminary • Sensed • Direct • Lower 	<ul style="list-style-type: none"> • Secondary • Integrated • Derived • Indirect • Aggregate 	Describes the way information is obtained: <ul style="list-style-type: none"> • Primary, sensed and typically directly obtained • Secondary, derived and usually obtained indirectly and reflects higher order context 	Samulowitz [46], Jang and Woo [50], Mostéfaoui et al. [117], Tang et al. [118], Kumar et al.[41]
Manual	Automatic	Describes the way information is obtained	Tang et al. [118], Thiele et al. [119]
<ul style="list-style-type: none"> • Internal • Context 	<ul style="list-style-type: none"> • External • Extra-Context 	Differentiates that any information within the system (application) as context (or internal) whereas information outside the system (eg: surrounding environment) as extra-context (or external)	Crowley et al. [21], Strang and Linnhoff-Popien [120], Van-Tuan Do [121]
<ul style="list-style-type: none"> • Active • Meaningful 	<ul style="list-style-type: none"> • Passive • Incidental 	Describes whether the information actively influences the decision or computation of CA computing	Anhalt et al. [55], Gunhee et al. [122], Bradley and Dunlop [42, 57]
Quantitative	Qualitative	Describes the type of information. Quantitative is typically associated with exact information, whereas qualitative is a logical state, typically not precise	Zimmermann et al. [123]

Classification of Context Elements

Table A1-2: Description and Related Works of the Physical Aspect

Category	Element	Sub-Element	Description	References
User	User Expression (Who)	-	Information relating to the user. Includes information about a user (Eg: name, identity etc).	Schmidt [124], Dey [30, 125], Samulowitz [46], Grimm [126], Kappel [127], Hess [19], Jang [50], Chen [128], Dogac [129], Mostefaoui [32], Ngo [130], De Neto [131], Castelli [132], Lee [133], Mostefaoui [134], Wang [33], Preuveneers [59], Wang [53], Riaz [135], Tang [118], Bradley [42], Kwon [136], Lundqvist [137], Roussaki [138], de Almeida [139] and Zimmermann [123]
	Role	-	Information about user role(s). (Eg: learner, teacher, consumer)	Crowley [21], Henrich [140], Mostefaoui [134], Preuveneers [59], De Neto [131], Kaltz [141], Thiele [119] and Lundqvist [137]
	Profile	-	Profile of user (eg: skill set) or information about the user (eg: age, gender, company etc)	Klemke [34], Anhalt [55], Jameson [56], Grimm [126], Baresi [142], Henrich [140], Ngo [130], Harroud [44, 45], Preuveneers [59], Ling [49], Riaz [135], De Neto [131], Thiele [119], Roussaki [138] and de Almeida [139]
	Preference	-	Information about user's preference (Eg: colour, connection mode)	Klemke [34], Jameson [56], Kappel [127], Baresi [142], Mostefaoui [134], Preuveneers [59], Ling [49], Kammanahalli [143], Lee [133], Bierig [144] and de Almeida [139]
	Current State	-	Current state of the user (Eg: in relation to the location, or the current role)	Lieberman [145], Jameson [56], Grimm [126] and Preuveneers [59]
Location	Location Expression (Where)	-	Information to identify the location (eg: room, country, Longitude/Latitude, within 1km).	Dey [30, 125], Klemke [34], Samulowitz [46], Anhalt [55], Lucas [146], Van Laerhoven [147], Hess [19, 20], Grimm [126], Kappel [127], Jang [50], Baresi [142], Schillit [148], Chen [128], Korpipaa [48], Henrich [140], Mostefaoui [32, 134], Bradley [42, 57], Pokraev [149], Dogac [129], Ngo [130], Rupnik [37], Wang [33], Harroud [44, 45], Preuveneers [59], Ling [49], Wang [53], Riaz

Classification of Context Elements

Category	Element	Sub-Element	Description	References
				[135], Tang [118], De Neto [131], Lee [133], Kaltz [141], Schmidt [124], Kwon [136], Thiele [119], Roussaki [138], Bierig [144], de Almeida [139], Zimmermann [123], Castelli [132] and Want [150]
	Definition	-	Defines the type of location information that is of interest, be it symbolic (room), geometric (address or GPS) or expression (within 1km)	Schillit [148], Ngo [130], Wang [53], Riaz [135], Bradley [42], Thiele [119], Roussaki [138], de Almeida [139] and Castelli [132]
	Profile (description)	-	Description or information about the particular location, including meta-information like services, shops etc	Grimm [126], Rupnik [37] and Bradley [57]
	Abstract Categorisation	-	Caters for abstract categorisation about location such as external vs. internal or quantitative (eg: GPS data) vs. qualitative aspects (eg: meeting place)	Strang [120], Bradley [42] and Zimmermann [123]
Temporal	Time Expression (When)	-	Information about time, could be current time stamp, duration or range.	Dey [30, 125], Klemke [34], Samulowitz [46], Anhalt [55], Hess [19, 20], Grimm [126], Kappel [127], Jang [50], Baresi [142], Korpipaa [48], Henrich [140], Mostefaoui [32, 134], Pokraev [149], Ngo [130], Wang [33], Harroud [44, 45], Preuveneers [59], Ling [49], Bradley [42, 57], Riaz [135], De Neto [131], Lee [133], Kaltz [141], Kwon [136], Thiele [119], Roussaki [138], Bierig [144], Zimmermann [123], Castelli [132]
	Granularity	-	Information about the measure of time. (Eg: minute, day, month, season)	Hess [19], Bradley [42], Thiele [119] and Castelli [132]
	History	General	Generic historical information that is time dependent. (Eg: time-stamped activities, time-stamped transactions)	Mostefaoui [32, 134, 151], Conlan [43], Anhalt [55], Bradley [42] and Zimmermann [123]
		Activity	Time-stamped past activities (or services used)	Lieberman [145], Yuan-Kai [33], Kammanahalli [143] and Bradley [57]
		User	Time-stamped past activities of a user (Eg: no. of logins, purchases, usage trends)s	Lieberman [145] and Kammanahalli [143]
		Others	Other types of historical contextual data.	Schmidt [124]

Classification of Context Elements

Category	Element	Sub-Element	Description	References
			(Eg: temperature, noise, crowd level)	
Activity	Activity Expression (What)	Activity	One of the 3 ways to describe an activity (what “user” is doing, or task)	Dey [30, 125], Samulowitz [46], Van Laerhoven [147], Grimm [126], Hess [19, 20], De Neto [131], Jang [50], Korpipaa [48], Pokraev [149], Ngo [130], Wang [33], Preuveneers [59], Ling [49], Wang [53], Riaz [135], Tang [118], Roussaki [138] and Zimmermann [123]
		Process/Task	Describes the related set of tasks that a user is undertaking, typically related to a higher order process or workflow	Schmidt [124], Crowley [21], Henrich [140], Preuveneers [59], Kaltz [141], Thiele [119] and de Almeida [139]
		Action	The “how” of executing an activity, through actions. (Eg: how to get to point A from point B (by bus or by car), or the route to take)	Jang [50] and Henrich [140]
	Intent / Goal (Why)	-	Information about the intention or purpose of undertaking an activity or sets of activities (why aspect)	Jang [50], Chen [128], Ling [49], Bradley [42] and Roussaki [138]
	Input Method	-	The way information is captured. (Eg: direct, inferred or supplied (manual))	Castelli [132]
	Others	-	Other artifacts that is either arising from an activity or related to an activity. (Eg: Project (scope), documentation, task-dependent profiles or interaction schema)	Henrich [140] and De Neto [131]
Others	Social Environment	-	The human-aspect of the environment that a user interacts with. (Eg: community, friends, relationship)	Bradley [57], Mostefaoui [134], Pokraev [149], Rupnik [37], Wang [33], Ling [49], Bradley [42, 57], De Neto [131], Schmidt [124] and de Almeida [139]
	Physical Environment	-	The physical environment that a user or service interacts with. (Eg: temperature, noise level, illumination levels.)	Lieberman [145], Korpipaa [48], Mostefaoui [134], Pokraev [149], Ngo [130], Rupnik [37], Preuveneers [59], Riaz [135], Bradley [42], De Neto [131] and Schmidt [124]
	Computing Environment	General	A general category to capture computer related parameters or profiles like network, software or	Mostefaoui [151], Conlan [43], Wang [33],

Classification of Context Elements

Category	Element	Sub-Element	Description	References
			computational capabilities.	Preuveneers [59], Ling [49], Wang [53] and Roussaki [138]
		Network	Information related to computing networks. (Eg: bandwidth, availability, types.)	Kappel [127], Mostefaoui [134], Pokraev [149], Rupnik [37], Harroud [44, 45], Wang [53], Thiele [119] and Roussaki [138]
		System (application)	Information about the types of applications or software that can function in a particular environment. (Eg: Given a device, what are the software that can be executed)	Lieberman [145], Crowley [21], Grimm [126], Kappel [127], Ngo [130], Harroud [44, 45], Riaz [135], Bradley [42] and Roussaki [138]
		Device	Information regarding the supported devices and device profiles. This includes information like the capabilities (in terms of compute power, memory etc), specifications etc.	Lucas [146], Kappel [127], Korpipaa [48], Pokraev [149], Mostefaoui [32], Ngo [130], Rupnik [37], Wang [53], Riaz [135], De Neto [131], Lee [133], Kaltz [141] and Thiele [119]
		Service	Information on services supported or available to a particular set of contextual information	Mostefaoui [32], Ngo [130], Preuveneers [59], Riaz [135] and Lee [133]

Supplier Selection Criteria – Categorisation and Analysis

Table A1-3: Description and Related Works of the Cognitive and Information Aspects

Aspect	Element	Description	References
Cognitive	User / Role	Information relating to the user, including background information	Prekop [40], Kaenampornpan [58] and Ling [49]
	Activity	Tasks or sequences of tasks	Prekop [40], de Almeida [139] and Kaenampornpan [58]
	Intent	Goal or intended outcome of activity	Kaenampornpan [58] and Bradley [42]
	History (Time-based)	Past activities	Kaenampornpan [58] and Bradley [42]
	Social	The human-aspect of the environment that a user interacts with. (Eg: community, friends, relationship)	Kaenampornpan [58], Bradley [42] and de Almeida [139]
	Emotional/mental	Psychological state of user, that may affect how the user interact or use the service/system	Jameson [56], Wang [33], Preuveneers [59], Ling [49], Lee [133], Bradley [42] and de Almeida [139]
	Others	Tools, rules or other artifacts that are contextually relevant, including context scope	Prekop [40], Kaenampornpan [58], Ling [49] and Ling [49]
Information Management	Information	Scope of information that computation takes place	Lucas [146], Rupnik [37], Bradley [42] and Lundqvist [137]
	Domain	Domain specific context information (Eg: position in company or project)	Klemke [34], Henrich [140], Bradley [42] and Lundqvist [137]
	Meta-data	Any type of meta-data that is tagged to information	Huang [35]

Appendix 2: Supplier Selection Criteria – Categorisation and Analysis

Table A2-1: Classification, description and related works of the Supplier Selection Categories

Category	Sub-Category	Factor	References
Cost	-	Cost/Price (quotes or sales price associated with a service or part)	Shipley and Prinja [152], Handfield [153], Vokurka et al. [154], De Toni and Nassimbeni [155], Masella and Rangone [156], Ghodsypour and O'Brien [157], Altuntas et al. [158], Garfamy [159], Dianting et al. [160], Hao and Ju [161], Huang and Keskar [162], Karthik [163], Narasimhan et al. [164], Wu and Shen [165], Wu et al. [166], Xiaoli and Purchase [167], Yang and Chen [168], Aguezzoul and Ladet [169], Chan et al. [170], Chan and Kumar [171], Jain et al. [172], Liu [173], Sevkli et al. [174], Tan et al. 2007b [175], Wang [176], Yee Ming and Pei-Ni [177], Yigin et al. [178], Zheng et al. [179], Zhu [180], Chan et al. [181], Che and Wang [182], Chou and Chang [183], Demirtas and Ustun [184], Kull and Talluri [185], Li et al. [186], Shin-Chan and Cho [187], Sen et al. [188], Sevkli et al. [189]
	-	Total Logistics Cost (incl. storing & holding cost, ordering/outsourcing cost)	Ghodsypour and O'Brien [157], Dan et al. [190], Wang et al. [191], Yee Ming and Pei-Ni [177], Zhang et al. [192], Jain et al. [172], Tan et al. 2007a [193], Chan et al. [181], Shin-Chan and Cho [187], Sen et al. [188]
	-	Pricing Structure (e.g. Linear / non-linear, Quantity discount)	Ghodsypour and O'Brien [157], Eon-Kyung et al. [194], Hao and Ju [161], Nukala and Gupta [195], Song et al. [196], Jain et al. [172], Kannan and Haq [197]
	-	Transportation Cost (transporting of goods to designated customer location)	Ghodsypour and O'Brien [157], Chan and Kumar [171], Jain et al. [172], Kannan and Haq [197], Tan et al. 2007a [193]
	-	Payment terms/Credit Terms	Shipley and Prinja [152], Xiaoli and Purchase [167], Jain et al. [172], Kannan and Haq [197]
	-	Tariff and Custom Duties	Chan and Kumar [171], Chan et al. [181], Sen et al. [188]
	-	Others (e.g. landed cost, warranty cost, returns, material, maintenance, mfg, inspection, indirect, quality, tech, after sales, transparency, foreign exchange fluctuation)	Ghodsypour and O'Brien [157], Kannan and Tan [198], Dan et al. [190], Wang et al. [191], Altuntas et al. [158], Garfamy [159], Narasimhan et al. [164], Nukala and Gupta [195], Zhang et al. [192], Gencer and Gurpinar [199], Jain et al. [172], Kannan and Haq [197], Tan et al. 2007a [193], Ozgen et al. [200], Pal and Kumar [201], Ustun and Demirtas [202]
Ability-to-Deliver (Speed, Responsiveness & Capacity)	-	Order Lead Time (incl. delivery & manufacturing lead time)	Shipley and Prinja [152], Handfield [153], Vokurka et al. [154], Masella and Rangone [156], Eon-Kyung et al. [194], Ghodsypour and O'Brien [157], Cebi and Bayraktar [203], Kannan and Tan [198], Wang et al. [191], Altuntas et al. [158], Chen et al. [204], Karthik [163], Wu and Shen [165], Aguezzoul and Ladet [200], Chan and Kumar [171], Gencer and Gurpinar [199], Kannan and Haq [197], Liu [173], Yee Ming and

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor	References
			Pei-Ni [177], Yigin et al. [178], Zheng et al. [179], Che and Wang [182], Chou and Chang [183], Kull and Talluri [185], Li et al. [186], Ozgen et al. [200], Pal and Kumar [201], Sevkli et al. [189], Shin-Chan and Cho [187], Ustun and Demirtas [202], Wang [176]
	-	Responsiveness to changes (Ability to accommodate changes incl. design and demand/order)	Masella and Rangone [156], Cebi and Bayraktar [203], Kannan and Tan [198], Wang et al. [191], Altuntas et al. [158], Hao and Ju [161], Karthik [163], Nukala and Gupta [195], Chan and Kumar [171], Huang and Keskar [162], Jain et al. [172], Kannan and Haq [197], Yee Ming and Pei-Ni [177], Carter et al. [205], Chan et al. [181], Kull and Talluri [185], Kung [206], Li et al. [186], Ozgen et al. [200], Sen et al. [188], Shin-Chan and Cho [187], Ustun and Demirtas [202]
	-	Delivery Performance (Reliability, speed, flexibility & compliance to quantity, on-time-delivery)	Shipley and Prinja [152], De Toni and Nassimbeni [155], Eon-Kyung et al. [194], Ghodsypour and O'Brien [157], Dan et al. [190], Wang et al. [191], Altuntas et al. [158], Karthik [163], Narasimhan et al. [164], Nukala and Gupta [195], Xiaoli and Purchase [167], Yang and Chen [168], Zhang et al. [192], Yee Ming and Pei-Ni [177], Zhu [180], Hao and Ju [161], Jain et al. [172], Chan et al. [181], Ozgen et al. [200], Sen et al. [188], Shin-Chan and Cho [187]
	-	Physical Proximity -location (Distance between supplier and delivery destinations)	Dan et al. [190], Zhang et al. [192], Altuntas et al. [158], Nukala and Gupta [195], Yang and Chen [168], Gencer and Gurpinar [199], Chan and Kumar [171], Jain et al. [172], Zheng et al. [179], Sevkli et al. [174], Chan et al. [181], Sen et al. [188]
	-	Production Capacity	Eon-Kyung et al. [194], Ghodsypour and O'Brien [157], Aguezzoul and Ladet [169], Garfamy [159], Yang and Chen [168], Jain et al. [172], Sevkli et al. [174], Tan et al. 2007a [193], Che and Wang [182], Chou and Chang [183]
	-	Fill rate (number of units filled as a percentage of total order)	Wang et al. [191], Jain et al. 2007[172], Yee Ming and Pei-Ni [177], Ozgen et al. [200]
	-	Response Time (to changes, incl. design, demand & supply chain)	Handfield 1994[153], Wang et al. [191], Wu and Shen [165], Song et al. [196], Jain et al. [172], Ozgen et al. [200]
	-	Logistics Capability (incl. distribution capacity & transportation modes support)	Shipley and Prinja [152], Jain et al. [172], Kannan and Haq [197]
	-	Others (e.g. Change process mgmt, contractual terms/conditions, track record of defect free delivery, production downtime, prototyping time, safety)	Jackson et al. [207], Eon-Kyung et al. [194], Cebi and Bayraktar [203], Kannan and Tan [198], Song et al. [196], Kannan and Haq [197], Sevkli et al. [174], Pal and Kumar [201]
Capabilit	-	Technical	De Toni and Nassimbeni [155], Oliveira and Lourenco

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor	References
y		Capability/Technology Levels (incl. know-how and problem solving)	[208], Cebi and Bayraktar [203], Kannan and Tan [198], Altuntas et al. [158], Garfamy [159], Nukala and Gupta [195], Song et al. [196], Wu and Shen [165], Wu et al. [166], Xiaoli and Purchase [167], Yang and Chen [168], Gencer and Gurpinar [199], Jain et al. [172], Kannan and Haq [197], Sevkli et al. [174], Bottani and Rizzi [209], Chan et al. [181], Chou and Chang [183], Sen et al. [188], Sevkli et al. [189]
	-	Design Capability (incl. innovation and co-design)	Masella and Rangone [156], Dan et al. [190], Kung [206], Nukala and Gupta [195], Song et al. [196], Wu and Shen [165], Zhang et al. [192], Jain et al. [172], Chou and Chang [183], Sevkli et al. [189], Shin-Chan and Cho [187], Ustun and Demirtas [202],
	-	R & D Capability (incl. patents, staff's qualification)	Eon-Kyung et al. [194], Karthik [163], Sheu Hua and Hong Tau [210], Chan and Kumar [171], Gencer and Gurpinar [199], Jain et al. 2007[172], Liu [173], Sevkli et al. [174], Sevkli et al. [189]
	Manufacturing	Manufacturing technology (incl. testing and packaging)	Shiple and Prinja [152], Handfield [153], Kannan and Tan [198], Hao and Ju [161], Gencer and Gurpinar [199], Jain et al. [172], Sen et al. [188]
		Manufacturing Competency (incl. applying JIT/Kanban, Lean, etc)	Kannan and Tan [198], Polansky [211], Zhang et al. [192], Xiaoli and Purchase [167], Liu [173], Yigin et al. [178], Zhu [180], Chan et al. [181], Chou and Chang [183], Sen et al. [188]
		Others (e.g. improvements, resources availability, similar product experience, product range/variety)	Shiple and Prinja [152], Cebi and Bayraktar [203], Kannan and Tan [198], Jain et al. [172], Kannan and Haq [197], Chan et al. [181], Sen et al. [188]
	Operational	ICT Capabilities (e.g. System, RFID, Internet, EDI etc)	Kannan and Tan [198], Sevkli et al. 2007[174], Yang and Chen [168], Jain et al. [172], Kannan and Haq [197], Sevkli et al. [189], Yee Ming and Pei-Ni [177]
		Production Planning (e.g. order handling, inventory mgmt, mfg planning)	Gencer and Gurpinar [199], Kannan and Haq [197], Pal and Kumar 2008[201]
	Service	Customer Service (handling requests/queries & follow-up)	Ghodsypour and O'Brien [157], Masella and Rangone [156], Dianting et al. [160], Wu and Shen [165], Yang and Chen [168], Wu et al. 2006[166], Kannan and Haq [197], Gencer and Gurpinar [199], Pal and Kumar [201]
		After Sales Service (include follow-ups)	Shiple and Prinja [152], Vokurka et al. [154], Garfamy [159], Hao and Ju [161], Wu and Shen [165], Kannan and Haq [197], Jain et al. [172], Liu [173]
		Customer Intelligence (incl. data collection & actions)	Jackson et al. [207], Bottani and Rizzi [209], Chan et al. [181]
		Others (e.g. staff competency, ease of product maintenance, spare	Shiple and Prinja [152], Wu and Shen [165], Kannan and Haq [197]

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor	References
		parts availability)	
Quality	-	Product Quality (condition of product according to specification, incl. product quality)	Shipley and Prinja [152], Handfield [153], Weber et al. 1991 [212], De Toni and Nassimbeni [155], Eon-Kyung et al. [194], Ghodsypour and O'Brien [157], Masella and Rangone [156], Dan et al. [190], Altuntas et al. [158], Chen et al. [204], Chen and Chen [213], Garfamy [159], Hao and Ju [161], Dianting et al. [160], Karthik [163], Kung [206], Narasimhan et al. [164], Wu and Shen [165], Wu et al. 2006[166], Xiaoli and Purchase [167], Yang and Chen [168], Zhang et al. [192], Chan and Kumar [171], Jain et al. [172], Kannan and Haq [197], Liu [173], Ni et al. [214], Yee Ming and Pei-Ni [177], Yigin et al. [178], Zheng et al. [179], Zhu [180], Che and Wang [182], Chou and Chang [183], Kull and Talluri [185], Li et al. [186], Shin-Chan and Cho [187], Demirtas and Ustun [184], Sen et al. [188], Wang [176],
	Quality Infrastructure	Quality Strategy & Management (incl. assurance / management & implementation of system)	Jackson et al. [207], Carvalho Oliveira and Lourenco [215], Oliveira and Lourenco [208], Kannan and Tan [198], Altuntas et al. [158], Wu and Shen [165], Hao and Ju [161], Song et al. [196], Gencer and Gurpinar [199], Chan and Kumar [171], Hsu and Hu [216], Kannan and Haq [197], Liu [173], Sevkli et al. [174], Chan et al. [181], Sen et al. [188], Sevkli et al. [189], Shin-Chan and Cho [187]
		Corrective Actions (incl. attitude, contingency / remedy actions & responsiveness)	Jackson et al. [207], Eon-Kyung et al. [194], Hao and Ju [161], Chan and Kumar [171], Pal and Kumar [201], Sen et al. [188]
	Product Performance	Reject / Defect Rate	Eon-Kyung et al. [194], Hao and Ju [161], Karthik [163], Wu and Shen [165], Chan and Kumar [171], Kannan and Haq [197], Tan et al. 2007b [175], Shin-Chan and Cho [187], Sen et al. [188]
		Product Reliability (e.g. On-time-delivery)	Wu and Shen [165], Jain et al. [172], Liu [173], Chan et al. 2008[181]
	-	Quality Certification	Oliveira and Lourenco [208], Altuntas et al. [158], Karthik [163], Gencer and Gurpinar [199], Jain et al. [172]
	-	Others (e.g. site evaluation, % of dissatisfied customers, improvement ability, quality capability, benchmark studies)	Jackson et al. [207], Oliveira and Lourenco 2002[208], Kannan and Tan [198], Sheu Hua and Hong Tau [210], Wu and Shen [165], Pal and Kumar [201]
Organisational	-	Financial Status / Position (Current & Past)	De Toni and Nassimbeni [155], Eon-Kyung et al. [194], Cebi and Bayraktar [203], Kannan and Tan [198], Altuntas et al. [158], Hao and Ju [161], Karthik [163], Nukala and Gupta [195], Sheu Hua and Hong Tau [210], Yang and Chen [168], Wu and Shen [165], Yee Ming and Pei-Ni [177], Chan and Kumar [171], Jain et al. [172], Kannan and Haq [197], Liu [173],

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor	References
			Chan et al. [181], Chou and Chang [183], Sen et al. [188], Shin-Chan and Cho [187]
	-	Company's Reputation (product and company)	Cebi and Bayraktar [203], Kannan and Tan [198], Hao and Ju [161], Karthik [163], Nukala and Gupta [195], Wu et al. [166], Wu and Shen [165], Xiaoli and Purchase [167], Gencer and Gurpinar [199], Jain et al. [172], Sevkli et al. [174], Yee Ming and Pei-Ni [177], Chan et al. [181], Chou and Chang [183], Sen et al. [188], Sevkli et al. [189]
	-	Level of Co-operation & Communication	Eon-Kyung et al. [194], Cebi and Bayraktar [203], Kannan and Tan [198], Karthik [163], Nukala and Gupta [195], Sheu Hua and Hong Tau [210], Wu and Shen [165], Xiaoli and Purchase [167], Zhang et al. [192], Chan and Kumar [171], Gencer and Gurpinar [199], Chan et al. [181], Chou and Chang [183], Sen et al. [188]
	-	Management Capability (incl. strategy, structure, outlook & skills)	Vokurka et al. [154], Oliveira and Lourenco [215], Cebi and Bayraktar [203], Hao and Ju [161], Carvalho Gencer and Gurpinar [199], Jain et al. [172], Liu [173], Yee Ming and Pei-Ni [177], Chou and Chang [183], Sevkli et al. [189]
	-	Cultural Compatibility (incl. ethical standards, integrity, ability to resolve differences, staff development)	Handfield [153], Jackson et al. [207], Kannan and Tan [198], Altuntas et al. [158], Chen et al. [204], Hao and Ju [161], Karthik [163], Wu and Shen [165], Gencer and Gurpinar [199], Jain et al. [172], Liu [173], Sevkli et al. [174], Carter et al. [205], Chou and Chang [183], Sen et al. [188], Sevkli et al. [189]
	-	Profitability (incl. Turnover)	Kannan and Tan [198], Chen et al. [204], Karthik [163], Wu and Shen [165], Yang and Chen [168], Gencer and Gurpinar [199], Shin-Chan and Cho [187]
	-	History (past relationships, level of trust built, past business)	Handfield [153], Kannan and Tan [198], Chen et al. [204], Wu and Shen [165], Chan and Kumar [171], Jain et al. [172], Levary [217], Chou and Chang [183], Sen et al. [188]
	Risk	Conduciveness for Business (incl. economic position, terrorism / crime rate, technological level, infrastructure, overseas exposure, outsourcing exposure, % of company's turnover etc)	Kannan and Tan [198], Hao and Ju [161], Levary [217], Chan and Kumar [171], Gencer and Gurpinar [199], Jain et al. [172], Carter et al. [205], Chan et al. [181]
		Safety track record & compliance	Carvalho Oliveira and Lourenco [215], Nukala and Gupta [195], Huang and Keskar [162], Chou and Chang [183]
		Political stability and foreign policies (political)	Hao and Ju [161], Chan and Kumar [2007], Levary [217], Carter et al. [205], Chan et al. [181]
		Industry knowledge (incl. years of operation & familiarity)	Kannan and Tan [198], Gencer and Gurpinar [199], Kannan and Haq [197]
	-	Societal Consciousness	Humphreys et al. [218], Ozgen et al. [200]

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor	References
Environmental		(e.g. Going Green, Helping the community, Design for environment)	
	-	Others (e.g. marketing, overseas business dealings, strategic alliance, company size)	Shipley and Prinja [152], Xiaoli and Purchase [167], Kannan and Tan [198], Gencer and Gulpinar [199], Jain et al. [172], Sevkli et al. [174], Sevkli et al. [189]
	-	Programs/Policies (code of conduct)	Humphreys et al. [218], Tate et al. [219], Hsu and Hu [216], Ozgen et al. [200]
	-	Certification (ISO 14001/OSHAS 18001/EMS)	Humphreys et al. [218], Tate et al. [219], Hsu and Hu [216], Jain et al. [172]
	-	Compliance with regulatory requirements such as RoHS (incl. Environmental Mgmt Systems for waste, and carbon emission, footprint etc)	Humphreys et al. [218], Tate et al. [219], Hsu and Hu [216], Ozgen et al. [200]
	-	Green Design Considerations (reuse, recycle, remanufacture, disassembly, disposal, material)	Humphreys et al. [218], Ozgen et al. [200]

Table A2-2: An analysis of supplier selection criteria for inclusion the context model

Category	Sub-Category	Factor ¹	Information Readiness & Importance				
			Type ²	Nature	Potential Sources	Difficulty ³	Importance ⁴
Cost	-	Cost/Price	QTT	Simple	<ul style="list-style-type: none"> List Price (catalogues) Quotations Invoices 	Easy	High
	-	Total Logistics Cost	QTT	Simple	<ul style="list-style-type: none"> Enterprise System 	Difficult	High
	-	Pricing Structure	QTT	Simple	<ul style="list-style-type: none"> Quotations Past transaction trends 	Easy	Medium
	-	Transportation Cost	QTT	Simple	<ul style="list-style-type: none"> Quotations List Price (catalogues) Published rates 	Easy	High
	-	Payment Terms	QTT	Simple	<ul style="list-style-type: none"> Quotations Contractual agreement 	Easy	Medium
	-	Tariff and	QTT	Simple	<ul style="list-style-type: none"> Quotations 	Easy	Medium

¹ Most factors in *Others* are ignored, as they are an assortment, and by virtue of appearing in *Others*, are not cited often

² QTT = Quantitative, QLT = Qualitative

³ Level of Difficulty in processing or obtaining the contextual information (easy, moderate, difficult)

⁴ Importance of information to support ad-hoc B2B collaboration

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor ¹	Information Readiness & Importance				
			Type ²	Nature	Potential Sources	Difficulty ³	Importance ⁴
		Custom Duties			<ul style="list-style-type: none"> Published country reports (eg: World Bank information) 		
	-	Other costs	QTT	Simple ⁵	<ul style="list-style-type: none"> Published country reports (eg: World Bank information) 	Easy	Medium
Ability to deliver - related to speed & capacity	-	Order Lead Time	QTT	Simple	<ul style="list-style-type: none"> Published reports Quotation 	Easy	High
	-	Responsiveness to changes	QLT	Aggregate	<ul style="list-style-type: none"> Past experiences 	Difficult	Medium
	-	Delivery Performance ⁶	QTT	Simple	<ul style="list-style-type: none"> Past experiences 	Easy	High
	-	Physical Proximity	QTT	Simple	<ul style="list-style-type: none"> GPS data 	Easy	Medium
	-	Production Capacity	QTT	Simple	<ul style="list-style-type: none"> Published reports Quotation 	Easy	High
	-	Fill rate	QTT	Simple	<ul style="list-style-type: none"> Forecast Past records 	Moderate	Medium
	-	Response Time	QTT	Simple	<ul style="list-style-type: none"> Past records 	Moderate ⁷	Low
	-	Logistics Capability	QTT ⁸ and QLT	Simple ⁸	<ul style="list-style-type: none"> Published reports Quotation Third party logistics provider (3PL) 	Easy ⁸	Medium
	-	Technical Capability / Technology Levels	QLT	Aggregate	<ul style="list-style-type: none"> Staff Profiles Past Records Patent Portfolio 	Difficult	Medium
Capability	-	Design Capability	QLT	Aggregate	<ul style="list-style-type: none"> Past Products Patent Portfolio 	Difficult	Low ⁹
	-	R & D Capability	QLT	Aggregate	<ul style="list-style-type: none"> Staff Profiles Patent Portfolio 	Difficult	Low
	-	Manufacturing Technology	QLT	Aggregate	<ul style="list-style-type: none"> Company profiles Past records 	Difficult	Low

⁵ If the different costs are accessed singly

⁶ Measured as On-Time Delivery

⁷ Needs to be accumulated over time

⁸ If different sub-elements of information is processed separately than it is quantitative, otherwise it becomes an aggregate qualitative type

⁹ This varies, if co-design is needed, this might be high, otherwise it would low.

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor ¹	Information Readiness & Importance				
			Type ²	Nature	Potential Sources	Difficulty ³	Importance ⁴
					• Equipment list		
	-	Manufacturing Competency	QLT	Aggregate	• Quality Manuals • Downtime records	Difficult	Low
	-	ICT Capabilities	QLT	Aggregate	• Published or shared reports	Moderate	Low
	-	Production Planning	QLT	Aggregate	• Published or shared reports	Difficult	Low
	-	Customer Service	QLT	Aggregate	• Published or shared reports • Past experiences	Difficult	High
	-	After Sales Service	QLT	Aggregate	• Published or shared reports • Past experiences	Difficult	High
	-	Customer Intelligence	QLT	Aggregate	• Published or shared reports	Difficult	Low
Quality	-	Product Quality	QTT	Aggregate	• Product Specifications • Quality Audit • Past quality records (work-in-progress, finished goods, incoming)	Moderate	Medium
	Quality Infrastructure	Strategy & Management	QLT	Aggregate	• On-site inspection • Quality Manual	Difficult	Medium
		Corrective Actions	QLT	Aggregate	• Quality Manual • Past Experiences	Difficult	High
	Product Performance	Reject / Defect Rate	QTT	Simple	• Past Records	Moderate ⁷	High
		Product Reliability	QTT	Aggregate	• Past Records • Published reports	Moderate	High
	-	Quality Certification	QLT	Simple	• Quality manuals • Certification records	Easy	High
Organisation	-	Financial Status	QTT	Aggregate	• External reports • Company reports	Easy ¹⁰	High
	-	Company's Reputation	QLT	Aggregate	• External reports • Worth of mouth • Past experiences	Difficult	Medium
	-	Level of Co-operation & Communication	QLT	Aggregate	• Past experiences ⁷	Difficult	Low
	-	Management Capability	QLT	Aggregate	• Past experiences • Past performance	Difficult	Low

¹⁰ If assessed as Financial Rating, otherwise will be difficult to process

Supplier Selection Criteria – Categorisation and Analysis

Category	Sub-Category	Factor ¹	Information Readiness & Importance				
			Type ²	Nature	Potential Sources of company	Difficulty ³	Importance ⁴
	-	Cultural Compatibility	QLT	Aggregate	<ul style="list-style-type: none"> Past experiences Company reports 	Difficult	Low
	-	Profitability (incl. Turnover)	QTT	Simple	<ul style="list-style-type: none"> Past records Published reports 	Easy	High
	-	History	QLT	Aggregate	<ul style="list-style-type: none"> Past experiences 	Difficult	Low
	Risk	Conduciveness for Business	QTT	Simple ¹¹	<ul style="list-style-type: none"> Published reports 	Easy	High
		Safety track record & compliance	QLT	Simple	<ul style="list-style-type: none"> Published reports Certification & audit records 	Medium	Medium
		Political stability and foreign policies	QLT	Aggregate	<ul style="list-style-type: none"> Published reports 	Difficult	Medium
	-	Industry knowledge	QLT	Aggregate	<ul style="list-style-type: none"> Past experiences Word of mouth 	Difficult	Medium
	-	Societal Consciousness	QLT	Aggregate	<ul style="list-style-type: none"> Published reports Past experiences 	Difficult	Low
Environmental	-	Programs / Policies	QLT	Aggregate	<ul style="list-style-type: none"> Published reports 	Difficult	Medium
	-	Certification	QLT	Simple	<ul style="list-style-type: none"> Published reports Certification records 	Simple	Medium
	-	Compliance with regulatory requirements such as RoHS	QLT	Simple	<ul style="list-style-type: none"> Published reports Audit records 	Medium	Medium
	-	Green Design Considerations	QLT	Aggregate	<ul style="list-style-type: none"> Past experiences Past designs 		Low ⁹

¹¹ Assumes the use of Ease of Doing Business (published data from World Bank) for country level assessment

Appendix 3: Details on RosettaNet Mapping

Table A3-1: RosettaNet PIP 3A1 Payload

RosettaNet XML Message Guidelines

3A2_MG_R02_01_00B_PriceAndAvailabilityRequest.htm (09-Apr-2002 00:00:00)

This document has been prepared by RosettaNet (<http://www.rosettanet.org>) from requirements gathered during the cluster/segment workshops and in conformance with the RosettaNet methodology.

1	1			fromRole.PartnerRoleDescription
2	1		--	ContactInformation
3	1			contactName.FreeFormText
4	1			EmailAddress
5	0..1			facsimileNumber.CommunicationsNumber
6	1			telephoneNumber.CommunicationsNumber
7	1		--	GlobalPartnerRoleClassificationCode
8	1		--	PartnerDescription
9	1			BusinessDescription
10	1			GlobalBusinessIdentifier
11	1			GlobalSupplyChainCode
12	1			GlobalPartnerClassificationCode
13	1			GlobalDocumentFunctionCode
14	1			ProductPriceAndAvailabilityQuery
15	0..n		--	BusinessConstraint
16	1..n		--	ProductPriceAndAvailability
17	0..n			GlobalPricingTypeCode
18	1			isAdditionalInformationAllowed.AffirmationIndicator
19	0..1			PriceCondition
20	0..1			contractIdentifier.ProprietaryDocumentIdentifier
21	0..1			generalServicesAdministrationNumber.ProprietaryDocumentIdentifier
22	0..1			specialPriceCondition.FreeFormText
23	0..1			priceListIdentifier.ProprietaryReferenceIdentifier
24	1..n			ProductPriceAndAvailabilityLineItem
25	0..1			estimatedAvailabilityDate.DatePeriod
26	0..1			beginDate.DateStamp
27	0..1			endDate.DateStamp
28	0..1			GlobalProductStatusCode
29	0..n			GlobalProductUnitOfMeasureCode
30	1			LineNumber
31	0..n			PriceList
32	1			priceListIdentifier.ProprietaryReferenceIdentifier
33	0..1			unitPrice.FinancialAmount
34	1			GlobalCurrencyCode
35	1			MonetaryAmount
36	1..n			ProductAvailability
37	0..1			estimatedAvailabilityDate.DatePeriod
38	0..1			beginDate.DateStamp
39	0..1			endDate.DateStamp
40	1			ProductQuantity
41	1			ProductIdentification
42	0..1			GlobalProductIdentifier

Details on RosettaNet Mapping

43	0..n						-- PartnerProductIdentification
44	1						-- GlobalPartnerClassificationCode
45	1						-- ProprietaryProductIdentifier
46	0..1						-- revisionIdentifier.FreeFormText
47	0..1						-- unitPrice.FinancialAmount
48	1						-- GlobalCurrencyCode
49	1						-- MonetaryAmount
50	0..n						-- WarehouseInformation
51	1						-- warehouseAddress.PhysicalAddress
52	0..1						-- addressLine1.FreeFormText
53	0..1						-- addressLine2.FreeFormText
54	0..1						-- addressLine3.FreeFormText
55	0..1						-- cityName.FreeFormText
56	0..1						-- GlobalCountryCode
57	0..1						-- GlobalLocationIdentifier
58	0..1						-- NationalPostalCode
59	0..1						-- postOfficeBoxIdentifier.FreeFormText
60	0..1						-- regionName.FreeFormText
61	0..n						-- WarehouseQuantityInformation
62	0..1						-- warehouseAvailabilityDate.DatePeriod
63	1						-- beginDate.DateStamp
64	0..1						-- endDate.DateStamp
65	0..1						-- warehouseQuantity.ProductQuantity
66	0..1						purchasedBy.PartnerRoleDescription
67	0..1						-- GlobalPartnerRoleClassificationCode
68	0..1						-- PartnerDescription
69	0..1						-- BusinessDescription
70	1						-- GlobalBusinessIdentifier
71	0..1						-- GlobalPartnerClassificationCode
72	1						thisDocumentGenerationDateTime.DateTimeStamp
73	1						thisDocumentIdentifier.ProprietaryDocumentIdentifier
74	1						toRole.PartnerRoleDescription
75	0..1						-- ContactInformation
76	1						-- contactName.FreeFormText
77	1						-- EmailAddress
78	0..1						-- facsimileNumber.CommunicationsNumber
79	1						-- telephoneNumber.CommunicationsNumber
80	1						-- GlobalPartnerRoleClassificationCode
81	1						-- PartnerDescription
82	1						-- BusinessDescription
83	1						-- GlobalBusinessIdentifier
84	1						-- GlobalSupplyChainCode
85	1						-- GlobalPartnerClassificationCode

Details on RosettaNet Mapping

Table A3-2: Detailed Mapping of Selected RossetaNet PIPs to the B2B Context Model (Version 1.0)

[illegible]

Details on RosettaNet Mapping

Table A3-3: Mapping results categorised by Influencing Factors

Influencing Factors		PIP Element (leaf and non-leaf node)	Definition	PIP Source	Mapped to? (B2B Context Model Version 1.0)
Primary	-	-	-	-	-
	Delivery Exception	-- DeliveryException -- DateTimeStamp -- FreeFormText	The collection of business properties which allows a Transport Service Provider to advise a consignee of delivery status exception reason and time.	3B3 Distribute Shipment Status	Location::TransportationMode Location::Geographical Expression
Secondary	Step Pricing	-- StepPricing -- DatePeriod -- beginDate.DateStamp -- endDate.DateStamp -- ProductPricing -- FinancialAmount -- GlobalCurrencyCode -- GlobalMonetaryAmountTypeCode -- InvoiceChargeTypeCode -- MonetaryAmount -- GlobalPriceTypeCode -- ProductQuantityRange -- maximumOrderQuantity.ProductQuantity --minimumOrderQuantity.ProductQuantity	The collection of business properties that describe a product's variance in pricing in regards to specified date ranges and quantities.	3A1 Request Quote	User::ProductService:Price
	Interest Information	-- InterestInformation -- interestAmountDue.FinancialAmount -- GlobalCurrencyCode -- MonetaryAmount -- interestDays.CountableAmount -- interestOnAmountDue.FinancialAmount -- GlobalCurrencyCode -- MonetaryAmount -- InterestRate -- GlobalIntervalCode	The collection of business properties that describe interest information.	3C5 Notify of Billing Statement	User::ProductService::Price::PaymentTerm

Details on RosettaNet Mapping

Influencing Factors	PIP Element (leaf and non-leaf node)	Definition	PIP Source	Mapped to? (B2B Context Model Version 1.0)
	-- PercentAmount			
Terms And Conditions Information	-- TermsAndConditionsInformation -- guaranteedPeriod.DatePeriod -- beginDate.DateStamp -- endDate.DateStamp -- termsAndConditions.FreeFormText	The collection of business properties that describe the terms and conditions agreed between two parties under which a product or service is provided.	3A1 Request Quote	User::ProductService::Price
Handling Charges	-- handlingCharges.FinancialAmount -- GlobalCurrencyCode -- GlobalMonetaryAmountTypeCode -- InvoiceChargeTypeCode -- MonetaryAmount	The monetary amount to be paid for product handling for pre-, during and post-transportation.	3A1 Request Quote 3C1 Return Product	User::ProductService::Price
Tertiary	Contact Information -- ContactInformation -- contactName.FreeFormText -- EmailAddress -- facsimileNumber.CommunicationsNumber -- telephoneNumber.CommunicationsNumber	The collection of business properties that provide communication and address information for contacting a person, organization or business.	All PIPs	User::UserExpression::ContactInformation
	Storage Description -- StorageInformation -- StorageDescription -- PhysicalDimension -- HeightDimension -- LengthDimension -- VolumeDimension -- WeightDimension -- WidthDimension	The collection of business properties that describe properties of goods or packages being held in storage.	3B1 Distribute Transport Projection	User::ProductService::Spec
	Mass Physical Dimension -- MassPhysicalDimension -- Volume -- GlobalPhysicalUnitOfMeasureCode -- Mass -- Weight -- GlobalPhysicalUnitOfMeasureCode -- Mass	The physical dimension of unit of mass used for measuring the masses of weights, volumes etc.	3B12 Requesting Shipping Order	User::ProductService::Spec
	Proprietary Information -- proprietaryInformation.FreeFormText	A free form textual description of information, relating to a product.	3A4 Request PO 3A6 Distribute	User::ProductService::Description

Details on RosettaNet Mapping

Influencing Factors	PIP Element (leaf and non-leaf node)	Definition	PIP Source	Mapped to? (B2B Context Model Version 1.0)
			Order Status 3C7 Notify of Self-Billing Invoice	
Product Identification	-- ProductIdentification -- GlobalProductIdentifier -- PartnerProductIdentification -- GlobalPartnerClassificationCode -- ProprietaryProductIdentifier -- revisionIdentifier.FreeFormText	The collection of business properties that describe proprietary and global identifier information regarding a product.	3A1 Request Quote 3A4 Request PO 3A6 Distribute Order Status 3B12 Requesting Shipping Order 3C1 Return Product 3C7 Notify of Self-Billing Invoice 4B3 Notify Of Consumption 4D1 Notify Of Material Release 7B1 Work In Process Notification	User::ProductService::Description

Detailed Description of B2B Context Model Version 2.0

Appendix 4: Detailed Description of B2B Context Model Version 2.0

Table A4-1: *OrganisationalProfile* Category of B2B Context Model

B2B Context (Version 2.0)	Mandatory?	Type	Description	Values (example)
Organisational Expression	Yes	Category	Category to store direct organisation	-
-- CompanyName	Yes	Descriptive	Name of the product or service	Car, nut, computer, hardisk
-- RegistrationNo	No	Alphn-num	Company registration number or unique identification	ROV registration number, DUNS number
-- ContactInformation	No	Descriptive	Details of contact person in the company	Mr Daniel Wong, General Manager
-- IndustrySector	No	Descriptive	Categorisation of the company based on industry cluster	Precision Engineering, Electronics, Semi-conductor, Infocomm, Tourism
Geographical Expression	Yes	Category	Category to store direct location	-
-- PostalAddress	Yes	Category	Postal Element to store company address (Linked to User category)	-
-- -- AddressLine1	Yes	Descriptive		
-- -- AddressLine2	No	Descriptive		
-- -- Postal Code	Yes	Numeric		
-- -- City	Yes	Descriptive		Shanghai, Kuala Lumpur, Kaoshiung
-- -- Country	Yes	Descriptive		Singapore, Malaysia, China
-- GPS	No	Category	Global Positioning System (GPS) Coordinates	eg. Using http://www.satsig.net/maps/lat-long-finder.htm
-- -- Longitude	Yes	Numeric	(Indirect - Derived from look-up table, based on City)	103.7638
-- -- Latitude	Yes	Numeric	(Indirect - Derived from look-up table, based on City)	1.3783
-- Country	No	Descriptive	(Indirect - Derived from PostalAddress:Country)	
-- State	No	Descriptive	State or province of a country (if available)	Selangor (of Malaysia), Yunnan (of China)
-- Region	No	Descriptive	Region which the country is in	Asia, North-East Asia, Europe, North
-- Current	No	Category	Current conditions of company	
-- Ease of Doing Business	No	Numeric	Measure of risk of doing business (country-based)	Translated from risk, info from World Bank
-- Quality Certification	No	Category	Quality Information	-
-- -- Name	Yes	Descriptive	Name of quality certification	ISO 9001
-- -- Description	No	Descriptive	Description related to the quality certificate	Quality certification fitness based on ISO 9001
-- Financial Rating	No	Numeric	Financial stability indicator of company	1 to 5 (1=worst, 5=best)
-- Turnover	No	Category	Category to describe company's size of business	-
-- -- Value	Yes	Numeric	Value of measure	200, 1, 300
-- -- UnitOfMeasure	Yes	Descriptive	Unit to measure turnover (usually \$\$)	millions
History	No	Category	Category to describe the historical aspect of a company	-
-- Years of Operation	No	Category	Number of years company in existence	-
-- -- Value	Yes	Quantitative	Value of time	10, 20
-- -- TimeScale	Yes	Descriptive	Measure of time	Month, Year, decade
-- TrackRecord	No	Category	Category to store past performances	-
-- -- Quality	No	Category	Quality measure	-
-- -- -- Value	Yes	Numeric	Value of measure	ISO 9001
-- -- -- UnitOfMeasure	Yes	Descriptive	Unit of measure	Quality certification fitness based on ISO 9001
-- On-time Delivery	No	Category	Category to measure	-
-- -- Value	Yes	Quantitative	Describe the level of performance	90, 95, 99.99
-- -- UnitOfMeasure	Yes	Descriptive	Unit of measure	Percent
-- Profitability	No	Descriptive	Gauge of company's profitability	Excellent, Good, Fair, Bad only
-- Past Turnover	No	Category	Category to describe company's size of business historically	-
-- -- Value	Yes	Numeric	Value of measure	200, 1, 300
-- -- UnitOfMeasure	Yes	Descriptive	Unit to measure turnover (usually \$\$)	millions

Detailed Description of B2B Context Model Version 2.0

Table A4-2: ProductService Category of B2B Context Model

B2B Context (Version 2.0)	Mandatory?	Type	Description	Values (example)
Product Identifier	Yes	Category	To uniquely identify product	-
-- GTIN	No	Alphn-num	Global Identifier	-
-- Name	Yes	Descriptive	Name of the product or service	Car, nut, computer, hardisk
Description	No	Category	Description of product	-
-- Category	Yes	Descriptive	Product or Service Category	Automotive (for car), Electronics (for computer, hardisk)
-- Specification	No	Descriptive	Technical Specification of product	Dimensions, operating conditions, etc
PricingInformation	Yes	Category	Terms of Sale and Pricing Information	-
-- Costing	Yes	Category	Cost of Product or Service	-
-- ProductService Price	Yes	Category	Price of Product or Service	-
-- Value	Yes	Quantitative	Value of charge	-
-- Currency	Yes	Descriptive	Type of currency	USD, SGD, Yen, RMB
-- SalesTerritory	No	Category	Information pertaining to location of product/service	-
-- Source Country	Yes	Descriptive	Country of manufacture	Singapore, Malaysia, China
-- Market Availability	Yes	Category	Available market locations	-
-- Country	No	Descriptive	Country where product is available	Singapore, Malaysia, China
-- Tariffs	No	Category	Relevant taxes and tariffs that may be imposed on the product or service,	-
-- Type	Yes	Descriptive	Type of imposition	Import Tariff, Export Tariff, GST, Sales Tax
-- Description	No	Descriptive	Description of the tax	For all export overseas, Any Sales
-- Mode	Yes	Category	How the tax/tariff is to be imposed	-
-- Value	Yes	Quantitative	Value of the tax/tariff	3, 50, 200
-- Currency	Yes	Descriptive	Type of currency	USD, SGD, Yen, RMB
-- UnitOfMeasure	Yes	Descriptive	Unit of measure for the tax	Percent, Absolute, Per kg, Per carton
-- MinimumLimit	No	Quantitative	Minimum sum imposed (if any)	3, 50, 200 (absolute amount only)
-- MaximumLimit	No	Quantitative	Maximum sum imposed (if any)	10,000 (absolute amount only)
-- SalesBasis	No	Category	Basis for sale and price quoted	-
-- Incoterms	Yes	Descriptive	Basis for sale and price quoted	CIF, CSCW, FOB
-- DeliveryInformation	No	Category	Delivery Information, including leadtime, cost and mode of transportation	-
-- Delivery Leadtime	No	Category	Time taken to transport the product	-
-- Value	Yes	Quantitative	Value of lead time	0 (means ex-stock), 5, 20
-- TimeScale	Yes	Descriptive	Measure of time scale	hour, day, week, month, year
-- Transportation	No	Category	Describing the transportation mode available and cost associated	-
-- Type	Yes	Descriptive	Type of transportation	Sea, Air, Road, Rail
-- Cost	Yes	Category	Cost associated	-
-- Value	Yes	Quantitative	Value of transportation cost	3, 50, 200
-- Currency	Yes	Descriptive	Type of currency	USD, SGD, Yen, RMB
-- Frequency	No	Category	Frequency of transport availability	-
-- Value	Yes	Quantitative	Value of frequency	2, 5
-- TimeScale	Yes	Descriptive	Measure of time scale	day, week, month
-- Manufacturing Leadtime	No	Category	Time taken to manufacture/make the product	-
-- Value	Yes	Quantitative	Value of lead time	0 (means ex-stock), 5, 20
-- TimeScale	Yes	Descriptive	Measure of time scale	hour, day, week, month, year
Payment	No	Category	Consists of terms and contracts of sale	-
-- PaymentTerm	No	Descriptive	Terms and Conditions of Sale	Local - Credit x days, COD Overseas - LC at-sight, deferred LC for x days
-- PaymentPenalties	No	Category	Penalties for late payment	-
-- Value	Yes	Quantitative	Value of penalty	3, 50, 200
-- Currency	Yes	Descriptive	Type of currency	USD, SGD, Yen, RMB
-- UnitOfMeasure	Yes	Descriptive	Unit of measure for penalty	Percent, Absolute
-- PaymentDuration	No	Category	Length of credit given (if any)	-
-- Value	Yes	Quantitative	Value of credit length	10, 30, 60 (1, 2)
-- TimeScale	Yes	Descriptive	Timescale of credit term	day, month
-- Validity	No	Category	Validity of price and conditions quoted	-
-- StartTime	Yes	Quantitative	Start Date	01/01/2008
-- Endtime	Yes	Quantitative	End Date	31/03/2008
-- TimeScale	Yes	Descriptive	Timescale of validity	Date, day, month
-- Quantity	Yes	Category	Category to store quantity pertaining to an order or quote	-
-- Type	Yes	Descriptive	Describes the type of quantity specified	Order, Minimum
-- Value	Yes	Quantitative	Quantity order/min quantity of quotation	20, 200, 10000
-- UnitOfMeasure	Yes	Descriptive	Unit of measure for quantity specified	unit, piece, kg, carton
-- Capacity	No	Category	Category to describe capacity of company to product product or service	-
-- Value	Yes	Quantitative	Quantity of capacity	10,000, 20,000
-- UnitOfMeasure	Yes	Descriptive	Measure of quantity	unit, piece, kg, carton
-- TimeScale	Yes	Descriptive	Measure of time	day, week, month, quarter, year

Detailed Description of B2B Context Model Version 2.0

Table A4-3: Governing business rules of the B2B Context Model (Expressed as Psuedo Codes)

Group	OP	Condition (Antecedent) Context Model Attribute	OP	Value(s)	Action (Consequent) Context Model Attribute	OP	Value(s)
LeadTime							
I	1	Provider::SalesBasis.Incoterms	=	"EXW"	Memory.OrderLeadTime	=>>	Provider::SalesBasis.Manufacturing LeadTime
	2	Provider::SalesBasis.Incoterms	=	any in the "List of Incoterms"	Memory.OrderLeadTime	=>>	Provider::SalesBasis.Manufacturing LeadTime + Provider::SalesBasis.DeliveryInformation.DeliveryLeadTime
	3	Provider::SalesBasis.Incoterms	=	Empty	Memory.OrderLeadTime	=>>	max of (Memory.OrderLeadtime of all providers)
* LIST of Incoterms CIF, FOB, FCA, FAS, CRF, CPT, CIP, DAF, DDU, DES, DDP, DEQ							
Product Cost							
II	4	Provider::Quantity.Type	=	"Minimum"	Memory.ProductCost	=>>	Provider::ProductService Price.Value * Requestor::Quantity.Value
		AND Provider::Quantity.Value	<=	Requestor.Quantity.Value			
	5	Provider::Quantity.Type	=	"Minimum"	Memory.ProductCost	=>>	Provider::ProductService Price.Value * Provider::Quantity.Value
		AND Provider::Quantity.Value	>	Requestor.Quantity.Value			
Transport Cost							
III	6	Provider::SalesBasis.Incoterms	=	"EXW" or "FCA" or "FOB" or "FAS"	Memory.TransportationCost	=>>	Provider::DeliveryInformation.Transportation.Cost.Value
		OR Provider::SalesBasis.Incoterms	=	Empty			
	7	Provider::SalesBasis.Incoterms	≠	"EXW" or "FCA" or "FOB" or "FAS"	Memory.TransportationCost	=>>	0
		AND Provider::SalesBasis.Incoterms	≠	Empty			
Tariff Cost							
IV	8	Provider::GeographicalExpression.Country	=	Requestor::GeographicalExpression.Country	Memory.TariffCost	=>>	Memory.TariffCost + (Provider::Tariffs.Mode.Value*0.01*Memory.ProductCost)
		AND Provider::Tariffs.Type	=	"Sales"			
		AND Provider::Tariffs.Mode.UnitOfMeasure	=	"percent"			
	9	Provider::GeographicalExpression.Country	=	Requestor::GeographicalExpression.Country	Memory.TariffCost	=>>	Memory.TariffCost + Provider::Tariffs.Mode.Value
		AND Provider::Tariffs.Type	=	"Sales"			
		AND Provider::Tariffs.Mode.UnitOfMeasure	≠	"percent"			
	10	Provider::GeographicalExpression.Country	≠	Requestor::GeographicalExpression.Country	Memory.TariffCost	=>>	Memory.TariffCost + (Provider::Tariffs.Mode.Value*0.01*Memory.ProductCost)
		AND Provider::Tariffs.Type	=	"Export"			
		AND Provider::Tariffs.Mode.UnitOfMeasure	=	"percent"			
	11	Provider::GeographicalExpression.Country	≠	Requestor::GeographicalExpression.Country	Memory.TariffCost	=>>	Memory.TariffCost + Provider::Tariffs.Mode.Value
		AND Provider::Tariffs.Type	=	"Export"			
		AND Provider::Tariffs.Mode.UnitOfMeasure	≠	"percent"			
	12	Provider::GeographicalExpression.Country	≠	Requestor::GeographicalExpression.Country	Memory.TariffCost	=>>	Memory.TariffCost + (Provider::Tariffs.Mode.Value*0.01*Memory.ProductCost)
		AND Requestor::Tariffs.Type	=	"Custom"			
		AND Provider::SalesBasis.Incoterms	≠	"DDP"			
		AND Provider::Tariffs.Mode.UnitOfMeasure	=	"percent"			
	13	Provider::GeographicalExpression.Country	≠	Requestor::GeographicalExpression.Country	Memory.TariffCost	=>>	Memory.TariffCost + Provider::Tariffs.Mode.Value
		AND Requestor::Tariffs.Type	=	"Custom"			
		AND Provider::SalesBasis.Incoterms	≠	"DDP"			
		AND Provider::Tariffs.Mode.UnitOfMeasure	≠	"percent"			
Order Cost							
V	14	For all potential providers			Memory.OrderCost	=>>	Memory.ProductCost + Memory.TariffCost + Memory.TransportationCost
Payment Penalty							
VI	15	Provider::Payment.PaymentPenalties.UnitOfMeasure	=	"percent"	Memory.PaymentPenalty	=>>	Memory.PaymentPenalty + (Memory.ProductCost*0.01*Provider::Payment.PaymentPenalties.Value)
	16	Provider::Payment.PaymentPenalties.UnitOfMeasure	≠	"percent"	Memory.PaymentPenalty	=>>	Memory.PaymentPenalty + (Provider::Payment.PaymentPenalties.Value)

Detailed Description of B2B Context Model Version 2.0

Table A4-4: List of Criteria used for Industry Verification Survey

Group Criterion/Criterion*	
1. Product Order Cost (All)	
1.1	Price
1.2	Tariff
1.3	Transportation and Handling Cost
2. Order Lead-time (Manufacturing , Delivery)	
3. Sales Basis (e.g. FOB, CIF, etc.)	
4. Payment terms (All)	
4.1	Payment Terms (e.g. LC-at-sight)
4.2	Payment Penalties
4.3	Payment Duration
5. Supplier Manufacturing Capacity	
6. Organisational Outlook (All)	
6.1	Quality Certification (e.g. ISO 9000)
6.2	Financial Rating
6.3	Customer Base
7. Track Record (All)	
7.1	Quality
7.2	On-Time Delivery
7.3	Profitability
7.4	Years of Operation
8. Product Origin	
9. Proximity	
Others (Please specify and rank accordingly)	
E.g. Recommendation, Associates ,etc ...	

*: These criteria are derived from the *B2B Context Model*, grouped according to what is expected to be used in industry

Detailed Description of B2B Context Model Version 2.0

Table A4-5: Survey results on Supplier Selection Criteria (from industry)

Company	SME-1	SME-2	SME-3	SME-4	SME-5	SME-6	MNC-1	MNC-2	MNC-3	MNC-4
Industry	Media Printing	Plastic Injection Moulding	Contract Manufacturer	Precision Engineering	Electronics	Logistics	Consumer Products	Equipment Maker (Semi-conductor Front End)	Medical Equipment	Equipment Maker (Semi-conductor Front End)
Considered Criteria	1. Product order cost	1. Product order cost	1. Product order cost	1. Product order cost	1. Product order cost	1. Product order cost	1. Product order cost, Lead Time, Sales Basis, Payment terms	1. Product order cost	1. Product Order cost	1. Quality
	Track record (Quality, On-Time Delivery)	3. Product Origin (Availability)	3. Order Leadtime	2. Track record(quality)	2. Order Lead Time	2. Organisational outlook (quality certification)	2. Organisational Outlook (all)	2. Track record(quality)	2. Order Lead Time	2. Product Order cost
	Organisational outlook (quality certification)	4. Payment Terms	4. Transportation, Payment Penalty		3. Payment terms (payment duration)	3. Track record (Quality and Years of Operation)	3. Supplier manufacturing Capacity		3. Payment terms	3. Order lead time, proximity
	Supplier manufacturing capacity		5. Capacity		4.Track record (Quality, On-Time Delivery)	4. Product origin	4.Track record (all)		4. Track record (Quality and on time delivery)	
			7. Quality			5. Organisational Outlook (Financial Rating)				
						6. Sales Basis				
						8. Customer Base				
Other criteria considered (Not in List)	Response to instruction	2. Relationship with supplier (sales support/history)	2. Quantity (to be purchased)	Commitment (responsiveness)	5. Technical support/ capability	7. RoHS (metal only)	Environmental certification (ROHS,WEEE,ISO14000)	3. Logistics Support	RoHS	4. Others: Service (responsiveness, attitude, integrity)
	Meet test requirement	5. Willingness to provide free test material	6. Product Category & Conditions of Tools	RoHS	6. RoHS		Indemnification against customer's customers claim	4. Technology		
	Honours warranties and guarantees			History/ Past relationship						
	Management commitment (responsiveness & accommodation)									
Relative Importance of Criteria	Equal importance		By weights	By weights	By weights	Sequentially	By weights	Sequentially	Equal importance	Sequentially
Weights Determination (if applicable)	Not applicable	Higher weightage for Order Cost	Experience-based/Gut feel	Product Order cost - 40%	Cost – 70%	Experience-based/Gut feel	Commodity – Order cost has higher weight	Experience-based/Gut feel	Not applicable	Experience-based/Gut feel
					Lead time -30%		Customised item –Lead time has higher weight			

Appendix 5: An OWL-based Ontology for B2B Context Model

Table A5-1: OWL Constructors (with equivalent DL syntax and examples)

OWL Constructor	DL Syntax	Example (DL)
intersectionOf	$C_1 \sqcap C_2 \dots \sqcap C_n$	Buyer $\sqcap$ Seller
unionOf	$C_1 \sqcup C_2 \dots \sqcup C_n$	Buyer $\sqcup$ Seller
complementOf	$\neg C_1$	$\neg$ Seller
oneOf	g	{QuickLite, ChingTsing}
allValuesFrom	$\forall P. C$	$\forall$ hasProduct.MemoryCard
someValuesFrom	$\exists r. C$	$\exists$ hasProduct.PhotoFrame
hasValue	$\exists r. \{x\}$	$\exists$ hasProduct.{MC-01234}
minCardinality	$(\geq n \ r)$	$(\geq 3 \ \text{hasProduct})$
maxCardinality	$(\leq n \ r)$	$(\leq 2 \ \text{hasProduct})$
inverseOf	r^-	hasProduct $^-$

Table A5-2: OWL Axioms (Classes and Properties)

OWL Axiom	DL Syntax	Example (DL)
subClassOf	$C_1 \sqsubseteq C_2$	Buyer $\sqsubseteq$ Company
equivalentClass	$C_1 \equiv C_2$	Buyer $\equiv$ Requestor $\sqcap$ Company
subPropertyOf	$P_1 \sqsubseteq P_2$	hasProduct $\sqsubseteq$ hasProductService
equivalentProperty	$P_1 \equiv P_2$	productCost $\equiv$ productPrice
disjointWith	$C_1 \sqsubseteq \neg C_2$	Buyer $\sqsubseteq \neg$ Company
sameAs	$\{x_1\} \equiv \{x_2\}$	{QuickLite} $\equiv$ {QuickLite Pte Ltd}
differentFrom	$\{x_1\} \sqsubseteq \neg \{x_2\}$	{QuickLite} $\sqsubseteq \neg$ {ChingTsing}
TransitiveProperty	P transitive role	hasCompany can be defined as a transitive role
FunctionalProperty	$T \sqsubseteq (\leq 1 \ P)$	$T \sqsubseteq (\leq 1 \ \text{hasProduct})$
InverseFunctionalProperty	$T \sqsubseteq (\leq 1 \ P^-)$	$T \sqsubseteq (\leq 1 \ \text{isProductOf}^-)$
SymmtericProperty	$P \equiv P^-$	sameLocation $\equiv$ sameLocation $^-$

Table A5-3: Sample listing of an OWL file for a requestor named QuickLite

```

<?xml version="1.0"?>
<rdf:RDF xml:base="http://www.owl-ontologies.com/B2BMain.owl" xmlns="http://www.owl-
ontologies.com/B2BMain.owl#" xmlns:a="http://www.owl-ontologies.com/QuickLite.owl#"
...(truncated) >
  <owl:Ontology rdf:about="http://www.owl-ontologies.com/QuickLite.owl"/>
...(truncated)
  <owl:Class rdf:ID="ProductServicePrice">
    <rdfs:subClassOf>
      <owl:Class rdf:ID="Costing"/>
    </rdfs:subClassOf>
  </owl:Class>
  <owl:Class rdf:ID="Capacity">
  <owl:Class rdf:about="#FOB">
    <rdfs:subClassOf rdf:resource="#Incoterms"/>
  </owl:Class>
  <owl:Class rdf:ID="SelectedProductService">
    <rdfs:subClassOf>
      <owl:Class rdf:about="#ProductService"/>
    </rdfs:subClassOf>
  </owl:Class>
  <owl:Class rdf:ID="Requestor">
    <rdfs:subClassOf>
      <owl:Class rdf:ID="SelectedOrganisation"/>
    </rdfs:subClassOf>
  </owl:Class>
  ...(truncated)
  <owl:DatatypeProperty rdf:ID="value">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <owl:Class rdf:about="#Capacity"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
  </owl:DatatypeProperty>
  ...(truncated)
</rdf:RDF>

```

*Note: This is not a full listing – certain portions truncated. Only sample classes and properties are shown

An OWL-based Ontology for B2B Context Model

Figure A5-1: Datatype properties in the ontology for *B2B Context Model*Table A5-4: Business rules of *B2B Context Model* expressed in SWRL

#	SWRL Rules (antecedent → consequent)
1	SelectedOrganisation(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ hasIncoterms(?ps, ?i) ∧ EXW(?i) ∧ hasManufacturingLeadTime(?ps, ?m) ∧ value(?m, ?v) → OrderLeadTime(?ps, ?v)
2	SelectedOrganisation(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ ManuLtPlusDeliveryLt(?ps) ∧ hasManufacturingLeadTime(?ps, ?m) ∧ value(?m, ?v) ∧ hasDeliveryLeadTime(?ps, ?d) ∧ value(?d, ?v2) ∧ swrlb:add(?sum, ?v, ?v2) → OrderLeadTime(?ps, ?sum)
3	SelectedOrganisation(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ hasIncoterms(?ps, ?i) ∧ Empty(?i) → OrderLeadTime(?ps, 0.0010)
4	Provider(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ hasQuantity(?ps, ?q) ∧ quantityType(?q, "Minimum") ∧ Requestor(?r) ∧ hasSelectedProductService(?r, ?ps2) ∧ hasQuantity(?ps2, ?q2) ∧ quantityType(?q2, "Order") ∧ value(?q, ?min) ∧ value(?q2, ?order) ∧ swrlb:lessThanOrEqual(?min, ?order) ∧

An OWL-based Ontology for B2B Context Model

#	SWRL Rules (antecedent → consequent)
	<p>hasProductServicePrice(?ps, ?pp) $\wedge$ value(?pp, ?ppv) $\wedge$ swrlb:multiply(?result, ?order, ?ppv) → ProductCost(?ps, ?result)</p>
5	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasQuantity(?ps, ?q) $\wedge$ quantityType(?q, "Minimum") $\wedge$ Requestor(?r) $\wedge$ hasSelectedProductService(?r, ?ps2) $\wedge$ hasQuantity(?ps2, ?q2) $\wedge$ quantityType(?q2, "Order") $\wedge$ value(?q, ?min) $\wedge$ value(?q2, ?order) $\wedge$ swrlb:lessThan(?order, ?min) $\wedge$ hasProductServicePrice(?ps, ?pp) $\wedge$ value(?pp, ?ppv) $\wedge$ swrlb:multiply(?result, ?min, ?ppv) → ProductCost(?ps, ?result)</p>
6	<p>SelectedOrganisation(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ WithTransportationCost(?ps) $\wedge$ hasTransportationCost(?ps, ?itc) $\wedge$ value(?itc, ?v) → ComputedTransportationCost(?ps, ?v)</p>
7	<p>SelectedOrganisation(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ NoTransportationCost(?ps) → ComputedTransportationCost(?ps, 0.0)</p>
8	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasTariffs(?ps, ?t) $\wedge$ tariffType(?t, "Sales") $\wedge$ unitOfMeasure(?t, "percent") $\wedge$ country(?o, ?provLoc) $\wedge$ Requestor(?r) $\wedge$ country(?r, ?reqLoc) $\wedge$ swrlb:equal(?provLoc, ?reqLoc) $\wedge$ value(?t, ?tariffValue) $\wedge$ ProductCost(?ps, ?pdtCost) $\wedge$ swrlb:multiply(?result, ?tariffValue, 0.01, ?pdtCost) → TariffCost(?ps, ?result)</p>
9	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasTariffs(?ps, ?t) $\wedge$ tariffType(?t, "Sales") $\wedge$ unitOfMeasure(?t, ?u) $\wedge$ swrlb:notEqual(?u, "percent") $\wedge$ country(?o, ?provLoc) $\wedge$ Requestor(?r) $\wedge$ country(?r, ?reqLoc) $\wedge$ swrlb:equal(?provLoc, ?reqLoc) $\wedge$ value(?t, ?tariffValue) → TariffCost(?ps, ?tariffValue)</p>
10	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasTariffs(?ps, ?t) $\wedge$ tariffType(?t, "Export") $\wedge$ unitOfMeasure(?t, "percent") $\wedge$ country(?o, ?provLoc) $\wedge$ Requestor(?r) $\wedge$ country(?r, ?reqLoc) $\wedge$ swrlb:notEqual(?provLoc, ?reqLoc) $\wedge$ value(?t, ?tariffValue) $\wedge$ ProductCost(?ps, ?pdtCost) $\wedge$ swrlb:multiply(?result, ?tariffValue, 0.01, ?pdtCost) → TariffCost(?ps, ?result)</p>
11	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasTariffs(?ps, ?t) $\wedge$ tariffType(?t, "Export") $\wedge$ unitOfMeasure(?t, ?u) $\wedge$ swrlb:notEqual(?u, "percent") $\wedge$ country(?o, ?provLoc) $\wedge$ Requestor(?r) $\wedge$ country(?r, ?reqLoc) $\wedge$ swrlb:notEqual(?provLoc, ?reqLoc) $\wedge$ value(?t, ?tariffValue) → TariffCost(?ps, ?tariffValue)</p>
12	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasIncoterms(?ps, ?i) $\wedge$ DDP(?i) $\wedge$ hasTariffs(?ps, ?t) $\wedge$ unitOfMeasure(?t, "percent") $\wedge$ value(?t, ?tariffValue) $\wedge$ country(?o, ?provLoc) $\wedge$ Requestor(?r) $\wedge$ country(?r, ?reqLoc) $\wedge$ swrlb:notEqual(?provLoc, ?reqLoc) $\wedge$ hasSelectedProductService(?r, ?ps2) $\wedge$ hasTariffs(?ps2, ?t2) $\wedge$ tariffType(?t2, "Import") $\wedge$ ProductCost(?ps, ?pdtCost) $\wedge$ swrlb:multiply(?result, ?tariffValue, 0.01, ?pdtCost) → TariffCost(?ps, ?result)</p>
13	<p>Provider(?o) $\wedge$ hasSelectedProductService(?o, ?ps) $\wedge$ hasIncoterms(?ps, ?i) $\wedge$ DDP(?i) $\wedge$</p>

An OWL-based Ontology for B2B Context Model

#	SWRL Rules (antecedent → consequent)
	hasTariffs(?ps, ?t) ∧ unitOfMeasure(?t, ?u) ∧ swrlb:notEqual(?u, "percent") ∧ value(?t, ?tariffValue) ∧ country(?o, ?provLoc) ∧ Requestor(?r) ∧ country(?r, ?reqLoc) ∧ swrlb:notEqual(?provLoc, ?reqLoc) ∧ hasSelectedProductService(?r, ?ps2) ∧ hasTariffs(?ps2, ?t2) ∧ tariffType(?t2, "Import") → TariffCost(?ps, ?tariffValue)
14	SelectedOrganisation(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ ProductCost(?ps, ?pc) ∧ TariffCost(?ps, ?tc) ∧ ComputedTransportationCost(?ps, ?tpc) ∧ swrlb:add(?result, ?pc, ?tc, ?tpc) → OrderCost(?ps, ?result)
15	SelectedOrganisation(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ hasPaymentPenalties(?ps, ?pp) ∧ unitOfMeasure(?pp, ?u) ∧ swrlb:equal(?u, "percent") ∧ value(?pp, ?penalty) ∧ ProductCost(?ps, ?pdtCost) ∧ swrlb:multiply(?result, ?penalty, 0.01, ?pdtCost) → ComputedPaymentPenalties(?ps, ?result)
16	SelectedOrganisation(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ hasPaymentPenalties(?ps, ?pp) ∧ unitOfMeasure(?pp, ?u) ∧ swrlb:notEqual(?u, "percent") ∧ value(?pp, ?penalty) → ComputedPaymentPenalties(?ps, ?penalty)
17	Requestor(?r) ∧ hasSelectedProductService(?r, ?ps) ∧ hasQuantity(?ps, ?q) ∧ quantityType(?q, "Order") ∧ value(?q, ?order) ∧ hasProductServicePrice(?ps, ?pp) ∧ value(?pp, ?ppv) ∧ swrlb:multiply(?result, ?order, ?ppv) → ProductCost(?ps, ?result)
18	Provider(?o) ∧ hasSelectedProductService(?o, ?ps) ∧ hasTariffs(?ps, ?t) ∧ tariffType(?t, "Sales") ∧ country(?o, ?provLoc) ∧ Requestor(?r) ∧ country(?r, ?reqLoc) ∧ swrlb:notEqual(?provLoc, ?reqLoc) → TariffCost(?ps, 0.0)

Note: Rules 1 to 16 correspond to the business rules defined in of Table A3-3 of Appendix 4: . Rule 17 is created to compute the requestor's product cost while rule 18 computes each provider's sales/tariff cost.

Table A5-5: Test Results from Test-1

Selected Providers #	Test Run	Ontology-based CIM module				Ranking Module	Total Time	Heap memory usage
		Retrieve ontologies	Combine KB	Evaluate query	Close & dispose query			
20	Run-1	1250	734	8594	359	47	11172	47
	Run-2	1187	734	8765	360	63	11266	43
	Run-3	1188	736	8782	437	78	11375	44
	Average	1208	735	8714	385	63	11271	45
25	Run-1	1265	859	11922	438	63	14765	62
	Run-2	1203	828	11907	422	63	14625	71
	Run-3	1172	828	11906	422	78	14547	67

An OWL-based Ontology for B2B Context Model

Selected Providers #	Test Run	Ontology-based CIM module				Ranking Module	Total Time	Heap memory usage
		Retrieve ontologies	Combine KB	Evaluate query	Close & dispose query			
	Average	1213	838	11912	427	68	14646	67
30	Run-1	1281	953	16094	469	78	19063	83
	Run-2	1172	906	16062	468	78	18890	76
	Run-3	1172	906	16109	469	78	18969	77
	Average	1208	922	16088	469	78	18974	79
35	Run-1	1203	1047	20985	547	109	24093	89
	Run-2	1219	1016	20906	547	109	23937	82
	Run-3	1125	1031	20828	547	109	23859	80
	Average	1182	1031	20906	547	109	23963	84
40	Run-1	1235	1188	26281	610	125	29890	91
	Run-2	1188	1110	25937	610	110	29140	84
	Run-3	1203	1110	26109	610	109	29313	85
	Average	1209	1136	26109	610	115	29448	87
45	Run-1	1172	1406	32859	687	110	36422	94
	Run-2	1172	1234	32875	703	125	36343	88
	Run-3	1219	1265	32906	687	125	36421	92
	Average	1188	1302	32880	692	120	36395	91
50	Run-1	1157	1484	40219	719	125	43906	96
	Run-2	1203	1297	40078	735	125	43594	98
	Run-3	1188	1391	40406	735	125	44141	102
	Average	1183	1391	40234	730	125	43880	99
55	Run-1	1266	1781	48344	812	140	52594	115
	Run-2	1187	1468	48218	812	141	52078	110
	Run-3	1204	1516	47547	797	157	51453	109
	Average	1219	1588	48036	807	146	52042	111
60	Run-1	1328	1547	58438	875	156	62516	117
	Run-2	1203	1484	57563	860	172	61562	112
	Run-3	1172	1516	59000	906	172	63015	110
	Average	1234	1516	58334	880	167	62364	113
65	Run-1	1266	1719	65797	906	187	70172	125

An OWL-based Ontology for B2B Context Model

Selected Providers #	Test Run	Ontology-based CIM module				Ranking Module	Total Time	Heap memory usage
		Retrieve ontologies	Combine KB	Evaluate query	Close & dispose query			
	Run-2	1156	1625	65735	922	172	69875	131
	Run-3	1125	1625	65953	938	172	70063	128
	Average	1182	1656	65828	922	177	70037	128
70	Run-1	1218	2188	74843	1015	172	79656	127
	Run-2	1187	1688	75078	1047	172	79422	133
	Run-3	1188	1735	75015	1016	172	79375	127
	Average	1198	1870	74979	1026	172	79484	129

Table A5-6: Test Results from Test-2 and Test-3

Selected Providers #	Test Run	Ontology-based (Total Time)			XML-based
		3-criterion	4-criterion	5-criterion	5-criterion
20	Run-1	11450	11856	11172	2.2
	Run-2	12122	11843	11266	6.1
	Run-3	11761	11490	11375	6.5
	Average	11778	11730	11271	3.9
25	Run-1	13844	14625	14765	2.7
	Run-2	14432	15375	14625	7.6
	Run-3	14104	14901	14547	7.7
	Average	14127	14967	14646	4.7
30	Run-1	18709	19787	19063	3.5
	Run-2	19761	19196	18890	7.9
	Run-3	18432	18954	18969	8.9
	Average	18967	19312	18974	5.7
35	Run-1	24625	24391	24093	3.9
	Run-2	23958	24984	23937	10.9
	Run-3	23417	23237	23859	11.9
	Average	24000	24204	23963	6.9
40	Run-1	29813	28890	29890	4.9
	Run-2	29906	30015	29140	10.8
	Run-3	28938	29341	29313	11.9
	Average	29552	29415	29448	7.8

An OWL-based Ontology for B2B Context Model

Selected Providers #	Test Run	Ontology-based (Total Time)			XML-based
		3-criterion	4-criterion	5-criterion	5-criterion
45	Run-1	36192	35764	36422	5.9
	Run-2	36541	36781	36343	13.1
	Run-3	35876	35611	36421	14.0
	Average	36203	36052	36395	9.5
50	Run-1	44512	45211	43906	6.9
	Run-2	45318	43512	43594	14.1
	Run-3	45612	44612	44141	16.5
	Average	45147	44445	43880	10.8
55	Run-1	52139	53113	52594	7.9
	Run-2	53450	52656	52078	15.4
	Run-3	52378	53658	51453	17.5
	Average	52656	53142	52042	12.0
60	Run-1	61430	63114	62516	8.8
	Run-2	63197	61878	61562	18.0
	Run-3	63452	62368	63015	20.0
	Average	62693	62453	62364	13.7
65	Run-1	70327	71230	70172	9.8
	Run-2	70844	70943	69875	18.6
	Run-3	69531	69754	70063	20.7
	Average	70234	70642	70037	14.7
70	Run-1	78663	79854	79656	10.8
	Run-2	79435	78043	79422	20.7
	Run-3	79831	80944	79375	22.7
	Average	79310	79614	79484	16.2

Appendix 6: Formula and Elicitations Steps of MCDM Techniques

This appendix details the elicitation steps of MCDM techniques for AHP, VIKOR, TOPSIS, ELECTRE and PROMETHEE class of methods. The common notations used in all these techniques are documented in the next section, under Table A6-1. Section A6.9 details the derivations for determining the maximum distance between two ordered sequences. This is used in the calculations of rank reversal introduced in Chapter 5.

A6.1 Notations used in the MCDM Techniques

Table A6-1: Common notations used in MCDM techniques

Notation	Description
A	A finite set of alternatives
a_j	j -th alternative in finite set n
G	A finite set of criteria
g_i	i -th criterion in set G
$g(a)$	Performance value of alternative a
$g_i(a)$	Performance value of the i -th criterion for alternative a
$g_i(a_j)$	Performance value of the i -th criterion for j -th alternative, a_j
w_i	Weight of i -th criterion
S	binary outranking relation between alternatives a and b

A6.2 AHP (Analytic Hierarchy Process)

An AHP model is hierarchical in nature, as illustrated in Figure A6-1, evaluating all alternatives pair-wise for a set of criteria. The generalised steps involved in an AHP evaluation process are as follows:

- (1) Determine the *weights* of the criteria, w_i , by pair-wise comparison using the *Saaty scale* and matrix normalisation, where

$$\sum_{i=1}^n w_i = 1$$

Formula and Elicitations Steps of MCDM Techniques

When there are multiple levels of criteria (i.e sub-criteria exist), this step is first performed at the lowest level of sub-criteria, and aggregated upwards in the hierarchy, as illustrated in Figure A6-1.

- (2) Determine the priority vector, P_i , for each criterion by pair-wise comparison between the alternatives, where $P_i = (P_{ij})_{j=1,2,\dots,n}$
- (3) Calculate the score for each alternative, S_j , where

$$S_j = \sum_{i=1}^n P_{ij} w_i$$

- (4) Rank these scores in descending order. The highest ranked alternative is the most preferred alternative.

Figure A6-1: AHP's hierarchical Decision Model

A6.3 VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje)

VIKOR was introduced by Opricovic in 1998 [97, 98]. VIKOR measures the distance of alternatives from the ideal solution using the following form of L_p -metric,

$$L_{pj} = \left\{ \sum_{i=1}^n [w_i (g_i^* - g_i(a_j)) / (g_i^* - g_i^-)]^p \right\}^{1/p}, \quad 1 \leq p \leq \infty; j = 1, 2, \dots, J$$

This is a form of Euclidean distance measure [220], for different p values as illustrated in Figure A6-2. In Step (2) of the elicitation process, $p = 1$ is used to calculate S_j and

Formula and Elicitations Steps of MCDM Techniques

$p = \infty$ is used to compute R_j . As can be seen from the illustration, $p = 1$ represents the minimum distance possible for a given point from the ideal solution, whereas $p = \infty$ represents the maximum distance possible.

Figure A6-2: p -metric circles

Then, a compromise solution, $F^c = (g_1^c, \dots, g_n^c)$, where F^c is a feasible solution closest to the ideal F^* is determined. The compromise is based on the following formula,

$$\Delta g_i = g_i^* - g_i^c, \quad i = 1, \dots, n$$

The various J alternatives are denoted as $a_1, a_2, \dots, a_j$ where f_{ij} is the performance value of the i -criterion for alternative a_j and n is the number of criteria. The steps in the compromise ranking algorithm VIKOR are:

- (1) Determine the best and worst performance values of each criterion, i

$$\text{Best value,} \quad g_i^* = \max_j g_i(a_j)$$

$$\text{Worst value,} \quad g_i^- = \min_j g_i(a_j)$$

- (2) Compute S_j (where $p = 1$) and R_j (where $p = \infty$) values

$$S_j = \sum_{i=1}^n w_i (g_i^* - g_i(a_j)) / (g_i^* - g_i^-)$$

$$R_j = \max_i [w_i (g_i^* - g_i(a_j)) / (g_i^* - g_i^-)]$$

where w_i are the weights of criteria, expressing their relative importance

- (3) Compute Q value

$$Q_j = v(S_j - S^*) / (S^- - S^*) + (1 - v)(R_j - R^*) / (R^- - R^*)$$

where

Formula and Elicitations Steps of MCDM Techniques

$$S^* = \min_j S_j, \quad S^- = \max_j S_j$$

$$R^* = \min_j R_j, \quad R^- = \max_j R_j$$

and v is the weight of the strategy of the “majority of the criteria” (maximum group utility). Initial $v = 0.5$

S^* represents maximum utility of the majority (or group) and R^* represents the minimum regret of the minority (or individual).

(4) Rank the alternatives by sorting S , R and Q values in decreasing order, resulting in 3 ranking lists

(5) Propose compromise solution (a') that is best ranked by Q measure (minimum) that meets the following 2 conditions:

C1: “Acceptable advantage”

$$Q(a'') - Q(a') \geq \Delta Q$$

where

$$a'' = 2nd \text{ ranked in list } Q$$

$$\Delta Q = 1/(J - 1)$$

C2: “Acceptable stability in decision making”

a' must be best ranked in S and/or R

(6) If C1 or C2 is not satisfied, then a set of compromise solutions is proposed, based on:

- If C2 is not satisfied, compromise solution set is a' and a''
- If C1 is not satisfied, compromise solution set is $a', a'', \dots, a^{(M)}$

where $a^{(M)}$ is the maximum M for $Q(a^{(M)}) - Q(a') \geq \Delta Q$

In this method, if criteria weights are not within the stability range, it will be replaced, based on the method presented by Opricovic [81].

A6.4 TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

TOPSIS was proposed by Cheng and Hwang [97, 98] for choosing alternatives based on the shortest distance from the ideal solution and farthest distance from the negative-ideal solution. The steps in TOPSIS can be generalised as follow:

Formula and Elicitations Steps of MCDM Techniques

(1) Calculate the normalised performance matrix

The normalised decision performance value for i -criterion in j -alternative, r_{ij} is

$$r_{ij} = \frac{g_i(a_j)}{\sqrt{\sum_{j=1}^J g_i(a_j)^2}}, \quad j = 1, \dots, J; i = 1, \dots, n$$

(2) Calculate the weighted normalised performance matrix

The weighted normalised value, v_{ij} is

$$v_{ij} = w_i r_{ij}, \quad j = 1, \dots, J; i = 1, \dots, n \quad \text{and} \quad \sum_{i=1}^n w_i = 1$$

(3) Determine the positive ideal (A^*) and negative-ideal (A^-) solutions

$$\begin{aligned} A^* &= \{v_1^*, \dots, v_n^*\} \\ &= \left\{ \left(\max_j v_{ij} \mid i \in I' \right), \left(\min_j v_{ij} \mid i \in I'' \right) \right\} \\ A^- &= \{v_1^-, \dots, v_n^-\} \\ &= \left\{ \left(\min_j v_{ij} \mid i \in I' \right), \left(\max_j v_{ij} \mid i \in I'' \right) \right\} \end{aligned}$$

where I' is associated with benefit criteria and I'' is associated with cost criteria

(4) Calculate the positive and negative distance measure, D_j^* and D_j^- for each alternative, using Euclidean distance measure, where $p=2$ (see Figure A6-2).

$$\begin{aligned} D_j^* &= \sqrt{\sum_{i=1}^n (v_{ij} - v_i^*)^2}, \quad j = 1, \dots, J \\ D_j^- &= \sqrt{\sum_{i=1}^n (v_{ij} - v_i^-)^2}, \quad j = 1, \dots, J \end{aligned}$$

(5) Calculate the relative closeness (ranking index) of j -alternative to the ideal solution, C_j^* with respect to A^*

$$C_j^* = D_j^- / (D_j^* + D_j^-)$$

(6) Rank the preference order based on C_j^*

A6.5 ELECTRE I, Iv, and IS

ELECTRE I [85, 221] the earliest of the ELECTRE methods, is meant to solve the *choice* decision type. The necessary and sufficient conditions for an alternative a to outrank another alternative b , denoted by aSb , are:

- (i) *Concordance*: the sum of weights of the criteria in which a performs better than b , should be at least as high as a specified *concordance threshold*, c^* .

$$\sum_{\{i: g_i(a) \geq g_i(b)\}} w_i \geq c^*$$

- (ii) *Non-discordance*: no criteria in b should be better than a by more than a given *non-discordance threshold*, v^* :

$$\max_{\{i: g_i(a) < g_i(b)\}} (g_i(b) - g_i(a)) \leq v^*$$

Both c^* and v^* are thresholds that must be specified by the decision maker.

The procedure involves traversing a directed graph $\langle A, E \rangle$, where A is the set of all alternatives and E is the set of ordered pairs (a, b) such that aSb . When there are loops in the graph, it means that the alternatives forming such loops are equal.

In ELECTRE Iv, the non-discordance requirement is replaced by a *no-veto condition* defined as:

$$g_i(a) + v_i^*(g_i(a)) \geq g_i(b), \forall i \in G$$

where v_i^* is a linear function of performance scores

This way, the veto threshold for different criteria changes with the range of values of each criterion. This can potentially give rise to inconsistencies, which remains unresolved even for the newer members of the ELECTRE family [221].

Formula and Elicitations Steps of MCDM Techniques

In ELECTRE IS uses the concept of *preference and indifference thresholds* instead of using the true-criteria procedure (where the entire weight of a criterion is assigned to the alternative that performs better). All three methods, ELECTRE I, ELECTRE Is and ELECTRE IV are designed to solve *choice* decision type problems only.

A6.6 Electre II

ELECTRE II [85] is a true-criteria procedure that constructs *embedded outranking relations* based on two concordance cut-off levels and a no-veto condition. The concordance level given to an assertion aSb , denoted by $c(a, b)$, is calculated as the sum of weights of every criterion for which a 's performance is at least as good as b 's. This is also known as the concordance index [82]:

$$c(a, b) = \sum_{\{i: g_i(a) \geq g_i(b)\}} w_i$$

This concordance index is used to build two embedded outranking relations of *strong outranking*, s^1 and *weak outranking*, s^2 , where $s^1 > s^2$; the index assumes arbitrary values between 0.5 and (1 – the lowest weight in the model). Thus, the concordance condition for $aS^r b$ is defined as:

$$c(a, b) \geq s^r \text{ and } c(a, b) \geq c(b, a) \text{ where } r = 1, 2$$

For the assertion aSb to be valid, it is also necessary that the no-veto condition be fulfilled. The definition of no-veto in ELECTRE II is the same as that of ELECTRE Iv.

The preference elicitation procedure of ELECTRE II constitutes descending and ascending distillation processes and the intersection of the two to generate a final partial pre-order. As described in [82], the descending distillation procedure is carried out as follows:

(1) *Partitioning the set of alternatives A:*

Formula and Elicitations Steps of MCDM Techniques

Considering only the strong outranking relations, s^1 and identify the alternatives in A that *are not outranked* by any other alternative. On the n -th repetition, this subset is the n -th rough distillate, B^n . This procedure is repeated with $A = A \setminus B^n$ until A is empty.

(2) Building a complete descending pre-order Z_{des} :

For every B^n with cardinality > 1 , Step (1) is repeated, but now considering only the weak outranking relations, s^2 . The result is a finer distillate with more complete pre-order.

The ascending distillation is done in a similar manner, except that the distillate consists of the alternatives in A that *do not outrank* any other alternatives instead. The outcome is the ascending pre-order, Z_{asc} .

The *final partial pre-order*, Z is calculated as the intersection of Z_{des} and Z_{asc} . Here a descending distillation of the final pre-order Z is constructed based on the following conditions [82]:

- If a is preferred to b in both the pre-orders (Z_{des} and Z_{asc}), this will be the case in the final pre-order
- If a is equivalent to b in one of the pre-orders, but is preferred to b in another, then a is preferred to b in the final pre-order
- If a is preferred to b in one pre-order, but b is preferred to a in another, then the two alternatives are incomparable (cannot be ranked)

When this occurs, the final pre-order is usually incomplete.

A6.7 ELECTRE III

ELECTRE III was introduced to deal with imprecise data in the *ranking decision type* by the use of *pseudo-criteria*. These pseudo-criteria are used to define the degree “ a outranks b ” via a *credibility index* [104], which is defined using concordance and discordance indices. A pseudo-criterion has a discriminating power, which is

Formula and Elicitations Steps of MCDM Techniques

characterised by the *strict preference threshold*, p and *indifference threshold*, q as [82], where $p > q$:

$$aPb \text{ (} a \text{ is strongly preferred to } b \text{)} \Leftrightarrow g_i(a) - g_i(b) \geq p$$

$$aQb \text{ (} a \text{ is weakly preferred to } b \text{)} \Leftrightarrow q < g_i(a) - g_i(b) < p$$

$$aIb \text{ (} a \text{ is indifferent to } b \text{)} \Leftrightarrow g_i(a) - g_i(b) \leq q$$

where $g(a)$ and $g(b)$ are the performance values of a and b respectively. The thresholds can either be constants (e.g. $p = 0.2$) or linear functions of the performance values of a or b (e.g. $p = \alpha + \beta \cdot g(a)$).

The individual criterion concordance index $c_i(a, b)$ shows the degree to which the i th-criterion supports the assertion aSb . It is calculated as follows (see Figure A6-3):

$$c_i(a, b) = \begin{cases} 1 & \text{if } g_i(b) - g_i(a) \leq q_i \\ 0 & \text{if } g_i(b) - g_i(a) > p_i \\ \frac{g_i(a) - g_i(b) + p_i}{p_i - q_i}, & \text{otherwise} \end{cases}$$

Figure A6-3: Individual criterion concordance index determination for ELECTRE III

The global concordance index is calculated as the weighted average of individual criterion concordance indices as follows:

$$GC(a, b) = \sum_i w_i c_i(a, b)$$

To determine the credibility of the global concordance index, veto threshold functions, v_i are defined for each criterion. When $g_i(b) - g_i(a) > v_i$ for any criterion i , the

Formula and Elicitations Steps of MCDM Techniques

assertion aSb is considered to be not credible at all. This veto effect is called the discordance index. For ascending preference on criterion i , the individual criterion discordance index is calculated as follows (see Figure A6-4):

$$d_i(a, b) = \begin{cases} 1 & \text{if } g_i(b) - g_i(a) \geq v_i \\ 0 & \text{if } g_i(b) - g_i(a) < p_i \\ \frac{g_i(b) - g_i(a) + p_i}{v_i - p_i}, & \text{otherwise} \end{cases}$$

Figure A6-4: Individual criterion discordance index determination for ELECTRE III

The credibility index for each assertion aSb is the global concordance index, $GC(a, b)$ weakened by possible individual veto effects:

$$R(a, b) = GC(a, b) \prod_{\{i: d_i(a, b) > GC(a, b)\}} \frac{1 - d_i(a, b)}{1 - GC(a, b)}$$

Similar to ELECTRE II, the preference elicitation of ELECTRE III consists of two distillation processes. However, they are carried out in a different manner. The distillations are based on the pair-wise outranking credibility values and λ cutting level. The descending distillation process as described by [222] is as follows:

- (1) $\lambda = \max_{a, b \in A, a \neq b} R(a, b)$
- (2) Calculate $S(\lambda) = \alpha + \beta \cdot \lambda$. The α and β are threshold values again. The typical assumed values are not clear and differ across implementations. For example, the ELECTRE III-IV software [223] uses $\alpha = 0.3$ and $\beta = 0.7$. No explanations are available, and remains a weakness in this ELECTRE III method.

Formula and Elicitations Steps of MCDM Techniques

(3) Define the matrix T as:

$$T(a, b) = \begin{cases} 1, & R(a, b) > \lambda - S(\lambda) \\ 0, & \text{otherwise} \end{cases}$$

(4) For each alternative, $a \in A$, its qualification $Q(a)$ is defined as the number of alternatives that it is λ -preferred to subtract by the number of alternatives that is λ -preferred to it.

(5) On the n th repetition, the subset of alternatives having the largest value of qualification is the distillate, D_n . If the cardinality of D_n is more than 1, the process is repeated on D_n .

(6) Otherwise, the procedure is repeated with $A = A \setminus D_n$.

As in ELECTRE II, the outcome of this process is called the *descending pre-order*, Z_{des} . The *ascending pre-order*, Z_{asc} is constructed using the same procedure, with the exception of step (5), where the alternatives having the lowest value of qualification become the distillate. The final partial pre-order Z is calculated as the intersection of Z_{des} and Z_{asc} , as in ELECTRE II.

A6.8 PROMETHEE Methods

In PROMETHEE, the preference function $P(a, b)$ takes real numbers in the $[0, 1]$ range, to represent the intensity of preference of an alternative a over b , with higher values indicating higher intensity of preference. The value of $P(a, b)$ is calculated as a function of the performance advantage of a over b . For criteria with ascending preference (i.e. where greater values are better), the difference d can be calculated as $g(a) - g(b)$. For criteria with descending preference (i.e. where smaller values are preferred), d 's value is $g(b) - g(a)$. PROMETHEE allows each criterion to have different preference functions. In a way, the criteria are treated according to their units of measure or scale. J. P. Brans *et al.* [105] generalised the preference functions required by different criteria types into six categories, as summarised in Table A6-2.

Formula and Elicitations Steps of MCDM Techniques

The *multi-criteria preference index* $\pi(a, b)$ represents the intensity of preference given to a over b , considering all the criteria. It is calculated as the weighted average of the individual criterion preference intensities:

$$\pi(a, b) = \sum_{i=1}^n (w_i P_i(a, b))$$

where w_i = weight of the i th criterion and

$$\sum_{i=1}^n w_i = 1$$

Table A6-2: Types of PROMETHEE criteria and its Preference Intensity function [105]

Criterion type	Definition	Parameters to determine
1. Usual criterion	$P(d) = \begin{cases} 0, & d \leq 0 \\ 1, & d > 0 \end{cases}$	None
2. Quasi criterion	$P(d) = \begin{cases} 0, & d \leq q \\ 1, & d > q \end{cases}$	q (indifference threshold)
3. Linear criterion	$P(d) = \begin{cases} 0, & d \leq 0 \\ \frac{d}{p}, & 0 < d \leq p \\ 1, & d > p \end{cases}$	p (preference threshold)
4. Level criterion	$P(d) = \begin{cases} 0, & d \leq q \\ \frac{1}{2}, & 0 < d \leq q \\ 1, & d > p \end{cases}$	q, p

Formula and Elicitations Steps of MCDM Techniques

Criterion type	Definition	Parameters to determine
5. Linear criterion with indifference	$P(d) = \begin{cases} 0, & d \leq q \\ \frac{d-q}{p-q}, & q < d \leq p \\ 1, & d > p \end{cases}$	q, p
6. Gaussian criterion	$P(d) = \begin{cases} 0, & d \leq 0 \\ 1 - e^{-\frac{d^2}{2\sigma^2}}, & d > 0 \end{cases}$	σ (standard deviation of Gaussian curve)

Each alternative, a has $(n - 1)$ other alternatives in A . The outranking flows used in PROMETHEE are:

- the *positive (leaving) outranking flow* which measures the outranking character of a :

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)$$

- the *negative (entering) flow* which measures the outranked character of a :

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x, a)$$

- the net flow of a , which measures the outranking the balance of the flows (where the higher the net flow, the better is the alternative):

$$\phi(a) = \phi^+(a) - \phi^-(a)$$

For pre-orders construction, PROMETHEE I makes use of the leaving and entering flows, while PROMETHEE II utilizes the net flows.

PROMETHEE I

PROMETHEE I results in a partial pre-order that is determined from the leaving and entering flows. The relation between every pair of alternatives, a and b , is determined via the following:

Formula and Elicitations Steps of MCDM Techniques

$$aP^I b \quad \text{iff} \quad \begin{cases} \emptyset^+(a) > \emptyset^+(b) \text{ and } \emptyset^-(a) \leq \emptyset^-(b), \text{ or} \\ \emptyset^+(a) = \emptyset^+(b) \text{ and } \emptyset^-(a) < \emptyset^-(b) \end{cases}$$

$$aI^I b \quad \text{iff} \quad \emptyset^+(a) = \emptyset^+(b) \text{ and } \emptyset^-(a) = \emptyset^-(b)$$

$$aR^I b \quad \text{iff} \quad \begin{cases} \emptyset^+(a) > \emptyset^+(b) \text{ and } \emptyset^-(a) > \emptyset^-(b), \text{ or} \\ \emptyset^+(a) < \emptyset^+(b) \text{ and } \emptyset^-(a) < \emptyset^-(b) \end{cases}$$

where P^I denotes preference, I^I denotes indifference, and R^I denotes incomparability.

Incomparability asserts that the leaving and entering flows provide inconsistent information about a pair of alternatives [113].

PROMETHEE II

PROMETHEE II provides a complete pre-order that is determined from the calculated net flows. Alternatives with positive net flows ($\emptyset(a) > 0$) relatively outrank the others based on all decision criteria, while those with negative net flows ($\emptyset(a) < 0$) are relatively outranked. The relation between every pair of alternatives, a and b , is determined via the following:

$$aP^{II} b \quad \text{iff} \quad \emptyset(a) > \emptyset(b)$$

$$aI^{II} b \quad \text{iff} \quad \emptyset(a) = \emptyset(b)$$

Using PROMETHEE II, all pairs of alternatives are considered comparable. As such complete pre-orders is possible with this method, unless the alternatives are identical.

A6.9 Determination of Maximum Distance between Two Ordered Sequences

The Spearman's foot-rule distance, d_n which measures the absolute distance between two ranks (or ordered sequence) has the following formula:

$$d_n = \sum_{i=1}^n |x_i - y_i|$$

where x_i = position in first rank sequence X

y_i = position in second rank sequence Y

Formula and Elicitations Steps of MCDM Techniques

For ordered sequences without tied ranks, the maximum distance between two ranks happens when the two complete ranks are the reverse of one another, see examples in Table A6-3 and Table A6-4. It can thus be calculated in closed form as the differences from two arithmetic sequences that are symmetric about the middle of the preorder.

Table A6-3: Maximum distance between two even numbered ordered sequences (without tied ranks)

Element	<i>k</i>	<i>l</i>	<i>m</i>	<i>n</i>	<i>o</i>	<i>p</i>	Sum
X Position	1	2	3	4	5	6	
Y Position	6	5	4	3	2	1	
Absolute Difference	5	3	1	1	3	5	18

Table A6-4: Maximum distance between two odd numbered ordered sequences (without tied ranks)

Element	<i>k</i>	<i>l</i>	<i>m</i>	<i>n</i>	<i>o</i>	<i>p</i>	<i>q</i>	Sum
X Position	1	2	3	4	5	6	7	
Y Position	7	6	5	4	3	2	1	
Absolute Difference	6	4	2	0	2	4	6	24

For sequences with even number of elements of n , the sequence is in the following form (see Table A6-3):

$$(n-1), (n-3), \dots, 3, 1, 1, 3, (n-3), (n-1)$$

where

$$\text{max. distance} = 2 * [(n-1) + (n-3) + \dots + 3 + 1]$$

For sequences with odd number of elements of n , the sequence is in the following form (see Table A6-4):

$$(n-1), (n-3), \dots, 2, 0, 2, (n-3), (n-1)$$

where

$$\text{max. distance} = 2 * [(n-1) + (n-3) + \dots + 4 + 2]$$

Formula and Elicitations Steps of MCDM Techniques

In closed form, the maximum distance between two order sequences without tied ranks, d_{n-max} can be generalised as:

$$d_{n-max} = 2 \times \left\lfloor \frac{n}{2} \right\rfloor \times \left(\left(re\left(\frac{n}{2}\right) + 1 \right) + \left(\left\lfloor \frac{n}{2} \right\rfloor - 1 \right) \right)$$

For ordered sequences with tied ranks, the maximum distance between two ranks occurs when the following conditions are satisfied:

- X is an ordered sequence without tied ranks,
- Y is an ordered sequence with $(n - 1)$ tied 1st ranks and 1 single n^{th} rank, and
- Y 's first ranked is the complete opposite of X

These conditions were derived using empirical methods. Table A6-5 and Table A6-6 show such examples for even numbered and odd numbered ordered sequences respectively.

Table A6-5: Maximum distance between two even numbered ordered sequences (with tied ranks)

Element	k	l	m	n	o	p	Sum
X Position	1	2	3	4	5	6	
Y Position	6	1	1	1	1	1	
Absolute Difference	5	1	2	3	4	5	20

Table A6-6: Maximum distance between two odd numbered ordered sequences (with tied ranks)

Element	k	l	m	n	o	p	q	Sum
X Position	1	2	3	4	5	6	7	
Y Position	7	1	1	1	1	1	1	
Absolute Difference	6	1	2	3	4	5	6	27

In closed form, the maximum distance between two order sequences with tied ranks, d_{n-max} can be generalised as:

Formula and Elicitations Steps of MCDM Techniques

$$\begin{aligned}d_{n-max} &= (n - 1) + \sum_{j=1}^{n-1} j \\&= \frac{1 + (n - 1)}{2} * (n - 1) + (n - 1) \\&= \frac{(n - 1)(n + 2)}{2}\end{aligned}$$

Appendix 7: Fuzzy Models of the Qualitative Criteria in B2B Context Model

Altogether, the *B2B Context Model* has 10 qualitative criteria. In this appendix, the source of information and how the fuzzy model was designed for selected qualitative criteria are documented.

A7.1 Ease of Doing Business

The **Ease of Doing Business Index** is an index created by the World Bank¹². Economies are ranked based on their ease of doing business, from 1 – 183, with first place being the best. A high ranking on the ease of doing business index means the regulatory environment is conducive to the operation of business, as this index is meant to measure regulations directly affecting businesses. The index is based on the average of 10 sub-indices; Starting a business, Dealing with licenses, Hiring and firing workers, Registering, Getting credit, Protecting investors, Paying taxes, Trading across, Enforcing contracts and Closing a business. These are all important considerations when identifying new partners or the decision to collaborate with a partner for a new project. As such this index provides a good indication on the suitability of a partner (by virtue of its company's location).

The index contains ranking of about 180 countries, where it is grouped into five linguistic values of Very High, High, Average, Low and Very Low. These groupings will provide a reasonable way of specifying ease of doing business when using the *B2B Context Model*. The detailed membership functions are described as in the graph of Figure A7-1.

¹² <http://www.doingbusiness.org/EconomyRankings/>

Fuzzy Models of the Qualitative Criteria in B2B Context Model

Figure A7-1: Ease of Doing Business Fuzzy Model

A7.2 Profitability

The net profit margin is used to represent the **Profitability** of a company. The following formula is a standard formula to calculate net profit margin¹³:

$$\text{Net profit margin} = \frac{\text{net profit, after taxes}}{\text{total revenue}} * 100\%$$

As this profitability measure could result in a very large range of quantitative values, it would be difficult to expect absolute preferred values to be specified accurately during a request. Thus, the qualitative approach is taken instead, where five linguistic values of Very High, High, Average, Low and Very Low. As any company's profitability of beyond 50% can be considered to be good or high, the peak of High membership function is set at around this mark. The other peaks are then distributed equally downwards to Very Low and a similar interval to Very High. The resultant detailed membership functions are as illustrated in Figure A7-2.

¹³ <http://thismatter.com/money/stocks/valuation/profitability-ratios.htm>

Fuzzy Models of the Qualitative Criteria in B2B Context Model

Figure A7-2: Profitability Fuzzy Model

A7.3 Payment Term

This criterion is part of the overall payment concept in the *B2B Context Model*, the other two being *payment duration* and *payment penalty*. It can be combined with the other two criteria to form the aggregated *Payment* criterion or to be used as a simple criterion on its own.

Payment term reflects the risk of conducting business with a particular partner, especially for partners that are new or without a long standing agreement. In typical B2B trading, payment term is specified using known payment methods. There are many forms of payment methods, depending on the trade types and nature of business¹⁴. For this research, six forms of payment methods are mapped, in ascending of risk to the customers, namely Open Account, Consignment, Drafts, Letter of Credit, Telegraphic Transfer and Cash in Advance. As these payment types are discrete in nature but not in quantitative values, there is a need to use the fuzzy approach. Payment term is modeled as a three category fuzzy model of High, Average and Low

¹⁴ <http://www.sitpro.org.uk/trade/paymentmethods.html>

Fuzzy Models of the Qualitative Criteria in B2B Context Model

only to reflect the risks associated with each payment method. The fuzzy model is detailed in Figure A7-3. For this model, each membership function was designed to intersect at truth values of 0.45 (Low and Average) and 0.5 (Average and High) respectively. This was done as it was deemed meaningless to have truth values of 0.0 for each of the categories. Furthermore, reflective of the degree of risk in each payment method, Open Account has a full truth value for Low risk, and likewise for Cash In Advance in the High risk.

Figure A7-3: Payment Fuzzy Model

Empirical Testing of Candidate MCDM Techniques

Appendix 8: Empirical Testing of Candidate MCDM Techniques

A8.1 Experimental Setup: Test Cases for Situation (1)

Run 1-1	Data Set	Criteria			QuickLite Values ^a		
		Cost	Lead time (day)	Location	Quantity	Sales Basis ^b	Tran Cost
	Set1-1-1	12.50	3	Singapore	1000	FOB	500
	Set1-1-2	9.50	5	Singapore	3000	FOB	500
	Set1-1-3	13.00	3	Shah Alam, Malaysia	1000	FOB	500
	Set1-1-4	10.00	5	Shah Alam, Malaysia	3000	FOB	500

Run 1-2	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment Duration (day)	Quantity	Sales Basis ^b	Tran Cost
	Set1-2-1	12.50	3	Singapore	60	1000	FOB	500
	Set1-2-2	9.50	5	Singapore	90	3000	FOB	500
	Set1-2-3	13.00	3	Shah Alam, Malaysia	60	1000	FOB	500
	Set1-2-4	10.00	5	Shah Alam, Malaysia	90	3000	FOB	500

Run 1-3	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment Penalty (%)	Quantity	Sales Basis ^b	Tran Cost
	Set1-3-1	12.50	3	Singapore	2%	1000	FOB	500
	Set1-3-2	9.50	5	Singapore	2%	3000	FOB	500
	Set1-3-3	13.00	3	Shah Alam, Malaysia	2%	1000	FOB	500
	Set1-3-4	10.00	5	Shah Alam, Malaysia	2%	3000	FOB	500

Run 1-4	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment (Overall)	Quantity	Sales Basis ^b	Tran Cost
	Set1-4-1	12.50	3	Singapore	2 %, 60 days	1000	FOB	500
	Set1-4-2	9.50	5	Singapore	2%, 90 days	3000	FOB	500
	Set1-4-3	13.00	3	Shah Alam, Malaysia	2 %, 60 days	1000	FOB	500

Empirical Testing of Candidate MCDM Techniques

	Set1-4-4	10.00	5	Shah Alam, Malaysia	2 %, 90 days	3000	FOB	500
--	----------	-------	---	---------------------	--------------	------	-----	-----

Run 1-5	Data Set	Criteria			QuickLite Values ^a		
		Cost	Lead time (day)	Capacity	Quantity	Sales Basis ^b	Tran Cost
	Set1-5-1	12.50	3	200000	1000	FOB	500
	Set1-5-2	9.50	5	600000	3000	FOB	500
	Set1-5-3	13.00	3	200000	1000	FOB	500
	Set1-5-4	10.00	5	600000	3000	FOB	500

Run 1-6	Data Set	Criteria					QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment (Overall)	Capacity	Quantity	Sales Basis ^b	Tran Cost
	Set1-6-1	12.50	3	Singapore	2%, 60 days	200000	1000	FOB	500
	Set1-6-2	9.50	5	Singapore	2%, 90 days	600000	3000	FOB	500
	Set1-6-3	13.00	3	Shah Alam, Malaysia	2%, 60 days	200000	1000	FOB	500
	Set1-6-4	10.00	5	Shah Alam, Malaysia	2%, 90 days	600000	3000	FOB	500

A8.2 Experimental Setup: Test Cases for Situation (2)

Run 2-1	Data Set	Criteria			QuickLite Values ^a		
		Cost	Lead time (day)	Location	Quantity	Sales Basis ^b	Tran Cost
	Set2-1-1	43.00	3	Singapore	3000	FOB	500
	Set2-1-2	45.00	7	San Diego, USA	3000	CIF	-

Run 2-2	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment Duration (day)	Quantity	Sales Basis ^b	Tran Cost
	Set2-2-1	43.00	3	Singapore	30	3000	FOB	500
	Set2-2-2	45.00	7	San Diego, USA	30	3000	CIF	-

Run 2-3	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment Penalty (%)	Quantity	Sales Basis ^b	Tran Cost
	Set2-3-1	43.00	3	Singapore	2%	3000	FOB	500

Empirical Testing of Candidate MCDM Techniques

	Set2-3-2	45.00	7	San Diego, USA	2%	3000	CIF	-
--	----------	-------	---	----------------	----	------	-----	---

Run 2-4	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment (Overall)	Quantity	Sales Basis ^b	Tran Cost
	Set2-4-1	43.00	3	Singapore	2 %, 30 days	3000	FOB	500
	Set2-4-2	45.00	7	San Diego, USA	2 %, 30 days	3000	CIF	-

Run 2-5	Data Set	Criteria			QuickLite Values ^a		
		Cost	Lead time (day)	Capacity	Quantity	Sales Basis ^b	Tran Cost
	Set2-5-1	43.00	3	60000	3000	FOB	500
	Set2-5-2	45.00	7	100000	3000	CIF	-

Run 2-6	Data Set	Criteria					QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment (Overall)	Capacity	Quantity	Sales Basis ^b	Tran Cost
	Set2-6-1	43.00	3	Singapore	2 %, 30 days	60000	3000	FOB	500
	Set2-6-2	45.00	7	San Diego, USA	2 %, 30 days	100000	3000	CIF	-

A8.3 Experimental Setup: Test Cases for Situation (3)

Run 3-1	Data Set	Criteria			QuickLite Values ^a		
		Cost	Lead time (day)	Location	Quantity	Sales Basis ^b	Tran Cost
	Set3-1-1	24.00	4	Singapore	500	FOB	500
	Set3-1-2	23.00	7	Singapore	1000	FOB	500
	Set3-1-3	27.00	4	Sydney, Australia	500	CIF	-
	Set3-1-4	26.00	7	Sydney, Australia	1000	CIF	-

Run 3-2	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment Duration (day)	Quantity	Sales Basis ^b	Tran Cost
	Set3-2-1	24.00	4	Singapore	60	500	FOB	500
	Set3-2-2	23.00	7	Singapore	90	1000	FOB	500
	Set3-2-3	27.00	4	Sydney, Australia	60	500	CIF	-

Empirical Testing of Candidate MCDM Techniques

	Set3-2-4	26.00	7	Sydney, Australia	90	1000	CIF	-
--	----------	-------	---	-------------------	----	------	-----	---

Run 3-3	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment Penalty (%)	Quantity	Sales Basis ^b	Tran Cost
	Set3-3-1	24.00	4	Singapore	2%	500	FOB	500
	Set3-3-2	23.00	7	Singapore	2%	1000	FOB	500
	Set3-3-3	27.00	4	Sydney, Australia	5%	500	CIF	-
	Set3-3-4	26.00	7	Sydney, Australia	5%	1000	CIF	-

Run 3-4	Data Set	Criteria				QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment (Overall)	Quantity	Sales Basis ^b	Tran Cost
	Set3-4-1	24.00	4	Singapore	2 %, 60 days	500	FOB	500
	Set3-4-2	23.00	7	Singapore	2 %, 90 days	1000	FOB	500
	Set3-4-3	27.00	4	Sydney, Australia	5 %, 60 days	500	CIF	-
	Set3-4-4	26.00	7	Sydney, Australia	5 %, 90 days	1000	CIF	-

Run 3-5	Data Set	Criteria			QuickLite Values ^a			
		Cost	Lead time (day)	Capacity	Quantity	Sales Basis ^b	Tran Cost	
	Set3-5-1	24.00	4	100000	500	FOB	500	
	Set3-5-2	23.00	7	200000	1000	FOB	500	
	Set3-5-3	27.00	4	100000	500	CIF	-	
	Set3-5-4	26.00	7	200000	1000	CIF	-	

Run 3-6	Data Set	Criteria					QuickLite Values ^a		
		Cost	Lead time (day)	Location	Payment (Overall)	Capacity	Quantity	Sales Basis ^b	Tran Cost
	Set3-6-1	24.00	4	Singapore	2 %, 60 days	100000	500	FOB	500
	Set3-6-2	23.00	7	Singapore	2 %, 90 days	200000	1000	FOB	500
	Set3-6-3	27.00	4	Sydney, Australia	5 %, 60 days	100000	500	CIF	-
	Set3-6-4	26.00	7	Sydney, Australia	5 %, 90 days	200000	1000	CIF	-

Empirical Testing of Candidate MCDM Techniques

A8.4 Weights Used for the Test Cases

Figure A8-1: 3-criteria weights combination (6 sets)

Figure A8-2: 4-criteria weights combination (6 sets)

Empirical Testing of Candidate MCDM Techniques

Figure A8-3: 5-criteria weights combination (6 sets)

Empirical Testing of Candidate MCDM Techniques

Table A8-1: Test Data - 20 candidate partners and their product offerings

[illegible]

*Empirical Testing of Candidate MCDM Techniques***A8.5 Rank Completeness Test Results****Table A8-2: Rank Completeness metric for Deviation Measure – Original (DMO)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set1-1-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-1-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-1-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-1-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-3	1.000	1.000	1.000	1.000	0.909	1.000
Set1-3-4	1.000	1.000	1.000	0.909	1.000	1.000
Set1-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-2	1.000	1.000	1.000	1.000	1.000	0.909
Set1-4-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-6-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-6-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-6-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-6-4	1.000	1.000	1.000	1.000	1.000	1.000
Set2-1-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-1-2	0.923	1.000	1.000	1.000	1.000	1.000
Set2-2-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-2-2	0.923	1.000	0.923	1.000	1.000	0.923
Set2-3-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-3-2	1.000	0.923	1.000	1.000	1.000	1.000
Set2-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-4-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-5-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-5-2	1.000	1.000	1.000	1.000	1.000	0.923
Set2-6-1	1.000	1.000	1.000	1.000	1.000	1.000

Empirical Testing of Candidate MCDM Techniques

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-6-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-2	0.917	1.000	1.000	1.000	1.000	1.000
Set3-1-3	0.917	1.000	1.000	1.000	1.000	1.000
Set3-1-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-4	1.000	1.000	1.000	1.000	0.917	1.000
Set3-3-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-2	1.000	1.000	1.000	1.000	0.917	1.000
Set3-5-3	1.000	1.000	1.000	1.000	0.917	1.000
Set3-5-4	1.000	1.000	1.000	0.917	1.000	1.000
Set3-6-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-6-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-6-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-6-4	1.000	1.000	1.000	1.000	1.000	1.000
Mean	0.997		Standard Deviation			0.016

Table A8-3: Rank Completeness metric for Deviation Measure – Modified (DMM)

Test\Weight	W1	W2	W3	W4	W5	W6
Set1-1-1	1.000	1.000	1.000	1.000	0.909	1.000
Set1-1-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-1-3	1.000	1.000	1.000	1.000	1.000	0.909
Set1-1-4	1.000	1.000	1.000	1.000	0.909	1.000
Set1-2-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-4	1.000	1.000	1.000	1.000	1.000	0.909

Empirical Testing of Candidate MCDM Techniques

Test\Weight	W1	W2	W3	W4	W5	W6
Set1-3-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-2	1.000	0.909	1.000	1.000	0.909	0.909
Set1-3-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-2	1.000	0.909	1.000	1.000	0.909	1.000
Set1-4-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-1	1.000	1.000	1.000	1.000	1.000	0.818
Set1-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-3	1.000	1.000	1.000	1.000	1.000	0.909
Set1-5-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-6-1	1.000	1.000	1.000	1.000	1.000	0.909
Set1-6-2	1.000	1.000	1.000	1.000	0.909	0.909
Set1-6-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-6-4	1.000	1.000	0.909	1.000	1.000	0.909
Set2-1-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-1-2	0.923	1.000	1.000	1.000	1.000	1.000
Set2-2-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-2-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-3-1	1.000	1.000	1.000	0.923	1.000	1.000
Set2-3-2	0.923	1.000	1.000	1.000	1.000	1.000
Set2-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-4-2	0.923	1.000	1.000	1.000	1.000	1.000
Set2-5-1	1.000	0.923	1.000	1.000	1.000	1.000
Set2-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-6-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-6-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-1	1.000	1.000	1.000	1.000	0.917	1.000
Set3-1-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-3	1.000	1.000	1.000	1.000	1.000	0.917
Set3-1-4	0.917	1.000	1.000	1.000	1.000	1.000
Set3-2-1	1.000	1.000	0.917	1.000	1.000	1.000
Set3-2-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-3	1.000	1.000	0.917	1.000	0.833	0.917
Set3-2-4	0.917	1.000	1.000	1.000	1.000	1.000
Set3-3-1	0.917	1.000	1.000	1.000	1.000	1.000
Set3-3-2	1.000	1.000	1.000	1.000	1.000	0.917

Empirical Testing of Candidate MCDM Techniques

Test\Weight	W1	W2	W3	W4	W5	W6
Set3-3-3	1.000	0.917	1.000	1.000	1.000	1.000
Set3-3-4	0.917	0.917	1.000	1.000	1.000	1.000
Set3-4-1	1.000	1.000	1.000	1.000	1.000	0.917
Set3-4-2	0.917	1.000	1.000	1.000	1.000	1.000
Set3-4-3	1.000	0.917	1.000	1.000	1.000	1.000
Set3-4-4	0.917	1.000	1.000	1.000	1.000	1.000
Set3-5-1	1.000	1.000	0.917	1.000	1.000	1.000
Set3-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-3	1.000	1.000	0.917	1.000	1.000	1.000
Set3-5-4	1.000	1.000	1.000	0.917	1.000	1.000
Set3-6-1	1.000	1.000	1.000	0.917	0.917	0.833
Set3-6-2	1.000	1.000	1.000	0.917	1.000	0.917
Set3-6-3	0.917	1.000	1.000	1.000	1.000	0.917
Set3-6-4	0.917	1.000	1.000	0.917	1.000	1.000
Mean	0.987	Standard Deviation				0.032

Table A8-4: Rank Completeness metric for PROMETHEE II

Test\Weight	W1	W2	W3	W4	W5	W6
Set1-1-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-1-2	1.000	1.000	0.909	1.000	1.000	1.000
Set1-1-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-1-4	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-1	1.000	1.000	1.000	1.000	1.000	0.909
Set1-2-2	1.000	1.000	1.000	1.000	1.000	0.909
Set1-2-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-2-4	1.000	1.000	1.000	1.000	1.000	0.909
Set1-3-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-3-4	0.909	1.000	1.000	1.000	1.000	1.000
Set1-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-3	1.000	1.000	1.000	1.000	1.000	1.000
Set1-4-4	0.909	1.000	1.000	1.000	1.000	1.000
Set1-5-1	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set1-5-3	1.000	1.000	1.000	1.000	1.000	1.000

Empirical Testing of Candidate MCDM Techniques

Test\Weight	W1	W2	W3	W4	W5	W6
Set1-5-4	1.000	1.000	1.000	1.000	1.000	0.909
Set1-6-1	0.909	1.000	1.000	1.000	1.000	1.000
Set1-6-2	1.000	1.000	1.000	0.909	1.000	1.000
Set1-6-3	0.909	1.000	0.909	1.000	1.000	1.000
Set1-6-4	1.000	1.000	1.000	1.000	1.000	1.000
Set2-1-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-1-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-2-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-2-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-3-1	0.923	1.000	1.000	1.000	1.000	1.000
Set2-3-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-4-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-4-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-5-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set2-6-1	1.000	1.000	1.000	1.000	1.000	1.000
Set2-6-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-1	1.000	0.917	1.000	1.000	1.000	0.917
Set3-1-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-4	1.000	1.000	1.000	1.000	0.917	1.000
Set3-2-1	1.000	1.000	1.000	1.000	1.000	0.917
Set3-2-2	1.000	1.000	1.000	0.917	1.000	1.000
Set3-2-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-3	1.000	1.000	1.000	1.000	1.000	0.917
Set3-3-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-1	1.000	1.000	1.000	1.000	0.917	1.000
Set3-4-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-3	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-1	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-3	1.000	1.000	1.000	1.000	1.000	0.917
Set3-5-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-6-1	1.000	1.000	1.000	1.000	1.000	1.000

Empirical Testing of Candidate MCDM Techniques

Test\Weight	W1	W2	W3	W4	W5	W6
Set3-6-2	1.000	1.000	0.917	1.000	1.000	1.000
Set3-6-3	1.000	1.000	1.000	1.000	0.917	1.000
Set3-6-4	1.000	1.000	1.000	1.000	1.000	1.000
Mean	0.995		Standard Deviation			0.021

Table A8-5: Rank Completeness metric for ELECTRE II

Test\Weight	W1	W2	W3	W4	W5	W6
Set1-1-1	0.636	0.909	0.636	0.636	0.727	0.636
Set1-1-2	0.727	0.636	0.545	0.455	0.636	0.727
Set1-1-3	0.545	0.818	0.727	0.545	0.727	0.818
Set1-1-4	0.727	0.545	0.455	0.455	0.818	0.727
Set1-2-1	0.636	0.545	0.636	0.818	0.636	0.636
Set1-2-2	0.727	0.636	0.636	0.545	0.636	0.545
Set1-2-3	0.727	0.636	0.727	0.636	0.727	0.636
Set1-2-4	0.636	0.636	0.636	0.455	0.545	0.636
Set1-3-1	0.636	0.455	0.455	0.818	0.727	0.727
Set1-3-2	0.636	0.545	0.636	0.727	0.636	0.727
Set1-3-3	0.545	0.545	0.545	0.636	0.818	0.727
Set1-3-4	0.636	0.636	0.636	0.545	0.727	0.818
Set1-4-1	0.636	0.636	0.545	0.727	0.636	0.727
Set1-4-2	0.545	0.545	0.636	0.545	0.545	0.545
Set1-4-3	0.545	0.545	0.545	0.636	0.727	0.727
Set1-4-4	0.545	0.545	0.545	0.455	0.727	0.636
Set1-5-1	0.364	0.636	0.727	0.636	0.545	0.545
Set1-5-2	0.455	0.636	0.364	0.455	0.545	0.636
Set1-5-3	0.364	0.636	0.636	0.545	0.727	0.545
Set1-5-4	0.455	0.636	0.364	0.455	0.545	0.636
Set1-6-1	0.545	0.727	0.636	0.364	0.636	0.636
Set1-6-2	0.455	0.636	0.636	0.636	0.545	0.455
Set1-6-3	0.727	0.727	0.727	0.727	0.727	0.636
Set1-6-4	0.636	0.636	0.636	0.636	0.636	0.545
Set2-1-1	0.462	0.692	0.769	0.769	0.692	0.692
Set2-1-2	0.538	0.615	0.846	0.538	0.538	0.769
Set2-2-1	0.615	0.462	0.462	0.769	0.615	0.615
Set2-2-2	0.692	0.615	0.538	0.692	0.692	0.692
Set2-3-1	0.615	0.615	0.615	0.538	0.615	0.538
Set2-3-2	0.692	0.538	0.538	0.538	0.615	0.769

Empirical Testing of Candidate MCDM Techniques

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-4-1	0.538	0.538	0.538	0.538	0.385	0.538
Set2-4-2	0.538	0.538	0.692	0.462	0.615	0.385
Set2-5-1	0.231	0.462	0.462	0.538	0.538	0.462
Set2-5-2	0.231	0.462	0.462	0.538	0.538	0.615
Set2-6-1	0.538	0.462	0.538	0.538	0.538	0.308
Set2-6-2	0.462	0.615	0.462	0.615	0.462	0.462
Set3-1-1	0.500	0.667	0.833	0.667	0.583	0.667
Set3-1-2	0.500	0.833	0.667	0.583	0.667	0.667
Set3-1-3	0.583	0.667	0.667	0.667	0.667	1.000
Set3-1-4	0.583	0.750	0.500	0.500	0.917	0.917
Set3-2-1	0.833	0.750	0.500	0.583	0.500	0.667
Set3-2-2	0.833	0.750	0.417	0.750	0.750	0.750
Set3-2-3	0.667	0.750	0.417	0.500	0.583	0.583
Set3-2-4	0.750	0.750	0.500	0.583	0.750	0.667
Set3-3-1	0.667	0.583	0.583	0.583	0.667	0.750
Set3-3-2	0.667	0.583	0.417	0.583	0.750	0.667
Set3-3-3	0.667	0.833	0.750	0.750	0.750	0.833
Set3-3-4	0.750	0.833	0.667	0.750	0.750	0.667
Set3-4-1	0.500	0.333	0.500	0.500	0.417	0.417
Set3-4-2	0.500	0.500	0.417	0.500	0.500	0.417
Set3-4-3	0.500	0.500	0.583	0.583	0.583	0.500
Set3-4-4	0.583	0.583	0.417	0.417	0.417	0.417
Set3-5-1	0.500	0.833	0.750	0.667	0.667	0.833
Set3-5-2	0.500	0.667	0.583	0.583	0.667	0.583
Set3-5-3	0.500	0.833	0.750	0.667	0.667	0.833
Set3-5-4	0.500	0.667	0.750	0.583	0.583	0.833
Set3-6-1	0.583	0.583	0.750	0.500	0.500	0.417
Set3-6-2	0.500	0.500	0.583	0.500	0.417	0.417
Set3-6-3	0.583	0.583	0.583	0.417	0.500	0.417
Set3-6-4	0.417	0.417	0.500	0.500	0.583	0.417
Mean	0.604		Standard Deviation			0.122

*Empirical Testing of Candidate MCDM Techniques***A8.6 Rank Correlation Test Results****Table A8-6: Rank Correlation metric for DMM – 5 alternatives, Step (a) vs. Step (b)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	1.000	0.900	1.000	1.000	1.000	1.000
Set2-1-2	0.959	1.000	1.000	1.000	1.000	1.000
Set2-2-1	0.900	1.000	0.900	1.000	0.900	1.000
Set2-2-2	0.900	1.000	0.900	1.000	0.900	1.000
Set2-3-1	0.900	1.000	0.800	1.000	0.900	1.000
Set2-3-2	0.300	0.900	1.000	0.900	0.900	1.000
Set2-4-1	0.800	1.000	0.900	0.900	0.900	1.000
Set2-4-2	0.400	0.900	0.900	0.900	0.900	1.000
Set2-5-1	0.900	0.900	0.900	1.000	1.000	1.000
Set2-5-2	0.900	0.900	0.900	1.000	1.000	1.000
Set2-6-1	0.900	0.900	0.900	0.800	1.000	1.000
Set2-6-2	0.600	0.900	0.849	0.800	1.000	1.000
Set3-1-1	1.000	1.000	1.000	1.000	0.900	1.000
Set3-1-2	1.000	1.000	0.900	1.000	1.000	1.000
Set3-1-3	0.962	1.000	0.900	1.000	1.000	0.700
Set3-1-4	0.900	1.000	1.000	0.900	1.000	0.700
Set3-2-1	1.000	0.900	1.000	0.900	1.000	0.900
Set3-2-2	1.000	1.000	1.000	0.900	1.000	0.900
Set3-2-3	1.000	1.000	0.900	0.900	0.972	0.700
Set3-2-4	0.900	1.000	1.000	0.900	0.900	1.000
Set3-3-1	1.000	0.900	0.900	1.000	0.900	0.900
Set3-3-2	1.000	0.900	1.000	0.900	1.000	0.700
Set3-3-3	0.900	1.000	0.959	0.800	0.884	1.000
Set3-3-4	0.900	1.000	0.900	0.800	0.900	1.000
Set3-4-1	1.000	0.900	0.900	1.000	0.900	0.900
Set3-4-2	1.000	1.000	1.000	0.900	1.000	0.700
Set3-4-3	1.000	1.000	1.000	0.800	0.800	0.900
Set3-4-4	1.000	1.000	0.900	0.866	0.900	1.000
Set3-5-1	0.900	1.000	1.000	1.000	0.700	0.700
Set3-5-2	0.900	1.000	1.000	0.900	1.000	0.700
Set3-5-3	0.900	1.000	1.000	1.000	0.700	0.700
Set3-5-4	0.900	1.000	1.000	0.900	1.000	0.700
Set3-6-1	1.000	1.000	1.000	0.900	0.900	0.900
Set3-6-2	1.000	1.000	1.000	1.000	0.900	0.300
Set3-6-3	0.900	1.000	1.000	0.900	0.700	1.000
Set3-6-4	1.000	0.972	1.000	0.900	1.000	0.900
Mean	0.927	Standard Deviation				0.109

*Empirical Testing of Candidate MCDM Techniques***Table A8-7: Rank Correlation metric for DMM – 5 alternatives, Step (a) vs. Step (c)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	1.000	0.900	1.000	1.000	0.900	0.900
Set2-1-2	0.900	0.700	1.000	0.900	0.900	1.000
Set2-2-1	0.900	1.000	0.900	0.800	0.900	1.000
Set2-2-2	0.500	0.900	0.700	0.800	0.900	1.000
Set2-3-1	0.600	1.000	0.600	1.000	0.900	1.000
Set2-3-2	0.300	0.900	1.000	0.800	0.900	1.000
Set2-4-1	0.900	1.000	0.600	0.900	0.900	1.000
Set2-4-2	0.400	0.800	0.900	0.800	0.900	1.000
Set2-5-1	1.000	0.700	0.300	0.800	0.900	1.000
Set2-5-2	1.000	0.700	0.300	0.800	0.900	1.000
Set2-6-1	0.500	0.300	0.800	0.800	0.900	1.000
Set2-6-2	0.700	0.300	0.485	0.900	1.000	1.000
Set3-1-1	0.900	1.000	1.000	1.000	1.000	1.000
Set3-1-2	0.900	1.000	1.000	0.900	1.000	0.900
Set3-1-3	0.962	1.000	1.000	1.000	1.000	1.000
Set3-1-4	0.962	1.000	1.000	1.000	1.000	1.000
Set3-2-1	0.900	1.000	1.000	1.000	1.000	0.900
Set3-2-2	0.900	1.000	1.000	1.000	0.900	0.700
Set3-2-3	1.000	1.000	1.000	1.000	0.972	0.900
Set3-2-4	0.959	1.000	1.000	0.900	1.000	1.000
Set3-3-1	0.700	1.000	0.900	0.900	1.000	0.900
Set3-3-2	0.900	1.000	1.000	1.000	0.900	0.700
Set3-3-3	0.700	1.000	0.959	1.000	0.972	1.000
Set3-3-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-1	0.700	1.000	0.900	0.900	1.000	0.959
Set3-4-2	1.000	1.000	1.000	1.000	0.900	0.900
Set3-4-3	0.700	1.000	0.900	1.000	1.000	1.000
Set3-4-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-5-1	0.900	1.000	1.000	1.000	1.000	1.000
Set3-5-2	0.900	1.000	0.900	0.700	0.700	0.400
Set3-5-3	0.900	1.000	1.000	1.000	1.000	1.000
Set3-5-4	0.900	1.000	0.900	0.700	0.700	0.400
Set3-6-1	1.000	1.000	1.000	1.000	1.000	0.900
Set3-6-2	0.900	0.900	0.900	0.770	0.700	0.300
Set3-6-3	0.900	0.900	1.000	0.900	1.000	1.000
Set3-6-4	0.700	0.700	0.700	0.900	0.900	0.700
Mean	0.894	Standard Deviation				0.162

*Empirical Testing of Candidate MCDM Techniques***Table A8-8: Rank Correlation metric for DMM – 8 alternatives, Step (b) vs. Step (c)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.881	0.976	0.976	0.952	0.976	0.976
Set2-1-2	0.980	0.857	0.929	0.976	0.976	1.000
Set2-2-1	0.976	0.976	0.976	0.976	0.976	1.000
Set2-2-2	0.819	0.976	0.905	0.881	1.000	1.000
Set2-3-1	0.833	0.952	0.905	0.976	1.000	1.000
Set2-3-2	0.992	0.970	0.976	0.905	1.000	1.000
Set2-4-1	0.810	0.976	0.929	0.976	1.000	1.000
Set2-4-2	0.976	0.952	0.929	0.905	1.000	1.000
Set2-5-1	0.881	0.976	0.762	0.905	0.976	0.976
Set2-5-2	0.881	0.976	0.762	0.905	0.976	0.976
Set2-6-1	0.595	0.425	0.952	0.905	0.952	1.000
Set2-6-2	0.976	0.812	0.905	0.929	0.976	1.000
Set3-1-1	0.929	0.929	0.976	0.976	0.905	1.000
Set3-1-2	0.929	0.810	0.952	0.952	1.000	0.976
Set3-1-3	1.000	0.976	0.929	0.929	0.976	0.929
Set3-1-4	0.968	0.976	0.976	0.976	1.000	0.929
Set3-2-1	0.929	0.976	0.967	0.905	0.976	0.952
Set3-2-2	0.929	1.000	0.976	0.881	0.976	0.976
Set3-2-3	1.000	0.905	0.915	0.929	0.903	0.952
Set3-2-4	0.990	0.905	0.976	0.976	0.976	1.000
Set3-3-1	0.850	0.976	0.905	0.929	0.952	1.000
Set3-3-2	0.833	0.976	0.976	0.905	0.976	0.992
Set3-3-3	0.786	0.923	0.952	0.857	0.952	1.000
Set3-3-4	0.857	0.952	0.810	0.905	0.976	0.976
Set3-4-1	0.762	0.976	0.905	0.929	0.952	0.990
Set3-4-2	0.976	1.000	1.000	0.905	0.976	0.929
Set3-4-3	0.905	0.941	0.881	0.857	0.905	0.952
Set3-4-4	0.968	0.905	0.857	0.923	0.976	0.976
Set3-5-1	0.738	0.870	0.952	0.952	0.857	0.929
Set3-5-2	0.738	0.952	0.929	0.929	0.857	0.786
Set3-5-3	0.738	0.870	0.952	0.952	0.857	0.929
Set3-5-4	0.738	0.952	0.929	0.943	0.857	0.786
Set3-6-1	0.952	0.952	1.000	0.923	0.918	0.990
Set3-6-2	0.905	0.881	0.929	0.920	0.905	0.945
Set3-6-3	0.810	0.857	0.976	0.952	0.857	1.000
Set3-6-4	0.920	0.859	0.929	0.905	0.905	0.976
Mean	0.929	Standard Deviation				0.074

*Empirical Testing of Candidate MCDM Techniques***Table A8-9: Rank Correlation metric for PROMETHEE II – 5 alternatives, Step (a) vs. Step (b)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	1.000	0.900	1.000	1.000	1.000	0.900
Set2-1-2	1.000	1.000	1.000	1.000	1.000	0.900
Set2-2-1	0.900	1.000	0.900	1.000	0.900	1.000
Set2-2-2	0.900	1.000	1.000	1.000	0.900	1.000
Set2-3-1	0.900	1.000	1.000	1.000	0.900	1.000
Set2-3-2	0.700	0.900	1.000	1.000	0.900	1.000
Set2-4-1	0.900	1.000	1.000	0.900	0.900	1.000
Set2-4-2	1.000	0.600	1.000	1.000	0.800	1.000
Set2-5-1	0.900	0.900	0.900	1.000	1.000	0.900
Set2-5-2	0.700	0.900	1.000	1.000	1.000	0.900
Set2-6-1	0.700	0.900	1.000	0.900	1.000	1.000
Set2-6-2	0.900	0.900	1.000	0.900	1.000	1.000
Set3-1-1	1.000	1.000	1.000	1.000	0.900	0.600
Set3-1-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-1-3	1.000	1.000	0.900	1.000	1.000	1.000
Set3-1-4	1.000	1.000	0.900	1.000	1.000	1.000
Set3-2-1	1.000	1.000	1.000	1.000	1.000	0.400
Set3-2-2	1.000	1.000	1.000	0.900	1.000	1.000
Set3-2-3	1.000	1.000	0.900	0.900	1.000	0.400
Set3-2-4	1.000	0.900	0.900	0.900	1.000	0.900
Set3-3-1	0.900	1.000	0.962	1.000	1.000	1.000
Set3-3-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-3-3	0.900	0.700	0.900	0.900	0.900	0.900
Set3-3-4	1.000	0.900	1.000	0.900	1.000	0.900
Set3-4-1	1.000	1.000	0.900	1.000	1.000	0.900
Set3-4-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-4-3	0.900	1.000	1.000	0.900	1.000	0.700
Set3-4-4	1.000	1.000	1.000	0.900	1.000	0.900
Set3-5-1	0.600	1.000	1.000	0.900	0.400	0.700
Set3-5-2	0.600	1.000	1.000	1.000	1.000	0.800
Set3-5-3	0.600	1.000	0.900	0.900	0.400	0.700
Set3-5-4	0.600	1.000	1.000	1.000	1.000	0.900
Set3-6-1	0.900	1.000	1.000	0.900	0.900	1.000
Set3-6-2	1.000	1.000	1.000	1.000	1.000	1.000
Set3-6-3	0.972	0.959	0.900	1.000	0.600	1.000
Set3-6-4	1.000	0.900	1.000	1.000	1.000	0.900
Mean	0.936	Standard Deviation				0.118

*Empirical Testing of Candidate MCDM Techniques***Table A8-10: Rank Correlation metric for PROMETHEE II – 5 alternatives, Step (a) vs. Step (c)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	1.000	0.900	1.000	1.000	0.900	0.900
Set2-1-2	0.700	0.900	1.000	0.900	0.900	0.900
Set2-2-1	0.900	1.000	0.900	0.900	0.900	1.000
Set2-2-2	0.900	0.300	0.700	0.900	0.900	1.000
Set2-3-1	0.600	1.000	0.700	1.000	0.900	1.000
Set2-3-2	0.900	0.100	1.000	0.900	0.900	1.000
Set2-4-1	0.800	1.000	0.700	0.800	0.900	1.000
Set2-4-2	0.900	0.000	0.900	0.900	0.900	1.000
Set2-5-1	0.900	0.700	0.300	0.800	0.900	0.900
Set2-5-2	1.000	0.700	0.500	0.800	0.900	0.900
Set2-6-1	0.500	0.300	0.900	0.600	0.700	1.000
Set2-6-2	1.000	0.900	0.600	0.900	1.000	1.000
Set3-1-1	0.900	0.959	1.000	1.000	1.000	1.000
Set3-1-2	0.900	1.000	1.000	1.000	1.000	0.900
Set3-1-3	1.000	1.000	1.000	1.000	1.000	0.600
Set3-1-4	1.000	1.000	1.000	1.000	1.000	1.000
Set3-2-1	0.900	1.000	1.000	1.000	1.000	0.900
Set3-2-2	0.900	1.000	1.000	1.000	0.900	1.000
Set3-2-3	1.000	0.900	1.000	1.000	1.000	0.700
Set3-2-4	1.000	1.000	1.000	1.000	1.000	0.900
Set3-3-1	0.900	1.000	0.962	0.900	1.000	1.000
Set3-3-2	1.000	1.000	1.000	1.000	0.900	1.000
Set3-3-3	0.900	0.900	1.000	1.000	1.000	1.000
Set3-3-4	0.900	0.900	1.000	1.000	1.000	1.000
Set3-4-1	0.700	1.000	0.900	0.900	1.000	0.900
Set3-4-2	1.000	1.000	1.000	1.000	0.900	0.900
Set3-4-3	0.800	0.700	0.800	1.000	1.000	1.000
Set3-4-4	0.900	0.900	1.000	1.000	1.000	1.000
Set3-5-1	0.900	0.900	0.900	1.000	1.000	0.900
Set3-5-2	0.900	0.900	0.700	0.700	1.000	0.300
Set3-5-3	0.900	0.900	1.000	1.000	1.000	0.962
Set3-5-4	0.900	0.900	0.700	0.700	1.000	0.400
Set3-6-1	1.000	1.000	1.000	1.000	0.900	0.900
Set3-6-2	0.900	0.900	0.853	0.900	0.600	0.800
Set3-6-3	0.795	1.000	0.900	0.900	1.000	1.000
Set3-6-4	0.700	0.900	0.700	1.000	0.800	0.900
Mean	0.896	Standard Deviation				0.162

*Empirical Testing of Candidate MCDM Techniques***Table A8-11: Rank Correlation metric for PROMETHEE II – 8 alternatives, Step (b) vs. Step (c)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.881	0.976	0.976	0.952	0.976	1.000
Set2-1-2	0.857	0.929	1.000	0.976	0.976	1.000
Set2-2-1	0.976	0.952	1.000	0.976	0.976	0.976
Set2-2-2	0.976	0.690	0.905	0.929	1.000	1.000
Set2-3-1	0.810	0.929	0.905	0.976	0.976	1.000
Set2-3-2	0.952	0.690	1.000	0.881	1.000	1.000
Set2-4-1	0.952	0.929	0.929	0.976	1.000	1.000
Set2-4-2	0.929	0.738	0.952	0.881	0.976	1.000
Set2-5-1	0.810	0.976	0.762	0.905	0.952	0.976
Set2-5-2	0.810	0.976	0.762	0.905	0.952	1.000
Set2-6-1	0.500	0.452	0.976	0.905	0.905	0.976
Set2-6-2	0.905	0.905	0.881	0.976	1.000	0.929
Set3-1-1	0.929	0.951	0.976	0.976	0.905	0.905
Set3-1-2	0.905	0.976	0.976	0.976	1.000	0.976
Set3-1-3	0.929	0.857	0.929	1.000	0.929	0.905
Set3-1-4	0.976	0.976	0.929	1.000	0.976	0.976
Set3-2-1	0.952	1.000	0.952	0.976	0.976	0.918
Set3-2-2	0.881	1.000	0.976	0.929	0.976	1.000
Set3-2-3	0.952	0.929	0.881	0.905	0.905	0.952
Set3-2-4	0.976	0.881	0.905	0.929	0.976	0.990
Set3-3-1	0.905	0.976	0.929	0.929	0.976	1.000
Set3-3-2	0.952	1.000	0.952	0.976	0.929	0.976
Set3-3-3	0.833	0.762	0.952	0.952	0.952	0.976
Set3-3-4	0.952	0.762	0.952	0.905	0.976	0.905
Set3-4-1	0.905	0.976	0.881	0.929	0.976	0.952
Set3-4-2	0.976	1.000	0.976	0.976	0.976	0.976
Set3-4-3	0.905	0.833	0.929	0.905	0.952	0.929
Set3-4-4	0.905	0.881	0.905	0.929	0.976	0.952
Set3-5-1	0.524	0.833	0.857	0.905	0.738	1.000
Set3-5-2	0.524	0.952	0.857	0.881	0.976	0.905
Set3-5-3	0.524	0.833	0.857	0.905	0.738	0.897
Set3-5-4	0.524	0.952	0.857	0.881	0.976	0.905
Set3-6-1	0.929	0.952	1.000	0.929	0.929	0.976
Set3-6-2	0.905	0.905	0.894	0.952	0.881	0.881
Set3-6-3	0.929	0.942	0.810	0.929	0.763	1.000
Set3-6-4	0.833	0.857	0.881	0.976	0.857	0.905
Mean	0.918	Standard Deviation				0.093

*Empirical Testing of Candidate MCDM Techniques***Table A8-12: Rank Correlation metric for ELECTRE II – 5 alternatives, Step (a) vs. Step (b)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	1.000	1.000	1.000	0.962	0.962	0.962
Set2-1-2	0.408	1.000	-0.162	0.885	0.972	1.000
Set2-2-1	0.959	0.967	0.963	0.735	0.923	0.919
Set2-2-2	0.919	0.774	0.972	0.545	1.000	0.735
Set2-3-1	0.879	0.886	0.843	1.000	0.969	0.923
Set2-3-2	0.967	0.730	0.919	1.000	0.677	0.967
Set2-4-1	0.906	0.967	0.945	0.481	0.969	0.923
Set2-4-2	0.873	0.873	0.972	0.903	1.000	0.967
Set2-5-1	0.746	0.662	0.873	0.778	0.509	0.739
Set2-5-2	0.746	0.968	0.873	0.958	0.500	0.739
Set2-6-1	1.000	0.828	0.889	0.778	0.500	0.802
Set2-6-2	0.748	0.770	0.748	0.970	0.967	0.843
Set3-1-1	0.972	0.970	0.945	0.943	0.938	0.945
Set3-1-2	0.972	0.970	0.545	0.975	0.843	0.834
Set3-1-3	0.972	1.000	0.967	0.923	0.871	1.000
Set3-1-4	0.972	1.000	1.000	0.885	0.923	0.959
Set3-2-1	0.943	0.866	0.943	0.748	0.770	0.408
Set3-2-2	0.943	0.884	1.000	0.863	0.868	0.944
Set3-2-3	0.943	0.866	0.943	0.748	0.962	0.834
Set3-2-4	1.000	0.866	1.000	0.825	0.896	0.943
Set3-3-1	0.622	0.622	0.863	0.866	0.873	0.967
Set3-3-2	0.622	0.863	0.863	0.662	0.863	1.000
Set3-3-3	0.977	0.863	0.863	0.866	0.635	0.972
Set3-3-4	0.977	0.863	0.977	0.639	0.970	1.000
Set3-4-1	0.906	0.662	0.906	0.845	0.873	0.903
Set3-4-2	1.000	0.961	1.000	0.961	0.967	1.000
Set3-4-3	0.885	0.906	0.906	0.845	0.919	1.000
Set3-4-4	0.977	0.977	1.000	1.000	1.000	1.000
Set3-5-1	0.713	1.000	0.923	0.967	0.770	1.000
Set3-5-2	0.713	1.000	0.774	0.867	0.972	1.000
Set3-5-3	0.683	1.000	0.923	0.967	0.770	1.000
Set3-5-4	0.713	1.000	0.641	0.735	0.866	0.962
Set3-6-1	0.867	0.867	0.748	0.968	0.688	0.919
Set3-6-2	0.968	0.968	0.919	0.962	0.919	1.000
Set3-6-3	0.867	0.867	0.968	0.968	0.892	1.000
Set3-6-4	0.968	0.968	1.000	0.919	0.919	1.000
Mean	0.880		Standard Deviation			0.144

*Empirical Testing of Candidate MCDM Techniques***Table A8-13: Rank Correlation metric for ELECTRE II – 5 alternatives, Step (a) vs. Step (c)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.630	1.000	1.000	0.962	0.962	0.962
Set2-1-2	0.408	1.000	-0.162	0.264	1.000	1.000
Set2-2-1	0.845	0.945	0.873	0.735	0.922	0.972
Set2-2-2	0.800	0.730	0.945	0.621	0.677	0.959
Set2-3-1	0.959	0.800	1.000	0.968	1.000	0.813
Set2-3-2	0.923	0.742	0.919	0.667	1.000	0.945
Set2-4-1	0.802	0.886	1.000	0.970	0.923	0.903
Set2-4-2	0.873	0.748	1.000	0.829	0.903	0.934
Set2-5-1	0.746	0.662	0.828	0.408	0.564	0.662
Set2-5-2	0.746	0.968	0.828	0.746	0.813	0.764
Set2-6-1	0.945	0.967	0.919	0.828	0.742	0.363
Set2-6-2	0.748	0.770	0.873	1.000	0.756	0.845
Set3-1-1	0.945	0.970	0.945	0.943	0.884	0.945
Set3-1-2	0.945	0.970	0.735	0.943	0.843	0.834
Set3-1-3	0.972	0.849	0.567	0.972	0.906	1.000
Set3-1-4	0.972	1.000	-0.044	0.863	0.972	0.959
Set3-2-1	0.970	0.866	1.000	0.829	0.630	0.368
Set3-2-2	1.000	0.884	0.843	0.938	0.944	0.577
Set3-2-3	0.943	0.866	1.000	0.748	0.962	0.843
Set3-2-4	0.943	0.866	0.843	0.937	0.825	0.943
Set3-3-1	0.977	0.863	0.977	0.840	0.945	0.567
Set3-3-2	0.977	0.863	0.977	0.455	0.938	1.000
Set3-3-3	0.977	0.938	0.977	0.868	0.873	1.000
Set3-3-4	0.977	0.938	0.977	0.938	0.970	1.000
Set3-4-1	0.845	0.662	0.977	0.938	0.873	0.903
Set3-4-2	1.000	0.938	0.977	0.938	0.873	0.903
Set3-4-3	0.845	0.845	0.977	0.938	0.795	0.943
Set3-4-4	0.906	0.977	0.977	0.970	1.000	1.000
Set3-5-1	0.778	0.959	0.853	0.853	0.770	1.000
Set3-5-2	0.713	0.843	0.891	0.958	0.972	0.972
Set3-5-3	0.778	0.959	0.853	0.853	0.770	1.000
Set3-5-4	0.713	0.843	0.492	0.829	0.866	0.866
Set3-6-1	0.774	0.774	0.748	0.968	0.688	0.919
Set3-6-2	0.892	0.892	0.919	0.907	0.919	0.903
Set3-6-3	0.774	0.774	0.968	0.968	0.892	0.970
Set3-6-4	0.968	0.892	0.795	0.907	0.919	1.000
Mean	0.860		Standard Deviation			0.163

*Empirical Testing of Candidate MCDM Techniques***Table A8-14: Rank Correlation metric for ELECTRE II – 8 alternatives, Step (b) vs. Step (c)**

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.889	1.000	0.979	0.990	1.000	0.991
Set2-1-2	0.968	1.000	0.672	0.844	0.978	1.000
Set2-2-1	0.926	0.889	0.923	1.000	0.940	0.987
Set2-2-2	0.913	0.904	0.983	0.975	0.839	0.932
Set2-3-1	0.958	0.892	0.927	0.923	0.912	0.881
Set2-3-2	0.898	0.951	0.684	0.936	0.857	0.937
Set2-4-1	0.875	0.767	0.956	0.885	0.936	0.908
Set2-4-2	0.953	0.921	0.693	0.851	0.912	0.865
Set2-5-1	1.000	0.975	0.986	0.933	0.824	0.850
Set2-5-2	1.000	0.992	0.986	0.933	0.824	0.978
Set2-6-1	0.879	0.851	0.961	0.968	0.939	0.765
Set2-6-2	1.000	1.000	0.979	0.956	0.784	0.881
Set3-1-1	0.923	1.000	0.943	0.937	0.991	0.991
Set3-1-2	0.923	0.988	0.471	0.968	1.000	1.000
Set3-1-3	0.939	0.920	0.634	0.914	0.986	1.000
Set3-1-4	0.921	0.991	0.296	0.966	0.990	1.000
Set3-2-1	0.742	0.965	0.908	0.951	0.968	0.939
Set3-2-2	0.856	0.965	0.930	0.991	0.979	0.909
Set3-2-3	0.891	0.965	0.914	0.992	1.000	0.978
Set3-2-4	0.947	0.965	0.930	0.966	0.992	0.990
Set3-3-1	0.820	0.831	0.839	0.968	0.803	0.926
Set3-3-2	0.820	0.665	0.850	0.945	0.847	0.912
Set3-3-3	1.000	0.807	0.860	0.919	0.932	0.967
Set3-3-4	0.938	0.935	0.991	0.878	0.921	0.926
Set3-4-1	0.992	1.000	0.904	0.954	1.000	1.000
Set3-4-2	0.990	0.939	0.973	0.944	0.740	0.866
Set3-4-3	0.933	0.989	0.918	0.955	0.929	0.906
Set3-4-4	0.956	0.961	0.843	0.779	1.000	1.000
Set3-5-1	0.938	0.966	0.946	0.935	0.977	0.977
Set3-5-2	0.968	0.783	0.740	0.846	0.991	0.992
Set3-5-3	0.938	0.966	0.946	0.935	0.977	0.977
Set3-5-4	0.968	0.783	0.824	0.854	0.965	0.976
Set3-6-1	0.976	0.976	0.983	0.877	0.947	0.891
Set3-6-2	0.806	0.806	0.992	0.934	1.000	0.877
Set3-6-3	0.924	0.923	0.792	0.877	0.838	0.826
Set3-6-4	0.780	0.753	0.842	0.879	0.906	0.859
Mean	0.915		Standard Deviation			0.091

Empirical Testing of Candidate MCDM Techniques

A8.7 Rank Reversal Test Results

Table A8-15: Degree of disagreement for DMM – 5 alternatives, Step (a) vs. Step (b)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.000	0.167	0.000	0.000	0.000	0.000
Set2-1-2	<i>0.071</i>	0.000	0.000	0.000	0.000	0.000
Set2-2-1	0.167	0.000	0.167	0.000	0.167	0.000
Set2-2-2	0.167	0.000	0.167	0.000	0.167	0.000
Set2-3-1	0.167	0.000	0.333	0.000	0.167	0.000
Set2-3-2	0.500	0.167	0.000	0.167	0.167	0.000
Set2-4-1	0.333	0.000	0.167	0.167	0.167	0.000
Set2-4-2	0.500	0.167	0.167	0.167	0.167	0.000
Set2-5-1	0.167	0.167	0.167	0.000	0.000	0.000
Set2-5-2	0.167	0.167	0.167	0.000	0.000	0.000
Set2-6-1	0.167	0.167	0.167	0.333	0.000	0.000
Set2-6-2	0.333	0.167	<i>0.214</i>	0.333	0.000	0.000
Set3-1-1	0.000	0.000	0.000	0.000	0.167	0.000
Set3-1-2	0.000	0.000	0.167	0.000	0.000	0.000
Set3-1-3	<i>0.071</i>	0.000	0.167	0.000	0.000	0.333
Set3-1-4	0.167	0.000	0.000	0.167	0.000	0.333
Set3-2-1	0.000	0.167	0.000	0.167	0.000	0.167
Set3-2-2	0.000	0.000	0.000	0.167	0.000	0.167
Set3-2-3	0.000	0.000	0.167	0.167	<i>0.071</i>	0.333
Set3-2-4	0.167	0.000	0.000	0.167	0.167	0.000
Set3-3-1	0.000	0.167	0.167	0.000	0.167	0.167
Set3-3-2	0.000	0.167	0.000	0.167	0.000	0.333
Set3-3-3	0.167	0.000	<i>0.071</i>	0.333	<i>0.214</i>	0.000
Set3-3-4	0.167	0.000	0.167	0.333	0.167	0.000
Set3-4-1	0.000	0.167	0.167	0.000	0.167	0.167
Set3-4-2	0.000	0.000	0.000	0.167	0.000	0.333
Set3-4-3	0.000	0.000	0.000	0.333	0.333	0.167
Set3-4-4	0.000	0.000	0.167	<i>0.214</i>	0.167	0.000
Set3-5-1	0.167	0.000	0.000	0.000	0.333	0.333
Set3-5-2	0.167	0.000	0.000	0.167	0.000	0.333
Set3-5-3	0.167	0.000	0.000	0.000	0.333	0.333
Set3-5-4	0.167	0.000	0.000	0.167	0.000	0.333
Set3-6-1	0.000	0.000	0.000	0.167	0.167	0.167
Set3-6-2	0.000	0.000	0.000	0.000	0.167	0.500
Set3-6-3	0.167	0.000	0.000	0.167	0.333	0.000
Set3-6-4	0.000	<i>0.071</i>	0.000	0.167	0.000	0.167
Mean	0.103		Standard Deviation			0.120

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-16: Degree of disagreement scores for DMM – 5 alternatives, Step (a) vs. Step (c)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.000	0.167	0.000	0.000	0.167	0.167
Set2-1-2	0.167	0.333	0.000	0.167	0.167	0.000
Set2-2-1	0.167	0.000	0.167	0.333	0.167	0.000
Set2-2-2	0.500	0.167	0.333	0.333	0.167	0.000
Set2-3-1	0.500	0.000	0.500	0.000	0.167	0.000
Set2-3-2	0.500	0.167	0.000	0.333	0.167	0.000
Set2-4-1	0.167	0.000	0.500	0.167	0.167	0.000
Set2-4-2	0.500	0.333	0.167	0.333	0.167	0.000
Set2-5-1	0.000	0.333	0.500	0.333	0.167	0.000
Set2-5-2	0.000	0.333	0.500	0.333	0.167	0.000
Set2-6-1	0.500	0.667	0.333	0.333	0.167	0.000
Set2-6-2	0.333	0.500	0.357	0.167	0.000	0.000
Set3-1-1	0.167	0.000	0.000	0.000	0.000	0.000
Set3-1-2	0.167	0.000	0.000	0.167	0.000	0.167
Set3-1-3	0.071	0.000	0.000	0.000	0.000	0.000
Set3-1-4	0.071	0.000	0.000	0.000	0.000	0.000
Set3-2-1	0.167	0.000	0.000	0.000	0.000	0.167
Set3-2-2	0.167	0.000	0.000	0.000	0.167	0.333
Set3-2-3	0.000	0.000	0.000	0.000	0.071	0.167
Set3-2-4	0.071	0.000	0.000	0.167	0.000	0.000
Set3-3-1	0.333	0.000	0.167	0.167	0.000	0.167
Set3-3-2	0.167	0.000	0.000	0.000	0.167	0.333
Set3-3-3	0.333	0.000	0.071	0.000	0.071	0.000
Set3-3-4	0.000	0.000	0.000	0.000	0.000	0.000
Set3-4-1	0.333	0.000	0.167	0.167	0.000	0.071
Set3-4-2	0.000	0.000	0.000	0.000	0.167	0.167
Set3-4-3	0.333	0.000	0.167	0.000	0.000	0.000
Set3-4-4	0.000	0.000	0.000	0.000	0.000	0.000
Set3-5-1	0.333	0.000	0.167	0.167	0.000	0.071
Set3-5-2	0.000	0.000	0.000	0.000	0.167	0.167
Set3-5-3	0.333	0.000	0.167	0.000	0.000	0.000
Set3-5-4	0.000	0.000	0.000	0.000	0.000	0.000
Set3-6-1	0.000	0.000	0.000	0.000	0.000	0.167
Set3-6-2	0.167	0.167	0.167	0.214	0.333	0.500
Set3-6-3	0.167	0.167	0.000	0.167	0.000	0.000
Set3-6-4	0.333	0.333	0.333	0.167	0.167	0.333
Mean	0.119		Standard Deviation			0.151

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-17: Degree of disagreement scores for DMM – 8 alternatives, Step (b) vs. Step (c)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.188	0.063	0.063	0.125	0.063	0.063
Set2-1-2	<i>0.057</i>	0.188	0.125	0.063	0.063	0.000
Set2-2-1	0.063	0.063	0.063	0.063	0.063	0.000
Set2-2-2	<i>0.257</i>	0.063	0.188	0.188	0.000	0.000
Set2-3-1	0.250	0.125	0.125	0.063	0.000	0.000
Set2-3-2	<i>0.029</i>	<i>0.086</i>	0.063	0.125	0.000	0.000
Set2-4-1	0.250	0.063	0.125	0.063	0.000	0.000
Set2-4-2	0.063	0.125	0.125	0.125	0.000	0.000
Set2-5-1	0.188	0.063	0.313	0.188	0.063	0.063
Set2-5-2	0.188	0.063	0.313	0.188	0.063	0.063
Set2-6-1	0.438	<i>0.429</i>	0.125	0.188	0.125	0.000
Set2-6-2	0.063	<i>0.257</i>	0.188	0.188	0.063	0.000
Set3-1-1	0.125	0.188	0.063	0.063	0.188	0.000
Set3-1-2	0.125	0.250	0.125	0.125	0.000	0.063
Set3-1-3	0.000	0.063	0.125	0.125	0.063	0.125
Set3-1-4	<i>0.086</i>	0.063	0.063	0.063	0.000	0.125
Set3-2-1	0.125	0.063	<i>0.086</i>	0.125	0.063	0.125
Set3-2-2	0.125	0.000	0.063	0.188	0.063	0.063
Set3-2-3	0.000	0.188	<i>0.143</i>	0.125	<i>0.143</i>	0.125
Set3-2-4	<i>0.029</i>	0.188	0.063	0.063	0.063	0.000
Set3-3-1	<i>0.200</i>	0.063	0.188	0.188	0.125	0.000
Set3-3-2	0.250	0.063	0.063	0.125	0.063	<i>0.029</i>
Set3-3-3	0.313	<i>0.143</i>	0.125	0.250	0.125	0.000
Set3-3-4	0.188	0.125	0.250	0.188	0.063	0.063
Set3-4-1	0.250	0.063	0.188	0.188	0.125	<i>0.029</i>
Set3-4-2	0.063	0.000	0.000	0.125	0.063	0.125
Set3-4-3	0.188	<i>0.143</i>	0.188	0.250	0.188	0.125
Set3-4-4	<i>0.086</i>	0.188	0.188	<i>0.143</i>	0.063	0.063
Set3-5-1	0.313	<i>0.200</i>	0.125	0.125	0.188	0.125
Set3-5-2	0.313	0.125	0.188	0.188	0.188	0.250
Set3-5-3	0.313	<i>0.200</i>	0.125	0.125	0.188	0.125
Set3-5-4	0.313	0.125	0.188	<i>0.143</i>	0.188	0.250
Set3-6-1	0.125	0.125	0.000	<i>0.143</i>	<i>0.143</i>	<i>0.029</i>
Set3-6-2	0.188	0.250	0.125	<i>0.143</i>	0.125	<i>0.143</i>
Set3-6-3	0.250	0.250	0.063	0.125	0.188	0.000
Set3-6-4	<i>0.143</i>	<i>0.257</i>	0.125	0.188	0.125	0.063
Mean	0.121		Standard Deviation			0.085

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-18: Degree of disagreement for PROMETHEE II – 5 alternatives, Step (a) vs. Step (b)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.000	0.167	0.000	0.000	0.000	0.167
Set2-1-2	0.000	0.000	0.000	0.000	0.000	0.167
Set2-2-1	0.167	0.000	0.167	0.000	0.167	0.000
Set2-2-2	0.167	0.000	0.000	0.000	0.167	0.000
Set2-3-1	0.167	0.000	0.000	0.000	0.167	0.000
Set2-3-2	0.333	0.167	0.000	0.000	0.167	0.000
Set2-4-1	0.167	0.000	0.000	0.167	0.167	0.000
Set2-4-2	0.000	0.333	0.000	0.000	0.333	0.000
Set2-5-1	0.167	0.167	0.167	0.000	0.000	0.167
Set2-5-2	0.333	0.167	0.000	0.000	0.000	0.167
Set2-6-1	0.333	0.167	0.000	0.167	0.000	0.000
Set2-6-2	0.167	0.167	0.000	0.167	0.000	0.000
Set3-1-1	0.000	0.000	0.000	0.000	0.167	0.333
Set3-1-2	0.000	0.000	0.000	0.000	0.000	0.000
Set3-1-3	0.000	0.000	0.167	0.000	0.000	0.000
Set3-1-4	0.000	0.000	0.167	0.000	0.000	0.000
Set3-2-1	0.000	0.000	0.000	0.000	0.000	0.500
Set3-2-2	0.000	0.000	0.000	0.167	0.000	0.000
Set3-2-3	0.000	0.000	0.167	0.167	0.000	0.500
Set3-2-4	0.000	0.167	0.167	0.167	0.000	0.167
Set3-3-1	0.167	0.000	0.071	0.000	0.000	0.000
Set3-3-2	0.000	0.000	0.000	0.000	0.000	0.000
Set3-3-3	0.167	0.333	0.167	0.167	0.167	0.167
Set3-3-4	0.000	0.167	0.000	0.167	0.000	0.167
Set3-4-1	0.000	0.000	0.167	0.000	0.000	0.167
Set3-4-2	0.000	0.000	0.000	0.000	0.000	0.000
Set3-4-3	0.167	0.000	0.000	0.167	0.000	0.333
Set3-4-4	0.000	0.000	0.000	0.167	0.000	0.167
Set3-5-1	0.333	0.000	0.000	0.167	0.500	0.333
Set3-5-2	0.333	0.000	0.000	0.000	0.000	0.333
Set3-5-3	0.333	0.000	0.167	0.167	0.500	0.333
Set3-5-4	0.333	0.000	0.000	0.000	0.000	0.167
Set3-6-1	0.167	0.000	0.000	0.167	0.167	0.000
Set3-6-2	0.000	0.000	0.000	0.000	0.000	0.000
Set3-6-3	0.071	0.071	0.167	0.000	0.333	0.000
Set3-6-4	0.000	0.167	0.000	0.000	0.000	0.167
Mean	0.082		Standard Deviation			0.119

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-19: Degree of disagreement scores for PROMETHEE II – 5 alternatives, Step (a) vs. Step (c)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.000	0.167	0.000	0.000	0.167	0.167
Set2-1-2	0.333	0.167	0.000	0.167	0.167	0.167
Set2-2-1	0.167	0.000	0.167	0.167	0.167	0.000
Set2-2-2	0.167	0.500	0.333	0.167	0.167	0.000
Set2-3-1	0.500	0.000	0.333	0.000	0.167	0.000
Set2-3-2	0.167	0.667	0.000	0.167	0.167	0.000
Set2-4-1	0.333	0.000	0.333	0.333	0.167	0.000
Set2-4-2	0.167	0.667	0.167	0.167	0.167	0.000
Set2-5-1	0.167	0.333	0.500	0.333	0.167	0.167
Set2-5-2	0.000	0.333	0.500	0.333	0.167	0.167
Set2-6-1	0.500	0.667	0.167	0.500	0.333	0.000
Set2-6-2	0.000	0.167	0.333	0.167	0.000	0.000
Set3-1-1	0.167	<i>0.071</i>	0.000	0.000	0.000	0.000
Set3-1-2	0.167	0.000	0.000	0.000	0.000	0.167
Set3-1-3	0.000	0.000	0.000	0.000	0.000	0.333
Set3-1-4	0.000	0.000	0.000	0.000	0.000	0.000
Set3-2-1	0.167	0.000	0.000	0.000	0.000	0.167
Set3-2-2	0.167	0.000	0.000	0.000	0.167	0.000
Set3-2-3	0.000	0.167	0.000	0.000	0.000	0.333
Set3-2-4	0.000	0.000	0.000	0.000	0.000	0.167
Set3-3-1	0.167	0.000	<i>0.071</i>	0.167	0.000	0.000
Set3-3-2	0.000	0.000	0.000	0.000	0.167	0.000
Set3-3-3	0.167	0.167	0.000	0.000	0.000	0.000
Set3-3-4	0.167	0.167	0.000	0.000	0.000	0.000
Set3-4-1	0.333	0.000	0.167	0.167	0.000	0.167
Set3-4-2	0.000	0.000	0.000	0.000	0.167	0.167
Set3-4-3	0.333	0.333	0.333	0.000	0.000	0.000
Set3-4-4	0.167	0.167	0.000	0.000	0.000	0.000
Set3-5-1	0.167	0.167	0.167	0.000	0.000	0.167
Set3-5-2	0.167	0.167	0.333	0.333	0.000	0.500
Set3-5-3	0.167	0.167	0.000	0.000	0.000	<i>0.071</i>
Set3-5-4	0.167	0.167	0.333	0.333	0.000	0.500
Set3-6-1	0.000	0.000	0.000	0.000	0.167	0.167
Set3-6-2	0.167	0.167	<i>0.214</i>	0.167	0.333	0.333
Set3-6-3	<i>0.214</i>	0.000	0.167	0.167	0.000	0.000
Set3-6-4	0.333	0.167	0.333	0.000	0.333	0.167
Mean	0.129		Standard Deviation			0.151

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-20: Degree of disagreement scores for PROMETHEE II – 8 alternatives, Step (b) vs. Step (c)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	0.188	0.063	0.063	0.125	0.063	0.000
Set2-1-2	0.188	0.125	0.000	0.063	0.063	0.000
Set2-2-1	0.063	0.125	0.000	0.063	0.063	0.063
Set2-2-2	0.063	0.313	0.188	0.125	0.000	0.000
Set2-3-1	0.313	0.188	0.188	0.063	0.063	0.000
Set2-3-2	0.125	0.313	0.000	0.188	0.000	0.000
Set2-4-1	0.125	0.188	0.125	0.063	0.000	0.000
Set2-4-2	0.188	0.250	0.125	0.188	0.063	0.000
Set2-5-1	0.250	0.063	0.313	0.188	0.125	0.063
Set2-5-2	0.250	0.063	0.313	0.188	0.125	0.000
Set2-6-1	0.500	0.500	0.063	0.188	0.188	0.063
Set2-6-2	0.125	0.188	0.188	0.063	0.000	0.125
Set3-1-1	0.125	0.125	0.063	0.063	0.188	0.125
Set3-1-2	0.125	0.063	0.063	0.063	0.000	0.063
Set3-1-3	0.125	0.188	0.125	0.000	0.125	0.125
Set3-1-4	0.063	0.063	0.125	0.000	0.063	0.063
Set3-2-1	0.125	0.000	0.125	0.063	0.063	<i>0.143</i>
Set3-2-2	0.188	0.000	0.063	0.125	0.063	0.000
Set3-2-3	0.125	0.125	0.188	0.125	0.188	0.125
Set3-2-4	0.063	0.188	0.188	0.125	0.063	<i>0.029</i>
Set3-3-1	0.188	0.063	0.188	0.188	0.063	0.000
Set3-3-2	0.125	0.000	0.125	0.063	0.188	0.063
Set3-3-3	0.250	0.250	0.125	0.125	0.125	0.063
Set3-3-4	0.125	0.250	0.125	0.188	0.063	0.125
Set3-4-1	0.188	0.063	0.250	0.188	0.063	0.125
Set3-4-2	0.063	0.000	0.063	0.063	0.063	0.063
Set3-4-3	0.188	0.188	0.188	0.188	0.125	0.125
Set3-4-4	0.188	0.188	0.125	0.125	0.063	0.125
Set3-5-1	0.438	0.188	0.250	0.188	0.313	0.000
Set3-5-2	0.438	0.125	0.250	0.188	0.063	0.188
Set3-5-3	0.438	0.188	0.250	0.188	0.313	<i>0.143</i>
Set3-5-4	0.438	0.125	0.250	0.188	0.063	0.188
Set3-6-1	0.125	0.125	0.000	0.188	0.188	0.063
Set3-6-2	0.125	0.188	<i>0.143</i>	0.125	0.188	0.188
Set3-6-3	0.125	<i>0.143</i>	0.250	0.188	0.281	0.000
Set3-6-4	0.250	0.250	0.250	0.063	0.250	0.188
Mean	0.133		Standard Deviation			0.097

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-21: Degree of disagreement for ELECTRE II – 5 alternatives, Step (a) vs. Step (b)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	<i>0.000</i>	<i>0.000</i>	0.000	<i>0.071</i>	<i>0.071</i>	<i>0.071</i>
Set2-1-2	<i>0.429</i>	<i>0.000</i>	<i>0.786</i>	<i>0.214</i>	<i>0.071</i>	0.000
Set2-2-1	<i>0.071</i>	<i>0.071</i>	<i>0.143</i>	<i>0.286</i>	<i>0.143</i>	<i>0.143</i>
Set2-2-2	<i>0.143</i>	<i>0.286</i>	<i>0.071</i>	<i>0.286</i>	0.000	<i>0.286</i>
Set2-3-1	<i>0.143</i>	<i>0.143</i>	<i>0.143</i>	0.000	<i>0.071</i>	<i>0.143</i>
Set2-3-2	<i>0.071</i>	<i>0.357</i>	<i>0.214</i>	0.000	<i>0.286</i>	<i>0.071</i>
Set2-4-1	<i>0.143</i>	<i>0.071</i>	<i>0.143</i>	<i>0.357</i>	<i>0.071</i>	<i>0.143</i>
Set2-4-2	<i>0.214</i>	<i>0.214</i>	<i>0.071</i>	<i>0.143</i>	0.000	<i>0.071</i>
Set2-5-1	<i>0.214</i>	<i>0.357</i>	<i>0.214</i>	<i>0.286</i>	<i>0.357</i>	<i>0.357</i>
Set2-5-2	<i>0.214</i>	<i>0.143</i>	<i>0.214</i>	<i>0.214</i>	<i>0.429</i>	<i>0.357</i>
Set2-6-1	0.000	<i>0.214</i>	<i>0.143</i>	<i>0.286</i>	<i>0.429</i>	<i>0.286</i>
Set2-6-2	<i>0.286</i>	<i>0.214</i>	<i>0.286</i>	<i>0.071</i>	<i>0.071</i>	<i>0.143</i>
Set3-1-1	<i>0.071</i>	<i>0.071</i>	<i>0.143</i>	<i>0.143</i>	<i>0.143</i>	<i>0.143</i>
Set3-1-2	<i>0.071</i>	<i>0.071</i>	<i>0.286</i>	<i>0.071</i>	<i>0.143</i>	<i>0.214</i>
Set3-1-3	<i>0.071</i>	0.000	<i>0.071</i>	<i>0.143</i>	<i>0.214</i>	0.000
Set3-1-4	<i>0.071</i>	0.000	0.000	<i>0.143</i>	<i>0.143</i>	<i>0.071</i>
Set3-2-1	<i>0.071</i>	<i>0.286</i>	<i>0.071</i>	<i>0.286</i>	<i>0.214</i>	<i>0.429</i>
Set3-2-2	<i>0.071</i>	<i>0.214</i>	0.000	<i>0.214</i>	<i>0.214</i>	<i>0.214</i>
Set3-2-3	<i>0.071</i>	<i>0.286</i>	<i>0.071</i>	<i>0.286</i>	<i>0.071</i>	<i>0.214</i>
Set3-2-4	0.000	<i>0.286</i>	0.000	<i>0.286</i>	<i>0.214</i>	<i>0.143</i>
Set3-3-1	<i>0.357</i>	<i>0.357</i>	<i>0.214</i>	<i>0.286</i>	<i>0.214</i>	<i>0.071</i>
Set3-3-2	<i>0.357</i>	<i>0.214</i>	<i>0.214</i>	<i>0.357</i>	<i>0.214</i>	0.000
Set3-3-3	<i>0.071</i>	<i>0.214</i>	<i>0.214</i>	<i>0.286</i>	<i>0.357</i>	<i>0.071</i>
Set3-3-4	<i>0.071</i>	<i>0.214</i>	<i>0.071</i>	<i>0.286</i>	<i>0.071</i>	0.000
Set3-4-1	<i>0.143</i>	<i>0.357</i>	<i>0.143</i>	<i>0.214</i>	<i>0.214</i>	<i>0.143</i>
Set3-4-2	0.000	<i>0.071</i>	0.000	<i>0.071</i>	<i>0.071</i>	0.000
Set3-4-3	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>	<i>0.143</i>	0.000
Set3-4-4	<i>0.071</i>	<i>0.071</i>	0.000	0.000	0.000	0.000
Set3-5-1	<i>0.214</i>	0.000	<i>0.143</i>	<i>0.071</i>	<i>0.214</i>	0.000
Set3-5-2	<i>0.214</i>	0.000	<i>0.286</i>	<i>0.214</i>	<i>0.071</i>	0.000
Set3-5-3	<i>0.286</i>	0.000	<i>0.143</i>	<i>0.071</i>	<i>0.214</i>	0.000
Set3-5-4	<i>0.214</i>	0.000	<i>0.286</i>	<i>0.286</i>	<i>0.214</i>	<i>0.071</i>
Set3-6-1	<i>0.214</i>	<i>0.214</i>	<i>0.286</i>	<i>0.143</i>	<i>0.286</i>	<i>0.143</i>
Set3-6-2	<i>0.143</i>	<i>0.143</i>	<i>0.143</i>	<i>0.071</i>	<i>0.143</i>	0.000
Set3-6-3	<i>0.214</i>	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>	0.000
Set3-6-4	<i>0.143</i>	<i>0.143</i>	0.000	<i>0.143</i>	<i>0.143</i>	0.000
Mean	0.114		Standard Deviation			0.159

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-22: Degree of disagreement scores for ELECTRE II – 5 alternatives, Step (a) vs. Step (c)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	<i>0.286</i>	<i>0.000</i>	0.000	<i>0.071</i>	<i>0.071</i>	<i>0.071</i>
Set2-1-2	<i>0.429</i>	<i>0.000</i>	<i>0.786</i>	<i>0.571</i>	<i>0.000</i>	<i>0.000</i>
Set2-2-1	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.286</i>	<i>0.143</i>	<i>0.071</i>
Set2-2-2	<i>0.286</i>	<i>0.357</i>	<i>0.143</i>	<i>0.286</i>	<i>0.286</i>	<i>0.071</i>
Set2-3-1	<i>0.071</i>	<i>0.286</i>	<i>0.000</i>	<i>0.143</i>	<i>0.000</i>	<i>0.286</i>
Set2-3-2	<i>0.143</i>	<i>0.286</i>	<i>0.071</i>	<i>0.286</i>	<i>0.000</i>	<i>0.143</i>
Set2-4-1	<i>0.214</i>	<i>0.143</i>	<i>0.000</i>	<i>0.071</i>	<i>0.143</i>	<i>0.143</i>
Set2-4-2	<i>0.214</i>	<i>0.286</i>	<i>0.000</i>	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>
Set2-5-1	<i>0.214</i>	<i>0.357</i>	<i>0.214</i>	<i>0.429</i>	<i>0.357</i>	<i>0.357</i>
Set2-5-2	<i>0.214</i>	<i>0.143</i>	<i>0.214</i>	<i>0.214</i>	<i>0.286</i>	<i>0.286</i>
Set2-6-1	<i>0.143</i>	<i>0.071</i>	<i>0.143</i>	<i>0.214</i>	<i>0.286</i>	<i>0.500</i>
Set2-6-2	<i>0.286</i>	<i>0.214</i>	<i>0.214</i>	<i>0.000</i>	<i>0.286</i>	<i>0.214</i>
Set3-1-1	<i>0.143</i>	<i>0.071</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>	<i>0.143</i>
Set3-1-2	<i>0.143</i>	<i>0.071</i>	<i>0.286</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>
Set3-1-3	<i>0.071</i>	<i>0.214</i>	<i>0.429</i>	<i>0.071</i>	<i>0.143</i>	<i>0.000</i>
Set3-1-4	<i>0.071</i>	<i>0.000</i>	<i>0.500</i>	<i>0.214</i>	<i>0.071</i>	<i>0.071</i>
Set3-2-1	<i>0.071</i>	<i>0.286</i>	<i>0.000</i>	<i>0.143</i>	<i>0.286</i>	<i>0.500</i>
Set3-2-2	<i>0.000</i>	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>	<i>0.429</i>
Set3-2-3	<i>0.143</i>	<i>0.286</i>	<i>0.000</i>	<i>0.286</i>	<i>0.071</i>	<i>0.143</i>
Set3-2-4	<i>0.071</i>	<i>0.286</i>	<i>0.143</i>	<i>0.214</i>	<i>0.286</i>	<i>0.143</i>
Set3-3-1	<i>0.071</i>	<i>0.214</i>	<i>0.071</i>	<i>0.214</i>	<i>0.143</i>	<i>0.286</i>
Set3-3-2	<i>0.071</i>	<i>0.214</i>	<i>0.071</i>	<i>0.357</i>	<i>0.143</i>	<i>0.000</i>
Set3-3-3	<i>0.071</i>	<i>0.143</i>	<i>0.071</i>	<i>0.214</i>	<i>0.214</i>	<i>0.000</i>
Set3-3-4	<i>0.071</i>	<i>0.143</i>	<i>0.071</i>	<i>0.143</i>	<i>0.071</i>	<i>0.000</i>
Set3-4-1	<i>0.214</i>	<i>0.357</i>	<i>0.071</i>	<i>0.143</i>	<i>0.214</i>	<i>0.143</i>
Set3-4-2	<i>0.000</i>	<i>0.143</i>	<i>0.071</i>	<i>0.143</i>	<i>0.214</i>	<i>0.143</i>
Set3-4-3	<i>0.214</i>	<i>0.214</i>	<i>0.071</i>	<i>0.143</i>	<i>0.214</i>	<i>0.071</i>
Set3-4-4	<i>0.143</i>	<i>0.071</i>	<i>0.071</i>	<i>0.071</i>	<i>0.000</i>	<i>0.000</i>
Set3-5-1	<i>0.286</i>	<i>0.071</i>	<i>0.214</i>	<i>0.214</i>	<i>0.214</i>	<i>0.000</i>
Set3-5-2	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>	<i>0.071</i>	<i>0.071</i>
Set3-5-3	<i>0.286</i>	<i>0.071</i>	<i>0.214</i>	<i>0.214</i>	<i>0.214</i>	<i>0.000</i>
Set3-5-4	<i>0.214</i>	<i>0.143</i>	<i>0.429</i>	<i>0.357</i>	<i>0.214</i>	<i>0.214</i>
Set3-6-1	<i>0.286</i>	<i>0.286</i>	<i>0.286</i>	<i>0.143</i>	<i>0.286</i>	<i>0.143</i>
Set3-6-2	<i>0.214</i>	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.143</i>	<i>0.143</i>
Set3-6-3	<i>0.286</i>	<i>0.286</i>	<i>0.143</i>	<i>0.143</i>	<i>0.214</i>	<i>0.071</i>
Set3-6-4	<i>0.143</i>	<i>0.214</i>	<i>0.214</i>	<i>0.143</i>	<i>0.143</i>	<i>0.000</i>
Mean	0.173		Standard Deviation			0.120

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

Table A8-23: Degree of disagreement scores for ELECTRE II – 8 alternatives, Step (b) vs. Step (c)

Test\Weight	W1	W2	W3	W4	W5	W6
Set2-1-1	<i>0.171</i>	<i>0.000</i>	<i>0.057</i>	-	<i>0.000</i>	<i>0.029</i>
Set2-1-2	<i>0.057</i>	<i>0.000</i>	0.344	<i>0.229</i>	<i>0.057</i>	<i>0.000</i>
Set2-2-1	<i>0.171</i>	<i>0.171</i>	<i>0.143</i>	<i>0.000</i>	<i>0.143</i>	<i>0.029</i>
Set2-2-2	<i>0.143</i>	<i>0.200</i>	<i>0.086</i>	<i>0.057</i>	<i>0.229</i>	<i>0.086</i>
Set2-3-1	<i>0.086</i>	<i>0.171</i>	<i>0.114</i>	<i>0.171</i>	<i>0.114</i>	<i>0.171</i>
Set2-3-2	<i>0.143</i>	<i>0.114</i>	<i>0.286</i>	<i>0.143</i>	<i>0.200</i>	<i>0.143</i>
Set2-4-1	<i>0.143</i>	<i>0.200</i>	<i>0.114</i>	<i>0.171</i>	<i>0.086</i>	<i>0.143</i>
Set2-4-2	<i>0.114</i>	<i>0.171</i>	<i>0.257</i>	<i>0.171</i>	<i>0.143</i>	<i>0.171</i>
Set2-5-1	<i>0.000</i>	<i>0.057</i>	<i>0.057</i>	<i>0.114</i>	<i>0.229</i>	<i>0.200</i>
Set2-5-2	<i>0.000</i>	<i>0.029</i>	<i>0.057</i>	<i>0.114</i>	<i>0.229</i>	<i>0.057</i>
Set2-6-1	<i>0.200</i>	<i>0.171</i>	<i>0.114</i>	<i>0.086</i>	<i>0.114</i>	<i>0.229</i>
Set2-6-2	<i>0.000</i>	<i>0.000</i>	<i>0.057</i>	<i>0.057</i>	<i>0.171</i>	<i>0.200</i>
Set3-1-1	<i>0.114</i>	<i>0.000</i>	<i>0.086</i>	<i>0.086</i>	<i>0.029</i>	<i>0.029</i>
Set3-1-2	<i>0.114</i>	<i>0.029</i>	<i>0.371</i>	<i>0.086</i>	<i>0.000</i>	<i>0.000</i>
Set3-1-3	<i>0.114</i>	<i>0.171</i>	<i>0.371</i>	<i>0.143</i>	<i>0.057</i>	<i>0.000</i>
Set3-1-4	<i>0.143</i>	<i>0.029</i>	<i>0.514</i>	<i>0.086</i>	<i>0.029</i>	<i>0.000</i>
Set3-2-1	<i>0.314</i>	<i>0.086</i>	<i>0.171</i>	<i>0.086</i>	<i>0.086</i>	<i>0.143</i>
Set3-2-2	<i>0.229</i>	<i>0.086</i>	<i>0.143</i>	<i>0.029</i>	<i>0.057</i>	<i>0.171</i>
Set3-2-3	<i>0.200</i>	<i>0.086</i>	<i>0.143</i>	<i>0.029</i>	<i>0.000</i>	<i>0.086</i>
Set3-2-4	<i>0.114</i>	<i>0.086</i>	<i>0.143</i>	<i>0.114</i>	<i>0.029</i>	<i>0.029</i>
Set3-3-1	<i>0.200</i>	<i>0.200</i>	<i>0.257</i>	<i>0.086</i>	<i>0.257</i>	<i>0.143</i>
Set3-3-2	<i>0.200</i>	<i>0.343</i>	<i>0.229</i>	<i>0.086</i>	<i>0.171</i>	<i>0.171</i>
Set3-3-3	<i>0.000</i>	<i>0.229</i>	<i>0.229</i>	<i>0.171</i>	<i>0.171</i>	<i>0.086</i>
Set3-3-4	<i>0.086</i>	<i>0.143</i>	<i>0.029</i>	<i>0.200</i>	<i>0.143</i>	<i>0.114</i>
Set3-4-1	<i>0.029</i>	<i>0.000</i>	<i>0.086</i>	<i>0.057</i>	<i>0.000</i>	<i>0.000</i>
Set3-4-2	<i>0.029</i>	<i>0.114</i>	<i>0.086</i>	<i>0.086</i>	<i>0.257</i>	<i>0.171</i>
Set3-4-3	<i>0.143</i>	<i>0.057</i>	<i>0.114</i>	<i>0.086</i>	<i>0.114</i>	<i>0.114</i>
Set3-4-4	<i>0.114</i>	<i>0.086</i>	<i>0.200</i>	<i>0.229</i>	<i>0.000</i>	<i>0.000</i>
Set3-5-1	<i>0.171</i>	<i>0.086</i>	<i>0.114</i>	<i>0.143</i>	<i>0.057</i>	<i>0.057</i>
Set3-5-2	<i>0.057</i>	<i>0.229</i>	<i>0.286</i>	<i>0.257</i>	<i>0.029</i>	<i>0.029</i>
Set3-5-3	<i>0.171</i>	<i>0.086</i>	<i>0.114</i>	<i>0.143</i>	<i>0.057</i>	<i>0.057</i>
Set3-5-4	<i>0.057</i>	<i>0.229</i>	<i>0.229</i>	<i>0.257</i>	<i>0.086</i>	<i>0.063</i>
Set3-6-1	<i>0.086</i>	<i>0.086</i>	<i>0.057</i>	<i>0.171</i>	<i>0.086</i>	<i>0.171</i>
Set3-6-2	<i>0.257</i>	<i>0.257</i>	<i>0.029</i>	<i>0.171</i>	<i>0.000</i>	<i>0.171</i>
Set3-6-3	<i>0.171</i>	<i>0.200</i>	<i>0.257</i>	<i>0.171</i>	<i>0.229</i>	<i>0.229</i>
Set3-6-4	<i>0.286</i>	<i>0.286</i>	<i>0.229</i>	<i>0.200</i>	<i>0.143</i>	<i>0.114</i>
Mean	0.126		Standard Deviation			0.088

* *Italic scores indicate sequence has tied ranks*

Empirical Testing of Candidate MCDM Techniques

A8.8 Sensitivity Analyses Test Results

Empirical Testing of Candidate MCDM Techniques

Figure A8-4: Sensitivity Analysis of the 4 candidate techniques for Set1-1-1

Figure A8-5: Sensitivity Analysis of the 4 candidate techniques for Set1-1-2

Empirical Testing of Candidate MCDM Techniques

Figure A8-6: Sensitivity Analysis of the 4 candidate techniques for Set1-1-3

Empirical Testing of Candidate MCDM Techniques

Figure A8-7: Sensitivity Analysis of the 4 candidate techniques for Set1-1-4

Empirical Testing of Candidate MCDM Techniques

Figure A8-8: Sensitivity Analysis of the 4 candidate techniques for Set1-5-1

Empirical Testing of Candidate MCDM Techniques

Figure A8-9: Sensitivity Analysis of the 4 candidate techniques for Set1-5-2

Empirical Testing of Candidate MCDM Techniques

Figure A8-10: Sensitivity Analysis of the 4 candidate techniques for Set1-5-3

Empirical Testing of Candidate MCDM Techniques

Figure A8-11: Sensitivity Analysis of the 4 candidate techniques for Set1-5-4

Empirical Testing of Candidate MCDM Techniques

Table A8-24: Summary of Ranking and Decision Rationale by Companies Surveyed

Company		SME-1	SME-2	SME-3	SME-4	SME-5	SME-6	MNC-1	MNC-3	MNC-4
Industry		Media Printing	Plastic Injection Moulding	Contract Manufacturer	Precision Engineering	Electronics	Logistics	Consumer Products	Medical Equipment	Equipment Maker (Semi-conductor Front End)
Ranking	1	ChenPo	ChenPo	Chen Po	CaiHan	CaiHan	Mangellan	CaiHan	Mat Salleh	CaiHan
	2	-	-	Mangellan	Mangellan	Mangellan	CaiHan	Mangellan	CaiHan	ChenPo
	3	-	-	Cai Han	-	Mat Salleh	Tech John	Mat Salleh	Mangellan	Mangellan
	4	-	-	Tech John	-	-	Mat Salleh	Tech John	Tech John	-
	5	-	-	Mat Salleh	-	-	-	ChenPo	ChenPo	-
Decision Rationale	Main Consideration	Cost - Per-unit Cost	Cost - Per-unit Cost	Cost - Per-unit Cost	Cost - Per-unit cost - Total cost eliminated ChenPo	Cost - Per-unit cost - Total cost eliminated ChenPo & TechJohn	Cost - Total cost	Cost - Total cost	Lead-time - Shortest lead-time	Cost - mixture of per-unit cost and total cost - TechJohn and MatSalleh not consider as per-unit Cost too high
	Secondary Considerations or Other observations	Company has buffer stock (non-urgent), thus lead time insignificant	Cash flow not an issue	Lead-time not an issue, non urgent purchase	Lead-time - CaiHan ranked above Mangellan due to lower lead-time	Lead-time - CaiHan ranked above Mangellan due to lower lead-time (cost comparable) - MatSalleh ranked 3rd as it is much more expensive compared to other two	Lead-time not an issue as company does not have many overseas suppliers	CaiHan ranked higher than Mangellan as it has longer payment duration (not a criterion listed)	- CaiHan ranked second due its lower lead-time when compared to Mangellan - Short lead-time is very important to company as it operates in a High Mix Low Volume (HMLV) environment	- Mangellan ranked 3rd as company believed the transportation cost would eventually make it less attractive then ChenPo

Worked Examples

Appendix 9: Worked Examples

A9.1 Worked Example for Deviation Measure – Original (DMO)

Consider 2-criteria $\{c_1, c_2\}$ with 5 alternatives $\{a_1, a_2, a_3, a_4, a_5\}$, for selecting the most suitable supplier for B2B collaboration:

	a_1	a_2	a_3	a_4	a_5
c_1	95000	36000	36000	39000	40500
c_2	9	5	7	8	1

In this problem, the following are the preferred values and objective of each criterion:

Criterion	Value	Unit of Measure	Objective
Product Cost, c_1	28500	SGD	Minimise
Lead-Time, c_2	5	days	Minimise

Using the steps enumerated in Section 5.3.5 for the proposed Deviation Measure, a worked example is shown below:

(1) Determine the weights of the criteria, w_i , by pair-wise comparison

1.1 Perform pair-wise comparisons between criteria using AHP's Saaty scale of 1 to 9

	c_1	c_2
c_1	1	8
c_2	1/8	1

1.2 Sum each column

	c_1	c_2
c_1	1	8
c_2	1/8	1
Sum	9/8	9

Worked Examples

1.3 Normalise each criterion by dividing it with the column sum

	c_1	c_2
c_1	8/9	8/9
c_2	1/9	1/9

1.4 Determine normalised weight by taking the mean of each row

	c_1	c_2	w_i
c_1	8/9	8/9	8/9 = 0.89
c_2	1/9	1/9	1/9 = 0.11
Sum			1.00

(2) Calculate the normalised performance matrix.

In this step, the normalised performance value of each criterion is calculated using the minimising function, as the criteria's objective is to minimise the cost and lead time. The individual normalised performance values are:

$$\begin{aligned}
 p_1(a_1) &= \left(\frac{28500 - 95000}{28500} \right) = -2.33 & p_2(a_1) &= \left(\frac{5-9}{5} \right) = -0.80 \\
 p_1(a_2) &= \left(\frac{28500 - 36000}{28500} \right) = -0.26 & p_1(a_2) &= \left(\frac{5-5}{5} \right) = 0.00 \\
 p_1(a_3) &= \left(\frac{28500 - 36000}{28500} \right) = -0.26 & p_1(a_2) &= \left(\frac{5-7}{5} \right) = -0.40 \\
 p_1(a_4) &= \left(\frac{28500 - 95000}{28500} \right) = -0.37 & p_1(a_2) &= \left(\frac{5-8}{5} \right) = -0.60 \\
 p_1(a_5) &= \left(\frac{28500 - 95000}{28500} \right) = -0.42 & p_1(a_2) &= \left(\frac{5-1}{5} \right) = 0.80
 \end{aligned}$$

Therefore, the normalised performance matrix would be

	a_1	a_2	a_3	a_4	a_5
c_1	-2.33	-0.26	-0.26	-0.37	-0.42
c_2	-0.80	0.00	-0.40	-0.60	0.80

(3) Calculate the weighted normalised performance matrix.

The weighted normalised individual criterion scores are:

$$\begin{aligned}
 ICS_{11} &= 0.89 \times -2.33 = -2.07 & ICS_{21} &= 0.11 \times -0.80 = -0.09 \\
 ICS_{12} &= 0.89 \times -0.26 = -0.23 & ICS_{21} &= 0.11 \times 0.00 = 0.00
 \end{aligned}$$

Worked Examples

$$ICS_{13} = 0.89 \times -0.26 = -0.23$$

$$ICS_{21} = 0.11 \times -0.40 = -0.04$$

$$ICS_{14} = 0.89 \times -0.37 = -0.33$$

$$ICS_{21} = 0.11 \times -0.60 = -0.07$$

$$ICS_{15} = 0.89 \times -0.42 = -0.37$$

$$ICS_{21} = 0.11 \times 0.80 = 0.09$$

Therefore, the weighted normalised performance matrix would be

	a_1	a_2	a_3	a_4	a_5
c_1	-2.07	-0.23	-0.23	-0.33	-0.37
c_2	-0.09	0.00	-0.04	-0.07	0.09

(4) Calculate the overall suitability score OSS_j for **all** n criteria for each j -th alternative.

	a_1	a_2	a_3	a_4	a_5
c_1	-2.07	-0.23	-0.23	-0.33	-0.37
c_2	-0.09	0.00	-0.04	-0.07	0.09
OSS_j	-2.16	-0.23	-0.28	-0.39	-0.29

(5) Rank all alternatives by their overall suitability scores in descending order.

	a_1	a_2	a_3	a_4	a_5
c_1	-2.07	-0.23	-0.23	-0.33	-0.37
c_2	-0.09	0.00	-0.04	-0.07	0.09
OSS_j	-2.16	-0.23	-0.28	-0.39	-0.29
Rank	5	1	2	4	3

In this example, it happened that all the alternatives are technically not viable, as all the OSS values are negative.

Worked Examples

A9.2 Worked Example for comparison with other methods

Considering the earlier sample problem of supplier selection, a worked example of PROMETHEE II is as shown in this section. As such, the weights for the two criteria are:

w_i	
w_1	0.89
w_2	0.11

In this worked example, the usual criterion for preference intensity function [105] is used to simplify calculations. The steps for eliciting the ranking sequence in PROMETHEE II can be enumerated as follows, illustrated using the example discussed:

- (1) Calculate the individual criterion preference intensities, $\pi(a, b) = \sum_{i=1}^n (w_i P_i(a, b))$.

$\pi(a, b)$	
$\pi(a_1, a_2)$	$0.00 + 0.00 = 0.00$
$\pi(a_1, a_3)$	$0.00 + 0.00 = 0.00$
$\pi(a_1, a_4)$	$0.00 + 0.00 = 0.00$
$\pi(a_1, a_5)$	$0.00 + 0.00 = 0.00$
$\pi(a_2, a_1)$	$0.89 + 0.11 = 1.00$
$\pi(a_2, a_3)$	$0.89 + 0.11 = 1.00$
$\pi(a_2, a_4)$	$0.89 + 0.11 = 1.00$
$\pi(a_2, a_5)$	$0.89 + 0.00 = 0.89$
$\pi(a_3, a_1)$	$0.89 + 0.11 = 1.00$
$\pi(a_3, a_2)$	$0.89 + 0.00 = 0.89$
$\pi(a_3, a_4)$	$0.89 + 0.11 = 1.00$
$\pi(a_3, a_5)$	$0.89 + 0.00 = 0.89$
$\pi(a_4, a_1)$	$0.89 + 0.11 = 1.00$
$\pi(a_4, a_2)$	$0.00 + 0.00 = 0.00$
$\pi(a_4, a_3)$	$0.00 + 0.00 = 0.00$
$\pi(a_4, a_5)$	$0.89 + 0.00 = 0.89$
$\pi(a_5, a_1)$	$0.89 + 0.11 = 1.00$
$\pi(a_5, a_2)$	$0.00 + 0.11 = 0.11$
$\pi(a_5, a_3)$	$0.00 + 0.11 = 0.11$
$\pi(a_5, a_4)$	$0.00 + 0.11 = 0.11$

- (2) Calculate positive outranking flow (outranked others), $\phi^+(a)$ and negative flow (outranked by others), $\phi^-(a)$ of each alternative.

Worked Examples

	$\phi^+(a)$	$\phi^-(a)$
a_1	$\frac{1}{4}(0.00 + 0.00 + 0.00 + 0.00) = 0.00$	$\frac{1}{4}(1.00 + 1.00 + 1.00 + 1.00) = 1.00$
a_2	$\frac{1}{4}(1.00 + 1.00 + 1.00 + 0.89) = 0.97$	$\frac{1}{4}(0.00 + 0.89 + 0.00 + 0.11) = 0.25$
a_3	$\frac{1}{4}(1.00 + 0.89 + 1.00 + 0.89) = 0.95$	$\frac{1}{4}(0.00 + 1.00 + 0.00 + 0.11) = 0.28$
a_4	$\frac{1}{4}(1.00 + 0.00 + 0.00 + 0.89) = 0.47$	$\frac{1}{4}(0.00 + 1.00 + 1.00 + 0.11) = 0.28$
a_5	$\frac{1}{4}(1.00 + 0.11 + 0.11 + 0.11) = 0.33$	$\frac{1}{4}(0.00 + 0.89 + 0.89 + 0.89) = 0.67$

(3) Calculate the net flow of each alternative, $\phi(a)$.

	$\phi(a)$
a_1	$0.00 - 1.00 = -1.00$
a_2	$0.97 - 0.25 = +0.72$
a_3	$0.95 - 0.28 = +0.67$
a_4	$0.47 - 0.28 = +0.19$
a_5	$0.33 - 0.67 = -0.34$

(4) Rank the alternatives in descending order of magnitude of net flows,. Where the net flows are the same, the two alternatives are considered indifferent.

	$\phi(a)$	Rank
a_1	$0.00 - 1.00 = -1.00$	5
a_2	$0.97 - 0.25 = +0.72$	1
a_3	$0.95 - 0.28 = +0.67$	2
a_4	$0.47 - 0.28 = +0.19$	3
a_5	$0.33 - 0.67 = -0.34$	4

The ranking results from PROMETHEE II and DMO are graphically shown in Figure A9-1. As shown, the sequences of rankings are relatively similar except for alternatives a_4 and a_5 whose ranks are reversed. As shown in this worked example, different MCDM techniques can yield differing ranking sequences because the performance values of alternatives and the weights are used differently in the techniques' elicitation process. The evaluation framework proposed in Section 5.2.3 assesses this phenomenon, and forms part of the empirical evaluation discussed in Chapter 6.

Worked Examples

Figure A9-1: Comparison of rankings by two different MCDM techniques – DMO and PROMETHEE II

Appendix 10: Large-scale Empirical Testing of DMO and PROMETHEE II

A selected large-scale experiment was conducted to re-affirm the empirical proofs provided in Chapter 6. For these experiments, DMO and PROMETHEE II were chosen. DMO was chosen as it was shown in Chapter 6 in a smaller scale empirical investigation that it is superior to Deviation Measure-Modified (DMM), both methods being proposed in this research. Of the other candidate MCDM techniques, namely PROMETHEE II and ELECTRE II, PROMETHEE was proven to be the better technique (see Chapter 6). The rest of this appendix documents this investigation.

A10.1 Experimental Setup

The experiments for this portion are based on the case study detailed in Section 6.3 and use the same base data of 20 candidate providers (alternatives). The values of these alternatives were then modified to create a total of 100 candidate providers (alternatives). The test cases used are as shown in Table A10-1. Each of the test cases is tested for three different criteria weights, detailed in Table A10-2.

Table A10-1: Test Cases for Large Scale Empirical Testing

Data Set	Criteria					QuickLite Values ^a		
	Cost	Lead time (day)	Location	Payment Duration	Capacity	Quantity	Sales Basis ^b	Tran Cost
Set0-1-2	9.50	5	-	-	-	3000	FOB	500
Set1-1-2	9.50	5	Singapore	-	-	3000	FOB	500
Set1-2-2	9.50	5	Singapore	90 days	-	3000	FOB	500
Set1-6-2	9.50	5	Singapore	90 days	600000	3000	FOB	500

Worked Examples

Table A10-2: Weights Used

No. of Criteria	Weights*	Individual Criterion Weight				
		c_1	c_2	c_3	c_4	c_5
2-criteria	W1	0.110	0.890	-	-	-
	W3	0.500	0.500	-	-	-
	W6	0.890	0.110	-	-	-
3-criteria	W1	0.054	0.473	0.473	-	-
	W3	0.334	0.333	0.333	-	-
	W6	0.818	0.091	0.091	-	-
4-criteria	W1	0.037	0.321	0.321	0.321	-
	W3	0.250	0.250	0.250	0.250	-
	W6	0.751	0.083	0.083	0.083	-
5-criteria	W1	0.028	0.243	0.243	0.243	0.243
	W3	0.200	0.200	0.200	0.200	0.200
	W6	0.692	0.077	0.077	0.077	0.077

*: The weights' numbering is based on the experimental setup discussed in Section 6.4.1 and detailed in Section A8.4 of Appendix 8.

A10.2 Results and Analysis

The results from these experiments were analysed for two of the metrics in the proposed MCDM evaluation framework discussed in Section 5.2.3, namely *Rank Completeness* and *Rank Reversal*. These two metrics were chosen as they can uniquely distinguish the quality of solution. Rank completeness measures the ability of a MCDM technique to completely rank all alternatives, whilst rank reversal shows the susceptibility of a technique to ranking sequence changes when new alternatives are added.

Table A10-3: Rank completeness metric for Deviation Measure – Original (DMO)

Test\Weights	W1	W3	W6
50 alternatives			
Set0-1-2	0.920	0.920	0.920
Set1-1-2	0.520	0.520	0.520
Set1-2-2	0.940	0.940	0.940
Set1-6-2	0.940	0.940	0.940
80 alternatives			
Set0-1-2	0.925	0.913	0.925
Set1-1-2	0.925	0.925	0.925

Worked Examples

Test\Weights	W1	W3	W6
Set1-2-2	0.938	0.938	0.938
Set1-6-2	0.938	0.938	0.938
100 alternatives			
Set0-1-2	0.910	0.900	0.910
Set1-1-2	0.930	0.930	0.930
Set1-2-2	0.940	0.940	0.940
Set1-6-2	0.940	0.940	0.940
Overall Mean	0.896	Standard Deviation	0.116

The rank completeness scores for DMO are shown in Table A10-3 whereas Table A10-4 details the PROMETHEE II scores. DMO has a mean of 0.896 (and a standard deviation of 0.116) whereas PROMETHEE II has a mean of 0.875 (with a standard deviation of 0.145). As in the earlier analyses discussed in Chapter 6, DMO performs better than PROMETHEE II in rank completeness as it has a superior rank completeness score (higher mean and lower standard deviation).

Table A10-4: Rank completeness metric for PROMETHEE II

Test\Weights	W1	W3	W6
50 alternatives			
Set0-1-2	0.920	0.520	0.520
Set1-1-2	0.520	0.520	0.520
Set1-2-2	0.940	0.940	0.940
Set1-6-2	0.940	0.940	0.940
80 alternatives			
Set0-1-2	0.925	0.925	0.925
Set1-1-2	0.925	0.925	0.925
Set1-2-2	0.938	0.938	0.925
Set1-6-2	0.938	0.938	0.938
100 alternatives			
Set0-1-2	0.910	0.910	0.910
Set1-1-2	0.930	0.930	0.930
Set1-2-2	0.940	0.940	0.940
Set1-6-2	0.940	0.940	0.940
Overall Mean	0.875	Standard Deviation	0.145

Worked Examples

The rank reversal tests require additional test steps, as documented in Section 6.4.3. In this large-scale experiment, the following test procedure is followed:

- (a) Test a particular test case using an initial list of 50 candidate providers (alternatives)
- (b) Add another 30 (a total of 50) candidate providers, and repeat the test
- (c) Add the remaining 20 (a total of 100) candidate providers, and repeat the test

For the analyses, additional steps are also required, documented in Section 6.4.3 also. Following the same steps, it was confirmed that DMO is immune to rank reversal as the elicitation process in DMO is not dependent on other alternatives' performance values. As such the scores for DMO are not tabulated, as the rank reversal scores are all 0.000. The rank reversal scores for PROMETHEE II are tabulated in Table A10-5. Similar to the analyses of Chapter 6, PROMETHEE II does suffer from rank reversal. In fact, as the number of alternatives increased, its propensity for rank reversal worsened. The mean value here is 0.252 (with a standard deviation of 0.202) as compared to a mean value of 0.115 (and a standard deviation of 0.126) recorded in Table 6-9 in Chapter 6. This is consistent with expectations, as with more alternatives, the chances of other alternatives influencing the ranking score of each candidate provider increase.

Table A10-5: Rank reversal metric for PROMETHEE II (using 50 alternatives as a base sequence)

Test/ Weights	Step (a) - Step(b)			Step (a) - Step(c)		
	W1	W3	W6	W1	W3	W6
Set0-1-2	0.007	0.424	0.440	0.007	0.424	0.441
Set1-1-2	0.400	0.416	0.421	0.407	0.416	0.459
Set1-2-2	0.073	0.094	0.038	0.117	0.126	0.061
Set1-6-2	0.500	0.032	0.027	0.589	0.075	0.046
Average	0.252		Standard Deviation		0.202	

A10.3 Summary

Large-scale experiment of 2x100 (no. of criteria x no. of alternatives), 3x100, 4x100 and 5x100 were conducted to further confirm the experimental results and empirical

Worked Examples

analyses conducted in Chapter 6. The results of analyses for rank completeness re-affirmed that DMO has better scores, outperforming PROMETHEE II. It was also confirmed that DMO is immune to rank reversal whilst PROMETHEE II's rank reversal scores are consistent with the expectations when more alternatives are tested.

These large scale experiments confirm that the results in Chapter 6 are also valid for experiments conducted with up to 100 alternatives. 100 alternatives (in this case candidate suppliers/partners) is a large number for any B2B collaboration, as most companies only work with a handful of pre-qualified or pre-identified suppliers. Hence, it would be logical to deduce that alternatives would not exceed 100 for B2B collaboration.