EVALUATION OF INFORMATION TECHNOLOGY INVESTMENTS IN THE WOOD INDUSTRY

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Abstract

Manufacturing industry is the largest business sector in Canada. It has contributed significantly to the Canadian prosperity in terms of employment and economic growth. However, this industry has faced increased competition from low-price producing regions. Also, appreciation of Canadian dollar and increasing price of energy and other resources lowered the profit margins of the Canadian manufacturing industry. In order to survive and gain higher profit margins, Canadian manufacturers have adapted various strategies one of which is to offer high-value customized products to best meet the changing needs of their customers. To that end, there have been significant investments made in advanced technologies such as information and communication technology (ICT) in Canadian manufacturing companies.

Due to expensive cost of acquiring ICT and its long term effect, it is important to use suitable holistic approaches for evaluation of this type of investments. The evaluation should involve inclusion of multiple tangible and intangible criteria. It may also include consideration and aggregation of different decision makers’ viewpoints. Unlike some other sectors in the manufacturing industry, systematic approach for assessing ICT investments have not often been used in the forest products industry. In this research project, the evaluation and selection of a design and manufacturing software package at a Canadian cabinet manufacturing company is addressed. A list of design and manufacturing software selection criteria is presented which could be modified and used by any other goods/service producing companies. The impact of interdependencies among the selection criteria on the results of the decision making process is also
investigated. Various sensitivity analyses were performed to investigate the stability of
the decision when the decision parameters changed.

The results show that the inclusion of intangible criteria would yield to a better
decision than that of revealed by just considering tangible factors. In the case study
presented in this research, a software package with reasonable cost and good features
(Software D) was chosen over the cheapest software which did not offer these features.

Furthermore, the results show that the inclusion of interdependencies among the
evaluation criteria would impact the decision outcome. In the considered case study, the
inclusion of such interdependencies not only changed the weights of the alternatives, but
also partially changed the ranking of the alternatives. In our case, the ranking of the top
alternative (Software D) did not change.

Finally, sensitivity analyses which were performed in this research project
revealed that the choice of Software D (top ranked software) was stable upon changes in
the influence of decision makers. Also, it was determined that this choice was stable upon
changes in the importance of selection criteria for the decision makers.
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## Glossary

**Analytic Hierarchy Process (AHP)**  
A multiple criteria decision making method that can be used to evaluate and rank several alternatives based on multiple tangible and intangible criteria.

**Analytic Network Process (ANP)**  
A decision making methodology that can be used to prioritize different alternatives based on multiple tangible and intangible evaluation criteria and the interdependencies between them.

**Cluster**  
A group of elements in the decision making model.

**Element**  
An important evaluation criterion in the decision making model.

**Inner-dependency**  
A condition in which the elements within a cluster affect (or are affected by) one another.

**Outer-dependency**  
A condition in which the elements within a cluster affect (or are affected by) the elements within other clusters.

**Sensitivity Analysis**  
The analysis of the impacts of changes in the inputs of a model on its final results.
Acknowledgement

I would like to sincerely thank my beloved parents, Azar Imani and Sadollah Assadi, my lovely sister, Atousa Assadi, and my dear brother, Peyman Assadi, for their continuous support without which I would not be able to succeed. I would like to dedicate this thesis to all of them.

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Co-Authorship Statement

The research studies carried out in this dissertation were defined and designed by Dr. Taraneh Sowlati. The company for which the evaluation and analysis were performed was introduced by Dr. Taraneh Sowlati. The research activities, including reviewing the related literature, interviewing industry experts, gathering data on the case study, evaluating the data, developing and running the models, performing the sensitivity analyses, and analyzing the results, were conducted by Pooria Assadi. The thesis was prepared in manuscript style. A version of Chapter 2 was accepted for publication in International Journal of Business Innovation and Research. A version of Chapter 3 was submitted for publication. The first manuscript was co-authored by Pocria Assadi and Dr. Sowlati, and the second manuscript was co-authored by Pooria Assadi, Dr. Sowlati and Dr. Paradi.
Chapter 1. Introduction

1.1 Background

1.1.1 Importance of the Manufacturing Industry in Canada

The manufacturing industry, which is the largest business sector in Canada, plays an important role in the Canadian economy. It contributed approximately $181 billion (15%) to the Canadian overall gross domestic product (GDP) (The Centre for the Study of Living Standards, 2007) in 2003 and generated about 15% of the total employment in Canada in 2004 (Canadian Manufactures and Exporters, 2004a). Its contribution to the overall Canadian GDP was well above that of other goods-producing industries such as (a) construction; (b) utilities; (c) mining, oil and gas extraction; and (d) agriculture, forestry, fishing and hunting industries (The Centre for the Study of Living Standards, 2007). As shown in Figure 1.1, from 1981 to 2003, approximately half of the total GDP in the Canadian goods-producing industries was generated by the manufacturing industry.

![Figure 1.1. Composition of the total GDP in Canadian goods-producing industries: 1981-2003 (Source: The Centre for the Study of Living Standards, 2007)]
1.1.2 Challenges of the Canadian Manufacturing Industry

This important sector has been facing major challenges recently. The global competition has been escalating as the export oriented companies in China, Mexico, South Korea, Southeast Asia, and South America have been emerging rapidly by introducing low-price products to the global marketplace (Canadian Manufactures and Exporters, 2004b). As a result, the profit margin of the Canadian manufacturing industry has decreased (Canadian Manufactures and Exporters, 2004b).

Furthermore, since Canada has been exporting more than half of its manufactured products overseas, the appreciation of the Canadian currency since 2003 has dropped this industry’s profit margin (Canadian Manufactures and Exporters, 2004b). This profit margin has also decreased even more by price increases in energy and other manufacturing inputs (Canadian Manufactures and Exporters, 2004b).

Canadian manufacturing companies have been adapting various strategies to overcome these challenges. One of the strategies is to offer high-value high-quality customized products by investing in advanced technologies and machineries (Canadian Manufactures and Exporters, 2004b).

Investments in new technologies, machineries and equipment, and new plants in the Canadian manufacturing industry were higher than that of any other business sector in Canada in 2003 (Canadian Manufactures and Exporters, 2004a). On average, approximately a third of the total investments and half of the total ICT investments made in Canadian goods-producing industries had been made in the manufacturing industry in the period of 1981-2003 as depicted in Figure 1.2 and Figure 1.3.
In particular, investment in software packages in this industry was significant in Canada as suitable software packages were crucial to help the manufacturers use their advanced machineries more effectively, and to innovate and produce high-value high-quality customized designs for their production purposes. Approximately, a two third of
the total software investments made in the goods-producing industries in Canada had been made in the manufacturing industry in the period of 1981-2003 (Figure 1.4).

![Figure 1.4. Composition of the total software investments in Canadian goods-producing industries: 1981-2003 (Source: The Centre for the Study of Living Standards, 2007)](image)

Furthermore, in the period of 1987-2006, investments in software in Canadian manufacturing industry had been escalating (Figure 1.5).

![Figure 1.5. Contribution of software, communication equipment, and computer investments to the total ICT investments in the manufacturing sector in Canada (Source: The Centre for the Study of Living Standards, 2007)](image)
In 2006, these investments contributed to more than half of the total ICT investments made in the Canadian manufacturing industry.

1.2 Literature Review

There have been various methodologies used for evaluation of IT investments such as cost-benefit analysis, critical success factor, Delphi method, balanced scorecard, analytic hierarchy process (AHP), analytic network process (ANP), decision analysis, goal programming, dynamic programming, benchmarking, game theory, portfolio methods, real options, value analysis, and benefit-risk analysis (Shoval and Lugasi, 1987; Renkema and Berghout, 1997; Sylla and Wen, 2002; Schniederjans et al., 2004; Wen and Shih, 2006).

In one classification according to Wen and Shih (2006), IT investment evaluation methods were classified into six groups: (1) ratio-based methods, (2) real options methods, (3) economic methods, (4) mathematical programming methods, (5) decision theory methods, and (6) scoring methods. Ratio-based methods evaluate the effectiveness of IT with respect to various organizational and financial factors (Wen and Shih, 2006) such as the ratio of current total assets to current total liabilities. Real option methods allow for and evaluate the option of investing in the future stages using the information collected along the way (Wen and Shih, 2006). Economic methods are built on the basis of economics. Cost-benefit method is one of the economic methods in which the costs of undertaking a project are measured against its benefits (Wen and Shih, 2006). In mathematical programming methods, such as dynamic programming and goal programming methods, an objective function is optimized subject to some constraints.
(Wen and Shih, 2006). Decision theory is a set of methods and principles to choose a single alternative from a group of alternatives (Schniederjans et al., 2004). Finally, in scoring methods a group of alternatives are easily compared and evaluated against each other based on multiple tangible and intangible criteria in order to achieve specific objectives (Wen and Shih, 2006).

Wen and Shih (2006) suggested that the ratio methods are not as much suitable for evaluation of projects within a single organization as they are for comparison of different projects among organizations. They also stated that real options method requires various assumptions on factors such as discount rates and cash flows which make it difficult to use for evaluation of IT investments. The economic or financial methods are not generally used as much as the multiple criteria methods for IT investments evaluation in the recent literature as they cannot capture the right value of IT including its tangible and intangible costs and benefits (Lee, 2004). These methods cannot explicitly include intangible costs and benefits in the assessment (Alshawi et al., 2003). Furthermore, they cannot recognize the risky and long term nature of IT investments (Milis and Mercken, 2004). Finally, mathematical programming methods lack when dealing with intangible factors in the analysis (Wen and Shih, 2006).

Wen and Shih (2006) suggested that the application of scoring methods which can deal with intangible factors as well as tangible ones is useful in the evaluation of IT investments. One of the multiple criteria scoring methods which can incorporate multiple tangible and intangible factors in the analysis is the AHP method which was introduced by Saaty (1980). AHP was used in a wide range of applications including manufacturing,
engineering, marketing, and research (Vaidya and Kumar, 2006). It has been widely used for systematic evaluation of IT investments and in particular software investments.

1.2.1 Analytic Hierarchy Process in Software Selection

Muralidhar et al. (1990) applied the AHP method to prioritize information system (IS) projects and select the most suitable one using a hypothetical example. For selection of a computer controlled cargo operation system, Roper-Lowe and Sharp (1990) applied the AHP method. This computer system was used to record bookings and also to record consignments location within warehouses in the airline industry. The authors found that although the method was useful and easy to use, it was not possible to consider interdependencies among the selection criteria, it was challenging to compare qualitative selection criteria with the quantitative ones, and finally, it was difficult to interpret final weights as AHP did not provide any statistical significance.

The AHP method was applied for selection of a suitable logistics software package which could be used for order processing, order entry, inventory control, vehicle routing, and vehicle scheduling (Min, 1992). For evaluation of the commercial off-the-shelf software, Finnie et al. (1993) applied the AHP method. Kontio (1996) used AHP to evaluate hypertext browsers which were needed in a program developed for NASA (National Aeronautics and Space Administration) to integrate the environmental data gathered from satellites for the use of scientists all over the globe. These studies included both tangible and intangible factors in the analyses.

AHP was used in a group decision setting to select a multimedia authoring system (Lai et al., 1999). This system was used to develop efficient interactive multimedia
systems in a computer service company. Teltumbde (2000) used AHP instead of conventional cost-benefit analysis for selecting an enterprise resource planning software which could undertake materials requirement planning and manufacturing resources planning. The method was applied in an Indian public sector corporation. The study was conducted on a real case and was focused more on the effectiveness of acquiring such software than efficiency improvements.

Lai et al. (2002) compared the application of the AHP technique and Delphi method in their case of multimedia authoring system evaluation. They found that the AHP method was preferable over Delphi method. Using Expert Choice computer program in a group decision setting, Mamaghani (2002) applied AHP for evaluation and selection of an antivirus and content filtering software package. AHP was used for commercial off-the-shelf software package evaluation by Morera (2002). These studies included several tangible and intangible selection criteria.

For evaluation of a sample of 42 customer relationship management software packages, Colombo and Francialci (2004) used AHP. These software packages could be used by companies to learn about and to forecast their customers' needs based on technical and quality measures as well as functional and cost criteria. Ngai and Chan (2005) applied AHP to select a suitable knowledge management tool. This tool could integrate the knowledge available in an organization and make it available to all the departments within the organization for business problem solving. The study was conducted in an integrated communication company in Asia.
In order to evaluate computer managed maintenance systems in the paper industry, Braglia et al. (2006) applied AHP. They considered tangible and intangible selection criteria such as cost, ease of use, technical features, ease of integration and implementation, data management, and security features in the analysis. Ahmad and Laplante (2006) used AHP to evaluate and select a software tool to manage their software projects effectively.

The AHP method has the potential and flexibility to be integrated with other methods such as fuzzy logic, ANP, and mathematical programming (Vaidya and Kumar, 2006). Bozdag et al. (2003) used four fuzzy multi-attribute approaches including a fuzzy analytic hierarchy process for evaluation and selection of a computer integrated manufacturing system which helped automate or archive the manufacturing systems. They gave numerical examples to build their case. A multi-stage multi-attribute decision model based on AHP and ANP was introduced by Sarkis and Sundarraj (2003) for evaluation of enterprise information technologies. These technologies can be used to share the information within organizations. They used a hypothetical example for illustration.

In combination with mathematical programming, Jung and Choi (1999) used AHP to evaluate various alternatives for modular software system. An AHP-based approach was applied to evaluate three AHP software packages considering several criteria such as functionality, usability, maintainability and portability based on the international norm ISO/IEC 9126 (Ossadnik and Lange, 1999). To evaluate an enterprise resource planning software, Wei et al. (2005) applied an AHP-based method using a practical case in an
electronics company considering several factors such as cost, time, reliability, flexibility, functionality, service, and reputation.

Table 1.1 summarizes the software selection studies in which AHP was used.
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Software type</th>
<th>Method</th>
<th>Notes/Findings/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muralidhar et al.</td>
<td>1990</td>
<td>IS project</td>
<td>AHP</td>
<td>AHP was used for IS project prioritization. A hypothetical example was discussed.</td>
</tr>
<tr>
<td>Roper-Lowe and Sharp</td>
<td>1990</td>
<td>Computer controlled cargo operation system</td>
<td>AHP</td>
<td>AHP was easy to use, but could not consider interdependencies among the selection criteria, it was hard to compare qualitative criteria with the quantitative ones, and it was difficult to interpret final weights.</td>
</tr>
<tr>
<td>Min</td>
<td>1992</td>
<td>Logistics software</td>
<td>AHP</td>
<td>The software could be used for order processing, order entry, inventory control, vehicle routing, and vehicle scheduling.</td>
</tr>
<tr>
<td>Finnie et al.</td>
<td>1993</td>
<td>Commercial off-the-shelf software</td>
<td>AHP</td>
<td>AHP was applied for commercial off-the-shelf software evaluation.</td>
</tr>
<tr>
<td>Kontio</td>
<td>1996</td>
<td>Hypertext browser software</td>
<td>AHP</td>
<td>The software needed in a program to integrate the environmental data gathered from satellites for the use of scientists.</td>
</tr>
<tr>
<td>Lai et al.</td>
<td>1999</td>
<td>Multimedia authoring system</td>
<td>AHP</td>
<td>The system was used to develop efficient interactive multimedia systems in a computer service company.</td>
</tr>
<tr>
<td>Jung and Choi</td>
<td>1999</td>
<td>Modular software system</td>
<td>AHP and mathematical programming</td>
<td>AHP was used in combination with the mathematical programming for software evaluation.</td>
</tr>
<tr>
<td>Ossadnik and Lange</td>
<td>1999</td>
<td>AHP software</td>
<td>AHP</td>
<td>Criteria such as functionality, usability, maintainability, and portability were considered based on international norm ISO/IEC 9126.</td>
</tr>
<tr>
<td>Teltumbde</td>
<td>2000</td>
<td>Enterprise resource planning software</td>
<td>AHP</td>
<td>AHP was used instead of conventional cost-benefit analysis. The software could undertake materials requirement planning and manufacturing resources planning.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Software type</td>
<td>Method</td>
<td>Notes/Findings/Results</td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td>--------------------------------------</td>
<td>-------------------</td>
<td>---------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Lai et al.</td>
<td>2002</td>
<td>Multimedia authoring system</td>
<td>AHP and Delphi</td>
<td>AHP was compared to Delphi method for multimedia authoring system and was found preferable.</td>
</tr>
<tr>
<td>Mamaghani</td>
<td>2002</td>
<td>Antivirus and content filtering software</td>
<td>AHP</td>
<td>The AHP method was used for antivirus and content filtering software packages.</td>
</tr>
<tr>
<td>Moreira</td>
<td>2002</td>
<td>Commercial off-the-shelf software</td>
<td>AHP</td>
<td>AHP was used to evaluate commercial off-the-shelf software.</td>
</tr>
<tr>
<td>Bozdag et al.</td>
<td>2003</td>
<td>Computer integrated manufacturing system</td>
<td>AHP and fuzzy logic</td>
<td>The system was used to help automate or archive the manufacturing systems.</td>
</tr>
<tr>
<td>Sarkis and Sundarraj</td>
<td>2003</td>
<td>Enterprise information technology</td>
<td>AHP and ANP</td>
<td>The technology can be used to share the information within organizations.</td>
</tr>
<tr>
<td>Colombo and Francalanci</td>
<td>2004</td>
<td>Customer relationship management software</td>
<td>AHP</td>
<td>The software could be used to learn about and to forecast the customers’ needs based on technical, quality, functional, and cost criteria.</td>
</tr>
<tr>
<td>Ngai and Chan</td>
<td>2005</td>
<td>Knowledge management software</td>
<td>AHP</td>
<td>The tool could integrate the knowledge available in an organization and make it available to all the departments within the organization for business problem solving.</td>
</tr>
<tr>
<td>Wei et al.</td>
<td>2005</td>
<td>Enterprise resource planning software</td>
<td></td>
<td>Criteria such as cost, time, reliability, flexibility, functionality, service, and reputation were considered.</td>
</tr>
<tr>
<td>Braglia et al.</td>
<td>2006</td>
<td>Computer managed maintenance system</td>
<td>AHP</td>
<td>Criteria such as cost, ease of use, technical features, ease of integration and implementation, data management, and security features were considered in the analysis.</td>
</tr>
<tr>
<td>Ahmad and Laplante</td>
<td>2006</td>
<td>Project management software</td>
<td>AHP</td>
<td>AHP was used project management software selection.</td>
</tr>
</tbody>
</table>
Although AHP is a widely used multiple criteria decision making method that can include both tangible and intangible criteria in the decision making process, it does not recognize the interdependencies among the selection criteria (Roper-Lowe and Sharp, 1990). Such interdependencies among the selection criteria could be considered using a feedback mechanism in the ANP method or supermatrix approach (Saaty, 1996). The ANP method is suitable to evaluate several alternatives in real-world situations as the evaluation criteria are often interdependent in reality (Erdogmus et al., 2005). The ANP method was also used for evaluation of IT investments.

1.2.2 Analytic Network Process in Software Selection

Sarkis and Sundarraj (2003) introduced a multi-stage multi-attribute decision model based on ANP and AHP for evaluation of an information sharing platform within an organization. They included several clusters of decision criteria in their analysis such as strategic performance metrics, IT requirements, planning horizon, functional areas, and alternatives. They also identified the interdependencies among the clusters. For instance, there was interdependency between strategic performance metrics cluster (including time, cost, quality, and flexibility elements) and planning horizon cluster (including short term and long term elements). That is, an element could be more important than another element in the strategic performance metrics cluster when a short term planning horizon was applied, but it might not be the case when a long term planning horizon was considered. Vice versa, they noticed that for a specific element in strategic performance metrics cluster, it could be determined whether short term or long term planning horizon should be of the focus. Furthermore, they suggested that the model for the enterprise IT evaluation should be tailored to the organization under investigation.
The ANP method was also applied to select the most suitable software for product development process of a product (pen) by Mulebeke and Zheng (2006). They considered clusters such as functions (including design, engineering analysis, manufacturing planning and control, and data management elements), measures (including performance, usability and data file support elements), and alternatives in their analysis. The ANP method was developed considering the interdependencies among the clusters. They suggested that there could be other factors added to the analysis. They also mentioned that the ANP method was a suitable approach for systematic evaluation of software packages capturing the interdependencies among the decision elements.

Kengpol and Tuominen (2006) used the ANP method along with the Delphi and maximize agreement heuristic methods as a framework for evaluation of IT systems in logistics companies. The IT systems included fully integrated computerized system, semi-integrated computerized system, and manual integrated system. Benefits, costs, and risks were considered in the analysis as the control criteria. A control criterion is a common property with respect to which the relative influence of one factor over the other factor is determined (Saaty, 1996). The control sub-criteria were tangibles and intangibles. For example, intangible costs and tangible benefits were two control factors in their analysis. They considered a number of decision clusters such as technical cluster (including time to implement, skills requirement, and resource requirement elements), marketing cluster (including create new market), financial cluster (including expenses and income), and alternatives cluster. For each combination of control criterion and control sub-criterion (e.g., tangible benefits), the interdependencies among clusters were identified. For instance, considering the tangible benefits, the financial cluster affected
the marketing and alternatives clusters, and vice versa. Furthermore, the elements within certain clusters were inner-dependent to one another. For instance, considering tangible benefits, the elements within financial cluster affected each other, which means the more the saving on the budget, the more budget would be available to spend on new options.

A fuzzy ANP approach was proposed by Ayag and Ozdemir (2007) to enterprise resource planning software selection for an electronic device manufacturer. The fuzzy logic was used to deal with the uncertainties in the pairwise comparisons needed for ANP. Several tangible and intangible factors such as competitive advantage (including system cost clusters), productivity (including vendor support clusters), and profitability (including flexibility, functionality, reliability, ease of use, and technology advance clusters) were considered in the analysis. Each cluster was also decomposed into several elements. They identified the interdependencies among the clusters and among the elements and incorporated those in their ANP network. For instance, when the productivity increases, the competitive advantage and profitability of the company increase (i.e., the production of more units in a specific time period would decrease the unit cost). Moreover, when the cost of the system increases, the system usually comes with more features and options which make the system more flexible, but not necessarily easy to use. Also, they identified that better support from the system supplier would increase the competitive advantage, productivity, and profitability of the company. The authors argued that their proposed method could deal with lack of precision and certainty in human comparison judgments, as well as with interdependencies among criteria.

Table 1.2 summarizes the studies in which the ANP method was used for software evaluation and selection.
Table 1.2. Software selection studies using the ANP method

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Software type</th>
<th>Method</th>
<th>Decision clusters</th>
<th>Interdependency example(s)</th>
<th>Notes/Findings/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarkis and Sundarraj</td>
<td>2003</td>
<td>Information sharing platform</td>
<td>ANP and AHP</td>
<td>Strategic performance metrics, IT requirements, planning horizon, functional areas, and alternatives</td>
<td>The strategic performance metrics cluster could change based on the considered planning horizon</td>
<td>The model for the enterprise IT evaluation should be tailored to the organization under investigation.</td>
</tr>
<tr>
<td>Mulebeke and Zheng</td>
<td>2006</td>
<td>Product development software</td>
<td>ANP</td>
<td>Functions, measures, and alternatives</td>
<td>Various interdependencies included in the analysis</td>
<td>Other factors could be added to the analysis.</td>
</tr>
<tr>
<td>Kengpol and Tuominen</td>
<td>2006</td>
<td>IT system</td>
<td>ANP, Delphi, and the maximize agreement heuristic method</td>
<td>Technical cluster, marketing cluster, financial cluster, and alternatives cluster</td>
<td>Financial cluster affected the marketing cluster, alternatives cluster, and itself</td>
<td>The tangible and intangible benefits, costs, and risks were considered as the control criteria in the analysis.</td>
</tr>
<tr>
<td>Ayag and Ozdemir</td>
<td>2007</td>
<td>Enterprise resource planning software</td>
<td>ANP and fuzzy logic</td>
<td>Competitive advantage, productivity, and profitability</td>
<td>As the productivity increases, the competitive advantage and profitability of the company increase. Also, as the system cost increase, the system would be more flexible, but not necessarily easy to use</td>
<td>The fuzzy logic was used to deal with the uncertainties in the pairwise comparisons.</td>
</tr>
</tbody>
</table>
1.2.3 Goal Programming in Software Selection

Mathematical programming models were used along with multiple criteria methods such as AHP and ANP in the literature for evaluation of software packages. Such literature often presented cases in which more than one alternative could be chosen among several alternatives.

Developed by Charnes and Cooper (1961), goal programming is a mathematical programming method which can determine the values of decision variables considering some resource constraints so that the deviation from the goal values is minimized (Charnes and Cooper, 1961). It has the ability to consider the constraints in its solution procedure based on the ranking of their importance, which means the constraint with the highest priority is considered and satisfied first, and so on (Schniederjans et al., 2004). Goal programming has also the potential to weight the constraints (Schniederjans et al., 2004).

Goal programming has been applied to various types of problems in many different sectors (Schniederjans et al., 2004) and in particular it was applied to IT investment decision problems. A zero-one linear programming (Muralidhar et al., 1988) and a zero-one goal programming (Santhanam et al., 1989) were used for information system (IS) project selection. Talluri (2000) used a goal programming model for evaluation of computer systems for supply chain manufacturing operations. Factors such as time, cost, quality and flexibility were considered in the analysis.

Schniederjans and Hamaker (2003) solved the case problem presented by Talluri (2000) in order to improve the information obtained by their proposed goal programming
model using a ranking/scoring method, as well as goal programming duality and sensitivity analysis. Karsak and Ozogul (2007) proposed a framework for enterprise resource planning system selection in an automotive parts manufacturing company using a combination of quality function deployment, fuzzy linear regression and zero-one goal programming. Their approach not only accounted for interactions between user needs and system characteristics, but also accounted for interdependencies among system characteristics. They considered criteria such as cost, functional fit, user friendliness, flexibility, vendor’s reputations, and vendor support.

Goal programming was used along with AHP and ANP in IT investment decisions literature. Schniederjans and Wilson (1991) used a combination of the goal programming and the AHP method for IS project prioritization and selection considering the resource limitation. They revisited a hypothetical problem presented by Muralidhar et al. (1990) as their case study. Factors such as efficiency, accuracy, organizational learning, and cost were included in the analysis. Also, the resource limitations such as programmer hours, analyst hours, clerical labor hours, and budgeted costs were included.

Sylla and Wen (2002) used integer goal linear programming and AHP for IT investment decisions considering tangible and intangible costs, benefits, and risks within certain resource constraints. Sarkis and Talluri (2004) used a model based on goal programming and the AHP method to evaluate and select an e-commerce software and communication system for a hypothetical supply chain. They considered multiple tangible and intangible selection criteria in the analysis such as security, reliability, ease of use, support, costs, and service within software system, communication system, and compatibility constraints.
A combined zero-one goal programming and the ANP method was presented by Lee and Kim (2000) in order to address the selection of interdependent IS project based on Schniederjans and Wilson (1991) hypothetical case problem. In their analysis, efficiency, accuracy, organizational learning and cost were important selection factors, while programmer hours, analyst hours, clerical labor hours and budgeted costs were resource limitations. The interdependencies among selection criteria and alternatives were also addressed in their analysis. It was suggested that while careful consideration of such relationships would provide greater cost savings and benefits to the organizations, not considering such relationships would result in a poor resource allocation in an organization.

Table 1.3 summarizes the studies in which goal programming was used for software selection.
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Software type</th>
<th>Method</th>
<th>Notes/Findings/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santhanam et al.</td>
<td>1989</td>
<td>IS project</td>
<td>Zero-one goal programming</td>
<td>A zero-one goal programming approach was used for IS project selection.</td>
</tr>
<tr>
<td>Schniederjans and</td>
<td>1991</td>
<td>IS project</td>
<td>Goal programming and AHP</td>
<td>The problem presented by Muralidhar et al. (1990) was revisited. Factors such as</td>
</tr>
<tr>
<td>Wilson</td>
<td></td>
<td></td>
<td></td>
<td>efficiency, accuracy, organizational learning, and cost were included considering resource</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>limitations such as programmer hours, analyst hours, clerical labor hours, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>budgeted costs.</td>
</tr>
<tr>
<td>Talluri</td>
<td>2000</td>
<td>Supply chain</td>
<td>Goal programming</td>
<td>Factors such as time, cost, quality, and flexibility were considered in the analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>operations</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>computer system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lee and Kim</td>
<td>2000</td>
<td>IS project</td>
<td>Zero-one goal programming and</td>
<td>Schniederjans and Wilson (1991)'s case was analyzed and the interdependencies among</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AHP</td>
<td>criteria and alternatives were addressed. It was suggested that careful consideration of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>such relationships would provide greater cost savings and benefits to the organizations.</td>
</tr>
<tr>
<td>Sylla and Wen</td>
<td>2002</td>
<td>IT investment</td>
<td>Integer goal programming and</td>
<td>They considered tangible and intangible costs, benefits, and risks within certain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AHP</td>
<td>resource constraints.</td>
</tr>
<tr>
<td>Schniederjans and</td>
<td>2003</td>
<td>Supply chain</td>
<td>Goal programming duality,</td>
<td>The case problem presented by Talluri (2000) was studied in order to extend its</td>
</tr>
<tr>
<td>Hamaker</td>
<td></td>
<td>manufacturing</td>
<td>sensitivity analysis, and a</td>
<td>informational value.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>operations</td>
<td>ranking/scoring method</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>computer system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1.3. Software selection studies using goal programming (continued)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Software type</th>
<th>Method</th>
<th>Notes/Findings/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarkis and Talluri</td>
<td>2004</td>
<td>E-commerce software and communication system</td>
<td>Goal programming and AHP</td>
<td>They considered criteria such as security, reliability, ease of use, support, costs, and service in the analysis within software system, communication system, and compatibility constraints.</td>
</tr>
<tr>
<td>Karsak and Ozogul</td>
<td>2007</td>
<td>Enterprise resource planning system</td>
<td>Zero-one goal programming, quality function deployment, and fuzzy linear regression</td>
<td>They accounted for interactions between user needs and system characteristics and for interdependencies among system characteristics considering factors such as cost, functional fit, user friendliness, flexibility, vendor's reputations, and vendor support.</td>
</tr>
</tbody>
</table>
Although goal programming method was used in the literature along with multiple criteria decision making methods such as AHP and ANP, in the case presented in this research, the goal programming method was not used, since only one alternative was required to be chosen from several short-listed alternatives.

1.3 Research Objectives

Systematic approach for evaluation of IT investment projects has not been used often in the wood industry (The IUFRO Task Force, 2005). The objectives of this research are as follows:

(1) To study the evaluation and selection of a design and manufacturing software package considering multiple tangible and intangible criteria in a group decision setting.

To achieve this objective, a real software selection case at a cabinet manufacturing company is considered. A group decision setting is adopted and several tangible and intangible criteria are included in the analysis using the AHP method. The importance of selection criteria and the suitability of the software packages are determined. Also, several sensitivity analyses are conducted to ensure the stability and accuracy of the decision outcome upon changes in the weights of decision criteria and changes in the influence of decision makers in the decision making process. Also, the circumstances under which the current second-ranked alternative would become the top-ranked alternative are analyzed for all decision makers.

(2) To investigate the potential effects of interdependencies among the decision criteria on the decision outcome.
This objective is achieved by studying the inter-relationships among the software selection criteria in a feedback network structure using a suitable multiple criteria decision making method, ANP. A real case of software selection is analyzed and a group decision environment is adopted.

To the best of the researcher’s knowledge, this is the first research to use a systematic multiple criteria framework in a group decision setting to assess IT investment projects in the wood industry.

1.4 Dissertation Outline

The organization of this thesis is as follows:

Chapter 2 focuses on the first objective. The evaluation and selection of a design and manufacturing software package considering multiple tangible and intangible software selection criteria in a group decision setting using the AHP method is explained in this chapter. The AHP analyses are explained and the results and discussion are presented. The chapter is concluded by presenting the major outcomes of the study.

The focus of Chapter 3 is on the second objective, analyzing the potential effects of interdependencies among the decision criteria on the outcome of the decision. This study is an extension of the first study. The ANP network and analysis are explained. Then, the results and discussions are presented.

Chapter 4 presents the major conclusions of this research. The limitations of this study are also indicated in this chapter. Furthermore, directions for the future research are also given.
References


Chapter 2. Design and Manufacturing Software Selection in the Wood Industry using Analytic Hierarchy Process

2.1 Introduction

Globalization, intense competition and advances in telecommunication, wireless networks and manufacturing technologies have increased investments in information and communication technologies (ICT). Approximately, half of ICT investments in the Canadian business sector was made on software, a quarter on communication equipments, and a quarter on computers in 2004, compared to their equal shares in 1987 (Sharpe, 2006; The Centre for the Study of Living Standards, 2007).

As shown in Figure 2.1, on average, the total ICT investments increased about 15% per year in the business sector in Canada from 1980 to 2006 (The Centre for the Study of Living Standards, 2005; Sharpe and Arsenault, 2008).

In particular, investments in software have been rapidly growing. The average annual increase rate of investments in software was about 13% in that period, well beyond the average annual increase rate of the investments in communication equipment (5%) and investments in computers (4%) (The Centre for the Study of Living Standards, 2005; Sharpe and Arsenault, 2008).

* A version of this chapter was accepted for publication. Assadi, P., Sowlati, T. (2008), Design and manufacturing software selection in the wood industry using analytic hierarchy process, International Journal of Business Innovation and Research.
It is essential for businesses to invest in information technology (IT) to remain competitive (Schniederjans et al., 2004). IT investment decisions are among the most important long term business decisions since (1) they involve several tangible and intangible criteria which may be difficult to quantify (Schniederjans et al., 2004), (2) they are subject to higher risk levels than any other capital investments (Schniederjans et al., 2004), and (3) their return on investment are highly uncertain (Lai et al., 1999; Schniederjans et al., 2004). It is challenging to identify and quantify the intangible criteria (Lai et al., 1999; Love et al., 2004; Schniederjans et al., 2004) including intangible benefits, opportunities, costs, and risks (Saaty, 1996). Moreover, different decision makers may have different points of view in evaluating IT investment projects. The aggregation of these individual viewpoints could be an extra challenge to deal with (Lai et al., 1999).
Customer satisfaction, competitive advantage, productivity, efficiency, and profitability growth could be gained by making a good IT investment decision (Hitt and Brynjolfsson, 1996; Schniederjans et al., 2004; Venkata Rao, 2007). On the other hand, not investing in IT could be unaffordable (Gunasekaran et al., 2006) and also “not making the right decision” or “making a bad decision” would be costly as it would increase the costs of capital and interest, and would generate competitive disadvantage (Lai et al., 1999; Teltumbde, 2000; Schniederjans et al., 2004). Therefore, it is important to evaluate and prioritize IT spending proposals systematically (Lai et al., 1999; Irani et al., 2006).

Numerous methodologies have been developed and/or applied for evaluation, prioritization, and selection of IT investments, in particular for evaluation and selection of software packages. It is advisable to use multiple criteria methods over purely financial ratios. A multiple criteria decision making method which has been widely used for evaluation of IT investments is the AHP method. Introduced by Saaty in 1980 (Saaty, 1980), it can be used to assess and rank different alternatives based on multiple tangible, intangible, and sometimes conflicting criteria. AHP was applied to select a computerized cargo operation system (Roper-Lowe and Sharp, 1990), a logistics software package for order processing, order entry, inventory control, vehicle routing, and vehicle scheduling (Min, 1992), a multimedia authoring system (Lai et al., 1999), an enterprise resource planning software (Teltumbde, 2000), an antivirus and content filtering software package in a group decision setting (Mamaghani, 2002), a customer relationship management software package (Colombo and Francalanci, 2004), a computerized maintenance system in paper industry (Braglia et al., 2006), and a geographic information system software...
package (Eldrandaly, 2007). The AHP method has also been used in combination with other methods such as goal programming, fuzzy logic (Schniederjans and Wilson, 1991; Ossadnik and Lange, 1999; Jung and Choi, 1999; Bozdag et al., 2003; Sarkis and Talluri, 2004), balanced score card method and grey relational theory (Huang et al., 2008) for software selection.

The AHP method was used for software selection in particular due to the fact that it is easy to understand and use, its results are easy to communicate with the decision makers, and it can be applied to group decision making settings (Lai et al., 1999; Vaidya and Kumar, 2006).

Although applied in a wide range of applications, AHP has some shortcomings (Belton and Gear, 1983; Dyer, 1990). It does not recognize the interdependencies among the selection criteria and does not provide statistical significance of the weights (Roper-Lowe and Sharp, 1990). The AHP method is also a data intensive technique (Sarkis and Talluri, 2004). When there are many alternatives considered in the AHP hierarchy and another alternative is added, there is a high possibility that the top-ranked alternative changes or at least the ranking of other alternatives changes (Zanakis et al., 1998). The change in the top-ranked alternative by adding one more alternative to the system could happen even if the added alternative is not the optimal option (Zanakis et al., 1998). Furthermore, the consistency ratio is hard to be kept in the acceptable range (below 10%), particularly when there are many criteria considered in the decision hierarchy (Roper-Lowe and Sharp, 1990).
Unlike other industries, systematic approach for evaluation of IT investment projects has not been used in the wood industry (The IUFRO Task Force, 2005). This study presents the evaluation and selection process of a design and manufacturing software package considering multiple tangible, intangible, and conflicting software selection criteria in a group decision setting at a cabinet manufacturing company using the analytic hierarchy process (AHP) technique. To the best of our knowledge, this is the first study to use a systematic multiple criteria framework in a group decision setting to assess IT investment projects in the wood industry.

2.2 The Analytic Hierarchy Process Method

In the AHP method, the overall decision problem is first decomposed into a hierarchical structure with the goal at the top level followed by criteria, sub-criteria, and alternatives in the lower levels (Figure 2.2).

![AHP's hierarchical structure](image)

Figure 2.2. AHP's hierarchical structure
The alternatives, criteria, and sub-criteria are then compared to one another in pairs with respect to the upper level element. These pairwise comparisons are conducted either based on actual data or simply based on human judgment using Saaty’s 1-9 scale, one representing the equal preference of a factor over the other one and nine representing the extreme preference of a factor over the other one.

Based on the pairwise comparison of alternatives/factors with respect to the upper level factors, the relative preference/importance matrix \((A)\) is formed. Suppose that matrix \(A\) is the matrix of comparisons between \(n\) elements, denoted by Equation 2.1 (Saaty, 1980).

\[
A\sub{n\times n} = [a_{ij}] \tag{2.1}
\]

where \(a_{ij} = w_i/w_j\) is Saaty value for pairwise comparison of the relative weight of the element in row \((i)\) over element in column \((j)\) and \((1 \leq a_{ij} \leq 9)\) for \(1 \leq i, j \leq n\). The diagonal values in this matrix are equal to one \((a_{ii} = a_{jj} = 1)\) for \(1 \leq i, j \leq n\). The reciprocal values \((a_{ji})\)’s are calculated as \(a_{ji} = 1/a_{ij}\) for \(1 \leq i, j \leq n\).

Then, each column of this matrix is summed and each value in that column is divided by its column sum to generate a normalized matrix \((A')\) as shown in Equation 2.2 (Saaty, 1980).

\[
A\sub{n\times n}' = [a_{ij}'] \tag{2.2}
\]

where \(a_{ij}' = a_{ij}/\sum_{k=1}^{n} a_{kj}\) for \(1 \leq i, j \leq n\).
Next, the relative weights matrix or eigenvector \( W \) is derived by calculating the average of the values in each row of the normalized matrix using Equation 2.3 (Saaty, 1980).

\[
W_{nk} = [w_k]
\]  

(2.3)

where \( w_k = \frac{\sum_{j=1}^{n} a_{kj}}{n} \) for \( 1 \leq k \leq n \).

The relative weights of alternatives, sub-criteria, and criteria are next aggregated top down to derive the composite weight for each alternative using Equation 2.4 (Saaty, 1980).

\[
C_{z} = [c_z]
\]  

(2.4)

where \( c_z = \sum_{i=1}^{n_t} w_i \times \prod_{l=1}^{n_l-1} w_l \) is the composite weight for alternative \( z \) for \( 1 \leq z \leq Z \), \( Z \) refers to the number of alternatives being considered, \( C_{z} \) refers to the matrix of alternatives' composite weights with \( Z \) rows and 1 column, \( n_t \) denotes the number of terminal nodes for alternative \( a \) (number of sub-criteria), \( n_l \) denotes the number of hierarchy levels, \( t \) refers to the terminal nodes, \( l \) refers to the level number, \( w_i \) denotes the relative weight of alternative \( z \) with respect to terminal node \( t \), and \( w_l \) denotes the relative weight of the element in level \( l \) (that is on the path which passes terminal node \( t \) and alternative \( z \)) with respect to its upper level element on the same path as explained by Lai et al. (1999).
Basically, the composite weight for an alternative is the sum of the products of all the relative weights of the elements along $n_i$ paths from the goal to that alternative as illustrated in Figure 2.3.

It is important to have consistent judgments in the pairwise comparisons. It means that if factor A is preferred over B and factor B is preferred over C, then factor A has to be preferred over C (transitive property) (Saaty, 1980).

The consistency of judgments in AHP can be calculated using consistency index ($CI$) shown in Equation 2.5 (Saaty, 1980).

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

(2.5)

where $CI$ is the consistency index of a set of $n$ elements for which pairwise comparisons were conducted, and $\lambda_{\max}$ is the principal/maximum eigenvalue of matrix $A$. 

38
Eigenvalue of matrix $A$ is the value that can satisfy Equation 2.6 and can be calculated using Equation 2.7.

\[ A \times W = \lambda_{\text{max}} \times W \]  
\[ \det(A - \lambda_{\text{max}} \times I) = 0 \]

where $I$ is the unity matrix in which $a_{ij} = 1$ for $i = j$ and $a_{ij} = 0$ for $i \neq j$ and also $\lambda_{\text{max}} \geq n$. Determinant of the matrix in Equation 2.7 is denoted as det(.).

The consistency ratio (CR) of matrix $A$ can be calculated using Equation 2.8 as the ratio of consistency index (CI) to random index (RI).

\[ CR = \frac{CI}{RI} \]

Random index (average consistency index for random judgments) for different matrix sizes ($n = 1, 2, \ldots, 10$) was simulated by Saaty and shown in Table 2.1.

<table>
<thead>
<tr>
<th>$n$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random index</td>
<td>0.00</td>
<td>0.00</td>
<td>0.52</td>
<td>0.89</td>
<td>1.11</td>
<td>1.25</td>
<td>1.35</td>
<td>1.40</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Consistency ratio of zero indicates a perfectly consistent set of judgments, while a consistency ratio of one indicates a perfectly inconsistent set of judgments (as if they were done randomly). Normally, a set of judgments considered as fairly consistent when the consistency ratio is below 10% or within the acceptable range of [0.0, 1.0] (Saaty, 1980).

Finally, in a group decision setting, the priorities generated by various decision makers are aggregated using the weighted geometric mean method (see for example
Saaty and Vargas, 2006) or geometric mean method (see for example Dyer and Forman, 1992; Lai et al., 1999; Wei et al. 2005). The aggregated alternative weight (AAW) for each alternative is calculated using Equation 2.9 (Saaty and Vargas, 2006).

\[
AAW = x_1^{q_1} \times ... \times x_m^{q_m}
\]  

(2.9)

where \( m \) is the number of managers involved, \( q_i \)'s are the influence of the different managers on the decision making process \( q_1 + q_2 + ... + q_m = 1 \), \( q_1, q_2, ..., q_m > 0 \) for \( 1 \leq i \leq m \), and \( x_i \)'s are the preference of different managers on a certain alternative.

2.3 Case of Software Selection in the Wood Industry

The design and manufacturing software package is a critical component of a cabinet manufacturing company, in particular a customized cabinet manufacturer. This software is used in various steps of the design and manufacturing activities, from the time an order is placed and being processed until it is manufactured and shipped, in order to generate the quotes, drawings, 3D shows, bills of materials, production schedules, purchase orders, shop paper-works, optimal cut lists, drilling patterns, CNC/saw machine codes, barcodes, labels, and packaging lists.

A cabinet manufacturing company in the province of British Columbia, Canada needed to acquire a design and manufacturing software package for its day-to-day use. The company is a high quality and growing cabinetry producer. Recently, the company purchased two pieces of modern equipment. It could not effectively use these new costly machineries, since the software packages in use were not compatible with these machines. Furthermore, the software packages in use for design, manufacturing, and accounting purposes were not compatible with one another and were labor intensive.
Consequently, manual re-entries were inevitable and would generate numerous errors which ultimately had a negative impact on the efficiency and productivity of the company and resulted in confusion, guessing and frustration of workers on the shop floor. Some of the generated problems were shop report shortcomings, low information quality, and information insufficiency and inaccuracy. The information errors had been escalating as the company was moving more towards customized production in order to be more competitive in the marketplace.

The management realized that there was a need to automate and integrate the company’s mainstream business processes such as design, sales/order entry, engineering/manufacturing, production planning and scheduling, reporting, and purchasing. This could potentially reduce the cost of quality, claims and warranty, improve the company’s resource utilization (by reducing inventory, and reducing time and materials wasted in the office and production processes), increase its sales volume (by reducing opportunity loss and delays, and increasing speed and accuracy of order entry and quote generation), and improve its productivity, efficiency and competitive advantage. Therefore, this research project was designed to assess and rank potential software packages for the company.

In order to assess and select a suitable design and manufacturing software package for the company, first the production process, flow of information and materials in the office and plant, and software packages in use (their purpose, inputs, and outputs) were studied. The company was visited many times and several interviews with the company’s management team, staff and workers were conducted.
Next, characteristics of a suitable software package for the company were determined and software selection criteria were derived. As a result, various documents were prepared and submitted to the company such as the facility layout, general manufacturing flowcharts, detailed manufacturing flowcharts, process maps, current software packages' characteristics, future software needs, and design and manufacturing software selection criteria and sub-criteria (Figure 2.4).

It was then determined who were the main decision makers for IT investments in the company. A work group formed consisting of three top managers, who are referred to Manager 1, Manager 2, and Manager 3 here. Then, based on managers' recommendations, alternative software packages were shortlisted. They are referred to as software A, B, C, and D here for confidentiality purposes.
Figure 2.4. Cabinet design and manufacturing software selection model for a cabinet manufacturing company.
Some of the criteria were derived from the software selection literature such as functionality, usability, security, reliability, support, cost, service, reputation, ease of integration, ease of implementation, technical capability, and flexibility (Ossadnik and Lange, 1999; Sarkis and Talluri, 2004; Wei et al. 2005; Braglia et al., 2006; Ayağ and Özdemir, 2007). The rest of the criteria were derived from the researcher's investigations based on software brochures, software vendor interviews, and finally viewpoints of the managers, staff, and workers. Appendix A presents the detailed explanation on the criteria and their sub-criteria.

Then, a questionnaire was developed based on the aforementioned selection criteria and was sent to a list of four cabinet design and manufacturing software vendors (Appendix B). Responses to the questionnaire were gathered and analyzed. After careful and timely follow-ups, a response rate of 100% was achieved. Each question targeted a certain aspect of each software package and the format of the answers was clear. The questionnaire was well designed so that it was easy to follow the questions. Check boxes and units of the answers were put to facilitate the process. Software vendors could check the boxes, give “yes/no” answers, put values, or provide detailed answers to the questions.

Next, alternatives were scored and compared against one another with respect to sub-criteria using information gathered from the questionnaire, phone call interviews with software vendors, experts who used the software packages, and vendors' web sites or brochures.
Then, another questionnaire was prepared for each decision maker to do two types of pairwise comparisons: (1) to compare the selection criteria to one another with respect to the goal, and (2) to compare the selection sub-criteria to one another with respect to the higher level criterion. The importance of the selection criteria and suitability of available software packages were assessed using AHP based on the viewpoints of each decision maker. The AHP analysis was done using the Expert Choice (2007) computer program.

2.4 Analysis and Results

For illustration purpose, the comparison of alternatives with respect to acquisition cost is shown here. The pairwise comparison matrix of alternatives with respect to acquisition cost \( A \) is formed using Equation 2.1 based on the viewpoints of Manager 1 and is shown in Table 2.2. Table 2.3 shows the normalized matrix \( A' \) which is calculated using Equation 2.2. The relative weights/preference \( W \) of alternatives with respect to acquisition cost is determined using Equation 2.3 and is shown in Table 2.4.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Software A</th>
<th>Software B</th>
<th>Software C</th>
<th>Software D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>1</td>
<td>1/7</td>
<td>1/9</td>
<td>1/7</td>
</tr>
<tr>
<td>Software B</td>
<td>7</td>
<td>1</td>
<td>1/3</td>
<td>1</td>
</tr>
<tr>
<td>Software C</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Software D</td>
<td>7</td>
<td>1</td>
<td>1/3</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2.3. Normalized matrix for alternatives based on acquisition cost

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Software A</th>
<th>Software B</th>
<th>Software C</th>
<th>Software D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>0.042</td>
<td>0.028</td>
<td>0.063</td>
<td>0.028</td>
</tr>
<tr>
<td>Software B</td>
<td>0.292</td>
<td>0.194</td>
<td>0.188</td>
<td>0.194</td>
</tr>
<tr>
<td>Software C</td>
<td>0.375</td>
<td>0.583</td>
<td>0.563</td>
<td>0.583</td>
</tr>
<tr>
<td>Software D</td>
<td>0.292</td>
<td>0.194</td>
<td>0.188</td>
<td>0.194</td>
</tr>
</tbody>
</table>
Table 2.4. Relative preference of alternatives based on acquisition cost

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Software A</th>
<th>Software B</th>
<th>Software C</th>
<th>Software D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative preference</td>
<td>0.040</td>
<td>0.217</td>
<td>0.526</td>
<td>0.217</td>
</tr>
</tbody>
</table>

In a similar way, the pairwise comparisons of cost’s sub-criteria with respect to cost criterion were performed. Tables 2.5 shows the pairwise comparison matrix of cost’s sub-criteria with respect to cost criterion \( A \) using Equation 2.1 based on the viewpoints of Manager 1. The normalized matrix \( A' \) is determined using Equation 2.2 and is shown in Table 2.6. The relative weights \( W \) of cost’s sub-criteria with respect to cost criterion is calculated using Equation 2.3 and is presented in Table 2.7.

Table 2.5. Pairwise comparison matrix for cost’s sub-criteria based on cost criterion

<table>
<thead>
<tr>
<th>Cost</th>
<th>Acquisition</th>
<th>Hardware</th>
<th>License</th>
<th>Maintenance</th>
<th>Extra</th>
<th>Service</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Hardware</td>
<td>1/8</td>
<td>1</td>
<td>1</td>
<td>1/2</td>
<td>1/4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>License</td>
<td>1/8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1/5</td>
<td>1/2</td>
<td>6</td>
</tr>
<tr>
<td>Maintenance</td>
<td>1/5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1/5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Extra</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Service</td>
<td>1/5</td>
<td>1</td>
<td>2</td>
<td>1/2</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Upgrade</td>
<td>1/8</td>
<td>1/3</td>
<td>1/6</td>
<td>1/3</td>
<td>1/8</td>
<td>1/4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2.6. Normalized matrix for cost’s sub-criteria based on cost criterion

<table>
<thead>
<tr>
<th>Cost</th>
<th>Acquisition</th>
<th>Hardware</th>
<th>License</th>
<th>Maintenance</th>
<th>Extra</th>
<th>Service</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition</td>
<td>0.360</td>
<td>0.462</td>
<td>0.440</td>
<td>0.384</td>
<td>0.265</td>
<td>0.465</td>
<td>0.242</td>
</tr>
<tr>
<td>Hardware</td>
<td>0.045</td>
<td>0.058</td>
<td>0.055</td>
<td>0.038</td>
<td>0.066</td>
<td>0.093</td>
<td>0.091</td>
</tr>
<tr>
<td>License</td>
<td>0.045</td>
<td>0.058</td>
<td>0.055</td>
<td>0.077</td>
<td>0.053</td>
<td>0.047</td>
<td>0.182</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.072</td>
<td>0.115</td>
<td>0.055</td>
<td>0.077</td>
<td>0.053</td>
<td>0.186</td>
<td>0.091</td>
</tr>
<tr>
<td>Extra</td>
<td>0.360</td>
<td>0.231</td>
<td>0.275</td>
<td>0.384</td>
<td>0.265</td>
<td>0.093</td>
<td>0.242</td>
</tr>
<tr>
<td>Service</td>
<td>0.072</td>
<td>0.058</td>
<td>0.110</td>
<td>0.015</td>
<td>0.265</td>
<td>0.093</td>
<td>0.121</td>
</tr>
<tr>
<td>Upgrade</td>
<td>0.045</td>
<td>0.019</td>
<td>0.009</td>
<td>0.026</td>
<td>0.033</td>
<td>0.023</td>
<td>0.030</td>
</tr>
</tbody>
</table>

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Table 2.7. Relative weights of cost's sub-criteria based on cost criterion

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Acquisition</th>
<th>Hardware</th>
<th>License</th>
<th>Maintenance</th>
<th>Extra</th>
<th>Service</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative weights</td>
<td>0.374</td>
<td>0.064</td>
<td>0.074</td>
<td>0.093</td>
<td>0.264</td>
<td>0.105</td>
<td>0.027</td>
</tr>
</tbody>
</table>

The last pairwise comparison sets were the comparisons of all criteria based on the goal using Manager 1's viewpoints (Table 2.8). Table 2.9 shows the normalized matrix and Table 2.10 is the eigenvector matrix.

Table 2.8. Pairwise comparison matrix for criteria based on goal

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Time</th>
<th>Cost</th>
<th>User friendliness</th>
<th>Reliability</th>
<th>Compatibility</th>
<th>Service</th>
<th>Technical capability</th>
<th>Flexibility</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>1</td>
<td>1/5</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>User friendliness</td>
<td>1/3</td>
<td>1/4</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Reliability</td>
<td>1/8</td>
<td>1/8</td>
<td>1/4</td>
<td>1</td>
<td>1/7</td>
<td>1</td>
<td>1</td>
<td>1/4</td>
<td>1</td>
</tr>
<tr>
<td>Compatibility</td>
<td>1/2</td>
<td>1/4</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Service</td>
<td>1/5</td>
<td>1/6</td>
<td>1/6</td>
<td>1</td>
<td>1/6</td>
<td>1</td>
<td>1/2</td>
<td>1/2</td>
<td>1</td>
</tr>
<tr>
<td>Technical capability</td>
<td>1/5</td>
<td>1/8</td>
<td>1/6</td>
<td>1</td>
<td>1/6</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Flexibility</td>
<td>1/5</td>
<td>1/3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1/2</td>
</tr>
<tr>
<td>Other</td>
<td>1/3</td>
<td>1/4</td>
<td>1/4</td>
<td>1</td>
<td>1/2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 2.9. Normalized matrix for decision criteria based on the goal

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Time</th>
<th>Cost</th>
<th>User friendliness</th>
<th>Reliability</th>
<th>Compatibility</th>
<th>Service</th>
<th>Technical capability</th>
<th>Flexibility</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>0.127</td>
<td>0.074</td>
<td>0.277</td>
<td>0.229</td>
<td>0.200</td>
<td>0.167</td>
<td>0.169</td>
<td>0.339</td>
<td>0.171</td>
</tr>
<tr>
<td>Cost</td>
<td>0.634</td>
<td>0.370</td>
<td>0.369</td>
<td>0.229</td>
<td>0.401</td>
<td>0.200</td>
<td>0.271</td>
<td>0.203</td>
<td>0.229</td>
</tr>
<tr>
<td>User friendliness</td>
<td>0.042</td>
<td>0.093</td>
<td>0.092</td>
<td>0.114</td>
<td>0.100</td>
<td>0.200</td>
<td>0.203</td>
<td>0.068</td>
<td>0.229</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.016</td>
<td>0.046</td>
<td>0.023</td>
<td>0.029</td>
<td>0.014</td>
<td>0.033</td>
<td>0.034</td>
<td>0.017</td>
<td>0.057</td>
</tr>
<tr>
<td>Compatibility</td>
<td>0.063</td>
<td>0.093</td>
<td>0.092</td>
<td>0.200</td>
<td>0.100</td>
<td>0.200</td>
<td>0.203</td>
<td>0.068</td>
<td>0.114</td>
</tr>
<tr>
<td>Service</td>
<td>0.025</td>
<td>0.062</td>
<td>0.015</td>
<td>0.029</td>
<td>0.017</td>
<td>0.033</td>
<td>0.017</td>
<td>0.034</td>
<td>0.057</td>
</tr>
<tr>
<td>Technical capability</td>
<td>0.025</td>
<td>0.046</td>
<td>0.015</td>
<td>0.029</td>
<td>0.017</td>
<td>0.067</td>
<td>0.034</td>
<td>0.068</td>
<td>0.057</td>
</tr>
<tr>
<td>Flexibility</td>
<td>0.025</td>
<td>0.123</td>
<td>0.092</td>
<td>0.114</td>
<td>0.100</td>
<td>0.067</td>
<td>0.034</td>
<td>0.068</td>
<td>0.029</td>
</tr>
<tr>
<td>Other</td>
<td>0.042</td>
<td>0.093</td>
<td>0.023</td>
<td>0.029</td>
<td>0.050</td>
<td>0.033</td>
<td>0.034</td>
<td>0.136</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Table 2.10. Relative importance of criteria based on the goal

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Time</th>
<th>Cost</th>
<th>User friendliness</th>
<th>Reliability</th>
<th>Compatibility</th>
<th>Service</th>
<th>Technical capability</th>
<th>Flexibility</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative weights</td>
<td>0.195</td>
<td>0.323</td>
<td>0.127</td>
<td>0.030</td>
<td>0.126</td>
<td>0.032</td>
<td>0.040</td>
<td>0.073</td>
<td>0.055</td>
</tr>
</tbody>
</table>

With a similar approach, the importance of all the decision criteria for each manager was determined and presented in Figure 2.5.
As shown in Figure 2.5, for Manager 1 and Manager 2, cost of software was the most important criteria, while Manager 2 was mainly concerned with the user friendliness of the new software.

Once the relative weights were calculated, the composite weight for each specific software package was determined by aggregating the relative weights over paths from the goal to that alternative. The composite weights for the alternatives were calculated for each manager and are presented in Table 2.11.

Table 2.11. Priorities of software alternatives for different decision makers

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Manager 1</th>
<th>Manager 2</th>
<th>Manager 3</th>
<th>Weighted geometric mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>0.206 (3)</td>
<td>0.327 (1)</td>
<td>0.179 (4)</td>
<td>0.232 (3)</td>
</tr>
<tr>
<td>Software B</td>
<td>0.193 (4)</td>
<td>0.188 (4)</td>
<td>0.204 (3)</td>
<td>0.198 (4)</td>
</tr>
<tr>
<td>Software C</td>
<td>0.247 (2)</td>
<td>0.191 (3)</td>
<td>0.281 (2)</td>
<td>0.240 (2)</td>
</tr>
<tr>
<td>Software D</td>
<td>0.354 (1)</td>
<td>0.294 (2)</td>
<td>0.336 (1)</td>
<td>0.330 (1)</td>
</tr>
</tbody>
</table>

Note: The numbers in brackets show the ranking of the software packages.
The final results show that Software D is ranked first by Manager 1 and Manager 3, whereas Manager 2’s first ranked alternative is Software A.

The aggregated priorities for each software package assuming that all decision makers had equal influence in decision making is calculated using Equation 2.9 (Table 2.11). Based on the aggregated priorities, Software D is the most suitable design and manufacturing software package for the company.

2.4.1 Consistency Ratio

It should be noted that throughout the analysis, the consistency ratios were calculated, analyzed, and kept within the acceptable range of 10%. This required re-examinations of judgments often times and required communication between company’s managers and the researchers for consensus.

For illustration purpose, the inconsistency ratio of the judgments made by Manager 1 to compare the decision criteria with respect to the goal (Table 2.8) is explained. Equation 2.7 was used to calculate the principal eigenvalue of the pairwise comparison matrix of the decision criteria as follows:

<table>
<thead>
<tr>
<th></th>
<th>1-λ</th>
<th>1/5</th>
<th>3</th>
<th>8</th>
<th>2</th>
<th>5</th>
<th>5</th>
<th>5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1-λ</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1/3</td>
<td>1/4</td>
<td>1-λ</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>1/8</td>
<td>1/4</td>
<td>1-λ</td>
<td>1/7</td>
<td>1</td>
<td>1</td>
<td>1/4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1/2</td>
<td>1/4</td>
<td>1</td>
<td>7</td>
<td>1-λ</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1/5</td>
<td>1/6</td>
<td>1/6</td>
<td>1</td>
<td>1/6</td>
<td>1-λ</td>
<td>1/2</td>
<td>1/2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1/5</td>
<td>1/8</td>
<td>1/6</td>
<td>1</td>
<td>1/6</td>
<td>2</td>
<td>1-λ</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1/5</td>
<td>1/3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1-λ</td>
<td>1/2</td>
<td></td>
</tr>
<tr>
<td>1/3</td>
<td>1/4</td>
<td>1/4</td>
<td>1</td>
<td>1/2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1-λ</td>
<td></td>
</tr>
</tbody>
</table>

\[ \det = 0 \]
Solving for $\lambda$ using MS Excel 2003 Solver, $\lambda_{\text{max}} = 10.1379$. Consistency index was calculated using the Equation 2.5 as follows:

$$CI = \frac{10.1379 - 9}{9 - 1} = 0.1422$$

From Table 2.1, random index for a matrix size of 9 equals to 1.45. Ultimately, the consistency ratio was calculated using Equation 2.8 as follows:

$$CR = \frac{0.1422}{1.45} = 0.0981$$

Since $CR < 0.1$, it could be concluded that Manager 1 was consistent in comparing the decision criteria with respect to the goal.

2.4.2 Discussion

As shown earlier, the decision criteria were ranked differently given different managers' viewpoints. Also, the overall priorities of the alternatives were different for different managers. In this section, the rankings of Software A and Software D are discussed focusing on two criteria: cost (the most important criterion for Manager 1 and Manager 3), and user friendliness (the most important criterion for Manager 2).

For Manager 1 and Manager 3, cost was the most important criterion, while user friendliness was determined the third important criterion. Software D, which was not the cheapest software, was determined to be the most suitable software package based on these two managers’ points of view. This reflects the effect of inclusion of other criteria (such as user friendliness) on the outcome of the analysis.
On the other hand, for Manager 2, the cost criterion was not the most important criterion, but rather the user friendliness was the most important one. It was determined that Software A was the most suitable alternative for this manager. This software was the most expensive software available, but at the same time was very user friendly. The choice of this software was also justified as this software was compatible with the machinery and the other software packages in use, and its vendor offered high-level service where the compatibility and service criteria were important for this manager.

Since the most suitable software package varied for different managers, there was a need for aggregation of the results. The aggregated result suggested that Software D was the most suitable software package for the needs of the company based on the managers’ preferences.

2.5 Sensitivity Analysis

The outputs of multiple criteria decision making methods are dependent on their inputs. The inputs of many methods, such as analytic hierarchy process (AHP), are uncertain as those inputs are based on human judgment. Therefore, outputs of such methods should be analyzed carefully to determine how sensitive they are to the changes in the inputs (Wolters and Mareschal, 1995; Chen and Kocaoglu, 2008).

Sensitivity analysis is an approach that can be used in order to analyze the stability of the outputs of multiple criteria decision making models when the inputs change. (Chen and Kocaoglu, 2008). It can also determine the critical factors in a decision making problem by identifying the factors that a change in their weights would change the results of the decision model (Triantaphyllou and Sanchez, 1997).
Basically, the purpose of the sensitivity analysis or "what-if" analysis was to study how the overall decision (purchasing Software D) would change if the decision making variables changed. Three different sensitivity analyses were performed.

2.5.1 Change in the Influence of Decision Makers

The first type of the sensitivity analysis was done to study how the final decision would change if the influence of decision makers changed in the decision making process at the company. Four scenarios were studied as follows: (1) base case (decision makers had equal influence in the decision making process), (2) the highest weight was given to the owner and president of the company (i.e., Manager 1, 0.750, Manager 2, 0.125, and Manager 3, 0.125 which is the real case scenario), (3) the highest weight was given to Manager 3 (i.e., Manager 1, 0.25, Manager 2, 0.25, and Manager 3, 0.50), and (4) the highest weight was given to Manager 2 (i.e., Manager 1, 0.25, Manager 2, 0.50, and Manager 3, 0.25). The weighted geometric mean method (Equation 2.9) was used in order to derive the aggregate decision in each scenario. The results are summarized in Table 2.12.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>0.232 (3)</td>
<td>0.215 (3)</td>
<td>0.219 (3)</td>
</tr>
<tr>
<td>Software B</td>
<td>0.198 (4)</td>
<td>0.195 (4)</td>
<td>0.199 (4)</td>
</tr>
<tr>
<td>Software C</td>
<td>0.240 (2)</td>
<td>0.244 (2)</td>
<td>0.250 (2)</td>
</tr>
<tr>
<td>Software D</td>
<td>0.330 (1)</td>
<td>0.346 (1)</td>
<td>0.332 (1)</td>
</tr>
</tbody>
</table>

Note: The numbers in brackets show the ranking of the software packages.
The results show that the decision (purchasing Software D) would not change if the influence of the decision makers in the decision making process changed, so the decision was stable in this regards.

2.5.2 Change in the Importance of Criteria

The second type of the sensitivity analysis investigated the change in the final decision when the importance of criteria changed. It was determined that the decision (purchasing Software D) was stable for up to 20% change in the importance of the selection criteria for Manager 1 assuming he had the most influence in the decision making process in the company (Scenario 2). Also, 20% change in the importance of the selection criteria for Manager 2 and 10% change in the importance of the selection criteria for Managers 3 in our case would not affect the decision either.

2.5.3 Minimum Changes of Criteria Weights to Change the Existing Ranking

In the third type of the sensitivity analysis, the minimum sum of changes in the importance of the factors that would make the second ranked alternative the top alternative was determined for each manager. This study determines the critical factors for each manager. As Triantaphyllou and Sanchez (1997) suggest, a critical factor is not necessarily the factor with the highest weight, but it could be a factor that a change in its weight would change the top alternative or change the ranking of any alternative.

To conduct the third type of the “what-if” analysis, a mathematical modeling approach was adopted based on Wolters and Mareschal (1995). They determined the minimum changes in the weights of variables so that an alternative would be ranked first.
in the preference ranking organization method (PROMETHEE) and suggested that this method can be applied to any other additive multiple criteria decision making methods. In this study, a similar mathematical modeling approach is used to conduct this type of sensitivity analysis in AHP. A sensitivity model was developed for each manager. The absolute changes in the weights are considered in this section and minimized.

The sensitivity model is presented for Manager 1 in this section (the sensitivity models for Manager 2 and 3 were similarly developed and only the results are presented). To that end, Equation 2.4 for calculation of composite weights of alternatives is extended in Equation 2.10.

$$P_z = \sum_{n=1}^{N} \sum_{m=1}^{M_n} AW_z SC_{nm} \times SCW_{nm} \times CW_n \quad \text{for } z = 1, 2, ..., Z \tag{2.10}$$

where $N$ denotes the number of criteria, $M_n$ denotes the number of sub-criteria for the $n^{th}$ criterion, $Z$ denotes the number of alternatives, $P_z$ denotes the weight of alternative $z$, $AW_z SC_{nm}$ denotes the weight of alternative $z$ with respect to the $m^{th}$ sub-criterion of the $n^{th}$ criterion, $SCW_{nm}$ denotes the weight of the $m^{th}$ sub-criterion of the $n^{th}$ criterion, and $CW_n$ denotes the weight of the $n^{th}$ criterion with respect to the goal.

As shown in Table 2.12, for Manager 1, Software A is ranked third ($P_3=0.206$), Software B is ranked fourth ($P_2=0.193$), Software C is ranked second ($P_3=0.247$), and Software D is ranked first ($P_4=0.354$). Equations 2.11-2.17 represent the mathematical model for Manager 1 which determine the minimum sum of changes in criteria weights to make the second ranked alternative (alternative 3 or Software C) the top one.
Objective function:

\[
\min \sum_{n=1}^{N} |CW_n^* - CW_n|
\]

Minimize the sum of changes in the criteria weights \(2.11\)

Subject to:

\[P_3^* > P_1^*\]

The new weight of Software C should be greater than the new weight of Software A \(2.12\)

\[P_3^* > P_2^*\]

The new weight of Software C should be greater than the new weight of Software B \(2.13\)

\[P_3^* > P_4^*\]

The new weight of Software C should be greater than the new weight of Software D \(2.14\)

\[\sum_{n=1}^{N} CW_n^* = 1\]

The sum of new weights of the selection criteria should be equal to unity \(2.15\)

\[CW_n^* \leq 1\]

for \(\forall n = 1, 2, \ldots, N\)

The new weight of each selection criterion should be less than one \(2.16\)

\[CW_n^* \geq 0\]

for \(\forall n = 1, 2, \ldots, N\)

The new weight of each selection criterion should be greater than zero \(2.17\)

In Equations 2.11-2.17, \(P_z^*\) denotes the new weight of alternative \(z\), and \(CW_n^*\) denotes the new weight of the \(n^{th}\) criterion with respect to the goal.

Equation 2.11 minimizes the sum of absolute changes in the weights of the criteria. Equations 2.11-2.14 guarantee that the alternative 3 would be the top alternative with new weights assigned to the selection criteria. The unity of sum of the new criteria weights is guaranteed by Equation 2.15. Also, Equations 2.16-2.17 guarantee that the new criteria weights would be in the range of [0.1, 1.0].
Linear programming techniques cannot be applied to optimize Equation 2.11 as it contains absolute functions. Equation 2.18 is used to transform an absolute non-linear function to a linear one.

\[ CW_n^* = CW_n + d_n^+ - d_n^- \quad \forall n=1,2,\ldots,N \quad (2.18) \]

where \( d_n^+ \) denotes increase in the weight of \( n^{th} \) criteria, and \( d_n^- \) denotes decrease in the weight of \( n^{th} \) criteria. Therefore, the modified mathematical model for Manager 1 could be presented by Equations 2.19-2.28.
Objective function:

$$\min \sum_{n=1}^{N}(d_n^+ + d_n^-)$$

Minimize the sum of deviations of the new weights from the existing weights of criteria

(2.19)

Subject to:

$$\sum_{n=1}^{N} \sum_{m=1}^{M} A_{nm} S_{nm} \times S_{nm} \times \left( CW_n + d_n^+ - d_n^- \right) > \sum_{n=1}^{N} \sum_{m=1}^{M} A_{nm} S_{nm} \times S_{nm} \times \left( CW_n + d_n^+ - d_n^- \right)$$

The new weight of Software C should be greater than the new weight of Software A

(2.20)

$$\sum_{n=1}^{N} \sum_{m=1}^{M} A_{nm} S_{nm} \times S_{nm} \times \left( CW_n + d_n^+ - d_n^- \right) > \sum_{n=1}^{N} \sum_{m=1}^{M} A_{nm} S_{nm} \times S_{nm} \times \left( CW_n + d_n^+ - d_n^- \right)$$

The new weight of Software C should be greater than the new weight of Software B

(2.21)

$$\sum_{n=1}^{N} \sum_{m=1}^{M} A_{nm} S_{nm} \times S_{nm} \times \left( CW_n + d_n^+ - d_n^- \right) > \sum_{n=1}^{N} \sum_{m=1}^{M} A_{nm} S_{nm} \times S_{nm} \times \left( CW_n + d_n^+ - d_n^- \right)$$

The new weight of Software C should be greater than the new weight of Software D

(2.22)

$$\sum_{n=1}^{N} (CW_n + d_n^+ - d_n^-) = 1$$

The sum of new weights of the selection criteria should be equal to unity

(2.23)

$$CW_n + d_n^+ - d_n^- \leq 1$$

for \( \forall n=1,2,\ldots,N \)

The new weight of each selection criterion should be less than one

(2.24)

$$CW_n + d_n^+ - d_n^- \geq 0$$

for \( \forall n=1,2,\ldots,N \)

The new weight of each selection criterion should be greater than zero

(2.25)

$$\sum_{n=1}^{N} (d_n^+ - d_n^-) = 0$$

for \( \forall n=1,2,\ldots,N \)

The increase in the weight of one criterion should be mitigated by the decrease in the weight of another criterion

(2.26)

$$d_n^+ \geq 0$$

for \( \forall n=1,2,\ldots,N \)

The increase factors in the weights of criteria should be non-negative

(2.27)

$$d_n^- \geq 0$$

for \( \forall n=1,2,\ldots,N \)

The decrease factors in the weights of criteria should be non-negative

(2.28)
Table 2.13 summarizes some of the inputs to the mathematical model for the case study discussed in this research.

<table>
<thead>
<tr>
<th>Description</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of criteria</td>
<td>( N )</td>
<td>9</td>
</tr>
<tr>
<td>Number of sub-criteria for the 1st criterion</td>
<td>( M_1 )</td>
<td>3</td>
</tr>
<tr>
<td>Number of sub-criteria for the 2nd criterion</td>
<td>( M_2 )</td>
<td>7</td>
</tr>
<tr>
<td>Number of sub-criteria for the 3rd criterion</td>
<td>( M_3 )</td>
<td>5</td>
</tr>
<tr>
<td>Number of sub-criteria for the 4th criterion</td>
<td>( M_4 )</td>
<td>3</td>
</tr>
<tr>
<td>Number of sub-criteria for the 5th criterion</td>
<td>( M_5 )</td>
<td>1</td>
</tr>
<tr>
<td>Number of sub-criteria for the 6th criterion</td>
<td>( M_6 )</td>
<td>6</td>
</tr>
<tr>
<td>Number of sub-criteria for the 7th criterion</td>
<td>( M_7 )</td>
<td>3</td>
</tr>
<tr>
<td>Number of sub-criteria for the 8th criterion</td>
<td>( M_8 )</td>
<td>3</td>
</tr>
<tr>
<td>Number of sub-criteria for the 9th criterion</td>
<td>( M_9 )</td>
<td>6</td>
</tr>
<tr>
<td>Number of alternatives</td>
<td>( Z )</td>
<td>4</td>
</tr>
</tbody>
</table>

Lingo 8.0 was used to solve the linear programming model. The results are summarized in Table 2.14 for all the managers. Note that for Manager 2, Equations 2.20-2.22 were modified as the alternative 4 was the second ranked alternative for this manager. Therefore, the new weight of alternative four was considered greater than the new weights of other alternatives as the constraints.

The percentage change in the weight of each criterion (\( \Delta CW \)) which was required to make the second ranked alternative the top one was calculated using Equation 2.29 and is summarized in Table 2.14.

\[
\Delta CW = \frac{d^+}{CW_n} + \frac{d^-}{CW_n} \times 100 \quad \text{for } \forall n=1,2,\ldots,N
\]  
(2.29)
Table 2.14. Sensitivity analysis on the changes in weights to make an alternative top

<table>
<thead>
<tr>
<th></th>
<th>Manager 1</th>
<th>ΔCW</th>
<th>Manager 2</th>
<th>ΔCW</th>
<th>Manager 3</th>
<th>ΔCW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original criteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weights</td>
<td>Time</td>
<td>0.195</td>
<td>-39%</td>
<td>0.078</td>
<td>0%</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>Cost</td>
<td>0.323</td>
<td>+85%</td>
<td>0.152</td>
<td>+153%</td>
<td>0.300</td>
</tr>
<tr>
<td></td>
<td>User friendliness</td>
<td>0.127</td>
<td>0%</td>
<td>0.185</td>
<td>0%</td>
<td>0.158</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>0.030</td>
<td>0%</td>
<td>0.084</td>
<td>0%</td>
<td>0.228</td>
</tr>
<tr>
<td></td>
<td>Compatibility</td>
<td>0.126</td>
<td>0%</td>
<td>0.160</td>
<td>0%</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>Service</td>
<td>0.032</td>
<td>-100%</td>
<td>0.147</td>
<td>-26%</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Technical capability</td>
<td>0.040</td>
<td>-100%</td>
<td>0.085</td>
<td>-100%</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>Flexibility</td>
<td>0.072</td>
<td>-100%</td>
<td>0.050</td>
<td>-100%</td>
<td>0.069</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0.055</td>
<td>-100%</td>
<td>0.059</td>
<td>-100%</td>
<td>0.027</td>
</tr>
<tr>
<td>Original alternative</td>
<td>Software A</td>
<td>0.206</td>
<td></td>
<td>0.327</td>
<td></td>
<td>0.179</td>
</tr>
<tr>
<td></td>
<td>Software B</td>
<td>0.193</td>
<td></td>
<td>0.188</td>
<td></td>
<td>0.204</td>
</tr>
<tr>
<td></td>
<td>Software C</td>
<td>0.247</td>
<td></td>
<td>0.191</td>
<td></td>
<td>0.281</td>
</tr>
<tr>
<td></td>
<td>Software D</td>
<td>0.354</td>
<td></td>
<td>0.294</td>
<td></td>
<td>0.336</td>
</tr>
<tr>
<td>Solution (d′)</td>
<td>d₁⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₂⁺</td>
<td>0.275</td>
<td>0.232</td>
<td>0.100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₃⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₄⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₅⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₆⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₇⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₈⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₉⁺</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solution (d&quot;)</td>
<td>d₁⁻</td>
<td>0.076</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₂⁻</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₃⁻</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₄⁻</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₅⁻</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₆⁻</td>
<td>0.032</td>
<td>0.038</td>
<td>0.000</td>
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</tr>
<tr>
<td></td>
<td>d₇⁻</td>
<td>0.040</td>
<td>0.085</td>
<td>0.031</td>
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</tr>
<tr>
<td></td>
<td>d₈⁻</td>
<td>0.072</td>
<td>0.050</td>
<td>0.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d₉⁻</td>
<td>0.055</td>
<td>0.059</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New criteria</td>
<td>Time</td>
<td>0.119</td>
<td>0.078</td>
<td>0.032</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost</td>
<td>0.598</td>
<td>0.384</td>
<td>0.400</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>User friendliness</td>
<td>0.127</td>
<td>0.185</td>
<td>0.158</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>0.030</td>
<td>0.084</td>
<td>0.228</td>
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<td></td>
<td>Compatibility</td>
<td>0.126</td>
<td>0.160</td>
<td>0.047</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Service</td>
<td>0.000</td>
<td>0.109</td>
<td>0.034</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical capability</td>
<td>0.000</td>
<td>0.000</td>
<td>0.074</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flexibility</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0.000</td>
<td>0.000</td>
<td>0.027</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New alternative</td>
<td>Software A</td>
<td>0.152</td>
<td>0.266</td>
<td>0.170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>weights</td>
<td>Software B</td>
<td>0.219</td>
<td>0.197</td>
<td>0.205</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Software C</td>
<td>0.315</td>
<td>0.268</td>
<td>0.313</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Software D</td>
<td>0.314</td>
<td>0.269</td>
<td>0.312</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The results show that if the weight of “cost” increased by 85% (i.e., “cost” was very more important than what it is), and at the same time the weights of “time”, “service”, “technical capability”, “flexibility”, and “other” criteria decreased by 39%, 100%, 100%, 100%, and 100%, respectively (i.e., these factors were less important than what they are or not at all important), then Software C would be the best choice based on the viewpoints of Manager 1. The fact that Software C is the cheapest alternative which offers not as high quality features as the other software packages verifies the results of the model. The results suggest that in case “cost“ was the most important criterion, and other features were not important in the decision making process, then an alternative with the lowest cost could be ranked top.

For Manager 2, the results suggest that in case the weight of “cost” increased by 153%, and at the same time the weights of “service”, “technical capability”, “flexibility”, and “other” criteria decreased by 26%, 100%, 100%, and 100%, respectively, then Software D would be the top ranked alternative. Moreover, the results show that if the weight of “cost” increased by 33%, and at the same time the weights of “technical capability” and “flexibility” criteria decreased by 30%, 100%, then Software C would be the best choice of Manager 3. Since such substantial changes in the weights of the criteria seem unlikely, the decision of investing in Software D seems to be stable.

2.6 Conclusion and Future Work

This study presented a real case of software selection in the wood industry in which for the first time to the best of our knowledge a systematic evaluation approach was used. Several tangible and intangible criteria were considered in the assessment. A
group decision setting was adapted where views of different decision makers were included. These views were then aggregated to derive the final decision. A sensitivity analysis was also performed to study how the changes in the influence of the decision makers and importance of the criteria would affect the final decision. Also, it was studied under what circumstances a specific alternative would rank first and how possibly those information could be used for the good of the company. The recommended software package was acquired by the company and has been integrated into their system.

This study also presented a list of design and manufacturing software selection criteria for the use of manufacturing companies. Generally, knowing the criteria for software evaluation is important as often times it is challenging for decision makers in companies to come up with the comprehensive list of “right questions to ask” when investing in IT and in particular in design and manufacturing software package.

Great deal of effort was put to get the required data from the staff, workers, and managers of the company. Moreover, as there were many criteria and sub-criteria in the case study, specific attention was made to make sure the inconsistency ratios were within the acceptable level. To that end, the lists of the top ten most inconsistent judgments of the managers were derived using the Expert Choice (2007) computer program and were presented to the managers. These lists were discussed in the group and the proper changes were made in pairwise comparisons to eliminate inconsistencies.

For the future work, the interdependencies among the selection criteria could be considered and analyzed. There may be dependencies among selection criteria/sub-criteria in the decision making problem. For instance, skills to learn the software could
affect the time required to learn the software (inner-dependency). Also, compatibility could affect the installation time and ease of integration for example (outer-dependency). This problem can be tackled using the ANP method.
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Information and Management, 12(3):117-129.


Chapter 3. Evaluation and Selection of a Design and Manufacturing Software Package Considering the Interdependencies between Criteria*

3.1 Introduction

Based on North American Industry Classification System, "Furniture and related product manufacturing" is a subsector of the manufacturing industry. "Household and institutional furniture and kitchen cabinet manufacturing" is a subsector of the furniture and related product manufacturing industry. The companies in this industry produce furniture (for the use of households, institutions, and public buildings) and wood kitchen cabinets, bathroom vanities, and counters (Industry Canada, 2006a; Statistics Canada, 2006). The GDP generated by this subsector increased from $1.8 billion in 1997 to $3.3 billion in 2004, a compounded annual growth rate of 9.3% (Industry Canada, 2006b).

Similar to the manufacturing industry in general, household and institutional furniture and kitchen cabinet manufacturing industry is also affected by the increasing global competition. While the manufacturing costs (including materials and supplies, production wages, and fuel and electricity) have been increasing in Canada since 1994 (Industry Canada, 2006c), the price of the products manufactured in this industry by the international competition has been decreasing. Just like manufacturing industry, household and institutional furniture and kitchen cabinet manufacturing industry has been

* A version of this chapter was submitted for publication. Assadi, P., Sowlati, T., Paradi, J. (2008), Multiple criteria evaluation of design and manufacturing software packages considering the interdependencies between criteria, International Journal of Information and Decision Sciences.
forced to change its focus to produce high-value high-quality custom-made products. Therefore, investments in advanced technology and suitable design and manufacturing software have increased.

Suitable software packages help companies generate customized designs and assist them integrate their processes. In general, such software packages generate quotes, drawings, bill of materials, production schedules, purchase orders, and shop paper-works. Since uninformed investment decisions could be costly, companies need to evaluate their investment options using proper methods.

In the previous chapter, a systematic procedure was used to assess and select a design and manufacturing software package at a cabinet manufacturing company in Canada. The objective of this study is to investigate the interdependencies among the criteria and to determine their effects on the results of the decision making process. Examples of interdependencies in our case include the effect of available service on the acquisition cost of the software and the impact of compatibility on installation and integration time. The effect of such interdependencies among the decision criteria on the final decision is investigated using the ANP method. To the best of our knowledge, this is the first study to consider such interdependencies in a systematic framework to evaluate IT investment options in the furniture and kitchen cabinet manufacturing industry.

3.2 Literature review

One of the major shortcomings of the AHP method (Saaty, 1980) is that it does not recognize the interdependencies among the selection criteria (Roper-Lowe and Sharp, 1990). Unlike the AHP method, interdependencies among the selection criteria can be
considered using a feedback mechanism in the ANP method to evaluate and prioritize different alternatives (Saaty, 1996). This allows ANP to deal with more complex problems than AHP as in real-world problems, the evaluation criteria are interdependent (Erdogmus et al., 2005). ANP was also used for evaluation of IT investments.

Sarkis and Sundarraj (2003) introduced a decision model based on a combination of ANP and AHP for evaluation of information sharing platforms within an organization considering various decision clusters and identified the interdependencies among the clusters. They further indicated that that the decision model for evaluation of the enterprise IT should be tailored to the organization under investigation. To select the most suitable software for product development process of a product, the ANP method was also applied including several clusters and interdependencies among them (Mulebeke and Zheng, 2006). It was pointed out that there could be other factors added to the analysis and it was found that the ANP method was a reliable approach for systematic evaluation of software packages.

Kengpol and Tuominen (2006) used the ANP method as part of a framework for evaluation of IT systems in the logistics companies. They included clusters such as technical cluster, marketing cluster, and alternatives cluster in the analysis and analyzed the inner- and outer-dependences among the decision elements. Ayag and Ozdemir (2007) proposed a fuzzy ANP approach for selection of enterprise resource planning software. Competitive advantage, productivity, and profitability factors were included and the interdependencies among the elements in the decision network were identified and incorporated in the analysis.
A combined ANP and zero-one goal programming was presented by Lee and Kim (2000) in order to address the selection of interdependent information system (IS) projects based on Schniederjans and Wilson (1991) case considering efficiency, accuracy, organizational learning, and cost criteria. They considered limitations such as programmer hours, analyst hours, clerical labor hours, and budgeted costs in the analysis. The interdependencies among selection criteria and alternatives were also addressed in their analysis.

It is important to identify and incorporate interdependencies among the selection criteria in the analysis as careful consideration of such interrelationships would provide greater cost savings and benefits to the organizations, while not considering such relationships would result in a poor resource allocation in an organization (Lee and Kim, 2000).

3.3 The Analytic Network Process Method

Unlike the AHP method in which the decision problem is structured into a hierarchy of criteria and sub-criteria, in the ANP method the overall decision problem is decomposed into a network of clusters and elements within each cluster as presented in Figure 3.1 (Saaty, 1996). Alternatives are grouped into a cluster as well.
Figure 3.1. Example of an ANP network

Interdependencies among the clusters are shown in the network using arrows are used to show the interdependencies. Basically, when at least one element in cluster \( X \) affects one element in cluster \( Y \), then there would be an arrow from cluster \( X \) to cluster \( Y \). There are two types of interdependencies in ANP: (1) outer-dependency, and (2) inner-dependency. Outer-dependency exist when at least one element in a cluster affects (or affected by) one element in another cluster. The outer-dependency is shown by an arrow from the affecting cluster (or source cluster) to the affected cluster (or sink cluster). Inner-dependency exist when at least one element in a cluster affects (or affected by) another element in the same cluster. The inner-dependency is shown by an arrow from the cluster to itself (Saaty, 1996). For example, in Figure 3.1, there is an outer-dependency between Cluster 1 and Cluster 2, and there is an inner-dependency between at least two elements within Cluster 1.
The decision clusters and also the decision elements are then compared to one another in pairs with respect to a control criterion to derive the degrees of influence and interdependencies in the network. A control criterion is a common property with respect to which the relative influence of one factor over the other one is determined (Saaty, 1996).

The comparisons are done as follows: when two or more elements are being influenced by a specific element in the network, those elements will be compared to one another to see which one is more influenced by that specific element and how much more. This is the basic concept behind the pairwise comparisons in ANP.

Generally, three types of questions could be asked in ANP as stated by Saaty (1996): (1) considering a particular element, which one of the two elements connected to that particular element has been influenced greater and how much more?, (2) considering a particular alternative, which one of the two elements connected to that particular alternative is more dominant in that alternative and how much more?, and (3) considering a particular control criterion and considering a specific element in any of the clusters, which one of the two elements (either in the same cluster or in different clusters) has greater influence on that specific element with respect to that particular criterion and how much more?

For each set of judgments, the weights and the consistency ratios can be determined similar to what was done in the previous chapter. Then, the following four steps are taken:
(1) In the first step, the un-weighted supermatix $W_U$ is formed (Equation 3.1).

Each block of this supermatrix represents the elements' weights derived from pairwise comparisons of those elements.

$$W_U = \begin{bmatrix}
  C_1 & C_2 & \ldots & C_N \\
  \begin{bmatrix}
    e_{11} & e_{12} & \ldots & e_{1n_1} \\
    e_{21} & e_{22} & \ldots & e_{2n_2} \\
    \vdots & \vdots & \ddots & \vdots \\
    e_{n_11} & e_{n_12} & \ldots & e_{n_1n_N} \\
  \end{bmatrix} & \\
  \begin{bmatrix}
    W_{11} & W_{12} & \ldots & W_{1N} \\
    W_{21} & W_{22} & \ldots & W_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    W_{N1} & W_{N2} & \ldots & W_{NN} \\
  \end{bmatrix}
\end{bmatrix}
$$

(3.1)

In this supermatrix, $C_k$ denotes the $k^{th}$ cluster for $1 \leq k \leq n$, $e_{km}$ denotes the $m^{th}$ element in the $k^{th}$ cluster, and $W_{ij}$ denotes a block matrix or weight vectors $w$ of the influence of the elements in the $i^{th}$ cluster over the elements in the $j^{th}$ cluster for $1 \leq i, j \leq n$. $W_{ij}$ denotes the outer-dependency between the clusters (or basically between the elements in different clusters) for $i \neq j$ and denotes inner-dependency within a cluster (or basically among elements within a cluster) for $i = j$. $W_{ii}$ is assigned zero when the $i^{th}$ cluster does not influence itself (i.e., there is no inner-dependency among the elements in that cluster). This supermatrix is also called the initial supermatrix as the
elements (weights) in it are the results of the pairwise comparisons conducted (Saaty, 1996).

(2) In the second step, the cluster supermatrix $W_c$ is generated from pairwise comparisons of clusters (Equation 3.2). With this, the priority weight of each block with respect to the control criterion is determined. The priority weight of a block or a cluster is basically the eigenvector which is calculated from the pairwise comparisons of the clusters with respect to the control criterion.

$$W_c = \begin{pmatrix}
C_1 & C_2 & \ldots & C_N \\
C_1 & w_{11}^* & w_{12}^* & \ldots & w_{1N}^* \\
C_2 & w_{21}^* & w_{22}^* & \ldots & w_{2N}^* \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
C_N & w_{N1}^* & w_{N2}^* & \ldots & w_{NN}^*
\end{pmatrix}
$$

(3.2)

In this supermatrix, $C_k$ denotes the $k^{th}$ cluster for $1 \leq k \leq n$, and $w_{ij}^*$ denotes the influence of the $i^{th}$ cluster over the $j^{th}$ cluster for $1 \leq i, j \leq n$. $w_{ij}^*$ denotes the outer-dependency between the clusters for $i \neq j$ and denotes inner-dependency within a cluster for $i = j$. $w_{ii}^*$ is assigned zero when the $i^{th}$ cluster does not influence itself (Saaty, 1996).

(3) In the third step, the un-weighted supermatrix is transformed to a weighted supermatrix $W_w$ (Equation 3.3). To that end, the elements in each block of the un-
weighted supermatrix are multiplied by the priority weight of that block with respect to
the control criterion, which was determined in the second step. The sum of elements in
each column of the weighted supermatrix equals to unity (Saaty, 1996).

\[
\begin{bmatrix}
C_1 & C_2 & \cdots & C_N \\
e_{11} & e_{12} & \cdots & e_{1n} \\
\vdots & \vdots & \ddots & \vdots \\
e_{in} & e_{2n} & \cdots & e_{nn}
\end{bmatrix}
\]

\[
W_w = \begin{bmatrix}
W_{11} & W_{12} & \cdots & W_{1N} \\
W_{21} & W_{22} & \cdots & W_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
W_{n1} & W_{n2} & \cdots & W_{nn}
\end{bmatrix}
\]

(3.3)

In this supermatrix, \(C_k\) denotes the \(k\)th cluster for \(1 \leq k \leq n\) and \(e_{km}\) denotes the
\(m\)th element in the \(k\)th cluster. \(W_{ij}^*\) is determined by Equation 3.4 and denotes a block
matrix of the influence of the elements in the \(i\)th cluster over the elements in \(j\)th cluster
for \(1 \leq i, j \leq n\).

\[
W_{ij}^* = w_{ij}^* \times W_y \quad \forall i,j = 1,2,\ldots,N
\]

(3.4)

\(W_{ij}^*\) denotes the outer-dependency between the clusters for \(i \neq j\) and denotes
inner-dependency within a cluster for \(i = j\). It is assigned zero when the \(i\)th cluster does
not influence itself (Saaty, 1996).
(4) In the fourth step, the limit supermatrix is derived. This supermatrix provides the influence weight of each element on every other element in the network considering all the relationship. Columns of the limit supermatrix represent the priority vectors of all the elements in the network. These column vectors could then be normalized according to clusters in order to provide the overall priorities.

To obtain the limit supermatrix, weighted supermatrix is raised to large powers using Equation 3.5 until it converges to a limit (Saaty, 1996).

\[
\lim_{k \to \infty} (W^k) \quad (3.5)
\]

In case the supermatrix is not converging to a limit when raised to large powers, then there would be \( N \) supermatrices. To calculate the priority weights, the Cesaro sum of those supermatrices is obtained using Equation 3.6 (Saaty, 1996). The Cesaro sum is an approach to assign a sum to an infinite series.

\[
\lim_{k \to \infty} \left( \frac{1}{N} \right) \sum W^k \quad (3.6)
\]

Finally, the priorities generated by various decision makers are then aggregated in a group decision setting using the geometric mean method as discussed in the previous chapter.

3.4 Software Selection Case with Interdependent Criteria

One of the most important components of a cabinet manufacturing company is its design and manufacturing software package. This component is even more important in a company that manufactures customized products and is used to generate quotes, drawings, bill of materials, production schedules, purchase orders, shop paper-works,
optimal cut lists, drilling patterns, CNC/saw machine codes, barcodes, labels, and packaging lists. A high quality and growing cabinetry manufacturing company in Canada was recently challenged to select a design and manufacturing software package for its office and shop operations. The company had purchased two pieces of expensive modern equipment that could not be used effectively due to the incompatibility of the software packages in use with these machines and with one another.

The problems such as manual re-entries of the production data had been escalating as the demand for customized products was growing. Therefore, company’s management recognized the need for automation and integration of the mainstream business processes at the company using a suitable design and manufacturing software package. They realized that this could potentially reduce the cost of quality, improve the resource utilization, increase the sales volume, and improve the productivity, efficiency and competitiveness of the company.

For systematic selection of a suitable design and manufacturing software package, it was first determined which aspects of the company’s business would be affected by the new software package. It was also determined who were the main IT investment decision makers at the company. Three managers referred here as Managers 1, 2, and 3 were found to have the most influence on this decision. Furthermore, alternative software packages were shortlisted. They are referred to as software A, B, C, and D here for confidentiality purpose.
Next, characteristics of a suitable software package for the company were determined and the network of clusters and elements was formed. Table 3.1 summarizes the list of the clusters which were used in the analysis and elements within each cluster.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Down time, installation time, test time</td>
</tr>
<tr>
<td>Cost</td>
<td>Acquisition cost, hardware cost, license cost, maintenance cost, extra cost, service cost, upgrade cost</td>
</tr>
<tr>
<td>User friendliness</td>
<td>Time to learn, skill to learn, use of graphics, design, use of color</td>
</tr>
<tr>
<td>Reliability</td>
<td>Data recovery, backup ability, security privilege</td>
</tr>
<tr>
<td>Compatibility</td>
<td>Compatibility</td>
</tr>
<tr>
<td>Service</td>
<td>Training, consulting, help desk, warranty, speed, documentation</td>
</tr>
<tr>
<td>Technical capability</td>
<td>Implementation ability, use of third party, technical support</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Upgrade ability, ease of integration, in-house development</td>
</tr>
<tr>
<td>Other</td>
<td>Contract type, trial version, reputation and status, expertise, payment term, main use</td>
</tr>
</tbody>
</table>

A questionnaire was next developed based on the selection factors and was sent to a list of four software vendors and responses to the questionnaire were gathered and analyzed. The answers were used to assess how well a certain alternative scored considering a certain factor. Also, it was used to determine the interdependent factors in the analysis. For example, studying the completed questionnaires by the vendor, it was determined the more the services provided by the vendor, the more expensive the service cost would be. Also, it was determined the more compatible the software package was with the current system, the less the installation time and the easier the integration
process would be. Other interdependencies were identified by conducting various interviews with the company’s management team, staff and workers, and studying the information flow and production processes at the company.

After all, the overall network of the decision problem derived by inclusion of the decision clusters, decision elements within decision clusters, and finally the outer-dependencies and inner-dependencies among the decision elements/clusters (Figure 3.2). The elements within each cluster which are listed in Table 3.1 are not included in this figure due to the space limitation.

Figure 3.2. Software selection clusters and interdependencies among them
The arrows connecting the clusters show the outer-dependencies among the clusters/criteria in Figure 3.2. These connections are originated from the connections between the element(s) in one cluster to the element(s) in another cluster. Furthermore, a loop on a cluster shows an inner-dependency among at least one pair of the elements within that cluster. For example, there is a loop arrow on user friendliness cluster, since skill to learn the software affects the time to learn the software. The higher the relevant software skill level of an operator was, the faster it would be to learn the software.

A complete list of the dependencies (outer/inner) among the network elements is given in Table 3.2. This list was determined for the case presented in this study. This list can be modified to use in other cases than ours. In this table, the positive sign (+) denotes a positive relationship between elements being connected, i.e., the increase in the amount/quality of the source element will result in increase in the amount/quality of the sink element. Moreover, in this table, the negative sign (-) represents a negative relationship between elements being connected, i.e., the increase in the amount/quality of the source element will result in decrease in the amount/quality of the sink element. For instance, as shown in rows 7 and 8 of Table 3.2, it was observed that the higher the skills to learn the software was and the better the design, graphics, and the use of color in the software were, the less the time to learn the software would be. It is worth mentioning that for some of the elements in the clusters, some indicators were considered. For example, software price, shipping cost, handling cost, and installation cost were the indicators of acquisition cost (in the “cost” cluster), and focus of the company, number of years active in design and manufacturing software development, number of employees for developing the software of interest and other similar software, historical ability of the
company to finish the project on-time and on-budget, and number of years in the business were the indicators for expertise (in the “other” cluster).

Table 3.2. Interdependencies among the decision elements

<table>
<thead>
<tr>
<th>Source Cluster</th>
<th>Element</th>
<th>Sink Cluster</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Acquisition cost</td>
<td>Cost</td>
<td>hardware cost, license cost, +</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>maintenance cost, service</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cost, upgrade cost</td>
</tr>
<tr>
<td>Cost</td>
<td>Acquisition cost</td>
<td>User friendliness</td>
<td>Time to learn, skill to learn, +</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>use of graphics, design, use of color</td>
</tr>
<tr>
<td>Cost</td>
<td>Acquisition cost</td>
<td>Service</td>
<td>Training, consulting, help</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>desk, documentation</td>
</tr>
<tr>
<td>Cost</td>
<td>Acquisition cost</td>
<td>Technical capability</td>
<td>Technical support</td>
</tr>
<tr>
<td>User friendliness</td>
<td>Skill to learn</td>
<td>User friendliness</td>
<td>Time to learn</td>
</tr>
<tr>
<td>User friendliness</td>
<td>Graphics, design, use of color</td>
<td>User friendliness</td>
<td>Time to learn</td>
</tr>
<tr>
<td>User friendliness</td>
<td>Graphics, design, use of color</td>
<td>Cost</td>
<td>Acquisition cost</td>
</tr>
<tr>
<td>Compatibility</td>
<td>Compatibility</td>
<td>Time</td>
<td>Installation time</td>
</tr>
<tr>
<td>Compatibility</td>
<td>Compatibility</td>
<td>Flexibility</td>
<td>Ease of integration</td>
</tr>
<tr>
<td>Service</td>
<td>Training, consulting, help desk, warranty, speed, documentation</td>
<td>Cost</td>
<td>Service cost</td>
</tr>
<tr>
<td>Technical capability</td>
<td>Technical support</td>
<td>Cost</td>
<td>Service cost</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Upgrade ability</td>
<td>Cost</td>
<td>Upgrade cost</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Ease of integration</td>
<td>Time</td>
<td>Installation time</td>
</tr>
<tr>
<td>Other Reputation</td>
<td>Cost</td>
<td>Acquisition cost</td>
<td></td>
</tr>
<tr>
<td>Other Reputation</td>
<td>Service</td>
<td>Training, consulting, help desk, documentation</td>
<td></td>
</tr>
<tr>
<td>Other Reputation</td>
<td>Technical capability</td>
<td>Technical support</td>
<td></td>
</tr>
<tr>
<td>Other Expertise</td>
<td>Other Reputation</td>
<td>Acquisition cost</td>
<td></td>
</tr>
<tr>
<td>Other Expertise</td>
<td>Cost</td>
<td>Acquisition cost</td>
<td></td>
</tr>
<tr>
<td>Other Expertise</td>
<td>Service</td>
<td>Training, consulting, help desk, documentation</td>
<td></td>
</tr>
<tr>
<td>Other Expertise</td>
<td>Technical capability</td>
<td>Implementation ability, +</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>technical support</td>
<td></td>
</tr>
</tbody>
</table>

Note: (+) denotes a positive relationship between elements being connected
Note: (-) represents a negative relationship between elements being connected
Next, by conducting pairwise comparisons, the degrees of influence and interdependencies were determined. The comparisons were made by the managers at the company and by the researcher. The data gathered from the vendors' completed questionnaires, the phone interviews with software vendors, the expert opinions who previously used the alternative software packages, and the vendors' websites/brochures were also used in conducting the pairwise comparisons.

Then, the influence and interdependence of the elements were derived and suitability of alternative software packages were determined using ANP based on the viewpoints of each decision maker. These viewpoints were aggregated to determine the overall suitability of software packages. Next, sensitivity analyses were performed. The ANP method was applied using Super Decisions (2007) computer program.

3.5 Analysis and Results

For illustration, the step-by-step calculations for deriving portions of the unweighted supermatrix, cluster supermatrix, weighted supermatrix, and limit supermatrix for acquisition cost element based on the viewpoints of Manager 1 are shown in this section (due to space limitation). Acquisition cost element was chosen as it influences other elements within its own cluster (inner-dependency) shown in Figure 3.3 and also elements within other clusters such as user friendliness, service, technical capability, and alternatives (outer-dependency) as listed in Table 3.2.
The supermatrices could similarly be completed for all other elements. The following steps are taken and the results are summarized:

(1) The relative influence of the acquisition cost on the elements within its own cluster such as hardware cost, license cost, maintenance cost, service cost, and upgrade cost was derived in the first step. The pairwise comparison matrix for such influence is given in Table 3.3 based on Saaty’s 1-9 scale and the patterns seen in the completed vendor questionnaires. For instance, acquisition costs affects upgrade cost and license cost and since the acquisition cost affected the upgrade cost more than license cost, number 3 is put in the intersection cell of upgrade cost and license cost (and its reciprocal 1/3 is put for the intersection of license cost and upgrade cost). Also, it was determined that when comparing license cost to hardware cost, acquisition cost influences license.
cost more than hardware cost (5, strong influence). A reciprocal value of 1/5 is given to the alternate cell. The diagonal values are equal to unity.

Table 3.3. Pairwise comparison matrix for inner-influence of acquisition cost

<table>
<thead>
<tr>
<th></th>
<th>Acquisition</th>
<th>Hardware</th>
<th>License</th>
<th>Maintenance</th>
<th>Service</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>1</td>
<td>1/5</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
</tr>
<tr>
<td>License</td>
<td>5</td>
<td>1</td>
<td>1/5</td>
<td>1/4</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Service</td>
<td>6</td>
<td>4</td>
<td>1/3</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Upgrade</td>
<td>6</td>
<td>3</td>
<td>1/3</td>
<td>1/2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

To determine the relative influence of acquisition cost on other elements in the cost cluster, the principal/maximum eigenvector is calculated as follows (Saaty, 1980):

\[
\begin{bmatrix}
1 & 1/5 & 1/6 & 1/6 \\
5 & 1 & 1/5 & 1/4 & 1/3 \\
6 & 5 & 1 & 3 & 3 \\
6 & 4 & 1/3 & 1 & 2 \\
6 & 3 & 1/3 & 1/2 & 1
\end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \end{bmatrix} = \lambda_{max} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \end{bmatrix}
\]

\[
det \begin{bmatrix}
1-\lambda_{max} & 1/5 & 1/6 & 1/6 \\
5 & 1-\lambda_{max} & 1/5 & 1/4 & 1/3 \\
6 & 5 & 1-\lambda_{max} & 3 & 3 \\
6 & 4 & 1/3 & 1-\lambda_{max} & 2 \\
6 & 3 & 1/3 & 1/2 & 1-\lambda_{max}
\end{bmatrix} = 0
\]
By solving a polynomial equation, the maximum eigenvector, \( \lambda_{\text{max}} \) would be 5.3731. To calculate \( w = (w_1, w_2, w_3, w_4, w_5) \), the following equation is solved (Saaty, 1980):

\[
\begin{align*}
1 & 1/5 & 1/6 & 1/6 & 1/6 & \quad w_1 = w_1 \\
5 & 1 & 1/5 & 1/4 & 1/3 & \quad w_2 = w_2 \\
6 & 5 & 1 & 3 & 3 & \times \quad w_3 = 5.3731 \times w_3 \\
6 & 4 & 1/3 & 1 & 2 & \quad w_4 = w_4 \\
6 & 3 & 1/3 & 1/2 & 1 & \quad w_5 = w_5
\end{align*}
\]

By solving this equation, \( w = \) (hardware cost, license cost, maintenance cost, service cost, upgrade cost) = (0.037, 0.091, 0.447, 0.249, 0.176). This result shows that in our case acquisition cost influenced the maintenance cost the most (0.447) and the hardware cost the least (0.037).

The consistency index \( \mu \) equals to \( (5.3731-5)/(5-1)=0.0933 \) (Saaty, 1980). The random index for a 5x5 matrix is 1.11 (Saaty, 1980) which results in an acceptable consistency ratio of 0.0933/1.11=0.0840 (Saaty, 1980) in this case. With a similar approach, other eigenvectors of the un-weighted supermatrix and consistency ratios were determined.

(2) Next, the relative influence of cost cluster on all the other clusters is determined. This would be a portion of cluster matrix. As listed in Table 3.2, cost cluster influences itself, user friendliness, service, technical capability, and alternatives clusters. The pairwise comparison matrix for such influence is given in Table 3.4 based on the questionnaires completed by Manager 1, design and manufacturing software expert opinion, and the investigations of the researcher. For example, the effect of cost cluster
was determined to be moderately greater on user friendliness than its own and that is why number 3 is put in the intersection of user friendliness and cost. Furthermore, the effect of cost on services was believed to be stronger than its effect on technical capability.

Table 3.4. Pairwise comparison matrix for influence of cost cluster

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>User friendliness</th>
<th>Service</th>
<th>Technical capability</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>1</td>
<td>1/3</td>
<td>1/6</td>
<td>1/4</td>
<td>1/8</td>
</tr>
<tr>
<td><strong>User friendliness</strong></td>
<td>3</td>
<td>1</td>
<td>1/3</td>
<td>2</td>
<td>1/5</td>
</tr>
<tr>
<td><strong>Service</strong></td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>1/6</td>
</tr>
<tr>
<td><strong>Technical capability</strong></td>
<td>4</td>
<td>1/2</td>
<td>1/5</td>
<td>1</td>
<td>1/8</td>
</tr>
<tr>
<td><strong>Alternatives</strong></td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

In order to determine the relative influence of cost cluster on all the clusters listed in Table 3.4, the principal/maximum eigenvector is calculated as follows (Saaty, 1980):

\[
\begin{array}{cccc}
1 & 1/3 & 1/6 & 1/4 & 1/8 \\
3 & 1 & 1/3 & 2 & 1/5 \\
6 & 3 & 1 & 5 & 1/6 \\
4 & 1/2 & 1/5 & 1 & 1/8 \\
8 & 5 & 6 & 8 & 1 \\
\end{array}
\]

\[
w_i = \frac{1}{\lambda_{\text{max}}} \times w_3
\]

\[
\det \begin{bmatrix}
1 - \lambda_{\text{max}} & 1/3 & 1/6 & 1/4 & 1/8 \\
3 & 1 - \lambda_{\text{max}} & 1/3 & 2 & 1/5 \\
6 & 3 & 1 - \lambda_{\text{max}} & 5 & 1/6 \\
4 & 1/2 & 1/5 & 1 - \lambda_{\text{max}} & 1/8 \\
8 & 5 & 6 & 8 & 1 - \lambda_{\text{max}} \\
\end{bmatrix} = 0
\]
From that, $\lambda_{\text{max}}$ is equal to 5.4477. To calculate $w=(w_1, w_2, w_3, w_4, w_5)$, the following equation needs to be solved (Saaty, 1980):

\[
\begin{array}{cccc|c}
1 & 1/3 & 1/6 & 1/4 & 1/8 & w_1 = w_1 \\
3 & 1 & 1/3 & 2 & 1/5 & w_2 = w_2 \\
6 & 3 & 1 & 5 & 1/6 & w_3 = 5.4477 \times w_3 \\
4 & 1/2 & 1/5 & 1 & 1/8 & w_4 = w_4 \\
8 & 5 & 6 & 8 & 1 & w_5 = w_5 \\
\end{array}
\]

By solving this equation, $w=(\text{cost, user friendliness, service, technical capability, alternatives})=(0.039, 0.106, 0.224, 0.080, 0.551)$. This result shows that in our case acquisition cost influenced the alternatives the most (0.551) and itself the least (0.039).

The consistency index $\mu$ equals to $(5.4477-5)/(5-1)=0.11$ (Saaty, 1980). The random index for a $5 \times 5$ matrix is 1.11 (Saaty, 1980) which results in an acceptable consistency ratio of $0.11/1.11=0.0991$. With a similar approach, the cluster supermatrix was completed.

(3) Next, the influence of acquisition cost element on all other elements in the network is determined to form a portion of the weighted supermatrix. This portion of the weighted supermatrix is presented here which is the influence of acquisition cost on the elements within its own cluster. This can be determined by multiplying the influence of acquisition cost on other elements within its own cluster from the un-weighted supermatrix (local weights) by the influence of the cost cluster on the clusters that is connected to (in this example itself) from the cluster supermatrix as follows:
This result shows that in our case acquisition cost influenced the maintenance cost the most (0.0174) and the hardware cost the least (0.0014) in the cost cluster in the weighted supermatrix. Similarly, this could be done for all other elements in the network to form the weighted supermatrix.

(4) Next, the global priority vector for the acquisition cost element which is a portion of the limit supermatrix is calculated using Equation 3.2 and is equal to (0.0284 [acquisition cost], 0.0166 [hardware cost], 0.0268 [license cost], 0.0220 [maintenance cost], 0.0236 [extra cost], 0.0230 [service cost], 0.0352 [upgrade cost]). These weights are located in Figure 3.4. The rest of the supermatrix can be populated with the same approach.
Cost

<table>
<thead>
<tr>
<th>Cost</th>
<th>Cost</th>
<th>Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition cost</td>
<td>0.028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extra cost</td>
<td>0.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware cost</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>License cost</td>
<td>0.027</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>0.022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service cost</td>
<td>0.023</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upgrade cost</td>
<td>0.035</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\begin{array}{cccccc}
  e_{12} & \ldots & e_{1n} & e_{22} & \ldots & e_{2n} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
  e_{n1} & \ldots & e_{nn} & W_{12} & \ldots & W_{1n} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
  e_{N1} & \ldots & e_{Nn} & W_{N1} & \ldots & W_{NN} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
\end{array}
\]

Figure 3.4. Limit supermatrix

With a similar approach, the global priority for all the elements in the network and for all the managers were derived and presented in Table 3.5. Also, the aggregated priorities are also presented in this table.

The aggregated results show that the compatibility of the new software package with the current system is the most influential factor from the managers’ points of view (0.055). Upgrade cost (0.027), installation time (0.026), acquisition cost (0.024), time to learn (0.023), and security privileges (0.023) are other influential factors in this decision making problem.
<table>
<thead>
<tr>
<th></th>
<th>Manager 1</th>
<th>Manage 2</th>
<th>Manager 3</th>
<th>Aggregated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alternatives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software A</td>
<td>0.116</td>
<td>0.149</td>
<td>0.108</td>
<td>0.124</td>
</tr>
<tr>
<td>Software B</td>
<td>0.124</td>
<td>0.093</td>
<td>0.130</td>
<td>0.115</td>
</tr>
<tr>
<td>Software C</td>
<td>0.087</td>
<td>0.095</td>
<td>0.092</td>
<td>0.091</td>
</tr>
<tr>
<td>Software D</td>
<td>0.147</td>
<td>0.140</td>
<td>0.148</td>
<td>0.145</td>
</tr>
<tr>
<td><strong>Compatibility</strong></td>
<td>0.057</td>
<td>0.075</td>
<td>0.033</td>
<td>0.055</td>
</tr>
<tr>
<td>Acquisition cost</td>
<td>0.028</td>
<td>0.016</td>
<td>0.027</td>
<td>0.024</td>
</tr>
<tr>
<td>Extra cost</td>
<td>0.024</td>
<td>0.010</td>
<td>0.021</td>
<td>0.018</td>
</tr>
<tr>
<td>Hardware cost</td>
<td>0.017</td>
<td>0.007</td>
<td>0.015</td>
<td>0.013</td>
</tr>
<tr>
<td>License cost</td>
<td>0.027</td>
<td>0.013</td>
<td>0.023</td>
<td>0.021</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>0.022</td>
<td>0.009</td>
<td>0.019</td>
<td>0.017</td>
</tr>
<tr>
<td>Service cost</td>
<td>0.023</td>
<td>0.017</td>
<td>0.022</td>
<td>0.020</td>
</tr>
<tr>
<td>Upgrade cost</td>
<td>0.035</td>
<td>0.017</td>
<td>0.030</td>
<td>0.027</td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of integration</td>
<td>0.017</td>
<td>0.014</td>
<td>0.015</td>
<td>0.016</td>
</tr>
<tr>
<td>In-house development</td>
<td>0.012</td>
<td>0.008</td>
<td>0.012</td>
<td>0.011</td>
</tr>
<tr>
<td>Upgrade ability</td>
<td>0.010</td>
<td>0.008</td>
<td>0.010</td>
<td>0.009</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contract type</td>
<td>0.005</td>
<td>0.006</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Expertise</td>
<td>0.004</td>
<td>0.006</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Main use</td>
<td>0.004</td>
<td>0.006</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Payment term</td>
<td>0.005</td>
<td>0.005</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Reputation</td>
<td>0.004</td>
<td>0.006</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Trial version</td>
<td>0.004</td>
<td>0.005</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backup ability</td>
<td>0.004</td>
<td>0.009</td>
<td>0.032</td>
<td>0.015</td>
</tr>
<tr>
<td>Data recovery</td>
<td>0.004</td>
<td>0.009</td>
<td>0.032</td>
<td>0.015</td>
</tr>
<tr>
<td>Security privilege</td>
<td>0.006</td>
<td>0.017</td>
<td>0.046</td>
<td>0.023</td>
</tr>
<tr>
<td><strong>Service</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consulting</td>
<td>0.006</td>
<td>0.014</td>
<td>0.005</td>
<td>0.008</td>
</tr>
<tr>
<td>Documentation</td>
<td>0.003</td>
<td>0.011</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>Help desk</td>
<td>0.003</td>
<td>0.012</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>Speed</td>
<td>0.002</td>
<td>0.011</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>Training</td>
<td>0.004</td>
<td>0.013</td>
<td>0.004</td>
<td>0.007</td>
</tr>
<tr>
<td>Warranties</td>
<td>0.003</td>
<td>0.014</td>
<td>0.004</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Technical capability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation ability</td>
<td>0.007</td>
<td>0.016</td>
<td>0.015</td>
<td>0.013</td>
</tr>
<tr>
<td>Technical support</td>
<td>0.008</td>
<td>0.014</td>
<td>0.014</td>
<td>0.012</td>
</tr>
<tr>
<td>Use of 3rd party</td>
<td>0.006</td>
<td>0.013</td>
<td>0.014</td>
<td>0.011</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down time</td>
<td>0.032</td>
<td>0.014</td>
<td>0.005</td>
<td>0.017</td>
</tr>
<tr>
<td>Installation time</td>
<td>0.044</td>
<td>0.020</td>
<td>0.014</td>
<td>0.026</td>
</tr>
<tr>
<td>Test time</td>
<td>0.032</td>
<td>0.014</td>
<td>0.005</td>
<td>0.017</td>
</tr>
<tr>
<td><strong>User friendliness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of color</td>
<td>0.011</td>
<td>0.017</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>Design</td>
<td>0.011</td>
<td>0.017</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>Graphics</td>
<td>0.011</td>
<td>0.017</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>Skill to learn</td>
<td>0.013</td>
<td>0.018</td>
<td>0.018</td>
<td>0.016</td>
</tr>
<tr>
<td>Time to learn</td>
<td>0.019</td>
<td>0.026</td>
<td>0.025</td>
<td>0.023</td>
</tr>
</tbody>
</table>
The global priorities presented in Table 3.5 can also be normalized to sum up to unity for each cluster and for each manager. The normalized priorities of the alternatives for all the managers are presented in Table 3.6.

<table>
<thead>
<tr>
<th>Software</th>
<th>Manager 1</th>
<th>Manager 2</th>
<th>Manager 3</th>
<th>Aggregated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>0.245 (3)</td>
<td>0.313 (2)</td>
<td>0.226 (3)</td>
<td>0.260 (2)</td>
</tr>
<tr>
<td>Software B</td>
<td>0.261 (2)</td>
<td>0.199 (3)</td>
<td>0.271 (2)</td>
<td>0.241 (3)</td>
</tr>
<tr>
<td>Software C</td>
<td>0.183 (4)</td>
<td>0.195 (4)</td>
<td>0.192 (4)</td>
<td>0.193 (4)</td>
</tr>
<tr>
<td>Software D</td>
<td>0.310 (1)</td>
<td>0.293 (1)</td>
<td>0.311 (1)</td>
<td>0.306 (1)</td>
</tr>
</tbody>
</table>

Note: The numbers in brackets show the ranking of the software packages.

The results of ANP suggest that Software D is the most suitable design and manufacturing software package for the company (Table 3.6) assuming that all the decision makers have equal influence in this particular decision making problem. The results also suggest that Software A, which is relatively an expensive software package with high quality features, is preferred over Software C, which is relatively a cheap software package with fewer quality features.

It should be noted that throughout the analysis, the consistency ratios were calculated, analyzed, and kept within the acceptable range of 10% as Saaty (1980) suggested. This required re-examinations of judgments often times and required extensive communication between the managers and the researcher.
3.6 Sensitivity Analysis

Two types of sensitivity analyses were done to study how the decision would change if (1) the influence of decision makers changed in the decision making process, (2) the interdependencies among the elements in the decision network removed.

For the first type of the sensitivity analysis, four scenarios were studied as follows: (1) base case, decision makers had equal influence in the decision making process, (2) the highest weight was given to the owner and president of the company (i.e., Manager 1, 0.750, Manager 2, 0.125, and Manager 3, 0.125 which is more realistic), (3) the highest weight was given to Manager 3 (i.e., Manager 1, 0.25, Manager 2, 0.25, and Manager 3, 0.50), and (4) the highest weight was given to Manager 2 (i.e., Manager 1, 0.25, Manager 2, 0.50, and Manager 3, 0.25). The weighted geometric mean method was used in order to derive the overall decision in each scenario.

As shown in Table 3.7, the results show that the decision (purchasing Software D) would not change if the influence of the decision makers in the decision making process changes based on the defined scenarios, so the decision is stable in this regards.

<table>
<thead>
<tr>
<th>Table 3.7. Sensitivity analysis on the influence of decision makers</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>0.260 (2)</td>
<td>0.251 (3)</td>
<td>0.250 (2)</td>
<td>0.271 (2)</td>
</tr>
<tr>
<td>Software B</td>
<td>0.241 (3)</td>
<td>0.253 (2)</td>
<td>0.247 (3)</td>
<td>0.228 (3)</td>
</tr>
<tr>
<td>Software C</td>
<td>0.193 (4)</td>
<td>0.186 (4)</td>
<td>0.192 (4)</td>
<td>0.193 (4)</td>
</tr>
<tr>
<td>Software D</td>
<td>0.306 (1)</td>
<td>0.308 (1)</td>
<td>0.306 (1)</td>
<td>0.302 (1)</td>
</tr>
</tbody>
</table>

Note: The numbers in brackets show the ranking of the software packages.
In the second type of the sensitivity analysis, all the interdependencies among the elements removed for all the managers and it was assessed how the aggregated decision would change consequently. The results are presented in Table 3.8. The results of the AHP analysis are also included in this table.

Table 3.8. Sensitivity analysis on the interdependencies among the decision elements

<table>
<thead>
<tr>
<th>Software</th>
<th>ANP considering dependencies</th>
<th>ANP not considering dependencies</th>
<th>AHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software A</td>
<td>0.260 (2)</td>
<td>0.223 (3)</td>
<td>0.223 (3)</td>
</tr>
<tr>
<td>Software B</td>
<td>0.241 (3)</td>
<td>0.199 (4)</td>
<td>0.199 (4)</td>
</tr>
<tr>
<td>Software C</td>
<td>0.193 (4)</td>
<td>0.243 (2)</td>
<td>0.243 (2)</td>
</tr>
<tr>
<td>Software D</td>
<td>0.306 (1)</td>
<td>0.328 (1)</td>
<td>0.328 (1)</td>
</tr>
</tbody>
</table>

Note: The numbers in brackets show the ranking of the software packages.

Comparison between the second and third columns of Table 3.8 shows that the final decision (Software D) did not change, however, the ranking of other alternatives changes. It can be observed that the results from the ANP analysis without interdependencies are similar to that of the AHP analysis. Furthermore, it can be observed that the weights of Software A and B were increased when interdependencies were considered. That is the weights of Software A and B are calculated higher in ANP than AHP. This could be due to the fact that these software packages offer more and better design and manufacturing features although they are relatively expensive.

However, the weights of Software C and D were decreased when interdependencies were considered. That is the weights of Software C and D are calculated higher in AHP than ANP. The reason could be the fact that these software packages do not offer as good features as Software A and B although they are relatively
cheap. For example, although software C is the cheapest software available, its weight decreased 20% (=100\times(0.243-0.193)/0.243) using ANP than AHP.

3.7 Conclusion and Future Work

This study investigated the effect of interdependencies among the selection criteria on an investment decision using ANP in a real case of design and manufacturing software selection in a cabinet manufacturing company. Also, a sensitivity analysis was performed to study how the changes in the influence of the decision makers and in the interdependencies among the selection criteria would affect the final decision. It was learned that interdependencies, where exist, should be considered in the analysis as they can change the ranking of alternatives. In our case, it was found that they not only changed the weights of the alternatives, but also partially changed their ranking.

The procedure presented in this study could also be used for other types of evaluation, prioritization, or selection problems in various industries dealing with wide range of problems in material selection, human resource hiring, machinery selection, etc in which the selection criteria are interrelated. A list of design and manufacturing software selection criteria which was presented in this study could also be used for software selection and evaluation in other manufacturing companies.

Moreover, this research could be useful for design and manufacturing software vendors as it presents insights regarding the influential factors managers take into account for this type of decision. Also, they could learn about their competition and explore the possibility of improving various features in their products. Furthermore, they could use
the same evaluation procedure for marketing/advertising purposes highlighting their strengths against their competition in relevant criteria.

To expand this research, investments in a number of software packages in the firm considering resource limitations such as budget, working hours, personnel, capacity, raw material, space, etc. could be analyzed.
References


Chapter 4. Conclusion and Future Research

4.1 Conclusion

Manufacturing industry is the largest business sector in Canada. It has contributed significantly to the Canadian prosperity in terms of employment and economic growth (Canadian Manufactures and Exporters, 2004a). However, this industry has faced many challenges as the result of (1) increased global competition, (2) appreciated Canadian dollar, and (3) increased price of energy and other manufacturing resources (Canadian Manufactures and Exporters, 2004b). These challenges lowered the profit margins of the Canadian manufacturing industry (Canadian Manufactures and Exporters, 2004b). In order to sustain and gain higher profit margins, Canadian manufacturers have adapted various strategies, one of which is to offer high-value customized products to meet their customers' changing needs (Canadian Manufactures and Exporters, 2004b).

To that end, there have been significant investments made in advanced technologies and machineries in Canadian manufacturing companies (Canadian Manufactures and Exporters, 2004b). In particular, large investments have been made in information and communication technology (ICT) and more specifically in design and manufacturing software packages in this industry. Suitable software packages are critical to the manufacturing companies as they generate high-value customized designs for production and enable companies to use their advanced machineries more effectively. Approximately, half of the total ICT investments made in the Canadian manufacturing industry were made in software in 2006 (The Centre for the Study of Living Standards, 2007).
As one of the sub-sectors of the manufacturing industry, household and institutional furniture and kitchen cabinet manufacturing industry is also affected by similar challenges. As a result of such challenges, household and institutional furniture and kitchen cabinet manufacturing industry has focused on production of high-value customized products. To that end, the companies in this industry also have realized the importance of investing in the advanced technologies such as information technology (IT). Particularly, software investments have got much attention since the design and manufacturing software packages are the critical components of any customized furniture and cabinet manufacturing company. It also generates what such companies need for their order processing, design, and manufacturing purposes such as quotes, drawings, bills of material, production schedules, purchase orders, and shop paper-works in a reasonable time.

Due to increasing availability and expensive acquisition cost of design and manufacturing software packages, and long term effect of investing in such software, it is important to use suitable holistic approaches for evaluation of these types of investments. The systematic evaluation should involve inclusion of multiple tangible and intangible criteria. It may also include consideration and aggregation of different decision makers' viewpoints.

Unlike other industries, systematic approach for assessing IT investments has not been used in the forest products industry (The IUFRO Task Force, 2005). This research was designed (1) to study the evaluation and selection of a design and manufacturing software package considering multiple tangible and intangible software selection criteria in a group decision setting, and (2) to investigate the potential effects of
interdependencies among the decision criteria on the decision outcome. Two studies were completed to achieve these objectives.

The first study, “Design and Manufacturing Software Selection in the Wood Industry using Analytic Hierarchy Process”, addressed the first objective of this research. A real software selection case at a cabinet manufacturing company was considered. A group decision setting was adopted and several tangible and intangible criteria were included in the analysis using the analytic hierarchy process (AHP) method. The importance of selection criteria and the suitability of the software packages were determined. Furthermore, several sensitivity analyses were conducted to ensure the stability of the decision outcome upon changes in the weights of decision criteria and changes in the influence of decision makers in the decision making process. Moreover, the situations under which the existing second-ranked alternative would become the top-ranked alternative were analyzed for all decision makers. It was learned that the inclusion of intangible criteria would yield to a better decision than that of revealed by just considering tangible factors.

The second objective of this research was addressed by the second study. “Evaluation and Selection of a Design and Manufacturing Software Package Considering the Interdependencies between Criteria”. The inter-relationships among the software selection criteria were studied in a feedback network structure using a suitable multiple criteria decision making method, analytic network process (ANP). A real case of software selection was analyzed and a group decision environment is adopted. Also, a sensitivity analysis was conducted to analyze how the outcome of the decision would change if the influence of the decision makers change in the decision making process. It was found that
the inclusion of interdependencies among the evaluation criteria would impact the decision outcome.

This research also presented a list of design and manufacturing software selection criteria. This list could be modified and used by any other goods-producing companies and also service-producing companies. Also, this research presented a procedure to include the viewpoints of different decision makers in the analysis in a consistent manner. Furthermore, the procedures presented in this research could also be used for other types of evaluation, prioritization, or selection projects in other industries dealing with problems such as material selection, human resource hiring, and machinery selection.

Moreover, this research could be useful for design and manufacturing software vendors and also any other type of software providers. It presents insights regarding the factors decision makers may take into account for their software investments. Also, software vendors can obtain knowledge by evaluating their products against their competition’s using the same procedure in order to improve the features in their products. This also could be used as a powerful and effective marketing or advertising tool highlighting the strengths of their products against their competition.

To the best of the researcher’s knowledge, this is the first research to use a systematic multiple criteria framework in a group decision setting to assess IT investment projects in the wood industry. One of the limitations of this research is that it requires numerous pairwise comparisons of selection criteria, and the interdependencies among them. This could be frustrating and confusing for the decision makers and could jeopardize the accuracy of the decision outcome.
4.2 Future Research

It is often the case that the decision makers get confused and frustrated of conducting the required pairwise comparisons of selection criteria. For the future research, strategies to reduce the number of pairwise comparisons needed to conduct the analysis could be studied.

As a result of decision makers’ confusion and frustration, it is also the case that the inputs of the decision models are incomplete and inaccurate. Therefore, the strategies to cope with the often incomplete and inaccurate inputs to the decision making model can be analyzed using suitable techniques such as the fuzzy theory.

Furthermore, research on decreasing the number of pairwise comparisons and coping with the incomplete decision models would increase the accuracy of the decision outcome. This is important as the technology investment has a long-term strategic nature and companies cannot afford making a bad decision in that regard as such decision would be very costly. A good decision however would generate competitive edge and increase the profit margin for the companies as discussed earlier.
References


Appendix A – Explanation on Criteria and Sub-criteria

Time

Time as a criterion had three sub-criteria as follows: (1) down time: the time that the design activities would be shot down due to the installation of the new software package, (2) installation time: the actual time to install the new software and modify the catalogs so that the software would be up and running, and (3) test time: the time to test the software package.

Cost

Cost criterion had several sub-criteria: (1) acquisition cost: the software price plus the shipping, handling and installation, (2) hardware cost: the cost of purchasing the new hardware to be able to effectively use the new software, (3) license/ownership cost, (4) maintenance cost: the cost of maintaining the software which would usually occur annually, (5) extra cost: the cost of extra modules and translators (translator programs translate the software packages' output data into machine specific data or code, they would be needed if the output of the new software package would not be readable by/compatible with the new machines), (6) service cost: the cost of providing the training required for using the new software package, providing the consulting needed by the company, providing 24-hour help desk, and providing warranties and documentation for the new software package, (7) upgrade cost: the cost of updating with the new versions/modules of the software of the interest in order to help the company to satisfy its growing software needs based on its changing customer demands.
**User friendliness**

User friendliness was decomposed as follows: (1) time to learn: how long it would take to learn the software, (2) skills to learn: skill level required to learn the software, (3) use of graphics, (4) design, and (5) use of color: use of the color in the software.

**Reliability**

Reliability criterion was studied with three sub-criteria as follows: (1) data recovery: the ability to recover the data in the case of unexpected events such as power outage, (2) backup ability: the ability to generate backups regularly, and (3) security privileges: different people would have different access authority.

**Compatibility**

The company preferred the new software to be as much compatible as possible with the software packages in use and with the machinery in use in the company. The software vendors were specifically asked in the questionnaire to tell us which software packages would remain and which ones would go in case the company buys their software package. They were further asked to specify if their software package would be compatible with the ones that would remain.

**Service**

Service criterion consisted of six sub-criteria as follows: (1) training, (2) consulting, (3) help desk, (4) warranties, (5) speed: how fast the software vendor would
react to a certain need at the company, and (6) documentation: how comprehensive the software documentations are and how easy it would be to understand them, if any.

Technical capability

Technical capability was another criterion important for choosing the most suitable design and manufacturing software package for the company. Its sub-criteria are as follows: (1) implementation ability: the ability to implement the software on time and within budget, (2) use of third party: if there would be a third party involved in any part of the project, and (3) technical support.

Flexibility

Flexibility was decomposed into its sub-criteria as follows: (1) upgrade ability: the ability to provide upgrades, (2) ease of integration: how easy it would be to integrate the new software package with the software packages and machinery in use in the company, and (3) in-house development: enabling the company to manipulate the software in response to its potential future needs.

Other

There were some other factors included: (1) contract type: license or ownership, (2) trial version: whether the company could get access to trial versions, (3) reputation and status: how well-known/well-established the company was in the design and manufacturing software package market, (4) expertise: whether the software vendor was an expert in producing the design and manufacturing software packages for the cabinet manufacturing industry, (5) payment term: whether the company had to pay for the
software upfront or had the chance to pay in later installments, and (6) main use: whether the software packages were believed to be useful for the cabinet manufacturers or it was designed for the dealers.
Appendix B – Questionnaire

General information:

Company Name of the company
Software Name of the software of our interest

Contact:
Name
Position
Email

When was your company established?
In __________________________

What is the legal form of your company (e.g. Ltd.)?
Is __________________________

Who is the owner of your company?
Is __________________________

What is the annual net revenue of your company?
Is __________________________ Million CND
□ In range of ___ & ___ Million CND
□ Can not provide

Can you provide us with your company’s latest annual report?
□ Yes (attach please)
□ No because __________________________

How many employees are working in your company?
~ __________________________

What is the focus of your company’s activities?
Is __________________________

How long have you been engaged in developing the software packages with design, manufacturing and accounting capabilities in cabinet manufacturing industry?
~ __________________________ Years __________________________ Months

How many of your company’s employees are actually involved in developing the software of our interest?
~ __________________________

Do you develop other products in your company besides the software of our interest for cabinet manufacturing industry?
□ Yes
1 __________________________
2 __________________________
3 __________________________
□ No

Do you have a research and development department in your company?
□ Yes
□ No

How many of your company’s employees are in your research and development team?
~ __________________________
□ Not applicable
Can you provide us with contacts of some of your customers, the name of the products they are using and their implementation size?

<table>
<thead>
<tr>
<th>1 Name, address and contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product name and version</td>
</tr>
<tr>
<td>Implementation size</td>
</tr>
</tbody>
</table>

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<tr>
<th>2 Name, address and contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product name and version</td>
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<tr>
<td>Implementation size</td>
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<th>3 Name, address and contact</th>
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<tbody>
<tr>
<td>Product name and version</td>
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<tr>
<td>Implementation size</td>
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<th>4 Name, address and contact</th>
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</thead>
<tbody>
<tr>
<td>Product name and version</td>
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<tr>
<td>Implementation size</td>
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<tr>
<th>5 Name, address and contact</th>
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</thead>
<tbody>
<tr>
<td>Product name and version</td>
</tr>
<tr>
<td>Implementation size</td>
</tr>
</tbody>
</table>

□ Yes  □ No because

How do you ensure finishing the project on time and within budget?

By

Will your company provide us with the training we need for using the software of our interest?

□ Yes  □ No because

Will your company provide us with the documentation we need for the software of our interest?

□ Yes  □ No because
Will your company be responsible for implementation of the software of our interest?

☐ Yes

☐ No because

Will there be a third party involved in implementation, technical support, customer service, etc. at anytime?

☐ Yes
Name, address and contact

☐ No because

Tasks

Responsibilities

What is your implementation timeline for the software of our interest?

1 Downtime

2 Installation time

3 Test time

4 Other

☐ No plan yet

Considering the following list of the current software packages in use in the company, can you tell us which software package(s) the company should keep and which one(s) should be replaced by the software of our interest?

1 Software 1  ☐ Remains  ☐ Replaced

2 Software 2  ☐ Remains  ☐ Replaced

3 Software 3  ☐ Remains  ☐ Replaced

4 Software 4  ☐ Remains  ☐ Replaced

5 Software 5  ☐ Remains  ☐ Replaced

6 Software 6  ☐ Remains  ☐ Replaced

☐ Comments

☐ Not sure

What are the main uses of the software of our interest (design, manufacturing, accounting, etc.)?

1

2

3

4

What are the main advantages of the software of our interest?

1

2

3

115
What are the main disadvantages of the software of our interest?

1 __________________________
2 __________________________
3 __________________________

What are the minimum system requirements of the software of our interest?

☐ Processor __________________
☐ RAM ______________________
☐ Hard Disk __________________
☐ Operating System __________
☐ Video Card __________________
☐ CD Drive ____________________
☐ Internet _____________________
☐ Other ______________________

What are the main inputs of the software of our interest?

☐ Hand drawings
☐ Dimensions
☐ Design
☐ Quote information
☐ Layout drawings
☐ Other

What are the recommended system requirements of the software of our interest?

☐ Processor __________________
☐ RAM ______________________
☐ Hard Disk __________________
☐ Operating System __________
☐ Video Card __________________
☐ CD Drive ____________________
☐ Internet _____________________
☐ Other ______________________

What are the main outputs of the software of our interest?

☐ Layout
☐ Quote
☐ Drawings
☐ Cut list
☐ Part list
☐ Shop paper-works
☐ Production schedule
☐ Purchase orders
☐ Accounting
☐ Bill of materials
☐ Order inquiry
☐ Optimal cut information
☐ CNC drilling information
☐ Labels
☐ 3D show
☐ Barcode
☐ Other

Are there any software packages such as AutoCAD or any translator software packages required to be able to efficiently use the software of our interest and communicate with the current software packages and machinery in use in the company?

☐ Yes
1 AutoCAD

2 Translators

3 Other

☐ No
How long will it take to learn the software of our interest for an average skilled technician?
~ __________________________ Days

What skill level is required for efficiently using the software of our interest?
~ __________________________

How well-designed is the software of our interest?
☐ Graphics
☐ Design
☐ Color
☐ Other

What will be the ownership/license status of the software of our interest if the company purchases it?
☐ Owns it
☐ Should renew its license
☐ Other

Does the software of our interest have the ability to recover the data in case some unexpected events happen?
☐ Yes
☐ No

Does the software of our interest have the ability to get back-ups on regular bases?
☐ Yes
☐ No

Can we get access to any trial version of the software of our interest?
☐ Yes

1 Requirements

☐ No because

2 Cost (in CND)

☐ No

Will you provide upgrades to the software of our interest for the company as new versions come up?
☐ Yes

1 Cost (in CND)

☐ No

2 Requirements
Are there any other modules/add-ons that should/must be purchased in order to be able to get all the outputs you already listed?

☐ Yes

1 Name

☐ Optional  ☐ Required

Cost (in CND)

Requirements

☐ No

☐ Optional  ☐ Required

Cost (in CND)

Requirements

2 Name

☐ Optional  ☐ Required

Cost (in CND)

Requirements

3 Name

☐ Optional  ☐ Required

Cost (in CND)

Requirements

☐ No because

4 Name

☐ Optional  ☐ Required

Cost (in CND)

Requirements

Is the software of our interest compatible with the software packages which are going to remain, and the machineries in use in the company?

1 Software 1

☐ Yes  ☐ No  ☐ NA

2 Software 2

☐ Yes  ☐ No  ☐ NA

3 Software 3

☐ Yes  ☐ No  ☐ NA

4 Software 4

☐ Yes  ☐ No  ☐ NA

5 Software 5

☐ Yes  ☐ No  ☐ NA

6 Software 6

☐ Yes  ☐ No  ☐ NA

7 Machinery 1

☐ Yes  ☐ No  ☐ NA

8 Machinery 2

☐ Yes  ☐ No  ☐ NA

☐ List any required translators please

Can you ensure supporting us in terms of customer service and technical support in Canada?

☐ Yes

☐ No

Do you have a help desk as part of your support?

☐ Yes

☐ No

Opening hours

Response time
What are the services available for the software of our interest?

<table>
<thead>
<tr>
<th>Service</th>
<th>Period</th>
<th>Cost (in CND)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warranties</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td></td>
<td></td>
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<tr>
<td>Consulting</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Please provide us with a detailed cost overview for the software of our interest plus any costs attached for any other software requirements, translators, etc. in Canadian dollar.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (in CND)</th>
<th>Cost (in CND)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td></td>
<td></td>
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<tr>
<td>Hardware</td>
<td></td>
<td></td>
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<tr>
<td>License/Ownership</td>
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<tr>
<td>Maintenance</td>
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<tr>
<td>Shipping and handling</td>
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<tr>
<td>Extra modules</td>
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<tr>
<td>AutoCAD</td>
<td></td>
<td></td>
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<tr>
<td>Translators</td>
<td></td>
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</tr>
</tbody>
</table>
For confidentiality purpose the name of software packages and machineries in use were not provided in this document.

9 Installation

10 Training

11 Technical support

12 Warranties

13 Upgrades

14 Other

☐ Can not provide

What is the payment schedule?

~

120