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Abstract

This thesis explores different group decision making methods using the Analytical Hierarchical Process (AHP) applied to the multi-criteria decision making problem of selecting a preferred “site” and develops a support system for group decision making. The group members consider sites to have alternative and often conflicting uses. It is imperative for decision makers in the responsible group to have an appropriate combination of tools, computer software and decisions support systems in order to make the most preferred decisions as a group despite potential inherent conflict among members of the decision making group. To support this idea and facilitate decision making, alternative group multi-criteria decision making (MCDM) evaluation techniques are examined. These include; AHP, Weighted Sum Method (WSM), Weighted Product Method (WPM), AHP Combined Method, Group Evaluation Method, Fuzzy AHP, Fuzzy AHP Combined, and Fuzzy AHP Group. A web-based comparison framework is developed as a prototype to facilitate model use. These methods are applied to the evaluation of coastal zone sites for alternate marine use including aquaculture or fish farming. Aquaculture is one of the fastest growing activities among coastal nations. At the same time, companies, researchers, and coastal communities are seeking assistance in identifying appropriate coastal zone sites for commercial fishing and aquaculture activities, habitat reserves, and marine recreation. The aquaculture case study evaluates four possible fish sites in the Grand Manan Island area of Atlantic Canada.

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"Success is a ladder that cannot be climbed with your hands in your pocket."

Multi-Criteria Group Decision Making Methods Using AHP and Integrated Web-Based Decision Support Systems

1. Introduction

This chapter introduces the multi-criteria group decision making problem, and the objectives and outline of the thesis research. Group decision is generally interpreted as aggregating different individual judgments on a given set of alternatives to a single joint preference. Group members in making a group decision are assumed to face the same problem and are all interested in finding a feasible solution. A group decision process involves multiple decision makers, each with different experience, skills, and knowledge relating to criteria of the problem. Therefore, the competence of decision makers should also be taken into account. Aquaculture site problem that will be used in this thesis also involves major decisions with multiple decision making groups. These decisions are at various levels: i) selection of criteria; ii) organization of the criteria; iii) evaluation of the criteria; iv) depending on the type of the problem, determination of the weight of the decision makers; and v) evaluation of the alternatives etc. Relative importance of these parameters can be applied by using multi-criteria decision making techniques.

1.1 Motivation / Problem Definition

Our minds have a limited capacity to assimilate and retain large amounts of information even for a short period of time. Due to such limitations and because in many situations sufficient data are not available, decision makers must base their decisions on information at hand and on the experiences they have accumulated over the years. In today's complex world, even large amounts of information seem inadequate to make sound, objective decisions on multifaceted problems. In addition, complex decisions are usually characterized by a large number of interacting factors. The problem is how to assess properly the relative importance of these factors in order to make tradeoffs among them; and, how to derive a system of priorities that can guide us to make better decisions by choosing a most preferred alternative. To answer this problem of decision making in the face of risk, uncertainty in inputs, diversity of factors and varying options, and judgments, a number of multi-criteria decision making techniques are examined.

Public and private decision making, include local, national, and even international level multiple criteria decisions, such as whether to build a bridge or a hospital, how to allocate funds within a government department, how to vote on a city council issue, how to negotiate trade-off items in a trade agreement, where to buy equipment, where to best focus to reduce environmental pollution, and where to build a fish farm to exploit marine sites where there are multiple decision makers and multiple criteria and sub-criteria to consider including environmental, social, economic, biological and administrative concerns as examined in this research.

Furthermore, in our personal lives, we constantly make choices concerning what tasks to do or not to do, and when to do them. Many problems such as buying the most cost effective home computer expansion, a car, a house, choosing a school or a career, investing money, deciding on a vacation place, or even voting for a political candidate are common everyday problems in personal decision making. Nevertheless, these are complex problems of choice requiring information, organization of thought, and the use of logic, intuition, and experience and often involving groups of decision makers.

When more than one decision maker is involved in a multi-criteria decision making problem, timing becomes an important issue. If the number of elements used in the problem is large, collecting the data from the decision makers, organizing, analyzing, synthesizing, and finally reaching a conclusion becomes a tremendous time factor. The use of technology can help to reduce the time that is spent on these issues. A visual and interactive decision making tool that is web-based, becomes an inevitable opportunity to assist in solving this problem.

The complexity of environmental problems demonstrates that there is a growing quantity of information to be considered and an increasing number of factors that can be addressed dealing with such complex problems. Environmental and natural resource problems affecting coastal regions and their conjoint consequences are hindering the basis of sustainable socioeconomic growth. These problems include the ongoing ecosystem and habitat losses and damages, resource degradation, and pollution including influence plumes from effluents. There is a strong interaction between resources, habitat, commercial activities and influence plumes in marine use so that every aspect that involves marine use has to be considered very carefully. On one hand, commercial activities may increase; however, on the other hand, these may cause huge damage due to negative effects on the habitat.

Aquaculture is thousands of years old. It was first practiced in Asia. The Japanese, Chinese, Romans, Egyptians, and Mayan Indians of South America farmed fish for food and recreation prior to 2000 BC (Helfrich et al. 1997). As an industry, it is currently growing faster than any other type of agriculture in the world. Production levels have increased globally by 85% (Marine Science Online Magazine 2006). Farmed fish accounted for 25% of all fish consumed in 2000, and it is predicted that by 2025 it will contribute 50% to global consumption of seafood (Fisheries Global Information System 2004).

Aquaculture, the cultivation of freshwater and marine plants and animals, is one of the fastest-growing segments of Canada agriculture as well, with production of 154,083 tonnes in 2005, up 49,594 tonnes from 1991, and with sales of \$738.84 million in 2005, up \$447.3 million from 1997 (Statistic Canada 2005). The main arguments promoting the development of aquaculture are: 1) increasing global demand for food; 2) decreasing natural stocks (by increasing the aquaculture production, the pressure on the natural populations would reduce) (Gradwohl 1995); and 3) promoting economic development.

Decision makers including federal scientists, representatives of industrial organizations, local communities leaders, non-governmental organizations (NGO's), and provincial governments managers, are all seeking solutions about where to locate an aquaculture site (or "fish farm") in the marine environment. The decision makers must take into account all aspects of the problem environment, e.g., the marine resources, habitat, effluents, and human-based activities. In this thesis, alternative multi-criteria decision making aids are applied to the multi-criteria decision making for the case of siting new aquaculture fish farms. These methods facilitate group decision making by aggregating judgments of the decision makers in the groups.

1.2 Objective of Thesis

In response to the problems and the requirements for multi-criteria group decision making problem solving, the general objective of this thesis is to complete the following research work:

1. examine multi-criteria decision making models to evaluate and rank policies for group decision making; review literature for options for resolution of differences in group preferences.
2. compare and contrast the use of the group decision making models and discuss the effect of those models by comparing them with the other models found in the literature.
3. build an object-oriented application tool as a prototype for multi-criteria group decision making and test the capabilities of the models with given examples.
4. apply the prototype tool to the specific application in marine ecosystem decision making for aquaculture siting and the evaluation and selection of coastal marine aquaculture sites.

1.3 Outline of the Thesis

This thesis consists of seven main parts:

- i) Introduction: In this Introduction Chapter, information about a brief history of coastal aquaculture with its benefits, environmental and public concerns has been given.
- ii) Literature Review: Extensive search and analysis of widely used multi-criteria decision making methods literature and discussion of the approaches are performed in the second Chapter.
- iii) MCDM Methods: In the third Chapter, seven multi-criteria group decision making methods (AHP, AHP Combined, WSM, WPM, Group Evaluation, Fuzzy AHP, Fuzzy AHP Combined, and Fuzzy AHP Group) are analyzed by investigating their requirements with strength and weakness. By doing so, this thesis underlines the importance of the method selection and helps to determine the most preferred method for different cases.

- iv) Illustration and Comparison of Methods: The fourth Chapter illustrates and supports the use of an appropriate model through defining a problem and working through methods. These methods are applied to a comparative problem for critical evaluation and comparison toward identifying an appropriate model method.
- v) Web-based Tool for GDMing: In the fifth Chapter, a web-based integrated system for coastal aquaculture siting decision making as a prototype is introduced and developed. The tool is created using Php/JavaScript programming. The web-based tool examines the group decision making methods and how the methods can be used to influence the decision makers. The web-based tool developed as a prototype then provides the most suitable method with the results based on the selected method.
- vi) Case Study: The analysis of the case study and its results for this thesis are presented in Chapter 6.
- vii) Conclusion and Future Research Construction: Finally, in Chapter 7, conclusions of the research and future research recommendations are presented.

2. Literature Review

This thesis reviews literature on multi-criteria group decision making methods, discusses how these methodologies may influence decision makers, and gives some suggestions on how the various methods may be applicable to different problems and decision making settings.

This literature review is structured as follows:

- 2.1. Multi-criteria Group Decision Model
- 2.2. AHP Applications
- 2.3. Site Selections Problem Solving
- 2.4. Web-based Tools for the Application Tools

These subsections recognize the multidisciplinary systems and applied focus of this research. The overall objective of the work is to gather methodologies from the theory of multi-criteria decision making, with emphasis on group decision making using the analytic hierarchy method (AHP). An applied web-based tool as a prototype is developed to assist decision making in the choose of site selections for aquaculture operations in the marine ecosystem environment. Arguably, there has been considerable scientific work on marine ecosystems; however, the resolution of problem solving from a systems perspective in these complex environments has been minimal. The following literature review presents a representative selection of published work that is of direct benefit to the current research.

2.1. Multi-criteria Group Decision Models

In this chapter, the literature review in multi-criteria group decision making models is investigated.

2.1.1. Usage of Analytic Hierarchy Methods for Group Decision Making

Malczewski et al. (1997) proposed an integrated Multi-criteria Group Decision-Making Model (MCDM), using AHP and an integer (0-1) mathematical programming method, for land suitability/use analysis in the Cape Region, Mexico. They used AHP to structure the problem and to incorporate the conflicting preferences of different interest groups into a formal procedure by using pairwise comparisons. The AHP procedure is summarized as follows:

- 1) Develop a graphical representation of the given problem in terms of a hierarchy structure;
- 2) Weight the elements at each level of the decision hierarchy (overall goal, interest groups/land use categories/objectives, and attributes);
- 3) Compute the weighted priorities for the hierarchy;
- 4) Develop priority ratings for the set of attributes, sub-criteria.

The outcome of AHP, a set of land suitability coefficients, is then analyzed through integer programming to obtain the 'best' land use pattern over a number of different sites. The resulting land use pattern provides a solution that minimizes the environmental conflicts.

In the Chwolka et al. (2000) study, two different procedures for generating group decision support options are analyzed using AHP. The authors used AHP as a decision aid for the group as a whole, where the AHP result is treated as one single 'decision-making body' ranking. An example of a group comprised of two managers who must choose one of seven research projects for each of two different products is illustrated. For this two-issue decision problem, there are $7^2=49$ alternatives at the lowest level (alternatives) of the hierarchy. The global problem is too complex for a direct application of the AHP, because there are $49 \times (49-1)/2=1176$ pairwise comparisons required for each individual. Since Saaty (1990) recommends limiting the number of items at any level to a maximum of nine, the authors used one-issue at a time so the number of alternatives is reduced. The authors discussed the Geometric Mean Method and Weighted Arithmetic Mean Method and concluded that both methods do not guarantee an efficient outcome for the global problem with issue-by-issue compromises where a large number of pairwise comparisons need to be computed. The results in the study indicate that groups can achieve better outcomes when parties' preferences are aggregated at the end of an individual assessment process than when they are harmonized in a group assessment process. The authors draw this conclusion not for the analysis of the AHP, but for decision support tools for general, when they are employed in group decision process.

In the Lai et al. (2002) study, AHP is used to select a multi-media authorizing system (MAS) in a group decision environment using the AHP software package, *ExpertChoice* where there are three MAS products and six software engineers as decision makers. The study compares two techniques: AHP and Delphi. In the use of AHP, there are four ways to set the priorities: consensus, vote/compromise, geometric mean of the individual's judgments, and separate models/players. Initially, the attempt is to achieve a consensus among the group members. If the consensus cannot be achieved, the group may choose to vote/compromise. If the group consensus cannot be achieved and the group members don't desire to vote/compromise, then the geometric mean of individual preferences is used for the group's judgments. If the group members cannot discuss their decisions and their individual judgments are used separately without combining, then each group member's judgment will be weighted and computed separately. Since the Delphi technique can be time consuming, the AHP method was recommended to use for the study in a group decision environment. The reasons are that the AHP offers more opportunities for participants to exchange ideas, a better structure for decision support, and more chances for corrections and evaluations.

In the Liberatore et al. (1997) study, AHP is used in higher education where the alternatives are evaluated by group members. The first step is structuring the hierarchy. After all the group members agreed on a set of criteria, each member determined weights associated with the criteria by using Saaty's 1-9 scale. The authors suggested *ExpertChoice* to enter pairwise comparisons to evaluate the alternatives and criteria to get a result. If there is inconsistency in any pairwise comparison matrix, a revision is required in the judgment. Since there are a number of decision makers in the case study used in this paper, two approaches are offered

to combine the judgments: 1) seeking a consensus through discussion by the group to resolve their differences; 2) using geometric mean approach to combine the judgments. Due to the time consumed, the authors used the geometric mean approach in this study. The AHP methodology is also used in a more complex problem in this study. As a result, the two examples used in this study demonstrated that AHP is a versatile tool that can be applied to many academic evaluation problems.

2.1.2. Integrated Analytic Hierarchy Process and DEA Methods

Sinuany-Stern et al.(2000) used AHP and Data Envelopment Analysis (DEA) as a two-stage method for ranking decision making units where each unit has multiple inputs and outputs. The authors proved that for single input and single output, the AHP/DEA ranking is perfectly compatible with the DEA results. In general, these two well-known methods, DEA and AHP were integrated. In the first stage, DEA is used to create the pairwise comparison matrix. In the second stage, a single level AHP is utilized for fully ranking the units, based on the pairwise comparison matrix of the first stage. Since the AHP pairwise comparison matrix is derived from input/output, by using DEA, there is no subjective evaluation. That is the advantage of AHP/DEA, even though each of these approaches has their own limitations. In this study, the authors suggested a new approach for rank scaling units with multiple inputs/outputs in the DEA, integrated with AHP. In the case of single input and output, the author found that the new approach, AHP/DEA, is perfectly compatible with the DEA results so that the pairwise comparison matrix is perfectly consistent. In the general case of multiple inputs/outputs, the authors suggested that the ranking approach is not necessarily compatible.

Feng et al. (2003) also used an integrated AHP/DEA method for measurement of the efficiency of R&D management activities in universities. Since both AHP and DEA fail to measure the performance of management work in many cases, they propose a two-stage method which combines the AHP and the DEA to assess the management efficiency of R&D activities in universities. In the first stage, AHP is used to measure the R&D strength of a group of universities. The weight of each indicator is established and then the weighted sum of all indicator data of a university is treated. In the second stage, the relative efficiency is assessed by DEA. As a result, using a two-stage method which combines AHP and DEA is helpful for motivating the managerial staff of the universities to improve their work.

In the Yang et al. (2002) study, the proposed methodology includes the steps: data collection, layout alternative generation, AHP for qualitative data evaluation, and DEA for final design. In the first stage, AHP is used to weight the qualitative measures. Four steps are required for AHP:

- 1) Structuring the hierarchy of criteria and alternative for evaluation;
- 2) Assessing the decision-makers' evaluations by pairwise comparisons;
- 3) Using the eigenvector method to yield priorities for criteria and for alternatives by criteria; and

4) Synthesizing the priorities of the alternatives by criteria into composite measures to arrive at a set of ratings for the alternatives.

A spreadsheet-based program is run to solve the AHP ranking problem. Also, a consistency ratio (CR) is calculated in order to avoid comparison consistency between pairs of categories. The CR value is found to be less than the commonly critical value of 0.1, so it demonstrates that there is no evidence of inconsistency. In the second stage, DEA is used to solve the problem by considering both qualitative and quantitative performance data. As a result, the proposed methodology simultaneously considered both quantitative and qualitative objectives for the facilities layout design problem.

2.1.3. Fuzzy Analytic Hierarchy Process Methods

In the Bozdag et al. (2003) study, fuzzy group decision making is applied to select among computer integrated manufacturing systems. Four different multi-attribute fuzzy group decision making methods are analyzed by developing computer software to compare the results of the methods used. In this paper, the authors underlined that the decision makers usually find providing interval judgments gives more confidence than providing fixed value judgments. Based on Laarhoven and Pedrycz's work (1983), the earliest study on fuzzy, Bozdag et al. (2003) used triangular fuzzy functions in this paper. Since decisions are made in increasingly complex environment, the theory of group decision making can be used. To overcome this type of difficulties, the authors suggested using a multi-attribute decision making method, fuzzy group decision making method. The authors also underlined that when humans are making quantitative predictions in qualitative problems, Fuzzy AHP would be the best tool to handle qualitative assessments. It is shown in this study that the Fuzzy AHP approach is 'capable of capturing a human's appraisal of ambiguity when complex multi-attribute decision making problems are considered'. If there is an incomplete information or vagueness, the authors suggest using fuzzy methods where they have the ability of taking care of uncertainty in inputs.

In the Enea and Piazza (2004) study, they used the Constrained Fuzzy AHP technique in the case of project selection. They focused on the constraints that have to be considered within Fuzzy AHP in order to take in account all the available information. In the first step, Fuzzy AHP, where the matrix is composed of triangular fuzzy numbers, is used to evaluate the relative importance of each factor and to build the pairwise comparison matrix. Once the matrix is built, Fuzzy AHP impact scores are evaluated. After evaluating all the Fuzzy AHP impact scores for each project, a fuzzy final score is obtained by adding the weights determined for each project multiplied by the weights of the corresponding criteria. In an application of Constrained Fuzzy AHP, the authors examined an example proposed by Laarhoven and Pedrycz (1983). In this case, three members of a committee have to decide among three different projects: P1, P2, and P3. There are also four criteria: A1, A2, A3, and A4. The members want to determine a ranking and a relative weight of each project, so they can apply fuzzy AHP. Once the fuzzy estimates of the criteria's weights are evaluated, the committee has to compare the three projects (P1, P2, and P3) with each criterion independently. Using the geometric mean, all entries in the cells of the matrices are replaced

with single fuzzy numbers representing the opinion of the committee on each pair of project in comparison with each criterion. The results of the matrices are used to evaluate fuzzy weights, in particular, the fuzzy weights of each project in comparison with each criterion. Finally, a final score for each project is calculated by adding the fuzzy weights per project multiplied by the fuzzy weight of the corresponding criteria. As a conclusion in the study of project selection, the authors claimed that their approach has a minor level of uncertainty in inputs than that the ones proposed by van Laarhoven.

Ayag (2004) used fuzzy AHP to evaluate concepts in a new product development environment. In the study, after constructing the hierarchy, the decision-maker is asked to compare the elements at a given level on a pairwise basis to estimate their relative importance in relation to the element at the immediately preceding level. In conventional AHP, the pairwise comparison is made using a ratio scale. A frequently used scale is the nine-point scale (Saaty, 1990). Although the discrete scale of one to nine has the advantage of being simple and easy to use, it does not take into account the uncertainty in inputs associated with the mapping of one's perception or judgment to a number.

In this study, triangular fuzzy numbers, $\tilde{1}$ to $\tilde{9}$, are used to represent pairwise comparisons in order to capture the vagueness. In the AHP method, if one alternative is preferred to another possibility, then its eigenvector component is larger than that of the other possibility. A vector of weights obtained from the pairwise comparisons matrix reflects the relative performance of the various factors. In the fuzzy AHP, triangular fuzzy numbers are utilized to improve the scaling scheme in the judgment matrices, and interval arithmetic is used to solve the fuzzy eigenvector.

The four-step-procedure of this approach is given as follows:

Step 1: Compare the performance score. Triangular fuzzy numbers ($\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, $\tilde{9}$) are used to indicate the relative strength of each pair of elements in the same hierarchy.

Step 2: Construct the fuzzy comparison matrix.

Step 3: Solve the fuzzy eigenvalue.

Step 4: The priority weight of each alternative can be obtained by multiplying the matrix of evaluation ratings by the vector of attribute weights and summing over all attributes.

According to the author, the time consuming fuzzy AHP may have some disadvantages if the required calculations are made manually. To overcome this problem, a fuzzy AHP model is developed and integrated with a simulation generator to make the fuzzy AHP easier and quicker for the user. In the fuzzy AHP module in the integrated system, the user only needs to enter all the requested data for the study using a data-driven interactive tool in a user-friendly environment after reading the instructions given in detail on the computer screen. 'The results of both fuzzy AHP and the simulation experiment for each alternative were then used to determine the best conceptual design alternative'.

Zhang et al. (2004) used Fuzzy and score ranking by combining these with the Delphi method to quantify the membership functions of the evaluation factors of soil productivity for intensive agriculture in China. A geographic information system (GIS) is used to manipulate the spatial database of the study area. The weight contributions of the individual

factors were determined using the Delphi method and AHP. In the hierarchy, there are five criteria, and nineteen sub-criteria used for the evaluation. Expert score ranking was used to determine the priority of the criteria and sub-criteria. Consistency ratio is calculated to check the inconsistency of the judgments. Each criterion, and sub-criterion is examined with regarding the combined weight for sub-criteria and criteria in the hierarchy. Due to the limitations in the area where the study is focused, the new evaluation approach identifies the limitations, and therefore it can be used to assist the decision makers and farmers to find appropriate measures to improve soil problems. As a result of the study, the authors provided some advantages of their approach: 1) if the study is limited to be small, the farmers would apply the same agricultural management problem, 'therefore, the proposed system can provide more precise recommendations for farmers'; 2) GIS system is a mechanism for further monitoring the effects of the implementation of recommended practices; 3) the system used in the study can be applied to other agricultural areas such as 'water and nutrient management modeling'; and 4) the system can be used for other kinds of land evaluation.

2.2. AHP Applications

The nature of AHP and Fuzzy AHP has led to many assorted applications used in solving elusive, large, and complex decision problems. There are many papers, articles, and books documenting the use of application of AHP and Fuzzy AHP. The following studies have been a guide to this thesis work for understanding the importance and the use of the application of AHP and Fuzzy AHP.

Vaidya and Kumar (2006) presented a literature review of the applications of AHP. The authors referred to 150 papers in their study. They classified the AHP applications into three groups: 1) applications based on a theme; 2) specific applications; and 3) applications combined with some other methodology. The first group consists of selection, evaluation, benefit-cost analysis, allocations, planning and development, priority and ranking, and decision making. The second group consists of specific applications in forecasting, medicine and related fields. In the last group, AHP was applied with Quality Function Deployment (QFD). The following table, Table 2.2.1, shows the number of papers that have been published in the applications of AHP according to the Vaidya and Kumar (2006) review. It shows that AHP has been used widely in large field of different areas such as 20 papers published in decision making in the applications of AHP, and six of them are used in personal use, one in social, two in manufacturing, four in engineering, one in education, three in industry, one in government, and two in other areas.

	Personal	Social	Manufacturing	Political	Engineering	Education	Industry	Government	Others
Selection	5	7	3	3	8	3	2	1	
Evaluation	3	4	4		3	4	1	5	2
Benefit-cost		1	2	1			1	2	1
Allocation	1		3	2	1	1		1	1
Planning and Development	1	3			6	1	3	2	2
Priority and Ranking	6	1	4		2		5	1	1
Decision Making	6	1	2		4	1	3	1	2
Forecasting					1				2
Medicine		5							
QFD	3	1			1	1		1	1

Table 2.2.1: Categorized list of references. Numbers in the table indicate the number of papers has been published. Source: Vaidya and Kumar (2006).

AHP is used not only in personal use but also social (23), manufacturing (18), political (6), engineering (26), education (11), industry (15), government (13), and others (12).

The following figure, Figure 2.1, from Vaidya and Kumar (2006), provides the percentage distribution of the review papers arranged theme-wise. The numbers in the brackets indicate the number of papers in that category.

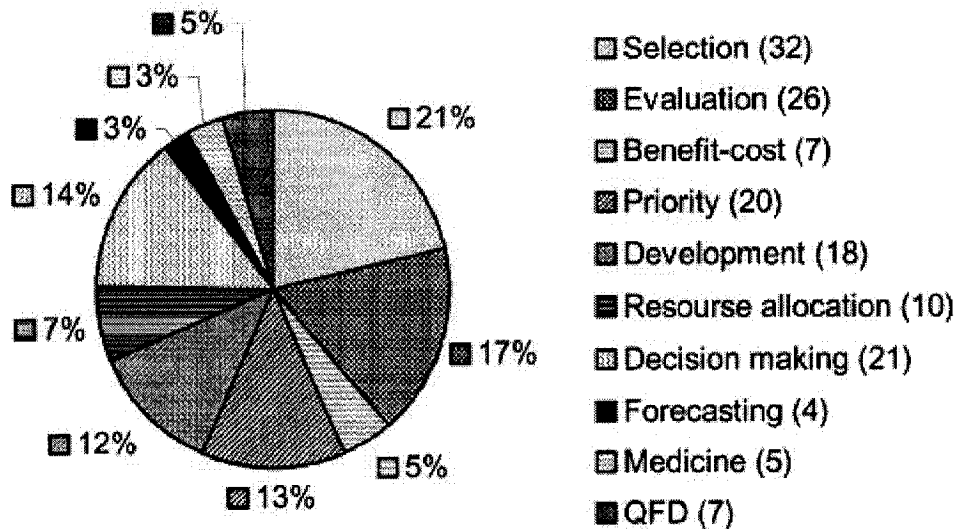


Figure 2.1: ‘Theme specific distribution of review papers’. Source: Vaidya and Kumar (2006).

Similarly, Figure 2.2 below also from Vaidya and Kumar (2006) represents the application area-wise percentage distribution.

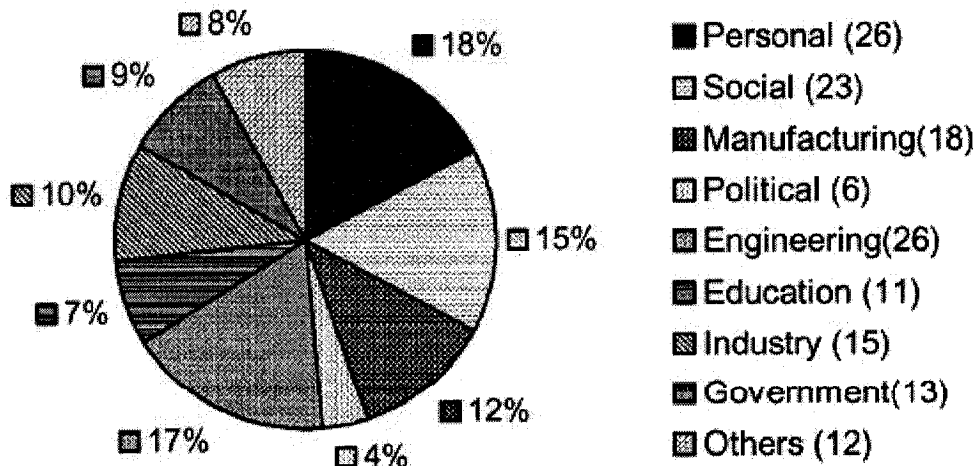


Figure 2.2: ‘Application area specific distribution of review papers’. Source: Vaidya and Kumar (2006).

Finally, Figure 2.3 below from Vaidya and Kumar (2006) shows the papers published by the respective years. It also indicates the growth in the use of AHP over the years. Since the Vaidya and Kumar (2006) study has been reviewed over 150 published papers, it ‘clearly supports the claim that AHP is being adopted as a widely used decision making tool’.

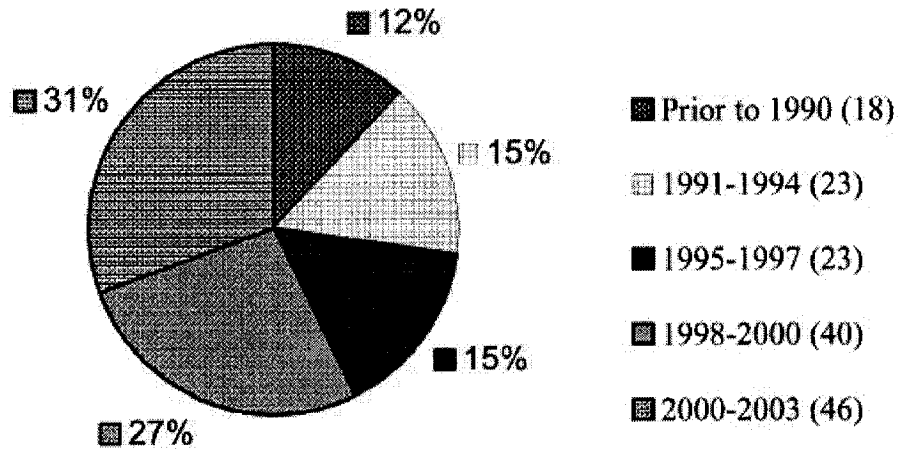


Figure 2.3: ‘Distribution of review papers over the years’. Source: Vaidya and Kumar (2006).

Al-Harbi (1999) used AHP in project management problem solving which involves complex decision making situations using the software package *ExpertChoice*. In his application, Al-Harbi examined five contractors in order to demonstrate the qualification for illustration purposes. The best contractor, in terms of skill, capability, and efficiency, are selected by using AHP technique. In that problem, the multiple criteria are experience, financial stability, quality performance, manpower resources, equipment resources, and current workload. Al-Harbi followed the suggestions given by the *ExpertChoice* software manual for using the AHP in a group decision making as follows:

- i) Even though it is assumed that the goal is the same for every single member in the group, it should be considered that each individual member’s decisions may be differ from the others that caused conflict. However, it is usually the best to work as a group and attempt to achieve a consensus.
- ii) A group member may be a shy person who is hesitant to speak up in a group discussion and may get influenced by other group members. Therefore, working in the environment of *ExpertChoice* reduces the influences of group think and dominance.
- iii) When *ExpertChoice* is used in a group session, group members can define and modify the problem through *ExpertChoice* based on their needs. Then, the group provide the judgments. If it is impossible to arrive at a consensus, then they may use some voting technique or may choose to take the average of the judgments.
- iv) It is important to have a meeting in which everyone is engaged.

After building the hierarchy, the AHP technique is used to evaluate and determine the criteria, calculate the priority for each criterion, calculate the consistency ratio, and check the consistency of the judgments. The author suggests the following possible scenario: if any of the contractors doesn't meet the minimum selected criteria, then it is the choice of the decision maker to eliminate the given contractor from the list. As a result of the study, the author suggests that the use of AHP in project management problem and the ability of AHP handling group decision making becomes a powerful tool to solve multi-criteria group decision making problems.

Leung et al (1998) used AHP in evaluation fisheries management options where they evaluated four alternatives - restricted vessel size, unrestricted upgrade, dual permit, open access – 'for limiting entry of longliners into the Hawaii pelagic fishery'. The criteria for achieving the goal are biological, economic, social, and political. According to the authors, there was only one published article in fishery management and a conference paper about applications of AHP in the literature until this paper has been published, DiNardo et al. (1989). Two questionnaire surveys were created to collect the judgments from the decision makers. These judgments were obtained by using AHP pairwise comparison approach. Once the pairwise comparisons were entered by the decision makers, AHP procedure applied to aggregate the weights to arrive a set of ratings for the alternatives. Despite having limitations, the authors found the AHP as a valuable tool and ideal as a decision-support system to be used in fisheries management. The study also showed that AHP can be adopted and applied to other decision making areas.

The main aim in the Soma (2002) study, 'how to involve stakeholders in fisheries management - a country case study in Trinidad and Tobago', is to show how the AHP methodology can be applied in the fisheries management in Trinidad and Tobago in order to show how it works and to identify strengths and weakness of the tool. The interest of stakeholders is widely known as an important role in fisheries management so that the stakeholders are more directly involved in decision making. Four steps are used in the AHP: 1) developing a hierarchy with the involvement of stakeholder groups, relevant objectives, criteria and management options; 2) providing data for the pairwise comparison matrix; 3) computing the relative weights; and 4) determining the ranking of the best alternatives. The criteria are economic, resources, employment, and governance/institutions. There are also some sub-criteria under each criterion. Due to the strength of the AHP where it has the capacity of i) involving stakeholder groups in decision making processes, and ii) assisting decision makers in fishery management, the authors suggested using AHP not only in fishery management but also in other decision making stages.

In the Chou and Liang (2001) study, AHP and fuzzy multiple criteria decision-making (MCDM) is used to evaluate shipping company performance in Taiwan. In the first stage, AHP is used to weight the criteria and sub-criteria of the decision hierarchy. Then, triangular and trapezoidal fuzzy numbers are used to denote the evaluation of alternatives. In the last stage, fuzzy MCDM is used to determine the best shipping company. Since the performance evaluation problem involves subjective assessment and may not reflect the nature, the non-fuzzy MCDM approach tends to be less effective. In practice, when decision makers evaluate subjective criteria with their objective assessments, the evaluation task becomes

difficult to define or determine. If such situation occurs, linguistics values such as ‘very important’, ‘very good’, and ‘about 300 dollars’ will be used. Thus the authors suggest using “a fuzzified-based decision model” would be “more appropriate and effective than traditional precision-based model” so that aspects of human thought processes would be included.

2.3. Site Selections Problem Solving

There are many articles and books written about the selection of a site decision problem which involves both the location and the site selection. The following papers reviewed in this specific application area are of particular relevance to the thesis case study provided in this research.

Bowen (1995) examined a comparison of AHP and PROSCAL for Nuclear Waste site selecting decision making. There are thirteen potential sites for the nuclear waste repository site selecting decision derived from U.S. Department of Energy (DOE). To select the best site, six criteria are used: human health and safety; archaeological, cultural and historical impacts; aesthetic impacts; biological impacts; socio-economic impacts; and economic costs. In the study, two of these parts are examined and compared. In the first part, Monte-Carlo simulation is used to compare the AHP and PROSCAL judgments. The simulation also compares the two methods in single decision-maker versus group decision situations. In the second part of the comparison, both methods are simulated for the site selection decision. In a single decision-maker situation, AHP outperforms PROSCAL in terms of a “correct” first site selection. When the number of decision-makers increased, however, both methods improved.

In the Liang and Wang (1991) study, a facility site selection algorithm based on fuzzy and the hierarchical structure analysis is proposed in order to determine the best facility site selection. They proposed two main attributes: (1) objective attributes that can be evaluated in monetary terms such as labor cost, building cost, investment cost, transportation cost; and (2) subjective attributes that are characterized by linguistic assessments such as discipline of workers, availability of workers, climatic conditions, etc. The authors emphasize that in real life, measuring subjective criteria may not be precisely defined for the decision makers so that a fuzzy multi-criteria decision-making method is needed to avoid the uncertainty in inputs. In order to obtain the weight of the criteria, fuzzy linguistic terms are used: ‘very low’, ‘medium’, ‘high’, ‘very poor’, ‘between very poor and poor’, ‘fair’, ‘very good’, etc. In the first step, fuzzy importance is evaluated based on the linguistic terms. In the second step, ratings are assigned to the facility sites under each criterion. There are two possible ratings can be used: fuzzy members and linguistic variable values. The decision makers may apply one of those based on practical needs. In this study, the authors suggested using a weighting set for the decision makers to evaluate the importance of the criteria, e.g., Weighting set, $W=\{VL, L, M, H, VH\}$, where VL=Very Low, L=Low, M=Medium, H=High, and VH=Very High. By using this approach, it helps the decision makers to make suitable decisions in a fuzzy environment.

Kuo et al (2002) used fuzzy AHP and neural networks for a decision support system to select convenience store locations. Since the conventional studies to select the best location provide only systematic steps without considering the relationships between the decision factors, this paper aims to develop a decision support system considering the relationships between the decision factors to select a convenience store location. The study consists of four components: 1) development of a hierarchical structure for fuzzy AHP; 2) weights determination; 3) data collection through government publications and actual investigation; and 4) decision making. In the first step, the hierarchical structure of fuzzy AHP is formulated. In order to determine the weight of the components, a questionnaire survey is conducted in the second step. The corresponding data are collected through some government publications and through investigation in the third step. Finally, a neural network is applied to study the relationships between the factors and the store performance. The authors provide a conclusion showing that the proposed system is able to provide a more accurate result.

In Eldin's et al (2004) study, three tools: AHP, Geographic Information System (GIS), and Expert System (ES) are integrated determine the optimum site for a specific facility. There are basically two steps in this study:

Step 1: Providing recommended values for the site criteria by using ES, and determining the alternatives based on the criteria by using GIS. To accomplish this, two components are used as follows: a) establishing suitability criteria (physical, environmental, geographical etc.); and b) identifying candidate sites based on the criteria.

Step 2: Providing recommended values for the site criteria by using ES, and determining the rank of alternatives by using AHP. To accomplish this, two components are used as follows: a) evaluation of the criteria by using AHP; and b) evaluation of the alternatives, candidate sites, by using AHP.

The authors suggest that by integrating two major tools (GIS and AHP), the user involvement and the level of the computer skills required are reduced. This study shows that three integrated tools successfully assist the decision maker in determining the optimum site.

2.4. Web-Based Tools for the Application Tools

The internet has become a powerful tool that enables researchers, decision makers, and managers to use it effectively in order to make better choices more efficiently. The purpose is for decision makers, especially those in different locations, with an access to the Internet, to make preferences or judgments in the pairwise comparisons so it becomes easier to do group decision making. The results are also shared among those users without using any other communication methods such as fax, telephone, or video conferences etc. The only requirement is Internet access. The following examples are some of the decision support tools that are currently available on the Internet. They are good examples for building a web-based decision support tool and contribute to the design of a web-based object-oriented

application tool for this thesis. The following papers and online interactive application tools are reviewed as related to the web-based tool for the thesis case study.

Xuan Zhu and Allan P.Dale (2000) used the web-based tool, JavaAHP, which implements the AHP in a general problem solving setting. It was written in Java and can be accessed globally via the internet. In this applet, decision makers (DMs) are allowed to construct a hierarchical model using graphical tools. The program allows users to create, edit, add, delete and move the elements by simply clicking and dragging the mouse. JavaAHP provides a framework for DMs to provide their pairwise comparisons. After the hierarchical model has been constructed and the pairwise comparisons have been made, JavaAHP presents a solution to the problem at hand. JavaAHP also measures inconsistency by calculating the inconsistency ratio of the AHP technique.

Click4DS Decision Support is a simple AHP web-based tool which provides decision support to DMs for specific problems in selecting computer software or choosing a girlfriend/boyfriend by implementing AHP. The system is available publically free of charge to users. The selected problem hierarchy is initially set with a number of fixed criteria in a single level. However, the program allows users to create their own list for a specific problem or to modify and enter their own criteria in the given specific problems as well. In the first step, DMs give the criteria list a name to manage the lists easily as a future reference. In the second step, the list of items is defined. At least two items must be selected to invoke pairwise comparison. In the third step, DMs provide pairwise comparison feedback between the elements in the criteria list. In the last step, users may review, print or e-mail the calculated weighted priorities across the selected criteria for the problem. The Summary Prioritization of the list of items is shown. DMs are also allowed to re-visit and adjust their choices.

Web-HIPRE (HIerarchical PREference analysis on the World Wide WEB) is a Java-applet for MCDM based on the decision support software HIPRE 3+ and announced as 'the first interactive MCDM software on the internet' developed by Hämäläinen and Mustajoki (1998). It provides AHP to support decision analysis. Web-HIPRE has unlimited global access as long as the DM has a Java-enabled browser. Web-HIPRE allows users, in a group process, to give their preferences in different locations. Results can easily be combined and shared among the users. The work can be secured by enabling the passwords so the only ones who can access relevant files are those who possess the password. Web-HIPRE also supports group decision making methods.

OPINIONS-Online (Hämäläinen and Kalenius, 1999) is an interactive tool that allows web-based group decision making, voting, and surveys. It can be accessed from anywhere with a Java enabled web-browser. The results can be seen by anyone or only for a certain group if protected by the users.

WINPRE (Workbench for Interactive Preference Programming) developed by Hämäläinen and Helenius (1998) and PRIME Decisions developed by Gustaffson et al. (2000) as Windows downloadable software. These software support multi-criteria decision analysis

under incomplete information. The software can be used individually or as a group modeling tool.

The citations referred to above treat Input-Output issues in different ways. In some cases the problems are fixed, in others DMs can set their own hierarchies and alternatives. In this thesis the web-based model developed as a prototype will contain a fixed hierarchy, criteria, sub-criteria, and alternatives for a group decision process in a well-defined problem setting. DMs are allowed to add or modify their preferences. The system identifies the DMs in order to store their judgments in an appropriate place, e.g., along with like decision makers from the same sub-group. If there is more than one DM in the group, individual weights can be aggregated into a group model with the geometric mean method. DMs are also allowed to modify their preferences by re-entering the system. Once all the inputs are entered by each group of DMs, the AHP provides priorities for each level in the hierarchy. An appropriate methodology will be used to evaluate the alternatives. The thesis web-based system is presented as a prototype in Chapter 5 of this thesis.

3. Group Decision Making Methods

In this chapter, a series of group decision making techniques and concepts are presented. The purpose of this chapter is to expose decision makers to a comprehensive and consistent overall evaluation of different methods and tools for decision support in a group setting. Our approach is based on the following methods: a) the AHP Method; b) the AHP Combined Method; c) the Weighted Sum Method; d) the Weighted Product Method; e) the Group Evaluation Method; f) the Fuzzy AHP Method; g) the Fuzzy AHP Combined Method; and h) the Fuzzy AHP Group Method.

3.1. The AHP Method

The analytic hierarchy process (AHP), provides a proven, effective means of dealing with complex decision making. AHP was first introduced by Thomas Saaty in the 1970's and has since been used in many application areas including finance, marketing, energy resource planning, sociology, architecture, engineering, industry, government, social, and group decision making. The importance of the AHP, its variants, and the use of pairwise comparisons in decision making is best illustrated in the more than 1,000 references cited in Saaty (1994) study. AHP (Saaty 1980) decomposes a complex MCDM problem into a system of hierarchies as presented below.

3.1.1. The AHP Decision Hierarchy

The below figure, Figure 3.1, is a basic hierarchical decision model in AHP which has a goal, criteria, and alternatives. Each criterion which is shown in Level I is pairwise compared for calculating their importance with respect to the goal (Level 0). In the last level, Level 2, each alternative is pairwise compared as to which is more preferred with respect to each criterion. Therefore, there is one main pairwise comparison matrix for criteria, and there are ' N ' pairwise comparison matrices for the alternatives with respect to the ' N ' criteria. Each set of alternatives would then be further divided into an appropriate level of detail, recognizing that the more criteria included, the relatively less important each individual criterion may become. Figure 3.1 provides an example of an AHP process design with level corresponding to the goal, the decision criteria, and the alternatives.

Using the AHP modeling in solving decision problems includes five steps:

- *Step 1:* Construct the hierarchical structure;
- *Step 2:* Obtain the input values by pairwise comparisons of each level;
- *Step 3:* Estimate the relative weights of criteria with respect to the goal, and each alternative with respect to each criterion;
- *Step 4:* Check for consistency; and
- *Step 5:* Combine the relative weights to determine the most preferred alternative.

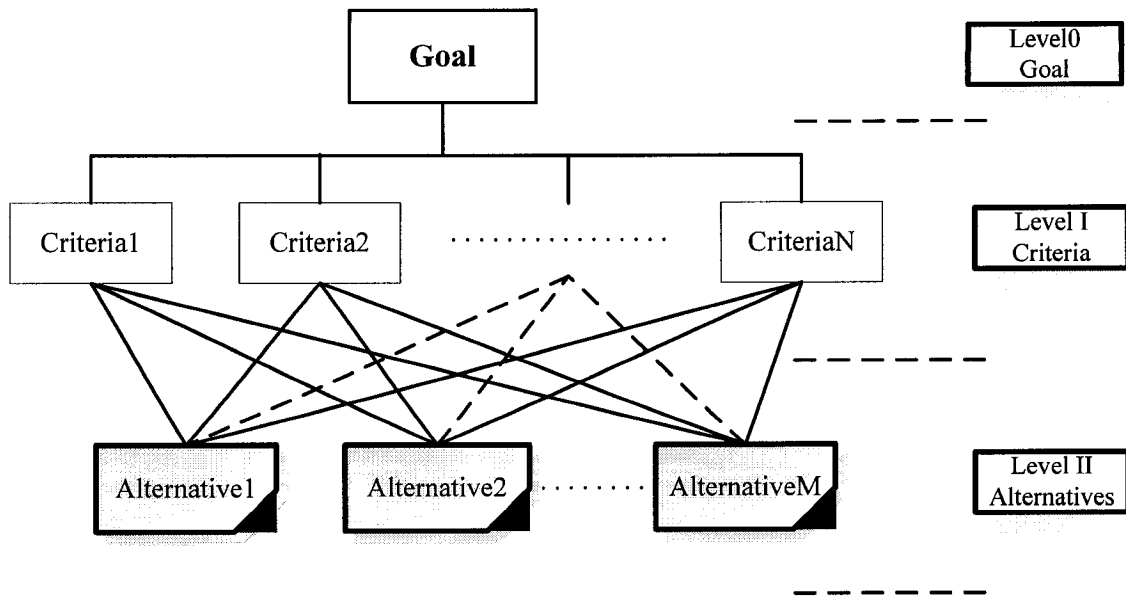


Figure 3.1: Analytic Hierarchy Process Design.

The comparisons in AHP are made in pairs. The numerical value assigned for each pairwise comparison is given by Table 3.3.1 (Saaty 1989, Table 1).

<u>Value</u>	<u>Definition</u>	<u>Explanation</u>
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance of one over another.	Experience and judgement strongly favor one activity over another.
5	Essential or strong importance.	Experience and judgment strongly favor one activity over another.
7	Very strong importance.	An activity is strongly favored and its dominance demonstrated in practice.
9	Extreme importance.	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgments.	When compromise is needed.

Table 3.3.1: Numerical 9-Point Scale of AHP Pairwise Comparisons.

First, the criteria are compared with respect to the goal. A $n \times n$ matrix, denoted as A , is created using the pairwise comparisons with elements a_{ij} indicating the value of i^{th} criterion relative to j^{th} criterion, as shown in the following formula.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{bmatrix}_{n \times n} \quad (3.1.1)$$

The values a_{ij} are obtained by the following rules:

$a_{ii} = 1$, $a_{ij} = 1/a_{ji}$, where $a_{ij} > 0$, for all i . Therefore, if a number is assigned to element i when compared to element j , then j has the reciprocal value when compared with i . Once constructing the matrix of comparison is done, the next step is to determine the weights of the criteria, in which w_i is the i^{th} criterion for n criteria. In order to determine w_i , and make w consistent, its entries is normalized by dividing them by their sum. This is repeated for all columns to obtain the normalized matrix A (A_{norm}) as follows.

$$A_{norm} = \begin{bmatrix} a_{11}/a'_1 & a_{12}/a'_2 & \cdots & \cdots & a_{1n}/a'_n \\ a_{21}/a'_1 & a_{22}/a'_2 & \cdots & \cdots & a_{2n}/a'_n \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1}/a'_1 & a_{n2}/a'_2 & \cdots & \cdots & a_{nn}/a'_n \end{bmatrix}_{n \times n} \quad (3.1.2)$$

a_{ij} in the above matrix is defined as the pairwise comparison of i^{th} row relative to i^{th} column, and a'_n is the sum of the pairwise comparisons in the i^{th} column. After the normalized weights are obtained, consistency check is required (Section 3.1.2).

The next step is to compare the alternatives pairwise with respect to each criterion. Since there are n criteria in a decision making problem, there will be n matrices of judgments for the alternatives. Each matrix contains the weights for each alternative and is determined in the same way as described above for determining the weights for the criteria.

Finally, the last step is to select the most preferred alternative among m alternatives. If there are n criteria and m alternatives, then a matrix $A_{AHP-Score}$ of size $n \times m$ is created. The $A_{AHP-Score}$ matrix contains the weight results a_{ij} for the alternative with respect to the criteria. According to the AHP, the best alternative (in the maximization case) is indicated by the following relationship.

$$A_{AHP-Score} = \max_i \sum_{j=1}^n a_{ij} w_j, \text{ for } i = 1, 2, 3, \dots, m. \quad (3.1.3)$$

The last step is finding the overall score of an alternative. Each of the alternatives defined at first hand are evaluated according to the objectives and their overall scores are calculated. The highest ranking or “best” alternative is chosen.

3.1.2. Consistency of Pairwise Comparisons

An important consideration of the decision relates to the consistency of judgments that DMs evaluate during the series of pairwise comparisons. In the DMs’ judgments, a desirable consistency is set, but it is not mandatory. In normal conditions, if A_1 is 2 times more preferred than A_2 , and A_2 is 3 times more preferred than A_3 , we can’t say that A_1 is 6 ($2*3$) times more preferred than A_3 . If this is the case, it indicates that some lack of consistency exists in the pairwise comparisons.

However, it is realized that complete consistency is very difficult to achieve and some lack of consistency is expected to exist in almost any set of pairwise comparisons. However, it is undesirable to have too much inconsistency. In order to handle the issue of consistency, Saaty (1974) developed an indicator, called a consistency index. If the degree of consistency is acceptable, the decision process can continue. However, if the degree of consistency is unacceptable, then the decision maker should reconsider and possibly revise the pairwise comparison judgments accordingly.

AHP provides a measure of the consistency of pairwise comparison judgments by computing a consistency ratio. If the value of the ratio exceeds 0.1, it indicates inconsistent judgments. In such cases, the decision maker should reconsider and revise the original values in the pairwise comparison matrix. Values of the consistency ratio of 0.1 or less are considered a reasonable level of consistency in the pairwise comparisons. The consistency ratio in AHP is calculated as follows:

Estimating the Consistency Ratio:

- *Step 1:* Multiply each value in each column of the pairwise comparison matrix by the relative priority of the first relative item considered. Sum the values across the rows to obtain the weighted sum.
- *Step 2:* Divide the elements of the vector of weighted sums obtained in step 1 by the corresponding calculated priority value.
- *Step 3:* Compute the average of the values computed in step 2; this average is denoted by λ_{max} .
- *Step 4:* Compute the consistency index (CI) as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.1.4}$$

where n is the number of items being compared.

- Step 5: Compute the consistency ratio (CR) as follows:

$$CR = \frac{CI}{RI} \quad (3.1.5)$$

where RI, the random index, is the consistency index of a randomly generated pairwise comparison matrix. RI depends on the number of elements being compared, N and takes on the following values:

N	2	3	4	5	6	7	8
R.I.	0.00	0.58	0.90	1.12	1.24	1.32	1.41

The following figure, Figure 3.2, is the schematic presentation of the AHP consistency ratio.

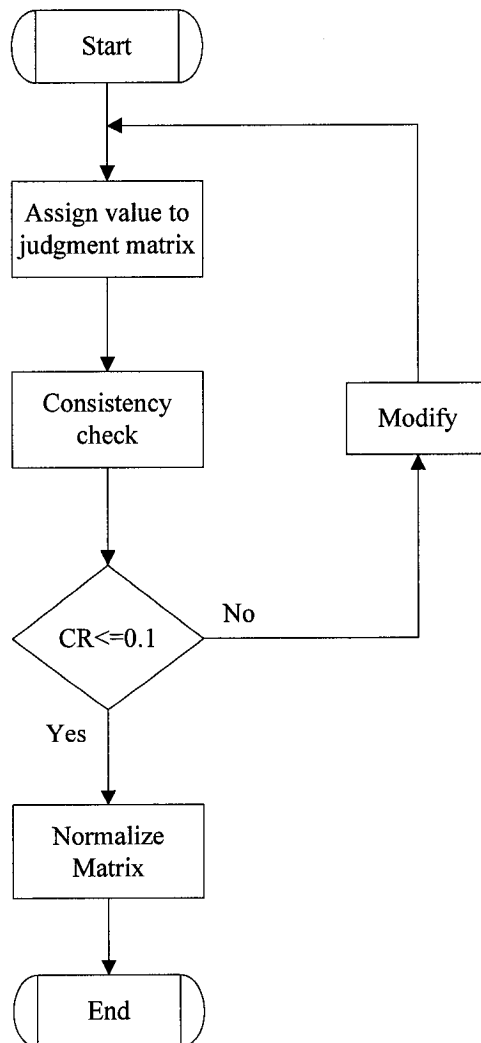


Figure 3.2: AHP consistency ratio flow diagram.

The above figure, Figure 3.2, shows the AHP consistency ratio flow diagram. Decision makers start making pairwise comparisons of criteria, sub-criteria and alternatives by using 9-point scale. Once the judgment values are assigned, the consistency of judgments for each matrix is checked. If consistency ratio is less than or equal to 0.1, the judgments are accepted. However, if consistency ratio is greater than 0.1, decision makers then is asked to modify their judgments. Once the modify process is done and the consistency ratio is less 0.1, the matrix is normalized.

3.1.3. AHP for Groups

AHP is used to solve multi-criteria decision making problems. It was first proposed by Thomas L. Saaty (1977, 1980) using four steps as explained in section 3.1.1. The flexibility of the AHP is allowed to use it in group decision making as well. There are three possible situations for AHP group decision making (Moreno, 2002): i) Group Decision where the decision makers are seeking a common decision by acting jointly; ii) Negotiated Decision where each decision maker has his/her own judgment and then through discussion with the other decision makers achieves a common solution; and iii) Systematic Decision where each decision maker acts independently.

The primary Group Decision method is the 'Delphi Technique'. It obtains decision makers' opinions and to seeks to achieve an input consensus among groups or group members. The Delphi Technique was developed by the RAND Corporation in the late 1950's. The technique has been used in a wide variety of different areas. According to Masser and Foley (Masser and Foley, 1987) there are three basic components of the Delphi method: i) "the creation of a panel of experts that can be consulted", ii) "the use of a series of questionnaires for consultation purposes", and iii) "the provision that is made for the feedback of findings to respondent". The aim of the Delphi technique is to organize the group communication without a direct discussion in order to purify group opinion and arrive at a consensus. It usually provides questionnaires to the individual experts or decision makers by protecting their anonymities. The main advantages of the Delphi technique are: i) elimination of bias by protecting the identities of the decision makers, and ii) elimination of the distance between decision makers because decision makers do not have to come together at a common location so this can reduce the cost of overall expenses.

3.1.4. AHP Combined in Group Decision Making

AHP Combined is also used in group decision making as a Systematic Decision tool. It provides several benefits. The more decision makers are involved in decision making, the more knowledge will be gained by all. If more than one person is affected by a decision, it is beneficial to have all those individuals involved in the decision process. By using AHP, each party is considered separately with respect to each criterion and, if required, with respect to each other. In general, the method of AHP Combined is appropriate for group decision support as a means of integrating the individual results of all involved decision makers.

In order to use AHP Combined in Group Decision Making, the inputs are combined by using a geometric mean approach across all individual decision makers. The geometric mean is the n^{th} root of the product of the all members of the set, e.g.,

$$\left(\prod_{i=1}^n a_i \right)^{1/n} = (a_1 * a_2 * \dots * a_n)^{1/n} \quad (3.1.6)$$

where n is the number of members, and a_i is the value of the i^{th} member.

As opposed to the arithmetic mean which yields the total value of n times the individual value if all the other data have the same value, the geometric mean calculates the individual value to the power of n if all the other data have the same value. Considering the outliers, use of the arithmetic mean may lie far from the median point. However, this problem is avoided with the geometric mean. In our study, each decision maker evaluates the criteria and the other decision makers with respect to the same criteria. The judgments are defined as multiplication, e.g., how much A is more or less important than B . The decision makers use this judgment to provide a pairwise comparison matrix. If the central tendency is violated, the geometric mean approach would fit better than using the arithmetic mean. However, if any member of a set is 'zero', then the calculation of the geometric mean may appear to be impossible. If such input happens, that value is set to '1' in order not to lose the data and to result in a feasible solution.

3.1.5. AHP Critique

One of the main advantages of the AHP method is the relative ease with which it handles multiple criteria. In addition to this, AHP is quite easy for most decision makers to understand and it can effectively handle both qualitative and quantitative data. The use of AHP does not involve complex mathematics, but integrates subjective judgments with numerical data. AHP involves the principles of decomposition, pair-wise comparisons, and priority vector generation and synthesis. The methodology by which the AHP assigns weights to criteria is simpler than that used by most of the other MCDM methods that rely upon an aggregate value function. A certain degree of inconsistency is allowed, which in most decision scenarios is realistic. The methodology of the AHP is similar to that used in common sense decision making. Users generally find the pairwise comparison form of data input straightforward and convenient.

On the other hand, there are some serious doubts and weakness of the AHP. Increasing in the number of levels and number of pairwise decisions, increases the data requirements of the process. Although the discrete scale of one to nine has the advantage of being simple and easy to use, it does not take into account the uncertainty in inputs associated with the mapping of one's perception or judgment to a number. The scale is very useful to compare two elements at a time in a decision making process, however, precisely because the scale is subjective, it is subject to human error. Though the purpose of the AHP is to capture the expert's knowledge, it doesn't reflect uncertainty in inputs in the judgment of a decision maker.

3.2. The Weighted Sum Method

The Weighted Sum Method (WSM) is probably the simplest and most commonly used group decision making method because of its simplicity in use. It continues to be used widely in multi-criteria group decision making applications. The basic principle in the WSM method is “the additive utility assumption” (Triantaphyllou and Baig 2005). That is, if all the units are the same for each criterion, then the most preferred alternative is the one with largest cumulative value.

Suppose there are ‘ m ’ alternatives and ‘ n ’ criteria then, the most preferred alternative among the other alternatives is the one that satisfies the following expression (Fishburn, 1967).

$$A^* = \max_i \sum_{j=1}^n a_{ij} w_j \quad , \text{ for } i = 1, 2, 3, \dots, m \quad (3.2.1)$$

where: A^* is the WSM score of the most preferred alternative, n is the number of criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion. This is similar to the AHP method; the only difference is that in WSM is based on absolute weights (weights assigned by decision makers directly) while in AHP come from a relative pairwise comparison procedure.

Even though the scoring method above is used for a single decision maker’s preference, group decision preference also can be built by using the same approach. AHP is used to obtain overall individual pairwise comparison matrix and priority. Weights, w_j , are assigned to each decision maker, j . The highest score among the alternatives would be the best alternative.

3.2.1. WSM Critique

The main advantage of the WSM is its ease of use by the decision makers. As opposed to AHP (see section 3.1) where the weights come from the pairwise comparison procedure, WSM is based on absolute weights that are assigned by decision makers directly. This method is based on the additive utility assumption (Triantaphyllou and Baig, 2005). The assumption is that the total value of each alternative is equal to the sum of products. Subjective and bias judgments in giving weights to the criteria, sub-criteria, and the alternatives cannot be eliminated.

3.3. The Weighted Product Method

The weighted product method (WPM) is very similar to the WSM. The main difference is that instead of addition in the model, as opposed to WSM, there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion.

“Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion” (Triantaphyllou and Baig, 2005). Then, the most preferred alternative is the one that is greater than or at least equal to the other alternatives. In general, in order to compare two alternatives A_K and A_L , the following product (Bridgman 1922, and Miller and Starr 1969) has to be calculated:

$$R(A_K / A_L) = \prod_{j=1}^n (a_{Kj} / a_{Lj})^{w_j} \quad (3.3.1)$$

where n is the number of criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion.

If the value of $R(A_K/A_L)$ is greater than or equal to one, then it indicates that alternative A_K is more desirable than alternative A_L (in the maximization case). The best alternative is the one that is better than or at least equal to all the other alternatives.

In WPM, there is no need to find the ranking for each DM. Rather; the preferred DM is determined by aggregating the pairwise comparison evaluation of the importance of each DM. This is determined by asking each DM to evaluate the importance of all other DMs (not including the DM doing the evaluation). After scoring each decision maker to find their relative importance, the DM with the highest score among the decision makers is selected. Assume X has the highest priority among X , Y , and Z . Decision makers have chosen X as the highest rated DM. To select the best alternative, we compare alternatives pairwise only using the rankings for X as the preferred decision maker.

In group WPM, the following product has to be calculated.

$$R(A_K / A_L) = \prod_{j=1}^n (a_{Kj} / a_{Lj})_q^{w_j} \quad (3.3.2)$$

where n is the number of criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion, and q is the preferred DM from the DMs' own comparisons.

3.3.1. WPM Critique

The WPM is sometimes called dimensionless analysis because in WPM the units are eliminated. Thus, the WPM, as opposed to the WSM, can be used in both single and multi-dimensional cases. The main advantage of this method is to use relative values instead of actual ones. In such situations, WPM can be used in any kind of cases without any difficulty. Nevertheless, in multi-criteria group decision making problem, decision makers will also be evaluated in some methods (Group Evaluation, WSM). If the weights of the decision makers are assumed equal, then there would be no solution in WPM.

Since WPM uses relative values by multiplying two elements to make a comparison between two alternatives, no solution will be reported if the equal weight assumption is warranted. After the decision makers are compared with each other, the one that has the highest score has priority to select the best alternative.

3.4. Group Evaluation Method

In this approach, decision makers are evaluated instead of alternatives with respect their comparison to each other relative to each criterion. In the group evaluation, overall weights applied to individuals results from DMs' feedback.

In the first step, each DM evaluates the other DMs, excluding the one who is doing the evaluation, with respect to each criterion by using pairwise comparison. In the second step, the weight of each criterion made by each DM is used to create a Group Evaluation by combining the weights. As a result, there will be only one matrix for each of the criterion with the weight of DMs. In the AHP model, each DM evaluates criteria with respect to criteria. The same weights are used in the Group Evaluation to get the overall weight of the criteria. To compute the overall priority, each value of the criterion given by each DM is multiplied by the given DM's weight. Summation of all the weights in a given row gives us the overall score of the given criterion. For example, consider the step by step calculation:

- *Step 1:* Weights of the DMs with respect to each criterion is calculated by using AHP pairwise comparison.
- *Step 2:* Weight of each criterion is computed given that assigned weight of each DM to the given criterion. AHP is used to calculate the weight of the criteria.
- *Step 3:* To get the overall priority of the alternatives in the group evaluation: the actual score of the i^{th} alternative by j^{th} criterion found in *Step 2* is multiplied by the weight of the given DM found in *Step 1*. Summing each of the possible outcomes will be the result of the overall priority in the Group Evaluation method for each alternative,

$$A_{GE} = \max \sum_{j=1}^n a_{ij} \alpha_j \quad (3.4.1)$$

where A_{GE} is the overall priority score for the alternative in the Group Evaluation model; a_{ij} is the actual score of i^{th} alternative in terms of the j^{th} criterion; and α_j is the overall weight of importance the j^{th} criterion.

3.4.1. Group Evaluation Critique

The main advantage in the Group Evaluation technique is to be able to calculate the weights assigned to the decision makers by using the pairwise comparison approach. This technique gives a unique advantage over some other methods. Since each DM evaluates the other DMs, the biasness of the weights is eliminated. For the sake of anonymity, no one is allowed to see the others' evaluation so this also eliminates biasness and none of the DMs is affected by the other decision makers' decision. Every single DM is given a direct and important role in the evaluation process of the DMs. That makes the technique very useful where it shows that the decision makers are satisfied with such a process instead of making an assumption about them e.g., equally important assumption.

However, some decision makers may find this technique threatening if they think that they don't have enough strength as some other DMs or they can't get the same weight after being evaluated by other decision making groups. In such situations, their weights on the judgments may be lower than the other decision makers' weights. It may not be easy to persuade those who strongly believe every decision making group should have equal weight on the vote. Also, if a DM has a subjective perspective, then the result is subject to evaluator bias. If a DM has no experience in a given field, the evaluation of that DM with respect to given field may end up with a bias decision. Having a large number of criteria, sub-criteria and a large number of decision makers makes the process problematic, slow, inefficient in terms of time, and it accordingly may also be expensive. This technique may not be appropriate if time has an important role on the decision, especially if all the calculations are done manually.

3.5. The Fuzzy Method

Zadeh (1965) first introduced fuzzy sets theory. He noted that "Much of the decision-making in the real world takes place in an environment in which the goals, the constraints and the consequences of possible actions are not known precisely" (Bellman and Zadeh 1970). Decision makers face many problems in their daily life and it is easier for them to give their opinions in a degree rather than as an absolute value.

Traditional or classical modeling techniques often do not capture the nature of complex systems, especially when humans are involved. Fuzzy logic performs very well in approximate environments and it can be used in mathematical operations. The following subsections define fuzzy numbers and arithmetic used in the analysis of fuzzy group decision making.

3.5.1. Triangular Fuzzy Numbers

Let \tilde{A} be a triangular fuzzy number and A be a crisp (non-fuzzy or real) number. The membership function $\mu_{\tilde{A}}(x)$ of \tilde{A} can be defined as (Bojadziev 1997):

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x - a_1}{a_M - a_1} & \text{for } a_1 \leq x \leq a_M, \\ \frac{x - a_2}{a_M - a_2} & \text{for } a_2 \leq x \leq a_M, \\ 0 & \text{otherwise.} \end{cases} \quad (3.5.1)$$

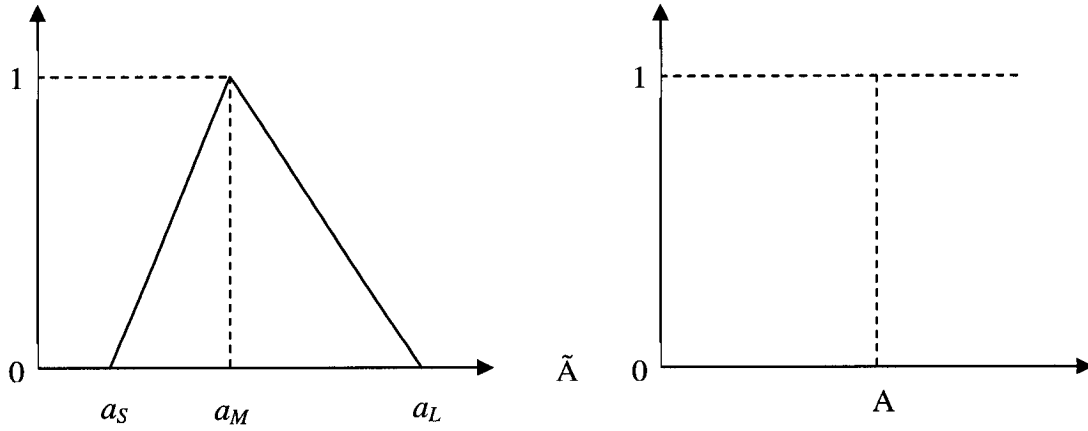


Figure 3.3: Triangular Fuzzy Number, \tilde{A} and Crisp Number, A .

Triangular numbers are very often used in fuzzy applications. Triangular numbers, \tilde{A} have only three possible outcomes denoted as (a_S, a_M, a_L) . The numbers represent the smallest possible value, the most probable value and the largest possible value, respectively for the phenomenon being described.

3.5.2. Basic Fuzzy Arithmetic

Let $\tilde{A} = (a, b, c)$ and $\tilde{B} = (d, e, f)$ be two positive triangular fuzzy numbers. The basic arithmetic operations are expressed as:

Changing Sign: $-(a, b, c) = (-c, -b, -a)$ (3.5.2)

Addition: $\tilde{A} \oplus \tilde{B} = (a + d, b + e, c + f)$ (3.5.3)

$$\text{Subtraction: } \tilde{A} - \tilde{B} = (a - f, b - e, c - d) \quad (3.5.4)$$

$$\text{Multiplication: } \tilde{A} \otimes \tilde{B} = (ad, be, cf) \quad (3.5.5)$$

3.6. The Fuzzy AHP Method

Although the purpose of AHP is to capture the expert’s knowledge, AHP does not really reflect human uncertainty in inputs (Buyukozkan et al. 2003). In the real world, a decision maker doesn’t give a precise judgment. Naturally, there is an uncertainty in a decision maker’s inputs/judgments. Due to the uncertainty and vagueness of judgments of decision makers, the AHP seems insufficient and too imprecise to capture the decision makers’ judgments correctly. However, this uncertainty in inputs can be modeled using the set of fuzzy theory by considering two more possible outcomes: smallest possible value and largest possible value. In the decision making environment of AHP, the relationship between criteria and alternatives are uncertain and imprecise as well as the input information. In order to improve these disadvantages of the AHP, a fuzzy extension of AHP, “Fuzzy AHP”, is applied to solve the hierarchical and MCDM problem.

Triangular and trapezoidal fuzzy numbers are used to express the decision makers’ pairwise comparison judgments on criteria and subcriteria. To prioritize the elements (criteria, and sub-criteria), their fuzzy utilities need to be compared and then ranked. However, this process can be quite complex especially if there are large numbers of criteria, sub-criteria, and decision makers. To facilitate the pairwise comparison process of the decision makers and to reduce the complexity, triangular fuzzy numbers are used in this thesis to obtain pairwise comparison judgments. Laarhoven and Pedrycz (1983) and Buckley (1985) take the lead in applying fuzzy logic principles to Saaty’s AHP. Laarhoven and Pedrycz (1983) initiate triangular fuzzy numbers based on arithmetic operations to express the decision maker’s evaluation of alternatives with respect to each criterion.

Importance	Fuzzy number	Definition	Membership function
1	$\tilde{1}$	Equally important	(1,1,2)
3	$\tilde{2}$	Moderately more important	(2,3,4)
5	$\tilde{3}$	Strongly more important	(4,5,6)
7	$\tilde{4}$	Very strongly more important	(6,7,8)
9	$\tilde{5}$	Extremely more important	(8,9,9)

Table 3.6.1: Numerical 9-Point Scale of Fuzzy AHP Pairwise Comparisons.

Once the decision hierarchy structure has been defined, the priorities of the factors of each level in the hierarchy are calculated by using pairwise comparisons. An assessment scale of nine levels (Table 3.6.1), as before is proposed and includes a translation to fuzzy numbers as follows:

Once decision makers make their judgments, the original values are assigned as modal so the smallest and largest values can be built into every pairwise comparison based on the translation table above. As explained in triangular fuzzy numbers (Laarhoven and Pedrycz 1983), the most probable value is between the smallest possible value and the largest possible value. Each of the triplets is defined as a triangular fuzzy number.

The first level of the hierarchy is analyzed through the use of the Fuzzy AHP Model. Decision makers are asked to weight the relative importance of each criterion separately, and rank each criterion with respect to other criteria as in AHP. Once the fuzzy pairwise comparison matrices are generated, a triangular fuzzy diagram is drawn to see which alternative is dominant. The consistency ratio (CR) is then used to check the consistency. (The CR is explained in the AHP Modeling section 3.1.2).

3.6.1. Fuzzy AHP Critique

As discussed in the AHP Method (see section 3.1), and the AHP Critique (see section 3.1.5), the AHP has many advantages over some other methods; however, the AHP doesn't take into account response uncertainty in inputs. The AHP judgments are subjective and may be uncertain. However, incorporating this human thinking style into the Fuzzy AHP method may become a time-consuming process, if all required calculations are made manually. In other words, as the number of attributes increases, the dimension of the problem naturally expands so the matrix size will be large. If a decision analyst asks the DMs to enter all possible outcomes: lowest possible value, modal value, and highest possible value, in the pairwise comparison matrix in order to consider their uncertainties, it becomes very complicated. In this situation, each DM enters the value three times more than that they enter in a regular AHP. This may cause a long time delay and difficulties with interpreting the use of the data.

3.7. The Fuzzy AHP Combined Method

After applying Fuzzy AHP for each individual, combining all the inputs as a Systematic Decision in group decision making is called Fuzzy AHP Combined. The geometric mean approach is used for combining individual input comparisons across a group. Each decision maker individually assesses alternatives following to the normal Fuzzy AHP procedures and from their assessments, the geometric mean is calculated to obtain the final decision.

As before, the geometric mean is calculated as follows:

$$G(a_1, \dots, a_n) = \left(\prod_{i=1}^n X_i \right)^{1/n} \quad (3.7.1)$$

where X_i are the values, represent each element of the same category from each group, taken the product to find the geometric mean, n is the number of values.

Once the geometric mean of each DM's judgment is calculated, there will be one fuzzy pairwise comparison matrix for each class which is the combination of the matrices of the same cluster. Another geometric mean is calculated, called a "vector", to get the lowest possible value of a given alternative by the lowest possible value of all the alternatives.

$$Va_i = \left(\prod_{i=1}^n L_{a_i} \right)^{1/n} \quad (3.7.2)$$

where a represents i^{th} alternative, Va_i represents the value of a_i^{th} alternative in the geometric mean; and L_{ai} represents the lowest possible value of the a_i^{th} alternative.

After obtaining all the vectors, the vector matrix is normalized.

To obtain the group fuzzy AHP combined overall scores for three possible outcomes: lowest, modal, and highest, the following equation is used:

$$P_i = r \sum N_{V_{a,r}} * M_{V_{cr}} \quad (3.7.3)$$

where P represents overall priority of i^{th} alternative; r represents each possible outcome: lowest, modal, and highest; $N_{V_{a,r}}$ represents r^{th} possible outcome of the normalized value found from Va_i^{th} vector where a_i is the i^{th} alternative; and M is the value in the normalized matrix calculated from the V_{cr} vector, where c is a given criterion and r is a possible outcome: lowest, modal, and highest.

Ranking triangular fuzzy numbers is used to select the best alternative as follows:

$e_{ij} = \max\{\min(\mu_i(x), \mu_j(y))\}$, for all $i, j=1, 2, 3, \dots, m$, and where $\mu_i(x)$ is the member function of x , $\mu_j(y)$ is the member function of y . If a_i dominates a_j then a_i is found as the best alternative if and only if $e_{ij}=1$ and $e_{ji}<Q$, where Q is some fixed positive fraction less than 1. Q is set by an analyst and could possibly be varied for a sensitivity analysis. The "rule of thumb" for setting Q is 0.9, as used in this thesis.

3.7.1. Fuzzy AHP Combined Critique

Decision makers specify their preferences in the form of AHP. The web-based tool developed as a prototype combines these preferences using fuzzy-AHP, with existing data, by using the geometric mean approach so the number of matrices is reduced distinctly. Although the fuzzy AHP Combined method reduces the time consuming input process compared to the regular fuzzy AHP, it can still become a time consuming process if there are large numbers of criteria, sub-criteria, alternatives, and decision makers. However, this process applies only if all the required calculations are made manually.

3.8. The Fuzzy AHP Group Method

In order to obtain the weighted sum of the criteria evaluated by fuzzy numbers in terms of rating and importance, the fuzzy weighted average is used for the calculation in the Fuzzy AHP Group Method. Weights for the decision makers were empirically defined according to the AHP whereby each DM responded to the overall importance of all other DMs for this decision. After collecting all the weights, there will be one overall fuzzy pairwise comparison matrix for each alternative set with respect to each criterion and one overall fuzzy pairwise comparison matrix for criterion with respect to the other criteria. As explained in the Fuzzy AHP Combined Method, the geometric mean approach is used to calculate the vectors. The next step is to normalize the vectors. Using the same approach above (Equation 3.7.3), the overall priority weights are calculated to get the three possible outcomes: lowest, modal, and highest for each alternative. If one alternative dominates the other alternatives, then that alternative is announced as the best alternative.

3.8.1. Fuzzy AHP Group Critique

Within a multi-criteria group decision making Fuzzy AHP problem, the traditional fuzzy AHP methods may not efficiently tackle group conflicting judgment. The main advantage of the Fuzzy AHP Group technique is to be able to determine the weights assigned the decision makers. In this approach, each DM evaluates the other DMs, excluding the one who's doing evaluation, by using pairwise comparison. The lowest and highest possible weights then will be determine based on the mode values which has been given by the decision makers. Since the weights of DMs are evaluated by the decision makers without making any assumption about them, the biasness of the weights is eliminated. Unlike the Delphi technique, in the Fuzzy AHP Group approach, no one is allowed to see the others' evaluation and this is done over the web-based tool developed as a prototype individually so this also eliminates biasness and none of the DMs is affected by the other decision makers' decision. This technique considers every single DM as an important role in making the decision. This makes the technique very useful where it shows that the decision makers are satisfied with such a process instead of making an assumption about them e.g., equally important assumption.

Beside the advantage of the Fuzzy AHP Group technique, there are some disadvantages. Some decision makers may find this technique threatening if they think that they don't have enough strength as some other DMs. It may not be easy to persuade those who strongly believe every decision making group should have equal weight on the vote. Also, if a DM has a subjective perspective, then the result is subject to evaluator bias. If a DM has no experience in a given field, the evaluation of that DM with respect to given field may end up with a bias decision. Having a large number of criteria, sub-criteria, alternatives and a large number of decision makers makes the process problematic, slow, inefficient in terms of time, and it accordingly may also be expensive. Computing the lowest and the highest of every single mode value is a double work if this is done manually which means to spend double time. This technique may not be appropriate if time has an important role on the decision, especially if all the calculations will be done manually.

4. Illustration and Comparison of Methods

In this chapter, a specific location problem is formulated and solved in order to illustrate and to demonstrate the practical application of multi-criteria problem solving with group decision making. This illustration assists in defining a framework for application of the methods presented in Chapter 3 above as well as a comparative analysis of the different methods.

4.1. The Problem

One of the most important decisions faced by any franchised business is where to locate outlets or branches. Location is usually the first factor considered in making a decision about a business. Concept, quality, service, and design are key factors in a business's success or failure. But if the selected location is not appropriate, accessibility is poor or there simply aren't enough people, no matter how good the product is, then the business will face difficulty.

Consider the following problem: the ABC Restaurant Corporation is offering franchise opportunities. After completing all the requirements from the applicants, the company seeks the best site location. Site selection has to be done very carefully because the success or failure of a restaurant depends to a great extent on its location. Since the restaurant site selection is an increasingly complicated business these days, the company wants to focus on four main criteria in order to select the best site location among three alternatives for the new franchise. These main criteria are:

- 1) *Visibility*: Being visible to local passing traffic is an important marketing characteristic. This factor can be one of the best forms of advertising and ensures that when the time comes for making a restaurant selection, the location will be recalled and considered by potential customers.
- 2) *Accessibility*: Accessibility concerns, such as the availability of parking, ease of entry, ease of transportation are also important characteristics of a successful restaurant.
- 3) *Traffic*: Traffic flow patterns and the volume of traffic around the location are important factors for the preferred analysis of a site selection.
- 4) *Convenience*: Convenience is also another important factor, especially where a customer has choice of multiple outlets within a local area.

Figure 4.1 below provides the decision hierarchy for the location problem including the goal of selecting the best site (Level 0), the four main criteria (Level I) and the three location alternatives (Level II).

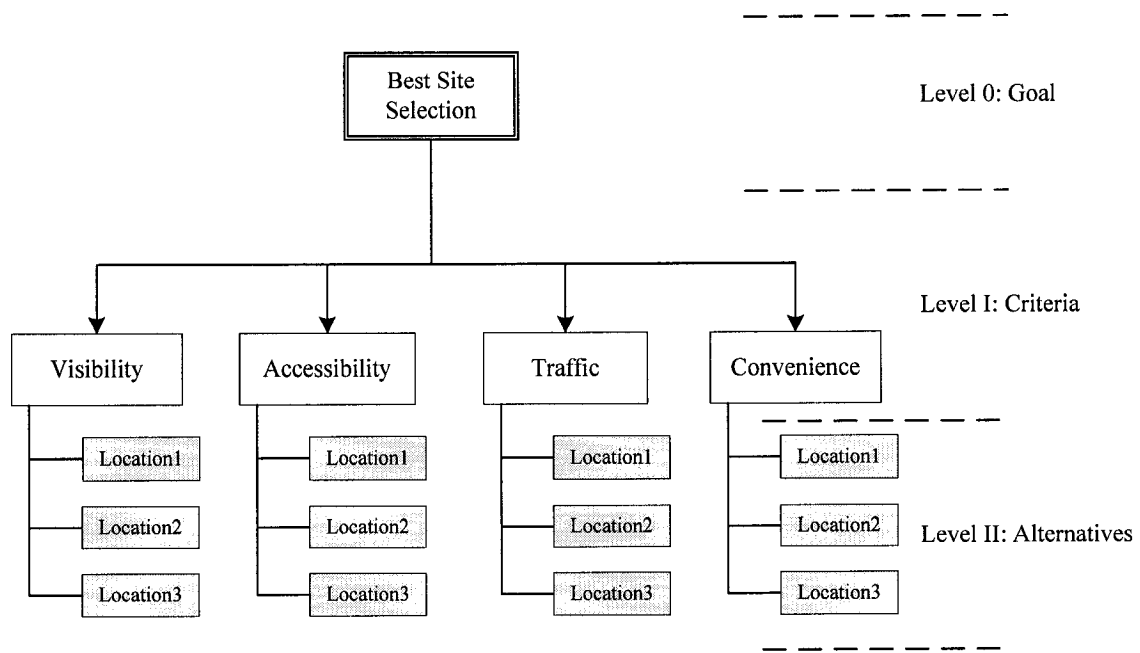


Figure 4.1: Hierarchy of selecting the best site location.

There are three decision makers involved in the site selection decision making process for the restaurant franchise: 1) the Chief Executive Officer (CEO); 2) the Chief Financial Officer (CFO); and 3) the Chief Information Officer (CIO).

Each of the decision makers are asked to compare each criterion pairwise, and to compare each location with respect to each criterion using a 9-point relative comparative scale. They also evaluate themselves on a similar 9-point scale as decision makers with respect to each criterion. The following sections present the results of the group decision making methods as discussed in Chapter 3 for the data of this problem. The results are then compared and analyzed.

The first set of comparisons determined which of the four top-level criteria, Visibility, Accessibility, Traffic, and Convenience, were judged as relatively important. This section below summarizes the three decision makers' comparisons, as well as synthesizing the individual pairwise comparison matrices. The tables in these sections provide the priorities of the criteria, alternatives, and decision makers based on the judgments in the individual pairwise comparison matrices.

4.2. AHP

Participants in the ABC Restaurant Corporation used a 9-point scale to express their pairwise comparisons preferences as in typical AHP Input. Actual illustrative data are presented below.

4.2.1. AHP Input

The inputs comparing Visibility, Accessibility, Traffic, and Convenience with respect to each of the other criteria for the CEO are given in Table 4.2.5 below. Comparisons of the alternatives with respect to each criterion for the CEO are also given in this section.

Criteria	Visibility	Accessibility	Traffic	Convenience	Priority
Visibility	1	3	2	2	0.398
Accessibility	-	1	1/4	1/4	0.085
Traffic	-	-	1	1/2	0.218
Convenience	-	-	-	1	0.299

Table 4.2.1: Criteria pairwise comparison matrix and priority by the CEO in AHP.

The above table shows that with respect to the overall goal of choosing a preferred site, that Visibility has the highest priority with 0.398 over the other criteria for the CEO. The relative importance of Visibility as an illustration can be calculated by reference relevant tables as follows:

$(1/2.333 + 3/12.000 + 2/5.250 + 2/3.750)/4 = 0.398$; where 2.333, 12.000, 5.250, and 3.750 are the sum of the columns of Visibility, Accessibility, Traffic, and Convenience, respectively.

Visibility has the highest importance value among the other criteria as a determinant of choosing a best location. This shows that according to the CEO, Visibility is the most important criterion with 0.398. Similarly, pairwise comparison matrices for each level of hierarchy of the company requirements for selecting a best location design are shown in the Appendix A.

The inputs comparing the locations with respect to Visibility for the CEO are given in Table 4.2.2 below. In this case, the CEO considers Location2 to be a factor of 3 more important than Location1 (1/3) while Location3 is a factor of 4 more important than Location1 (1/4) with respect to this criterion.

Visibility	Location1	Location2	Location3	Priority
Location1	1	1/3	1/4	0.123
Location2	-	1	1/2	0.320
Location3	-	-	1	0.557

Table 4.2.2: Alternatives pairwise comparison matrix and priorities with respect to the Visibility criterion for the CEO in AHP.

The above table shows that the Location3 has the highest priority with 0.557 over the other two locations with respect to Visibility for the CEO.

The inputs comparing the locations with respect to each criterion for the CEO are provided. Table 4.2.3 below shows the inputs comparing the locations with respect to the Accessibility criterion for the CEO. The CEO considers Location1 to be a factor of 3 more important than Location2 and a factor 4 more important than Location3 with respect to the Accessibility criterion. (See also Appendix A, section A.1 for the Accessibility location comparisons of all decision makers).

Accessibility	Location1	Location2	Location3	Priority
Location1	1	3	4	0.608
Location2	-	1	3	0.272
Location3	-	-	1	0.120

Table 4.2.3: Alternatives pairwise comparison matrix and priorities with respect to the Accessibility criterion for the CEO in AHP.

The above table shows that the Location1 has the highest priority with 0.608 over the ranked priorities of the other two locations with respect to Accessibility for the CEO.

The inputs comparing the locations with respect to Traffic for the CEO are given in Table 4.2.4 below. In this case, the CEO considers Location1 to be a factor of 3 more important than Location2 while Location1 is a factor of 5 more important than Location3 with respect to this criterion.

Traffic	Location1	Location2	Location3	Priority
Location1	1	3	5	0.619
Location2	-	1	4	0.284
Location3	-	-	1	0.096

Table 4.2.4: Alternatives pairwise comparison matrix and priority with respect to Traffic by the CEO in AHP.

The above table shows that the Location1 has the highest priority with 0.619 over the other two locations with respect to Traffic for the CEO.

The inputs comparing the locations with respect to Convenience for the CEO are given in Table 4.2.4 below. In this case, the CEO considers Location2 to be a factor of 3 more important than Location1 (1/3) while Location1 is a factor of 4 more important than Location3 with respect to this criterion.

Convenience	Location1	Location2	Location3	Priority
Location1	1	1/3	4	0.265
Location2	-	1	7	0.656
Location3	-	-	1	0.080

Table 4.2.5: Alternatives pairwise comparison matrix and priority with respect to the Convenience for the CEO in AHP.

The above table shows that the Location2 has the highest priority with 0.656 over the other two locations with respect to Convenience for the CEO.

4.2.2. AHP Results

Combining the results for the criteria comparisons and the location by criteria comparisons, the overall result comparing Location1, Location2, and Location3 for the CEO are given in Table 4.2.6 below. For the complete results for three decision makers, please see Appendix B, Section B.2.

	Overall Priority
Location1	0.315
Location2	0.408
Location3	0.277

Table 4.2.6: Alternatives priorities overall by the CEO.

The above table for the overall AHP results shows that the Location2 has the highest priority with 0.408 over the other two locations for the CEO. Therefore, Location2 is the preferred location to select for this decision maker. The CEO has given Location2 the highest weight with 0.408, whereas Location3 received the lowest priority. Similarly, pairwise comparison matrices for each criterion for the CEO and the other DMs for selecting a best location design are provided in the Appendix A. The following table, Table 4.2.7 presents the overall AHP priority ranking for three decision makers.

	Priority		
	CEO	CFO	CIO
Location1	0.315	0.135	0.483
Location2	0.408	0.304	0.323
Location3	0.277	0.561	0.194

Table 4.2.7: Overall alternatives priorities by the CEO, CFO, and CIO.

In the above table, each DM has given the highest weight to different alternatives. As discussed in Table 4.2.6 according to the CEO, Location2 is preferred among the other alternatives, whereas, the CFO prefers Location2 with the weight of 0.561, and the CIO prefers Location1 with the weight of 0.483. This overall result table shows that there is no harmony in the decision between three decision makers in the group.

4.3. AHP Combined

In the AHP combined methodology, the geometric mean is used to determine an overall output for evaluation for all decision makers together (see also Section 3.1.3). Each cell in the combined pairwise comparison input matrices were generated by calculating the geometric mean from all of the DM's individual inputs.

4.3.1. AHP Combined Input

After obtaining the geometric means of the pairwise comparison matrices, AHP was used to obtain rankings in the hierarchy as for a single decision maker, e.g. (see Appendix A, Section A.2 for AHP combined inputs).

Visibility	Location1	Location2	Location3	Priority
Location1	1.00	0.79	0.53	0.242
Location2	1.26	1.00	0.69	0.308
Location3	1.88	1.44	1.00	0.450

Table 4.3.1: Alternatives calculated pairwise comparison matrix and priority with respect to Visibility for AHP Combined.

Table 4.3.1 above shows that the Location3 has the highest priority with 0.450 over the other two locations with respect to Visibility for all the decision makers together in the AHP Combined method.

Accessibility	Location1	Location2	Location3	Priority
Location1	1.00	0.55	0.76	0.246
Location2	1.82	1.00	0.79	0.369
Location3	1.31	1.26	1.00	0.386

Table 4.3.2: Alternatives calculated pairwise comparison matrix and priority with respect to Accessibility for AHP Combined.

Table 4.3.2 above shows that the Location3 has the highest priority with 0.386 over the other two locations with respect to Accessibility for all the decision makers together in the AHP Combined method.

Traffic	Location1	Location2	Location3	Priority
Location1	1.00	1.55	1.71	0.449
Location2	0.64	1.00	0.87	0.268
Location3	0.58	1.14	1.00	0.284

Table 4.3.3: Alternatives calculated pairwise comparison matrix and priority with respect to Traffic for AHP Combined.

Table 4.3.3 above shows that the Location1 has the highest priority with 0.449 over the other two locations with respect to Traffic for all the decision makers together in the AHP Combined method.

Convenience	Location1	Location2	Location3	Priority
Location1	1.00	0.69	3.63	0.380
Location2	1.44	1.00	4.12	0.506
Location3	0.28	0.24	1.00	0.114

Table 4.3.4: Alternatives calculated pairwise comparison matrix and priority with respect to Convenience for AHP Combined.

Table 4.3.4 above shows that the Location2 has the highest priority with 0.506 over the other two locations with respect to Convenience for all the decision makers together in the AHP Combined method.

Criteria	Visibility	Accessibility	Traffic	Convenience	Priority
Visibility	1.00	2.62	1.39	1.39	0.357
Accessibility	0.38	1.00	0.57	0.69	0.149
Traffic	0.72	1.75	1.00	0.91	0.247
Convenience	0.72	1.44	1.10	1.00	0.247

Table 4.3.5: Criteria calculated pairwise comparison matrix, priority for AHP Combined.

Table 4.3.5 above shows that the Visibility has the highest priority with 0.357 among the other criteria in the AHP Combined method. Traffic and Convenience have the same priority with 0.247, and Accessibility has the lowest priority with 0.147.

The reason why using geometric mean is appropriate was explained in section 3.1.4. As opposed to the arithmetic mean which yields the total value of n times the individual value if all the other data have the same value, the geometric mean calculates the individual value to the power of n if all the other data have the same value. In our study, each decision maker evaluates the criteria and the other decision makers with respect to the same criteria. The judgments are defined as multiplication, e.g., how much A is more or less important than B . The decision makers use this judgment to provide a pairwise comparison matrix. However, if any member of a set is 'zero', then the calculation of the geometric mean may appear to be

impossible. If such input happens, that value is set to '1' in order not to lose the data and to result in a feasible solution.

4.3.2. AHP Combined Results

Once the geometric mean approach is used to obtain AHP Combined priorities from the pairwise comparison matrices, the overall priority for each location is given below in Table 4.3.6.

	Overall Priority
Location1	0.328
Location2	0.356
Location3	0.316

Table 4.3.6: Overall priority matrix for selecting the best location for AHP Combined.

Table 4.3.6 above for the AHP Combined results shows that the Location2 has the highest overall priority with 0.356 over the other two locations. Therefore, Location2 is the preferred location to select under this method.

4.4. WSM

Section 4.2, individual AHP, above provided the most preferred location according to each decision maker, the CEO, the CFO, and the CIO. The WSM criterion weights the output rankings of the individual decision maker to obtain a simple overall output result as shown below.

4.4.1. WSM Input

In the following table, Table 4.4.1, WSM inputs are collected by using individual AHP explained in AHP Method above (Section 4.2). (See Appendix A, A.3).

	Priority		
	CEO	CFO	CIO
Location1	0.315	0.135	0.483
Location2	0.408	0.304	0.323
Location3	0.277	0.561	0.194

Table 4.4.1: Individual AHP alternatives priorities for overall by CEO, CFO, and CIO.

Table 4.4.1 above shows the AHP individual DM output that used as input in WSM. The WSM inputs are twofold: 1) ranked priorities of each of the DMs (from individual AHP results) as in Table 4.4.1 and 2) the weights attached to the overall "importance" of each

DM. In the following example, the overall weights are found by asking each DM for the relative importance of their fellow DMs, not including themselves, with respect to the elements of the decision hierarchy (Figure 4.1). (See Appendix A, A.4).

	<u>Priority</u>
CEO	0.622
CFO	0.218
CIO	0.160

Table 4.4.2: DMs self-evaluation pairwise comparison matrix and overall priority for Group Evaluation.

Table A.5.6, is derived by using the criteria priorities for each decision makers in the AHP (Appendix A, A.1), and the decision makers’ priorities (Appendix A, A.5) with respect to each criterion in the Group Evaluation. See Section 4.6 (Group Evaluation) for detailed explanation.

4.4.2. WSM Results

In order to choose the best location considering all three DMs, we created the following table based on the weighted group evaluation of the DMs.

	C r i t e r i a				
	0.622	0.218	0.160		
	CEO	CFO	CIO		Priority
Location1	0.315	0.135	0.483	==>	0.302
Location2	0.408	0.304	0.323	==>	0.372
Location3	0.277	0.561	0.194	==>	0.326

Table 4.4.3: Overall weighted priority of the location alternatives under WSM.

In the above table, the alternatives were ranked and weighted with respect to the DMs. Overall, it is noted that Location2 has priority 0.372 over the other two locations.

4.5. WPM

The main difference between WSM and WPM is that instead of the addition of weighted sums in the model there is relative comparison through multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. The results below compare one alternative to others for each DM under WPM for the restaurant location problem.

4.5.1. WPM Input

From the AHP method, individual decision maker's preferences with respect to the four main criteria are determined (e.g., see Table 4.2.4 for the CEO above). WPM inputs are collected by using the AHP method above. As well, DMs are also evaluated (Section 4.6.7) and only the highest ranking DM's preferences are designated as relevant for WPM, while all the other DMs are eliminated. Table 4.6.7 described the overall priority of the DMs.

The overall pairwise comparison matrix and priority for CEO, CFO, and CIO given in Section 4.6 and Table 4.6.7 shows that the CEO has the highest priority with 0.622 over the other decision makers, the CFO, and the CIO. The CEO has significantly higher position.

4.5.2. WPM Results

Since the CEO has the highest Group Evaluation priority over the other two decision makers, the CEO's ranking is the most preferred. From the CEO's perspective, below table (Table 4.5.2), the calculated $R(.)$ ratio factor (Equation 3.2.1) for the main criteria of Location1 divided by Location2 gives a value that less than 1, implying that the weight of Location1 overall is less than that that the CEO assigns to Location2. Similarly, the $R(\text{Location2}/\text{Location3})$ ratio factor is equal to 2.043. This indicates that the overall weight of Location2 is much greater than that Location3 for the CEO. Also, the $R(.)$ ratio factor for Location1 divided Location3 equals to 1.349 which means Location1 is greater than Location3. In summary, Table 4.5.2 below notes the WPM preference for Location2.

CEO	Criteria					Priority
	0.398	0.085	0.218	0.299		
	Visibility	Access.	Traffic	Conv.		
Loc.1	0.123	0.608	0.619	0.265	=> $R(\text{Loc.1}/\text{Loc.2})=$	0.660
Loc.2	0.320	0.272	0.284	0.656	=> $R(\text{Loc.1}/\text{Loc.3})=$	1.349
Loc.3	0.557	0.120	0.096	0.080	=> $R(\text{Loc.2}/\text{Loc.3})=$	2.043

Table 4.5.1: Alternatives pairwise comparison matrix and priority by the CEO for WPM.

From the above table, it is noted that the CEO has the highest priority with among the other DMs, so the CEO's option is considered first. The best location to select would be Location2 since the CEO has the highest priority and Location2 is the CEO's preference.

4.6. Group Evaluation

In Group Evaluation, as below, each DM evaluates all other DMs with respect to each criterion by using pairwise comparison as in AHP inputs. However, instead of obtaining the weight of the alternatives, the Group Evaluation results obtain the relative weight of importance of each DM in the overall decision problem.

4.6.1. Group Evaluation Input

Each DM is asked to assign a weight to compare the other two DMs with respect to each of the four main criteria of this application. The importance weight of each of the DMs with respect to each criterion is as provided in the tables below.

Visibility	CEO	CFO	CIO	Priority
CEO	1	5	8	0.711
CFO	-	1	5	0.223
CIO	-	-	1	0.066

Table 4.6.1: DMs pairwise comparison matrix and priority with respect to Visibility.

Finally, with respect to Visibility, Table 4.6.1 above for the Group Evaluation shows that the CEO has the highest importance priority with 0.711 over the other two decision makers (CFO, CIO).

Accessibility	CEO	CFO	CIO	Priority
CEO	1	2	7	0.580
CFO	-	1	6	0.350
CIO	-	-	1	0.070

Table 4.6.2: DMs self-evaluation pairwise comparison matrix and priority with respect to Accessibility for Group Evaluation.

Table 4.6.2 above aggregated pairwise comparison table for each of the DMs Group Evaluation feedback shows that the DMs judge the CEO to have the highest importance priority with 0.580 over the other two decision makers (CFO, CIO) with respect to the Accessibility criterion.

Traffic	CEO	CFO	CIO	Priority
CEO	1	2	4	0.557
CFO	-	1	3	0.320
CIO	-	-	1	0.123

Table 4.6.3: DMs self-evaluation pairwise comparison matrix and priority with respect to Traffic for Group Evaluation.

Table 4.6.3 above for the Group Evaluation shows that the CEO has the highest priority with 0.557 over the other two decision makers (CFO, CIO) with respect to Traffic.

Convenience	CEO	CFO	CIO	Priority
CEO	1	4	2	0.557
CFO	-	1	1/3	0.123
CIO	-	-	1	0.320

Table 4.6.4: DMs self-evaluation pairwise comparison matrix and priority with respect to Convenience for Group Evaluation.

Similarly, Table 4.6.4 above for the Group Evaluation shows again that the CEO has the highest importance priority with 0.557 over the other two decision makers (CFO, CIO) with respect to Convenience.

4.6.2. Group Evaluation Results

The overall priority of the alternatives in the group evaluation is determined by multiplying the actual score of the i^{th} alternative by j^{th} criterion found above by the overall weights of the each DM for each criterion. Summing each of the possible outcomes will be a result of the overall priority in the group evaluation method for each alternative.

	CEO	CFO	CIO	Priority	Scaled Priority
Visibility	0.398	0.503	0.145	0.405	0.376
Accessibility	0.085	0.273	0.098	0.152	0.141
Traffic	0.218	0.145	0.327	0.208	0.193
Convenience	0.299	0.079	0.430	0.314	0.291
Total	1	1	1	1.078	1

Table 4.6.5: DMs criteria and overall priority for Group Evaluation.

Table 4.6.5 above for the Group Evaluation Results shows that Visibility has the highest priority with 0.376 over the other criteria. Traffic has the lowest priority with 0.193.

	Criteria				Priority
	Visibility	Accessibility	Traffic	Convenience	
Location1	0.152	0.402	0.462	0.320	0.296
Location2	0.304	0.303	0.263	0.572	0.474
Location3	0.544	0.295	0.274	0.109	0.330

Table 4.6.6: Alternatives pairwise comparison matrix and priority for Group Evaluation.

Table 4.6.6 above for the Group Evaluation results shows that Location2 has the highest priority with 0.474 over the other locations overall. Therefore Location2 is the preferred location under the Group Evaluation method.

Following table, Table 4.6.7, is derived by using the criteria priorities for each decision makers in the AHP (Appendix A1), and the decision makers' priorities (Appendix A5) with respect to each criterion in the Group Evaluation. In order to calculate the overall priority of each decision maker, the priority of the selected decision maker is multiplied by the relative priority of the criterion made by the same decision maker. The sum of the entries is stored as the overall priority of the selected decision maker.

	Overall Priority
CEO	0.622
CFO	0.218
CIO	0.160

Table 4.6.7: DMs self-evaluation pairwise comparison matrix and overall priority for Group Evaluation.

Table 4.6.7 above for the Group Evaluation shows the overall ranking of the decision makers. The CEO has the highest importance priority with 0.662 over the other two decision makers (CFO, CIO).

4.7. Fuzzy AHP

This section illustrates the use of the Fuzzy AHP method. Fuzzy AHP matrices are generated by using AHP pairwise comparison matrices conducted in AHP. For fuzzy arithmetic, the AHP data values are assigned to the fuzzy modes (middle range value). The left (minimum) and right (maximum) fuzzy parameters of the pairwise comparison inputs are assigned using a simple algorithm as explained below to provide the complete fuzzy data requirements for illustration purposes.

See Appendix A, A.6 for all decision makers data related to Fuzzy AHP.

4.7.1. Fuzzy AHP Input

In the following tables, each column is named based on the fuzzy parameter definition: *L* represents the least possible value, *M* represents the mode value and *H* represents the highest (or the most) possible value. This notation is used throughout the analysis of the fuzzy matrices.

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	2	3	4	1	2	3	1	2	3
Access.	1/4	1/3	1/2	1	1	1	1/5	1/4	1/3	1/5	1/4	1/3
Traffic	1/3	1/2	1	3	4	5	1	1	1	1/3	1/2	1
Conv.	1/3	1/2	1	3	4	5	1	2	3	1	1	1

Table 4.7.1: Criteria fuzzy pairwise comparison matrixes by the CEO for Fuzzy AHP.

Table 4.7.1 above for the Fuzzy AHP shows the CEO's fuzzy pairwise comparisons for the criteria for each possible outcome: low, mode, and high.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/4	1/3	1/2	1/5	1/4	1/3
Location2	2	3	4	1	1	1	1/3	1/2	1
Location3	3	4	5	1	2	3	1	1	1

Table 4.7.2: Alternatives fuzzy pairwise comparison matrixes with respect to Visibility by the CEO in Fuzzy AHP.

Table 4.7.2 above for the Fuzzy AHP shows the CEO's fuzzy pairwise comparisons for the locations with respect to Visibility for each possible outcomes: low, mode, and high.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	2	3	4	3	4	5
Location2	1/4	1/3	1/2	1	1	1	2	3	4
Location3	1/5	1/4	1/3	1/4	1/3	1/2	1	1	1

Table 4.7.3: Alternatives fuzzy pairwise comparison matrixes with respect to Accessibility by the CEO in Fuzzy AHP.

Table 4.7.3 above for the Fuzzy AHP shows the CEO's fuzzy pairwise comparisons for the locations with respect to Accessibility for each possible outcome: low, mode, and high.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	2	3	4	4	5	6
Location2	1/4	1/3	1/2	1	1	1	3	4	5
Location3	1/6	1/5	1/4	1/5	1/4	1/3	1	1	1

Table 4.7.4: Alternatives fuzzy pairwise comparison with respect to Traffic by the CEO in Fuzzy AHP.

Table 4.7.4 above for the Fuzzy AHP shows the CEO's fuzzy pairwise comparisons for the locations with respect to Traffic for each possible outcome: low, mode, and high.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/4	1/3	1/2	3	4	5
Location2	2	3	4	1	1	1	6	7	8
Location3	1/5	1/4	1/3	1/8	1/7	1/6	1	1	1

Table 4.7.5: Alternatives fuzzy pairwise comparison matrixes with respect to Convenience by the CEO in Fuzzy AHP.

Table 4.7.5 above for the Fuzzy AHP shows the CEO's fuzzy pairwise comparisons for the locations with respect to Convenience for each possible outcome: low, mode, and high.

4.7.2. Fuzzy AHP Results

Once the tables are generated for each DM as above (Section 4.7), the geometric mean (analogous to the AHP Combined approach) is calculated. Let v_i denote the geometric mean of each alternative. The normalized vectors by criterion are:

Criteria		Low	Mode	High	Normalized Matrix		
					Low	Mode	High
Visibility	v1	1.190	1.860	2.450	0.083	0.130	0.171
Accessibility	v2	0.320	0.380	0.490	0.022	0.027	0.034
Traffic	v3	0.760	1.000	1.500	0.053	0.070	0.104
Convenience	v4	1.000	1.410	1.970	0.070	0.099	0.137
<i>Total</i>		3.270	4.660	6.400	14.320		

Table 4.7.6: Criterion fuzzy normalized matrix for the CEO for Fuzzy AHP.

Table 4.7.6 above for the Fuzzy AHP shows the normalized matrix of the Table 4.7.5 for each possible outcome: low, mode, and high.

Each DM weighted the criteria separately and the ranking of the criterion was computed. Multiplying and then summing those weights, gives us the weight of alternatives in the Fuzzy AHP method. Given these results, the preferred alternatives are noted by drawing the triangular fuzzy diagram to observe dominant alternatives.

	CEO			CFO			CIO		
	Low	Mode	High	Low	Mode	High	Low	Mode	High
Location1	0.020	0.034	0.057	0.008	0.012	0.018	0.038	0.064	0.099
Location2	0.025	0.044	0.075	0.021	0.031	0.047	0.010	0.016	0.028
Location3	0.015	0.030	0.048	0.021	0.033	0.049	0.008	0.014	0.024

Table 4.7.7: Alternatives overall priority for Fuzzy AHP.

Table 4.7.7 above for the Fuzzy AHP method shows the priorities of the three locations for all the decision makers for each possible outcome: low, mode, and high.

The figures below (Figure 4.2, Figure 4.3, Figure 4.4) show the triangular fuzzy graphical outputs for the three decision makers (CEO, CFO, CIO), respectively. In the first figure, Figure 4.2, Location2 dominates the other two locations which represents Location2 as the best location to select for the CEO. Location1 and Location3 have almost the same characteristics in terms of weights in fuzzy triangular crisp numbers. The difference in terms of mode values between those two locations is 0.004 (0.034-0.030).

In the second figure, Figure 4.3, Location3 dominates the other two locations which represents Location2 as the best location to select for the CFO. However, Location3 and Location2 are so close each other and the difference in terms of mode values is only 0.002 (0.033-0.031).

In the third figure, Figure 4.4, Location1 doesn't overlap with the other locations. Therefore, it cannot be said that Location1 has priority over the other two locations. However, the comparison is possible between the other two locations. In this figure Location2 dominates Location3. Thus, Location3 is the best location to select for the CIO. However, Location2 and Location3 are so close each other and the difference in terms of mode values is only 0.002 (0.016-0.014).

Since the figures below have the same scales, it is possible to determine which location is the most preferred location among three decision makers. According to the final fuzzy priority scores with the highest fuzzy priority ranking of the decision makers, Location2 in the CEO's preferences dominates the other decision makers' preferences. Therefore, Location2 is selected as the best alternative for all the decision makers.

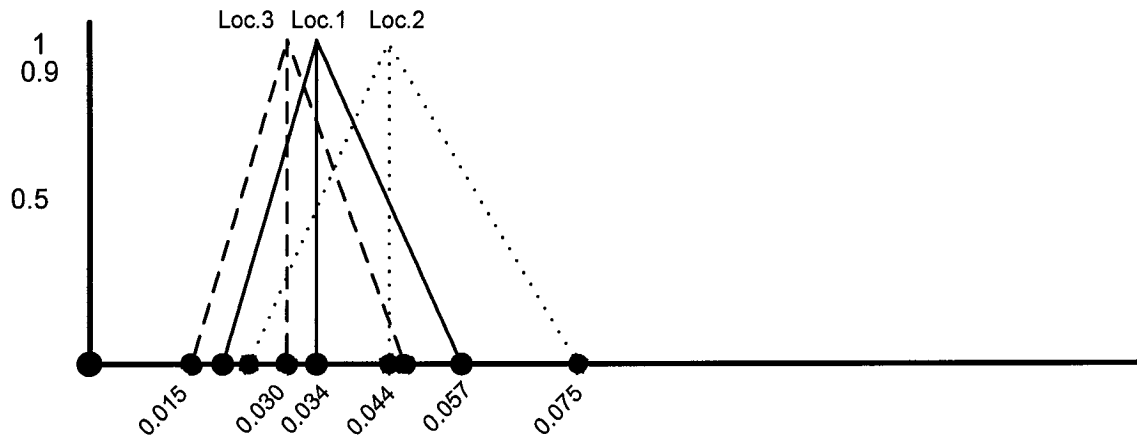


Figure 4.2: Triangular fuzzy graphical output for the CEO in the Fuzzy AHP Method.

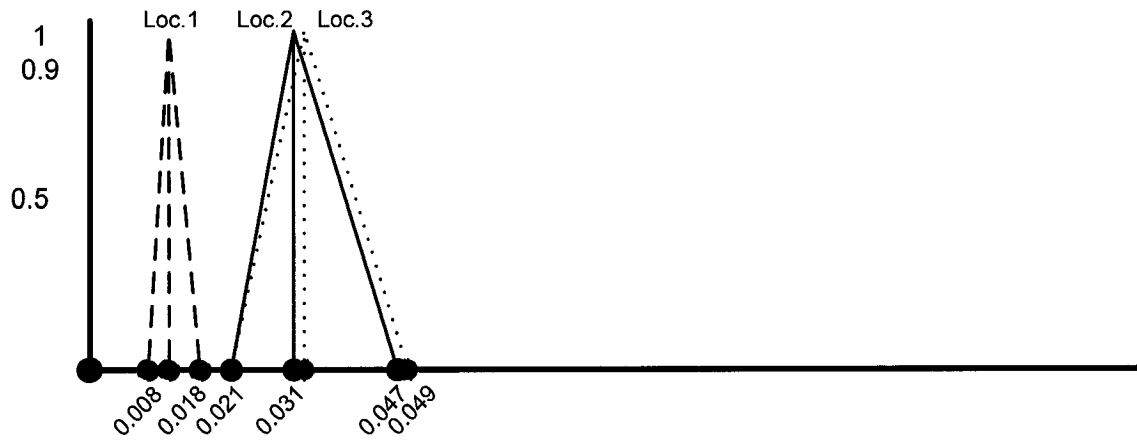


Figure 4.3: Triangular fuzzy graphical output for the CFO in the Fuzzy AHP Method.

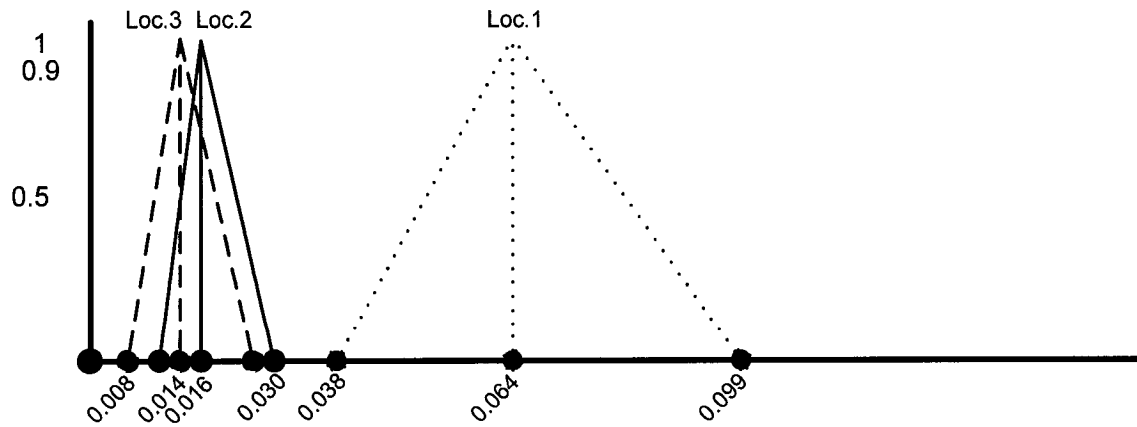


Figure 4.4: Triangular fuzzy graphical output for the CIO in the Fuzzy AHP Method.

4.8. Fuzzy AHP Combined

The inputs above for the Fuzzy AHP method are used via the geometric mean approach to obtain the Fuzzy AHP Combined analogous to the AH Combined approach presented in Section 4.3.1 above.

4.8.1. Fuzzy AHP Combined Input

In the following tables, each column is named based on the fuzzy parameter definition: *L* represents the least possible value, *M* represents the mode value, and *H* represents the highest (or the most) possible value. This notation is used throughout the analysis of the fuzzy matrices.

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	1.587	2.621	3.634	0.909	1.387	1.957	0.909	1.387	1.957
Access.	0.275	0.382	0.630	1	1	1	0.431	0.572	0.693	0.531	0.693	0.941
Traffic	0.511	0.721	1.101	1.442	1.747	2.321	1	1	1	0.606	0.909	1.587
Conv.	0.511	0.721	1.101	1.063	1.442	1.882	0.630	1.101	1.651	1	1	1

Table 4.8.1: Criteria fuzzy pairwise comparison for the CEO in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined shows the fuzzy pairwise comparisons once the geometric mean is used to obtain the combined matrix for the criteria for each possible outcome: low, mode, and high.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.630	0.794	1.053	0.405	0.531	0.693
Location2	0.950	1.260	1.587	1	1	1	0.437	0.693	1.145
Location3	1.442	1.882	2.466	0.874	1.442	2.289	1	1	1

Table 4.8.2: Alternatives fuzzy pairwise comparison with respect to Visibility for Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined shows the fuzzy pairwise comparisons once the geometric mean is used to obtain the combined matrix for the three locations with respect to Visibility for each possible outcome: low, mode, and high.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.630	0.794	1.053	0.405	0.531	0.693
Location2	0.950	1.260	1.587	1	1	1	0.437	0.693	1.145
Location3	1.442	1.882	2.466	0.874	1.442	2.289	1	1	1

Table 4.8.3: Alternatives fuzzy pairwise comparison with respect to Accessibility for Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined shows the fuzzy pairwise comparisons once the geometric mean is used to obtain the combined matrix for the locations with respect to Accessibility for each possible outcome: low, mode, and high.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.170	1.554	2	1.387	1.710	2.080
Location2	0.500	0.644	0.855	1	1	1	0.630	0.874	1.357
Location3	0.481	0.585	0.721	0.737	1.145	1.587	1	1	1

Table 4.8.4: Alternatives fuzzy pairwise comparison with respect to Traffic for Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined shows the fuzzy pairwise comparisons once the geometric mean is used to obtain the combined matrix for the locations with respect to Traffic for each possible outcome: low, mode, and high.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.531	0.693	0.941	2.466	3.634	4.718
Location2	1.063	1.442	1.882	1	1	1	2.884	4.121	5.241
Location3	0.212	0.275	0.405	0.191	0.243	0.347	1	1	1

Table 4.8.5: Alternatives fuzzy pairwise comparison with respect to Convenience for Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined shows the fuzzy pairwise comparisons once the geometric mean is used to obtain the combined matrix for the locations with respect to Convenience for each possible outcome: low, mode, and high.

4.8.2. Fuzzy AHP Combined Results

After applying Fuzzy AHP for each individual, the geometric mean is used to combine the relative inputs as shown in Fuzzy AHP Combined Input above. In order to obtain overall scores for three possible fuzzy outcomes - lowest, modal, and highest - each matrix is normalized. Ranking the triangular fuzzy numbers is used to select the best alternative. If one alternative dominates the others, it is the preferred location. Q is set as fixed positive fraction that is less than 1 for the determining the preferred alternatives. In this study, Q is set to 0.9 (see Section 3.7).

The tables below show the normalized matrices for each criterion and overall criteria for the Fuzzy AHP Combined results.

Criteria		Low	Mode	High		Normalized Matrix		
Visibility	v1	1.070	1.498	1.932		0.088	0.125	0.159
Access.	v2	0.501	0.624	0.801		0.039	0.049	0.062
Traffic	v3	0.817	1.034	1.419		0.055	0.072	0.099
Convenience	v4	0.765	1.034	1.360		0.059	0.083	0.111
<i>Total</i>		<i>3.153</i>	<i>4.191</i>	<i>5.511</i>	<i>12.855</i>			

Table 4.8.6: Normalized Matrix for ranking the alternatives with respect to overall criteria in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined Results shows the fuzzy normalized matrix for the criteria for each possible outcome: low, mode, and high.

Visibility		Low	Mode	High		Normalized Matrix		
Location1	v1	0.634	0.750	0.900		0.067	0.079	0.095
Location2	v2	0.746	0.956	1.220		0.079	0.101	0.129
Location3	v3	1.080	1.395	1.781		0.114	0.147	0.188
<i>Total</i>		<i>2.460</i>	<i>3.101</i>	<i>3.901</i>	<i>9.463</i>			

Table 4.8.7: Normalized Matrix for ranking the alternatives with respect to Visibility in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined Results shows the fuzzy normalized matrix for the locations with respect to Visibility for each possible outcomes: low, mode, and high.

Accessibility		Low	Mode	High		Normalized Matrix		
Location1	v1	0.619	0.749	0.926		0.066	0.080	0.099
Location2	v2	0.907	1.130	1.448		0.097	0.121	0.155
Location3	v3	0.903	1.182	1.470		0.097	0.127	0.157
<i>Total</i>		<i>2.430</i>	<i>3.061</i>	<i>3.844</i>	<i>9.334</i>			

Table 4.8.8: Normalized Matrix for ranking the alternatives with respect to Accessibility in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined Results shows the fuzzy normalized matrix for the locations with respect to Accessibility for each possible outcome: low, mode, and high.

Traffic		Low	Mode	High		Normalized Matrix		
Location1	v1	1.175	1.385	1.608		0.126	0.148	0.172
Location2	v2	0.680	0.825	1.051		0.073	0.088	0.112
Location3	v3	0.708	0.875	1.046		0.076	0.094	0.112
<i>Total</i>		<i>2.563</i>	<i>3.085</i>	<i>3.705</i>	<i>9.353</i>			

Table 4.8.9: Normalized Matrix for ranking the alternatives with respect to Traffic in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined Results shows the fuzzy normalized matrix for the locations with respect to Traffic for each possible outcome: low, mode, and high.

Convenience		Low	Mode	High		Normalized Matrix		
Location1	v1	1.094	1.361	1.644		0.102	0.126	0.153
Location2	v2	1.453	1.811	2.145		0.135	0.168	0.199
Location3	v3	0.343	0.406	0.520		0.032	0.038	0.048
<i>Total</i>		<i>2.890</i>	<i>3.578</i>	<i>4.308</i>	<i>10.776</i>			

Table 4.8.10: Normalized Matrix for ranking the alternatives with respect to Convenience in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined Results shows the fuzzy normalized matrix for the locations with respect to Convenience for each possible outcome: low, mode, and high.

To compute the lowest possible value for Location1, the weight of each criterion in terms of Location1 is multiplied by the relevant weight of the same criterion from the overall criteria. Summation of each multiplied weight from four criteria gives the importance of weight for Location1 in terms of the lowest possible outcome. The same approach is followed to compute the mode, and high weights for the remaining alternatives. The following table is compiled after all the necessary computation is done.

	Priority		
	L	M	H
Location1	0.022	0.035	0.056
Location2	0.023	0.038	0.062
Location3	0.020	0.034	0.056

Table 4.8.11: Alternatives priority matrix with three possible outcomes in Fuzzy AHP Combined.

The above table for the Fuzzy AHP Combined Results shows the priorities of the three locations: Location1, Location2, and Location3. The priorities are divided into three possible outcomes: Low, Mode, and High.

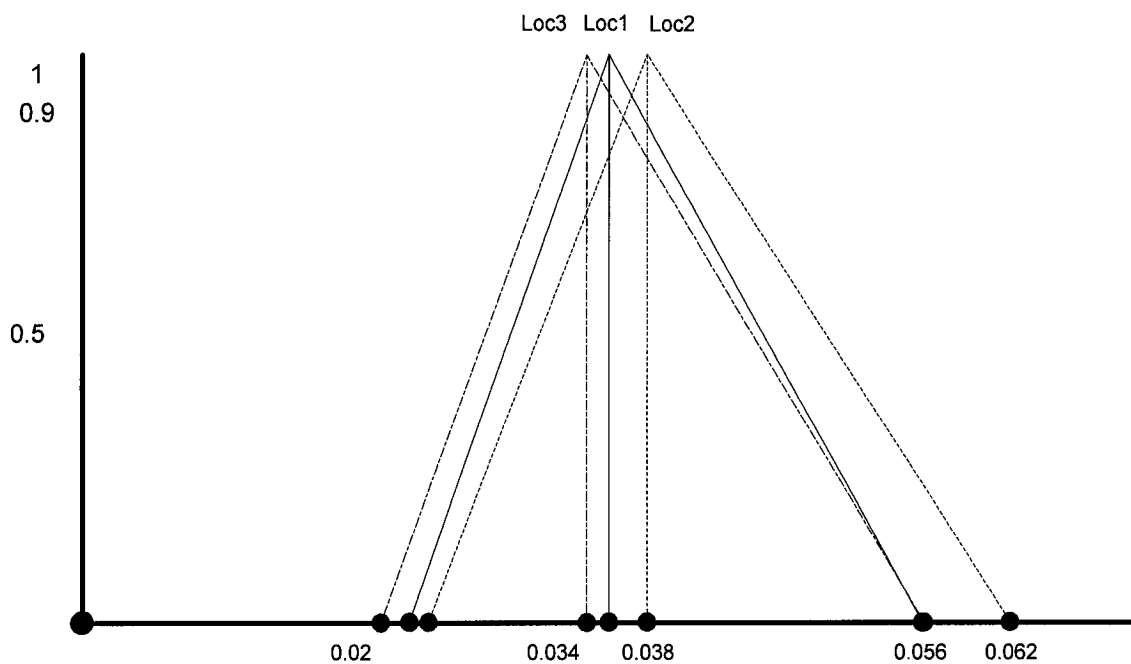


Figure 4.5: Alternatives priority fuzzy diagram with three possible outcomes in Fuzzy AHP Combined.

The above figure, Figure 4.5, is the diagrammatical presentation of the locations in the Fuzzy AHP Combined method. For $Q=0.9$, since Location2 dominates the other two locations, then Location2 is the preferred location.

4.9. Fuzzy AHP Group

Fuzzy weighted average for the calculation in the Fuzzy AHP Group is used in order to obtain the weighted sum of the criteria. Weights for the Decision Makers were defined according to the Group Evaluation (see Section 3.4). After collecting all the weights, there

will be one overall fuzzy pairwise comparison matrix for each alternative set with respect to each criterion and one overall fuzzy pairwise comparison matrix for criteria with respect to criteria as analogous to the Group Evaluation analysis (section 4.6).

4.9.1. Fuzzy AHP Group Input

Following matrices are the inputs for each criterion and overall criteria in Fuzzy AHP Group for the three decision makers: CEO, CFO, and CIO. The results below already weighted by the group feedback.

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	1.587	2.621	3.634	0.909	1.387	1.957	0.909	1.387	1.957
Access.	0.275	0.382	0.630	1	1	1	0.431	0.572	0.693	0.531	0.693	0.941
Traffic	0.511	0.721	1.101	1.442	1.747	2.321	1	1	1	0.606	0.909	1.587
Conv.	0.511	0.721	1.101	1.063	1.442	1.882	0.630	1.101	1.651	1	1	1

Table 4.9.1: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Criteria in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group shows the fuzzy pairwise comparisons for the criteria for each possible outcome: low, mode, and high.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.552	0.689	0.892	0.311	0.420	0.557
Location2	2.101	3.036	3.972	1	1	1	0.359	0.562	1.020
Location3	3.042	3.981	4.926	1.179	2.124	3.091	1	1	1

Table 4.9.2: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Visibility in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group shows the fuzzy pairwise comparisons for the locations with respect to Visibility for each possible outcome: low, mode, and high.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.228	1.822	2.425	1.845	2.460	3.110
Location2	2.034	2.502	3.018	1	1	1	1.271	1.892	2.565
Location3	0.956	1.405	1.873	0.915	1.383	1.899	1	1	1

Table 4.9.3: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Accessibility in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group shows the fuzzy pairwise comparisons for the locations with respect to Accessibility for each possible outcome: low, mode, and high.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.669	2.365	3.071	2.772	3.463	4.159
Location2	1.120	1.491	1.910	1	1	1	1.792	2.397	3.068
Location3	1.394	1.737	2.091	0.875	1.345	1.835	1	1	1

Table 4.9.4: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Traffic in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group shows the fuzzy pairwise comparisons for the locations with respect to Traffic for each possible outcome: low, mode, and high.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.571	0.756	0.998	3.395	4.395	5.395
Location2	2.100	2.983	3.871	1	1	1	4.154	5.154	6.154
Location3	0.198	0.254	0.372	0.197	0.264	0.444	1	1	1

Table 4.9.5: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Convenience in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group shows the fuzzy pairwise comparisons for the locations with respect to Convenience for each possible outcome: low, mode, and high.

4.9.2. Fuzzy AHP Group Results

After normalizing the matrices, the overall result for lowest, modal, and a highest possible outcome is computed as follows.

Criteria	Low	Mode	High	Normalized Matrix			
Visibility	v1	1.070	1.498	1.932	0.083	0.117	0.150
Access.	v2	0.501	0.624	0.801	0.039	0.049	0.062
Traffic	v3	0.817	1.034	1.419	0.064	0.080	0.110
Convenience	v4	0.765	1.034	1.360	0.059	0.080	0.106

3.153 4.191 5.511 12.855

Table 4.9.6: Normalized fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Criteria in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group Results shows the fuzzified normalized matrix for the criteria for each possible outcome: low, mode, and high. According to final fuzzy priority scores:

	Priority		
	L	M	H
Location1	0.021	0.033	0.051
Location2	0.025	0.041	0.066
Location3	0.020	0.034	0.055

Table 4.9.7: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes in Fuzzy AHP Group.

The above table for the Fuzzy AHP Group Results shows the priorities of the three locations: Location1, Location2, and Location3. The priorities are divided into three possible outcomes: Low, Mode, and High.

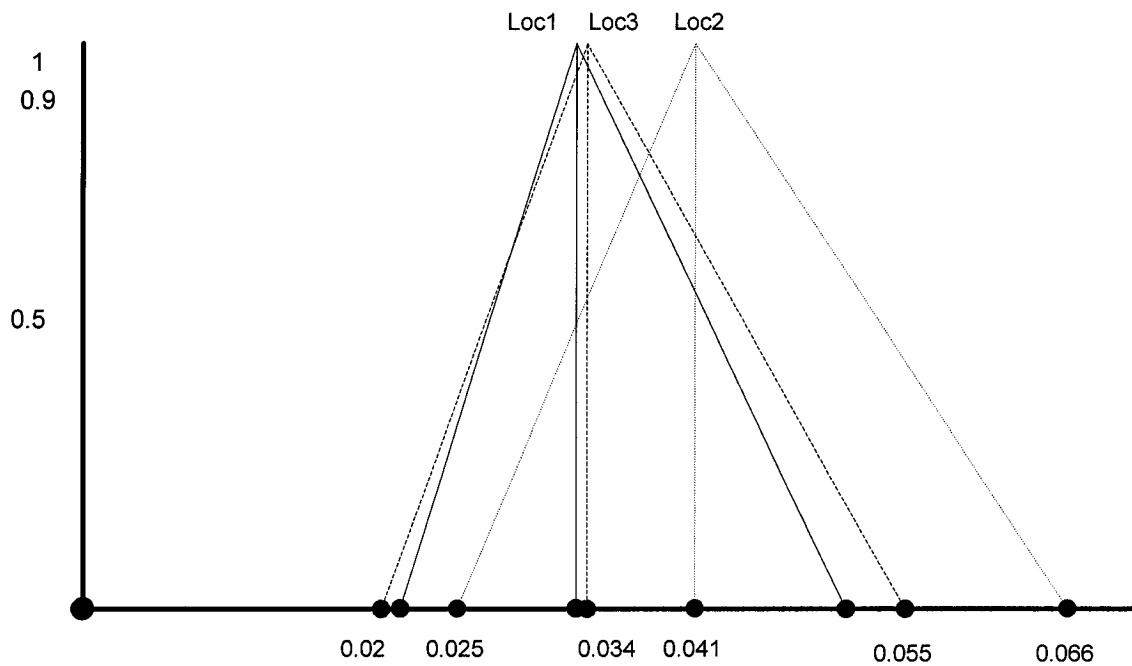


Figure 4.6: Alternatives priority fuzzy diagram with three possible outcomes in Fuzzy AHP Group.

The above figure, Figure 4.6, is the diagrammatical presentation of the locations in the Fuzzy AHP Group. For $Q=0.9$, Location2 dominates the other two locations. Therefore, Location2 is the preferred location for the Fuzzy Group method.

4.10. Comparison of Methods

In this section, seven multicriteria group decision making methods are compared using the Comparison of Group Decision Making Methods table (Table 4.10.1), and the Process Flow table (Table 4.10.2). Each method can be used in a wide range of fields based on different theoretical foundations such as the needs of the decision makers, the ability of the selected method in terms of dealing with uncertainty in inputs problems etc. The common aim of those diverse methods is to be able to evaluate and select the most preferred alternative based on multiple criteria in group decision making. Different methods require different types of input, and follow different procedure to evaluate the alternatives. Some techniques rank alternatives with respect to criteria overall, some rank decision makers with respect to criteria, some can deal with uncertainty in data inputs, and others provide easy but powerful tool.

An overview of seven multicriteria group decision making methods is provided in the remainder of this section. The following table (Table 4.10.1) presents the strengths and the weaknesses of each group decision making methods.

Method	Strengths	Weaknesses
AHP	Handles multiple criteria	Ranking reversal may occur in the presence of irrelevant alternatives
	Appropriate for GDM	Data greedy and time consuming for problems with large hierarchies
	Demonstrably intuitive approach that doesn't involve complex math	Doesn't take into account potential uncertainty in data input
	A certain value of inconsistency is allowed and measured	Consistency is sometimes very difficult to maintain, especially for larger problems
	Easy to capture data and convenient to set-up and apply	
	Can combine qualitative and quantitative data	
WSM	More relevant for single criteria problems	Interpretation difficulty emerges in multi-criteria problems
	Intuitive group results as "averages" that avoid problems of rank reversal in AHP	Scaling problems associated with summing different of types of weighted data (e.g. cost, quality, memory, amount)

WPM	Dimensionless ratio comparisons that eliminate different scales and multiple units of measure; thus, can be used in single and multi dimensional MCDM	No solution evident when DMs are equally weighted
AHP Combined	Simplifies the group pairwise comparisons to act as an aggregated single DM	Doesn't take into account potential uncertainty in data input
	Advantages of AHP (individual) apply to aggregated group input	Geometric mean sometimes leads to non-intuitive results, e.g., compared to simple weighted average of individuals (WSM)
Group Evaluation	Self-evaluation among DMs is informative	Doesn't take into account potential uncertainty in data input
	Reducing the noise by having DMs weights	Additive utility
		Data greedy and time consuming for problems with large hierarchies
Fuzzy AHP	Deals with uncertainty in data inputs	Data greedy and time consuming for problems with large hierarchies
	Similar scale to Saaty's can be used	Hard to convince DMs
Fuzzy AHP Combined	Deals with uncertainty in data inputs	Data greedy and time consuming for problems with large hierarchies
	Reduces the matrix input requirements	
Fuzzy AHP Group	Deals with uncertainty in data inputs	Data greedy and time consuming for problems with large hierarchies
	Considers the self-evaluation weight of DMs	

Table 4.10.1: Comparison of Group Decision Making Methods.

The AHP method, which forms the basis of these group decision making methods, is easy to acquire data on, to apply and to obtain the alternatives ranking results. Applying pairwise comparison judgments to determine the matrices is straightforward. The AHP technique relies on that humans are more capable of making relative judgments than absolute judgments. A certain level of inconsistency is allowed. However, the illustrative problem (Chapter 4) shows that the large volume of individual assessments in the AHP method is one

of its main weaknesses. Also, if there is an uncertainty in the judgments of the decision makers, the AHP technique is unable to deal with it.

The AHP Combined approach used the geometric mean to aggregate individuals' AHP responses. This approach is meaningful since AHP requires having reciprocal logic. By doing so, the number of matrices for this method is distinctively reduced so the computation becomes easier than computing all the matrices separately.

The scoring method, WSM, is probably the simplest one among the methods used in this analysis. All the required calculations are made easily to blend individual's AHP results. However, scoring using the same idea in WPM is somewhat more problematic. The computation for WPM is more difficult than that in WSM. WPM requires the eliminating of the rest of the decision makers leaving only the one with the highest self-evaluation score. For this reason, WPM may not be acceptable to the decision makers since their input is effectively ignored if they are eliminated.

The main advantage in the Group Evaluation technique is to be able to calculate the weights assigned to the decision makers by using the pairwise comparison approach. This technique gives a unique advantage over some other methods. Since each decision maker evaluates the other decision makers, the biasness of the weights is subsumed by the decision makers own feedback. For the sake of anonymity, no one is allowed to see the others' evaluation so this also eliminates biasness and none of the decision makers is affected by the other decision makers' decision. Every single decision maker is given a direct and important role in the evaluation process of the decision makers. That makes the technique very useful where it shows that the decision makers are satisfied with such a process instead of making an assumption about them e.g., equally important assumption. Apart from the advantages of the Group Evaluation Method, there are also some disadvantages. If a decision maker has a subjective perspective, then the result is subject to evaluator bias. If a decision maker has no experience in a given field, the evaluation of that decision maker with respect to given field may end up with a biased decision. Having a large number of criteria, sub-criteria and a large number of decision makers makes the process problematic, slow, inefficient in terms of time, and it accordingly may also be expensive. This technique may not be appropriate if time has an important role on the decision, specifically if all the calculations are done manually.

If there is uncertainty in the decision makers' inputs, the fuzzy methods provide a quite powerful tool. In order to reduce uncertainty in the judgments, fuzzy methods provide a range of possible inputs from low to high. However, the fuzzy techniques (Fuzzy AHP, Fuzzy AHP Combined, and Fuzzy AHP Group) has some problems: i) solving the complex decision making problems with large number of inputs can be too computationally expensive, ii) as the number of attributes are increased, the more time required to evaluate the alternatives, and iii) the other difficulty associated with fuzzy methods is the difficulties with interpreting the use of the data. The observations above, assists to define the requirements of the methods based on the input/output process, and the needs of the decision makers.

The following table (Table 4.10.2) analyses the link between the input/output and the needs of the decision makers in order to develop the web-based tool as a prototype. This analysis is used to assist in the conceptualization of an appropriate model selection procedure as a web-based decision support tool as a prototype for multi-criteria group decision making problems.

Method	DMs	Input Requirements	Process	Results
AHP	<ul style="list-style-type: none"> • Individual DMs • Can be treated equally • DM's data assumed precise; Uncertainty in inputs not considered • Uncertainty in inputs not considered 	<ul style="list-style-type: none"> • Pairwise comparisons over the decision hierarchy • Weights for criteria, sub-criteria • Certain degree of inconsistency allowed 	<ul style="list-style-type: none"> • Each DM's individual feedback as input • Generate pairwise matrices • Assign weights • Check consistency • Normalize weights 	<ul style="list-style-type: none"> • Individually preferred ranking • Use individual analyses
AHP Combined	<ul style="list-style-type: none"> • Can be treated equally • DM's data assumed precise; Uncertainty in inputs not considered 	<ul style="list-style-type: none"> • Weights for criteria, sub-criteria • Certain degree of inconsistency allowed 	<ul style="list-style-type: none"> • Generate pairwise matrices • Assign weights • Check consistency • Normalize weights • Apply geometric mean for input 	<ul style="list-style-type: none"> • Use combined analyses
WSM	<ul style="list-style-type: none"> • May assign equitable weights to DMs • Weights may be assigned directly or from group evaluations • DM's data assumed precise; Uncertainty in inputs not considered 	<ul style="list-style-type: none"> • Relative weights for each DM (if using Group Evaluation) • Weights for criteria, sub-criteria • Additive utility assumption 	<ul style="list-style-type: none"> • Each DM to evaluate all other as in group self evaluation • Each DM to evaluate criteria, sub-criteria 	<ul style="list-style-type: none"> • Use all individual analyses
WPM	<ul style="list-style-type: none"> • Binary decision on selection of 	<ul style="list-style-type: none"> • Weights for criteria, 	<ul style="list-style-type: none"> • Each DM to evaluate 	<ul style="list-style-type: none"> • Use only individual

	<p>highest ranked DM; Cannot treat DMs equally Relative values assigned</p> <ul style="list-style-type: none"> DM's data assumed precise; Uncertainty inputs not considered 	sub-criteria	<p>criteria, sub-criteria</p> <ul style="list-style-type: none"> Eliminate the rest except the DM with highest score Equity of DMs is not a condition 	<p>analyses for the criteria, sub-criteria based on the highest score of the DM</p>
Group Evaluation	<ul style="list-style-type: none"> DMs opinions are treated equally Eliminate equally important assumption Evaluate DMs Evaluate criteria 	<ul style="list-style-type: none"> Weights for DMs Weights for criteria, sub-criteria Certain degree of inconsistency allowed 	<ul style="list-style-type: none"> Generate pairwise matrices Assign weights Check consistency Normalize weights 	<ul style="list-style-type: none"> Use individual analyses
Fuzzy AHP	<ul style="list-style-type: none"> Can be treated equally Uncertainty in inputs considered 	<ul style="list-style-type: none"> Weights for criteria, sub-criteria Certain degree of inconsistency allowed 	<ul style="list-style-type: none"> Generate pairwise matrices Assign weights Check consistency Fuzzified crisp numbers Normalize fuzzified weights 	<ul style="list-style-type: none"> Use individual fuzzified analyses
Fuzzy AHP Combined	<ul style="list-style-type: none"> Can be treated equally Uncertainty in inputs considered 	<ul style="list-style-type: none"> Weights for criteria, sub-criteria Certain degree of inconsistency allowed 	<ul style="list-style-type: none"> Generate pairwise matrices Assign weights Check consistency Fuzzified crisp numbers Normalize fuzzified weights Apply geometric mean to normalized fuzzy weights 	<ul style="list-style-type: none"> Use fuzzy combined analyses

Fuzzy AHP Group	<ul style="list-style-type: none"> • Can be treated equally • Uncertainty in inputs considered • Eliminate equally important assumption • Evaluate DMs • Evaluate criteria 	<ul style="list-style-type: none"> • Weights for DMs • Weights for criteria, sub-criteria • Certain degree of inconsistency allowed 	<ul style="list-style-type: none"> • Generate pairwise matrices • Assign weights • Check consistency • Fuzzified crisp numbers • Normalize fuzzified weights 	<ul style="list-style-type: none"> • Use individual fuzzy analyses
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Table 4.10.2: Process Flow table.

The above table, Table 4.10.2, summarizes the comparison of group decision making methods that are used in this thesis in terms of the needs of decision makers, input requirements, process, and results. The purpose of creating the process flow table is to show the process dependencies between all elements mentioned above. Understanding the requirements of the elements in the process of decision making is an important consideration in understanding the scope of method selection. It can be seen from the above table that a change in the process such as different method, decision makers' needs, input requirements etc may affect the results.

It is known that not every method can be applicable to every single problem. The methods are selected based on the requirements of the selected problem and the needs of the decision makers. Knowing this condition, a framework is created in the web-based tool as a prototype which is presented in the following chapter in order to identify the methods associated with the problem context. Once each key question is answered by the administrator/decision analyst through the prototype web-based tool based on the information obtained from the above two tables, the prototype web-based tool provides the most appropriate group decision making method(s) associated with the problem context.

5. Prototype Web-based Tool for Group Decision Making

This chapter presents the web-based tool developed as a prototype and Php/JavaScript Net application for multi-criteria group decision making methods decision support. In particular, this tool has been designed to present the aquaculture case study to be discussed in the next chapter. The following figure, Figure 5.1, is the graphical representation of the web-based tool as a prototype that visualizes how the tool for the group decision making works.

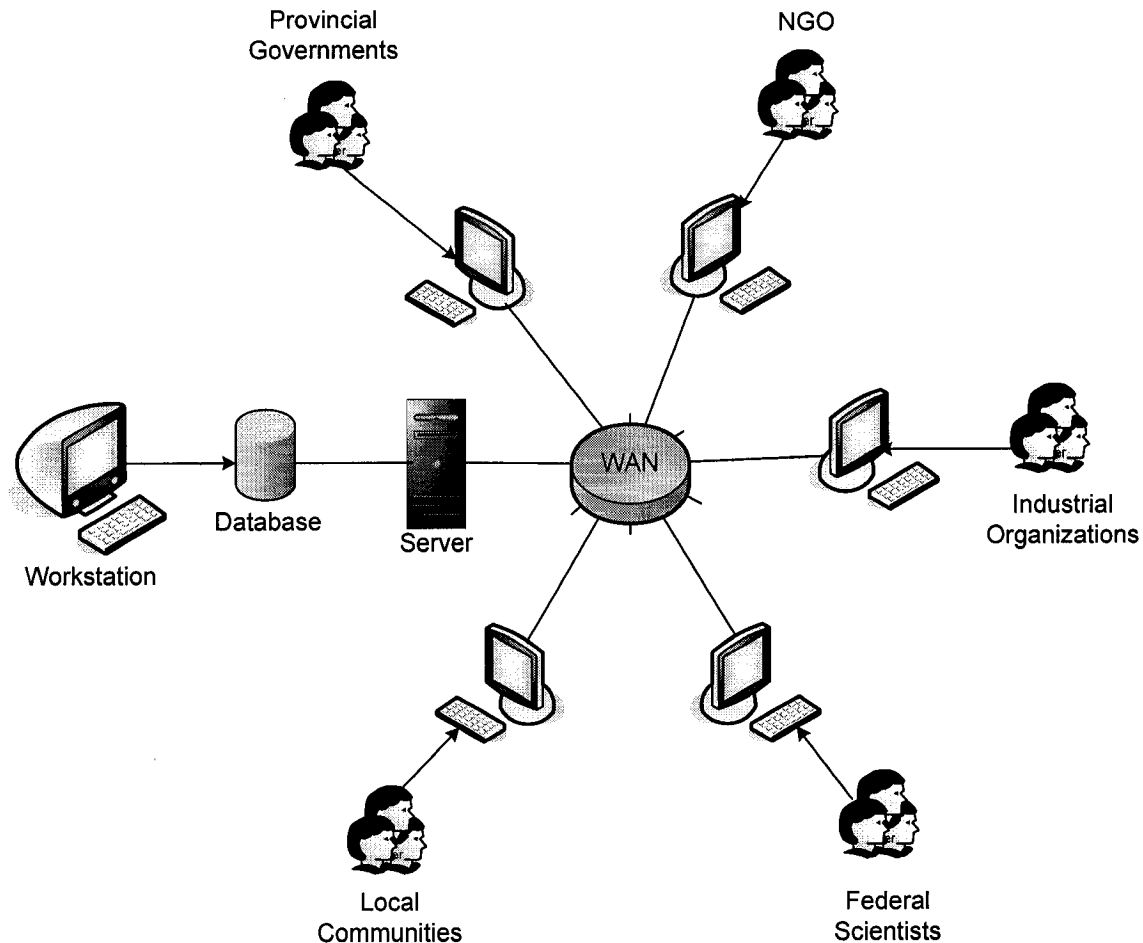


Figure 5.1: Graphical representation of the Php/JavaScript Net Application.

The above graphical representation shows how the client-machine information flow works. Each client, as a decision maker, is provided with a password to enter the system as a member of a particular group, e.g., NGO or local community member, etc. In the Php/JavaScript environment, the system recognizes each client based on the username and the password that a client uses. If there is more than one client under each group, the system provides a separate entry for each of the group members. Inside the application, the geometric mean approach is used to calculate an overall matrix for all the clients under the

same group. Once a client enters each necessary score to the system, it is saved in the database. After collecting all the pairwise comparisons from the clients, the Php/JavaScript Net application will calculate the result and provide it to the administrator of the application. This application also checks the consistency of each pairwise comparison matrix that is obtained as input from the client decision makers. This part is done by JavaScript. If any consistency occurs, the system reports and then reminds the decision maker to revise the pairwise comparisons that have already been entered.

5.1. Architecture of the Php/JavaScript Net Application

The aim of this section is to show the development of the systems architecture for the web-based tool developed as a prototype used to illustrate the aquaculture case study. The following schematic figure, Figure 5.2, depicts the architecture of the Java, Java Script, MySQL, and PHP application. It illustrates the main components and data flows of the system.

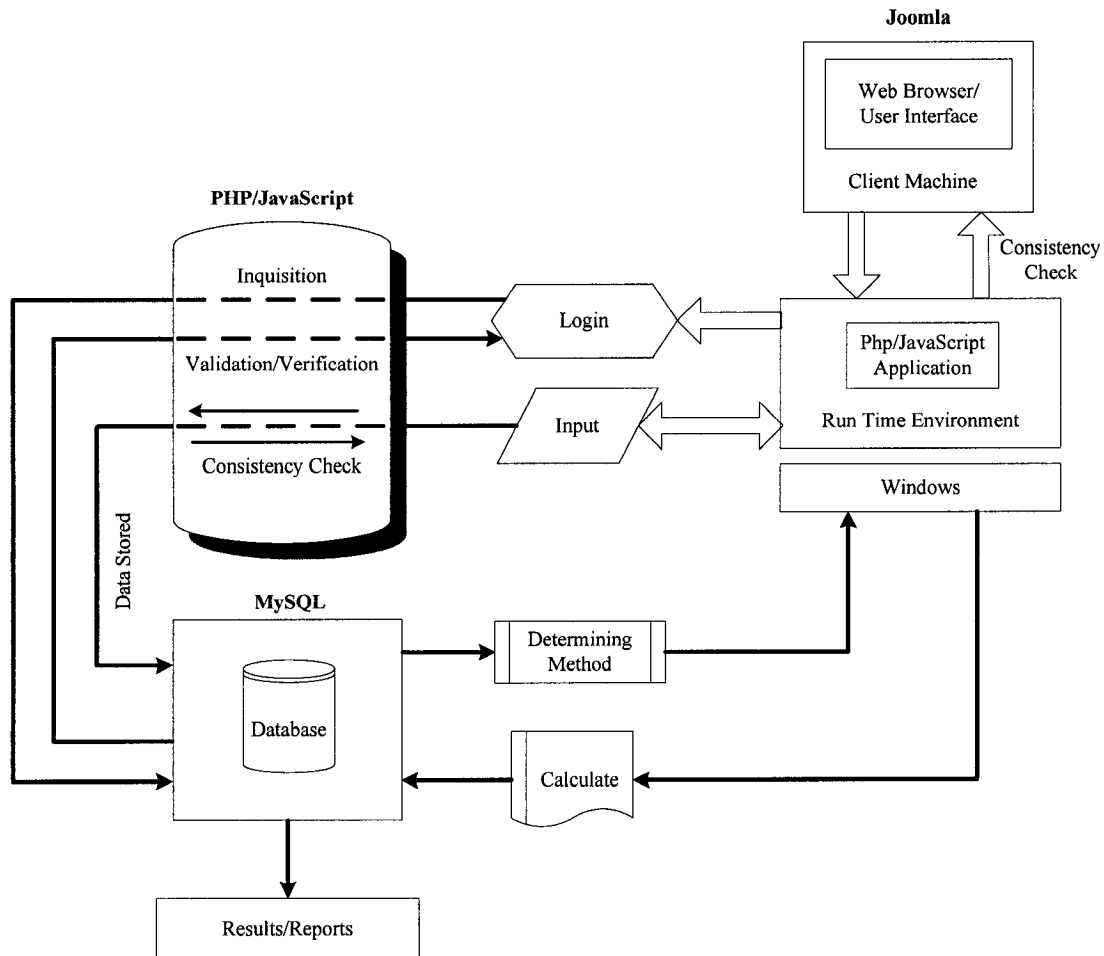


Figure 5. 2: Architecture of the Php/JavaScript Net Application.

The above figure represents the Php/JavaScript Net Application to show how the web-based tool as a prototype works such as inquisition and validation/verification process, entering the scores, checking the consistency, storing the data etc. The detail explanation for each process is given below.

The prototype web-based tool has been created by and is managed through an open source, Joomla, Content Management System (CMS 2005). The administrator of the *Aquaweb site* (www.aquaweb site.com) manages the contents of the site and the interface through Joomla. Since Joomla is an open source software package, it is free to use and a quite powerful tool for developing online applications.

In the above typical scenario, the active pages from the Run Time Environment, evaluate the client's pairwise comparisons. On completion, the resulting hierarchy weights are delivered to the Web browser for viewing by the Administrator. Clients access their own computers to the *Aquaweb site* where the tool has been built on to enter scores on the page. However, clients don't see the calculation steps. On each page, clients have a friendly user-interface in which to enter their pairwise comparisons for the evaluation of criteria, sub-criteria, and the decision makers.

Each client in a group is given a specific username and a password by the administrator in order to be able to enter pairwise comparisons. Once a client enters the *Aquaweb site*, in order to move on to the login page, the client's identification is tested in the database to check whether the username and the password of the client match the stored information correctly. Once the inquisition process is validated, the client, then, is able to enter pairwise comparison judgments in the system. The *Aquaweb site* provides a graphical representation with an illustration of entering the scores. The weights that are entered by clients are delivered to the server and stored in the MySQL database. Once the pairwise comparison judgments are entered, by clicking 'Save' button on the web page, JavaScript determines whether the stored data for each matrix provided by the client is consistent. If there is an inconsistency, the system reports the inconsistency of the specific matrix/matrices to the client. The client is then asked to revise the stated pairwise comparisons.

MySQL is also an open source package and popular for web applications. It is used as the database component of the platforms. In the prototype web-based application used in this study, the Php platform is used on the web server to collect data that are entered by the decision maker clients and are then sent to store in the MySQL database (MySQL 2006).

JavaScript is used to develop the application in order to check the consistency of each pairwise comparison matrix provided by the decision makers. It is the most popular and versatile scripting language on the Internet (JavaScript 2005). It is used to create menus, to validate forums, and to improve the design and much more. In our web-based application developed as a prototype, JavaScript is used to check the consistency of the matrices. If there is any inconsistency occurs, the system reports the inconsistency issue to the decision makers with a note to revise the pairwise comparisons of the relevant matrix. However, due to the large number of matrices used in the aqua case study, a certain level of inconsistency is accepted. The current level is set to 0.1. Changing a pairwise comparison in a matrix may

not affect the whole process where there are more than 500 matrices are used to calculate the overall scores of the alternatives. For this reason, if the consistency ratio is not over 0.2, the system stores the input data. Otherwise, the client (decision maker) is asked to re-enter or change the pairwise comparisons. Php is used to calculate the most preferred alternative by using the most appropriate method based on information about the problem context and the decision makers (see also Chapter 4, Section 4.10). Php is to help the decision analyst to determine which group decision making method is most appropriate for a given problem. This allows the decision analyst to explore the appropriate method and then to report the result based on the chosen method. In Figure 5.2, the execution environment of Php/JavaScript Net Application is used in the run-time environment to carry out the required calculations and results based on the appropriate methodology. Once all the pairwise comparison judgments are entered by each client, DM, the results and reports becomes available for the Administrator/Decision Analyst. The DMs are able to modify their preferences. However, they are not authorized to see the other DMs' judgments. Once the decision makers securely enter the system and provide their judgments for the criteria, sub-criteria and the other decision makers, the decision analyst answers the key questions (Figure 5.3) to conceptualize of the method selection. The prototype web-based tool then provides the most suitable method with the results based on the selected method according to the analyses presented in Chapter 4, Section 4.10. This analysis is described further below.

5.2. Conceptualization of Method Selection

The basic concept involved in the selecting of a group decision making model is based on the problem context scenario, and the needs of the decision makers to the specific method. In Chapter 4, a specific problem (selecting the best location among three where there are three decision makers and four criteria) was formulated and solved in order to demonstrate a practical case with group decision making to facilitate the approach that will be applied to the case study of this thesis. The *Aquaweb* is designed to provide a tool to visualize and perform the full range of group decision making methods in a valuable quantitative analysis. There are two aspects to conceptualize in the method selection: i) the methods comparison; and ii) the process flow. In order to bring these two aspects together so that it can be found out what best group decision making method to apply, the following decision diagram (Figure 5.3) is illustrated for the conceptualization of a method selection.

The numbers in the above figure, Figure 5.3, represent specific questions asked sequentially of the decision analyst. Responses to the questions narrow down the appropriateness of each method for the given problem situation. The questions are used to assess the conceptualized method based on the nature of the decision makers and the type and context of the problem.

The first question in Figure 5.3 distinguishes whether the “information content” assigned weights (inputs) by the decision makers are assumed to be certain, or whether there they should be considered to be more uncertain in their pairwise comparisons:

Question #1- Information Content: Are the decision makers generally certain about the information content of the decision or there should the information on comparisons be considered as vague or uncertain?

Rationale: If the response and rationale to the answer to this first question is, e.g., if “yes” (more certain), then this immediately eliminates the fuzzy group methods (Fuzzy AHP, Fuzzy AHP Combined, Fuzzy AHP Group); if “no”, then this immediately eliminates the other decision making methods (AHP, AHP Combined, WSM, WPM, Group Evaluation).

The second question is whether or not for the given problem, the group decision making members should be considered as equally important to the resolution overall:

Question #2- Decision Makers Evaluation: Is it possible for the decision makers to evaluate each other?

Rationale: Decision makers may acknowledge specific expertise among fellow decision makers in the problem. Their inputs be weighted based on their inherent abilities in relation to the problem. For instance, if it is generally agreed that a particular decision maker of the group is an expert on “marine science”, then the other decision makers know that the expert should have more weight than that the others related to problem criteria involving “marine science”.

Third question is used to analyze the units of the decision problem:

Question #3- Scale of Measure: Are the units in the criteria/sub-criteria of the decision hierarchy the same? Can we combine those units? Can we assume that regardless of the units, we can treat all the units as one?

Rationale: If the response and rationale to the answer to this question is “Yes”, then this immediately considers WSM (“Weighted Sum Method”) as a possible method with the others since WSM is applied to a problem where the units are the same; if “no”, then this immediately eliminates WSM.

The fourth question attempts to isolate the importance of any one prominent decision makers of the group. This question responds to the situation where one decision maker, e.g., the CEO, may carry more responsibility than other group members.

Question #4: Decision Makers' Equities: Is there at least one member of the decision making group who is weighted the same or more than the others?

Rationale: If the response and rationale to the answer to this question is, e.g., if “yes” (same weight), then this immediately eliminates WPM where there will be no solution if more than one member in the group is weighted the same as highest; if “no”, then this immediately considers WPM as one of the possible methods.

Finally, information on the ability of the decision makers to combine their inputs and achieve some level of input consensus is requested. In some group decision problems, the decision makers “agree to disagree” and may not be willing at the outset to negotiate or be subject to persuasion of their fellow decision makers.

Question #5: Input Combination: Is combining the assign weights/inputs necessary?

Rationale: If the response and rationale to the answer to this question is, e.g., if “yes” (combining the assign inputs necessary), then this immediately eliminates non-combined methods so the combined methodologies will be considered (AHP Combined, Fuzzy AHP Combined). The preferred method may be determined dependent on the combination of responses to *Question #1* and *Question #5*. If *Question #5* is answered ‘Yes’, and *Question #1* is answered as ‘Yes’, then the fuzzy group methods are eliminated; otherwise, the preferred method will be AHP Combined; if *Question #5* is answered ‘Yes’, and *Question #1* is answered as ‘No’, then the Fuzzy Combined is selected as most appropriate.

If *Question #1* is answered as ‘Yes’, then all the fuzzy group methods are eliminated. Once *Question #1* is answered as ‘No’, if *Question #2*, *Question #4*, and *Question #5* are answered as ‘No’, the preferred method will be WSM. If *Question #2* is answered as ‘Yes’, and *Question #4* and *Question #5* are answered as ‘Yes’, the preferred method will be AHP Combined. If the response to *Question #5* is ‘No’, then the preferred method will be AHP. If the response to the first two questions is ‘Yes’, (no matter what answer to give to the third question), to the fourth question is ‘No’, and to the fifth question is ‘Yes’, then the preferred method will be Group Evaluation.

It is recognized that different organization and presentation of these questions may lead to different conclusions with respect to a more appropriate method. The order of questions, and question content have been reviewed for this prototype in order to correspond to the attributes, strengths and weaknesses of the remains methods. These questions do not include other possible arrangements.

5.3. Snapshots of *Aquaweb*site

This section shows the snapshots of the *Aquaweb*site. The screenshots show the progression of the clients' flow through the Java application to the presentation of the group decision making results.

The following screenshot is an Introduction page. It explains the problem generally and the purpose of the web-based tool developed as a prototype. The clients access the tool at the *Aquaweb*site at digital address: www.aquaweb.com.

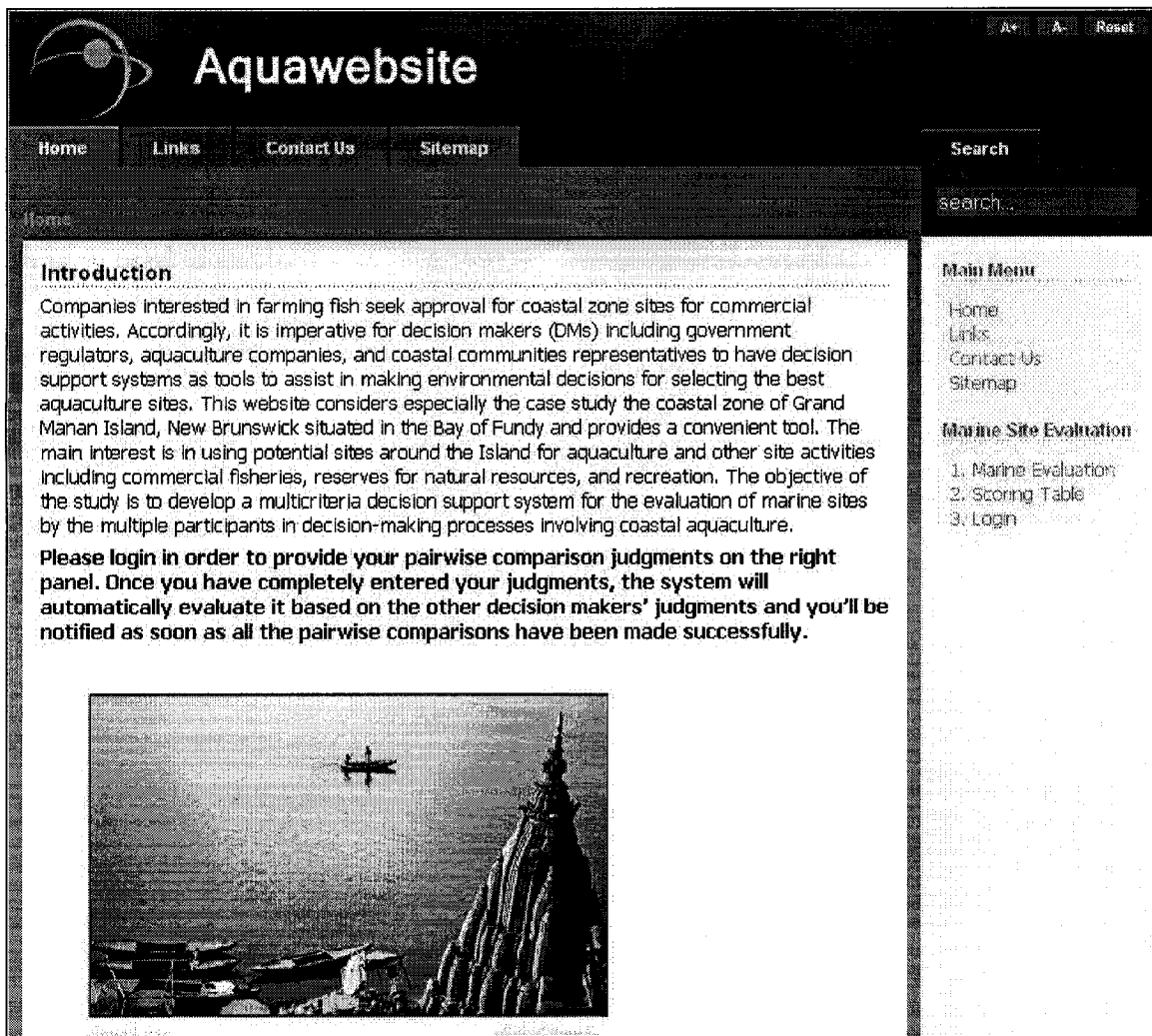


Figure 5.4: Screenshot of Introduction page in the *Aquaweb*site application.

In the event that users have difficulty understanding or logging in, or any other technical difficulties, clients are instructed to use 'Contact Us' form to inform the website Administrator. Clients' messages will be sent via email to the administrator's email address as shown below in Figure 5.4.

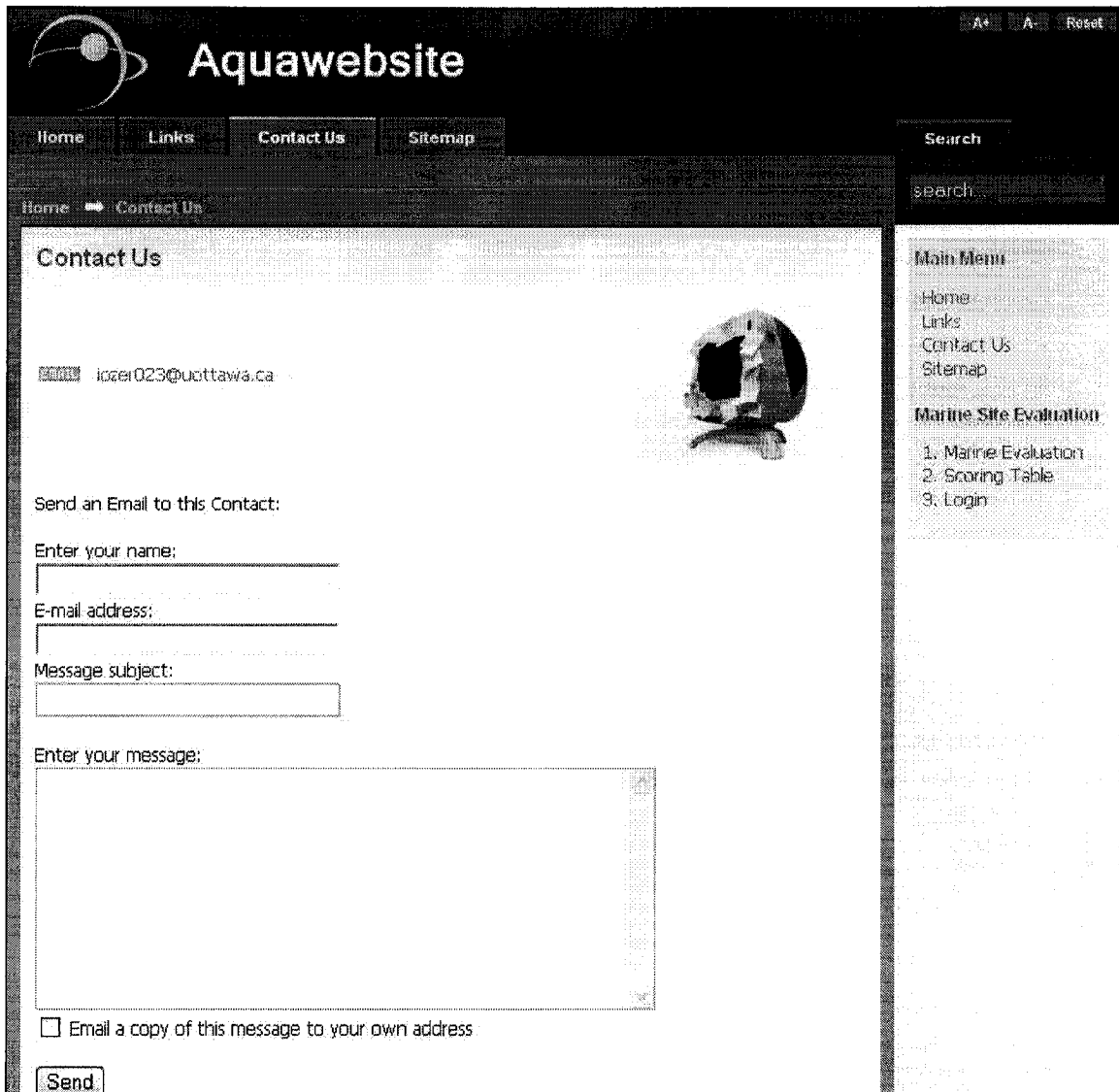


Figure 5.5: Screenshot of Contact Us page in the *Aquaweb site* application.

Once a client enters the name, email address, message subject and the message text regarding about any kind of comments or technical difficulties, the form will be sent to the Administrator via email.

The web-based tool developed as a prototype also explains how to enter the pairwise comparison judgments for each level of the defined decision hierarchy for the aquaculture problem.

In the first page, Figure 5.6, the overall decision hierarchy scheme is shown to explain how the pairwise comparison matrices will be conducted. The second page, Figure 5.7, shows how to read the Scoring Table. An example is provided for the scoring approach. The third page, Figures 5.8 and 5.9 is about the Level I components of the decision hierarchy. The clients will be able to see which type of components they deal with and what numbers will

be used in order to determine their judgments in the pairwise comparison. The fourth page, Figure 5.10 is the Level II in the hierarchy with sub-components. Once the idea of the Marine Site Evaluation is given and clear, the clients will click on the Login link (Figure 5.11) in order to login with their unique username and provided password in order to enter their judgments.

Aquawebsite

Home Links Contact Us Sitemap Search

Route → 1. Marine Evaluation

Marine Site Evaluation

The following is a hierarchy of the marine ecosystem and their subcomponents. In that web-based tool, decision makers are requested to provide their feedback on the relative importance of these components and their subcomponents in order to construct a quantitative evaluation of decision makers' preferences. They're also asked to evaluate the other decision makers with respect to each criteria and sub-criteria.

Multicriteria Coastal Zone Site Evaluation

- Resources**
 - Herring Day
 - Herring Night
 - Lobster
 - Scallops
 - Urchins
- Habitat**
 - Rockweed
 - Salt Marshes
 - Current Flow
 - Bottom Structure
- Effluents**
 - Chemical A
 - Chemical B
 - Chemical C
- Activities**
 - Herring Weirs
 - Fish Farms
 - Lobster Traps
 - Scallop Drags
 - Urchin Drags
 - Recreation

[Back] Next >

Main Menu

- Home
- Links
- Contact Us
- Sitemap

Marine Site Evaluation

1. Marine Evaluation
2. Scoring Table
3. Login

Figure 5.6: Screenshot of the Marine Site Evaluation in the *Aquawebsite* application.

The above figure depicts the marine ecosystem and their components hierarchically for the aquaculture case study.

2. Scoring Table

The following table presents the scores to be assigned to the comparison of components and subcomponents as presented in the hierarchy.

Value	Definition	Explanation
1	Equally important	Two component contribute equally to the objective
2	Intermediate judgment value	Judgment values between equally and moderately important
3	Moderately more important	One component is moderately more important than the other
4	Intermediate judgment value	Judgment values between moderately and strongly important
5	Strongly more important	One component is strongly more important than the other
6	Intermediate judgment value	Judgment values between strongly and very strongly important
7	Very strongly more important	One component has significantly more importance over the other
8	Intermediate judgment value	Judgment values between very strongly and extremely important
9	Extremely more important	Component is extremely significant

Figure 5.7: Screenshot of the Scoring Table in the *Aquawebsite* application.

The above figure shows the 1-9 AHP scale that will be assigned to the comparison of components and subcomponents as presented in the hierarchy.

Example: The table below compares the importance of Resources, Habitat, Effluents, and Activities.

	<i>Resources</i>	<i>Habitat</i>	<i>Effluents</i>	<i>Activities</i>
<i>Resources</i>		3	5	-4

Here are the comparisons:

- Resources to Habitat is 3 which means Resources are 'moderately more important' than Habitat.
- Resources to Effluents is 5 which means Resources are 'strongly more important' than Effluents.
- Resources to Activities is -4 which means Activities are 'between moderately and strongly important' than Effluents.

[Back] < Prev Next >

Figure 5.8: Screenshot of an example to show how to use the Level I Scoring Table in the *Aquawebsite* application.

The above figure, Figure 5.8 shows how to assign weights to the comparison of components and subcomponents. Decision makers use pairwise comparison to provide their judgments with respect to given criteria, sub-criteria, and evaluation of the other decision making groups. If one component is more important than another one, decision maker selects a positive value according to the Scoring Table below.

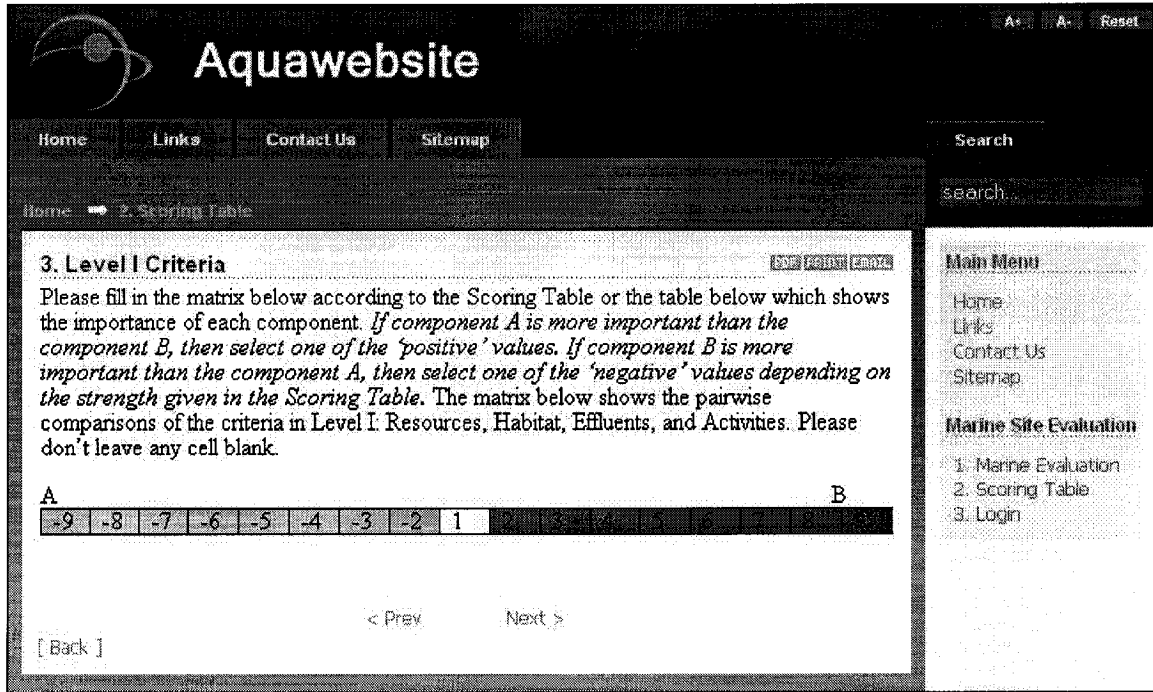


Figure 5.9: Screenshot of the Level I page in the *Aquaweb* application.

The above figure shows how to assign weights to the comparison of criteria as Level I in the hierarchy according to the Scoring Table. If component A is more important than the component B, decision maker selects one of the 'positive' values. However, if component B is more important than the component A, then decision maker selects one of the 'negative' values depending on the strength given in the Scoring Table such as 9 is the most extreme, 3 moderately more important.

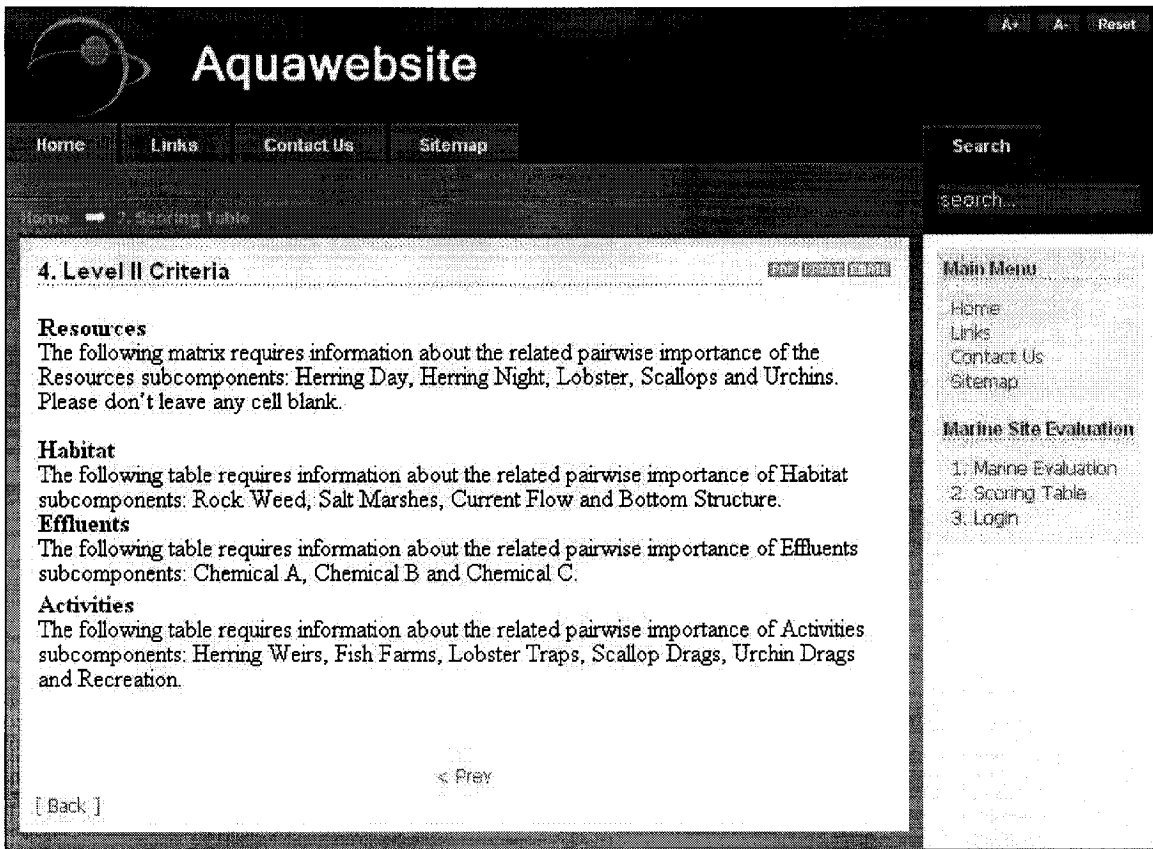


Figure 5.10: Screenshot of the Level II page in the *Aquawebsite* application.

The above snapshot shows how to assign weights to the comparison of sub-criteria as Level II in the hierarchy.



Figure 5.11: Screenshot of the Login page in the *Aquawebsite* application.

The above snapshot, The Figure 5.11, shows how to login the *Aquawebsite* client page. Once the username and the password are validated by the system, client will be directed to another page to enter their pairwise comparisons.

In order to control the information flow in the *Aquawebsite* application and check the data to see what group finished entering the data in the matrices, the administrator has the ability to access the individual matrices.

Figure 5.12 is the screenshot of the administrator's page:

Welcome **System Administrator** [Logout](#)

User selection

Select from the next dropdownlist the scientist you want to see and modify matrix data.

Scientists:

Multicriteria Group Decision Making

Support Tool for Coastal Aquaculture Sites

Select one to modify the matrix data from the selected scientist.

[Resources](#)

[Habitat](#)

[Effluents](#)

[Activities](#)

Matrix calculation

Insert Data Grid values

[Data Grid](#)

Select to compute the geometric mean.

[Evaluation of criteria](#)

Figure 5.12: Screenshot of the Administrator's page in the *Aquawebsite* application.

The above figure shows the Administrator is able to see each decision maker's judgments with respect to criteria, sub-criteria and the evaluation of the decision makers.

Model conceptualization [Logout](#)

Model conceptualization

Answer the next questionnaire to evaluate the methodology needed to perform the matrix calculation.

Information Content: Are the decision makers generally certain about the information content of the decision or there should the information on comparisons be considered as vague or uncertain?

Yes
 No

Decision Makers Evaluation: Is it possible for the decision makers to evaluate each other? ?

Yes
 No

Scale of Measure: Are the units in the criteria/sub-criteria of the decision hierarchy the same? Can we combine those units? Can we assume that regardless of the units, we can treat all the units as one?

Yes
 No

Decision Makers' Equities: Is there at least one member of the decision making group who is weighted the same or more than the others?

Yes
 No

Input Combination: Is combining the assign weights/inputs necessary?

Yes
 No

Figure 5.13: Screenshot of the questions for the Conceptualization of Model Selection.

The above figure shows the conceptualization of the method selection. After the decision analyst answers all those key questions appropriately, and clicks on the 'Evaluate' button, the system provides the most preferred method. An example of the selected the most appropriate method is shown in Figure 4.14 below.

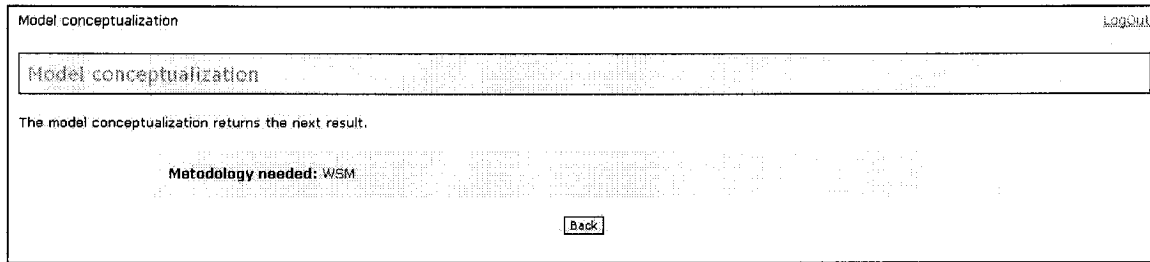


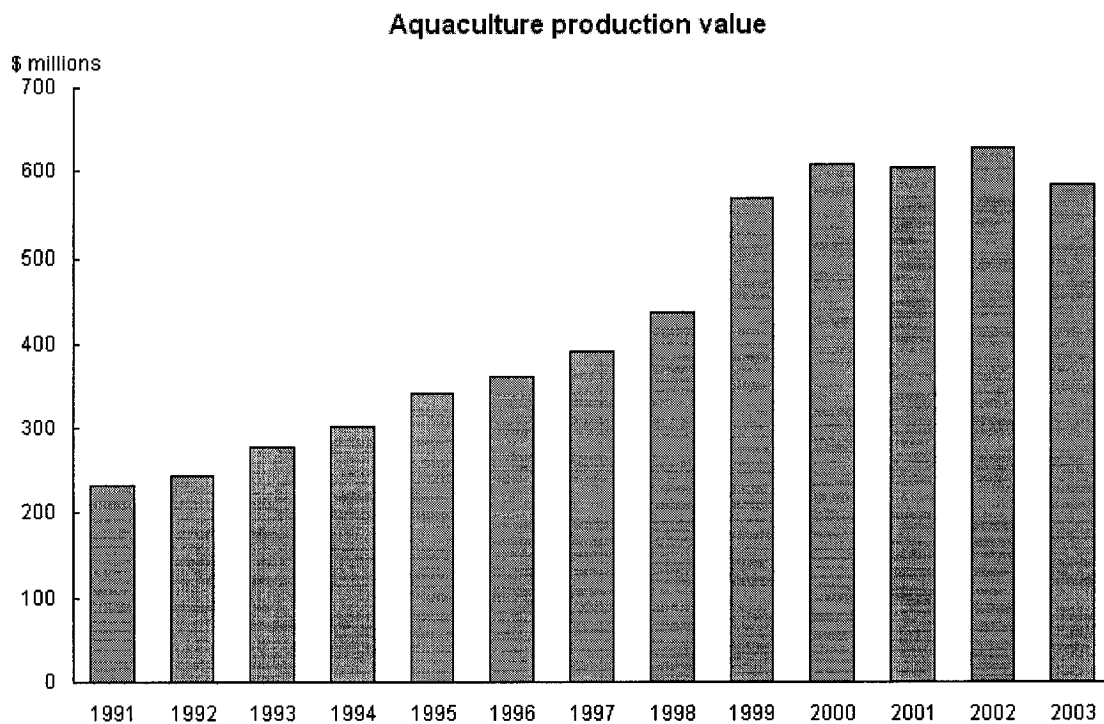
Figure 5.14: Screenshot of the Method Selection.

The above figure shows the method selection as an example after answering the key questions randomly.

Since the basic concept of this chapter is selecting a most preferred group decision making model based on the attributes of the given problem and of the decision makers to the specific method (see Chapter 5.2 for more detail), the web-based tool developed as a prototype (*Aquawebsite*) has become a need in order to satisfy the needs of the decision makers. The need of key questions have been analyzed in Chapter 4 and selected based on the Comparison of the Decision Making Methods table (Table 4.10.1), and the Process Flow Table (Table 4.10.2) which provides a figure to understand the rationale of the method, and the rationale of the decision makers. By combining those two rationales in the prototype web-based tool, a number of key questions will lead the decision makers to be able to select the most preferred method. The tool will, then, automatically provide the result based on the selected method.

6. Case Study

Aquaculture is thousands of years old and is the world's largest fastest growing sector. After the aquaculture industry was established in Canada in the 1980s, production increased rapidly from 36,462 tonnes of fish in 1990, to 155,634 tonnes of fish in 2003 (Statistics Canada 2006). Also the sales increased from \$738.84 million of aqua products and services in 2005, to \$447.3 million in 1997 (Statistic Canada 2005). "Aquaculture production in 2001 accounted for 10.7% of total fish production in Canada" (Fisheries and Oceans Canada 2006).



Source: Statistics Canada, Catalogue no. 23-222-XWE2003000.

Figure 6.1: Aquaculture production value.
(Source: Statistics Canada, Catalogue no. 23-222-XWE2003000)

In Figure 6.1, the aquaculture production value in Canada increased rapidly since 1991 from \$230 million, to \$550 million.

The case study used in this thesis focuses on the coastal zone of Grand Manan Island, comprises a total area of 1602 km², New Brunswick situated in the Bay of Fundy. The main interest of the case is on the use of potential marine sites for the expanding aquaculture sector. These marine sites also are opportunistic sites for other activities such as commercial fisheries, and reserves for recreation on natural resources. The objective of this case analysis will be in developing a multi-criteria decision support system for the evaluation of marine sites by multiple participants in decision-making processes involving coastal aquaculture

(Zhao, 2005). The decision hierarchy of the Grand Manan Island for the case is described by the four criteria presented in Figure 6.2.

1. “Biological - the dynamic spatial distributions of natural resources of several select species’, e.g., herring schools staging areas and inshore feeding areas distributions, lobster molting area and feeding area distributions, scallops and urchins population area distributions;
2. Habitat – the spatial distributions of natural habitats of the area, e.g., rockweed, salt marshes, benthic community and bathymetry description, and dynamic current flow;
3. Effluents - the pollution of specific chemicals attributed to fish farm sites;
4. Activity – the areal distribution of human commercial activities, e.g., herring weirs, fish farms, lobster traps, scallop and urchin dragging gear.” (Zhao, 2005)

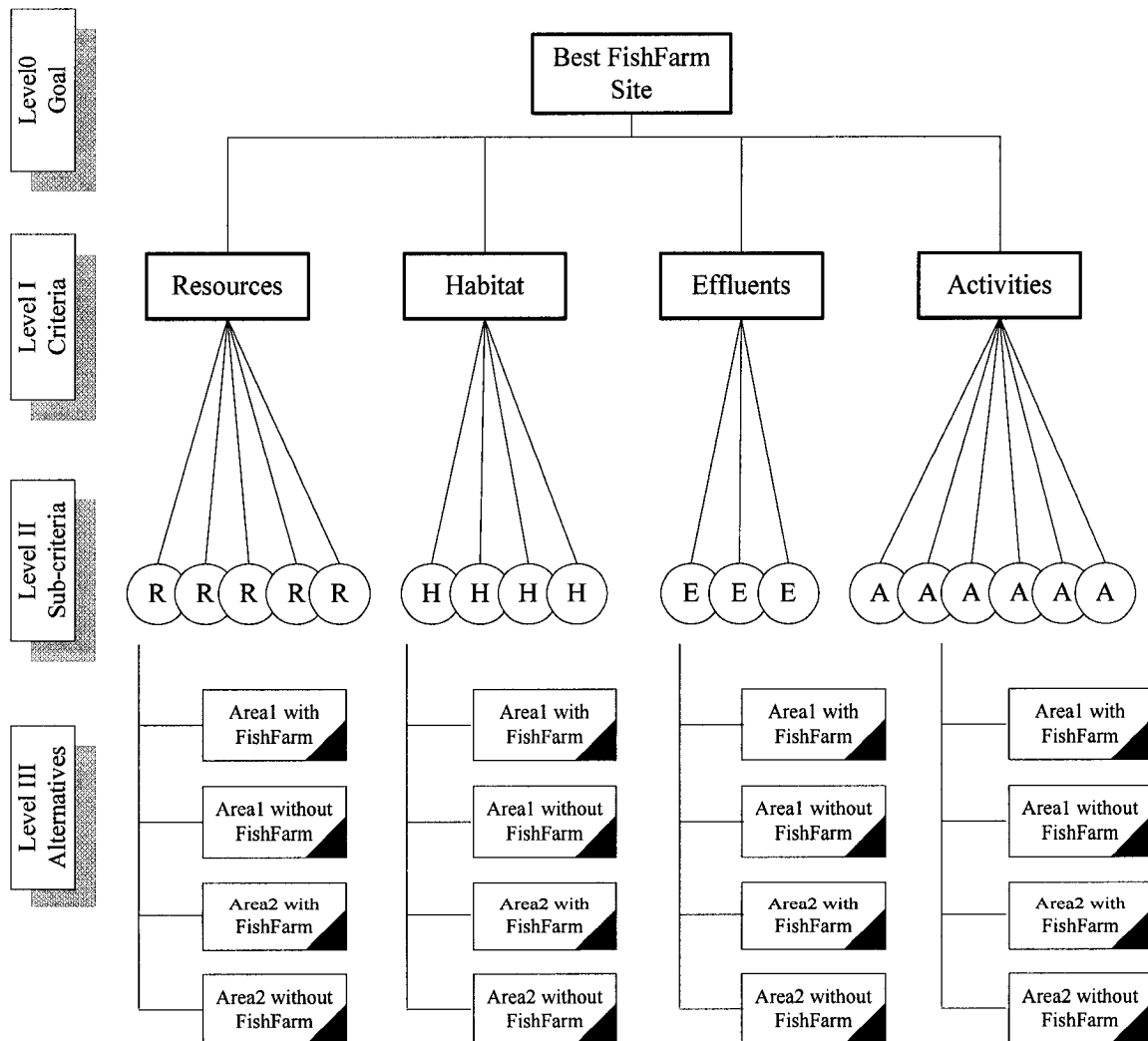


Figure 6. 2: Hierarchical problem formulation of the case study.

The above figure represents the problem that is decomposed into a hierarchy of criteria, sub-criteria and alternatives. The weights of each level of the hierarchy are assigned directly by the decision makers/participants. Decision makers use pairwise comparison to compare each criterion in Level II, and sub-criterion in Level III. The decision makers groups are representatives denoted as:

- 1) Federal Scientists,
- 2) Provincial Government,
- 3) Non-governmental Organizations (NGO's),
- 4) Industrial Organizations, and
- 5) Local Communities.

There are two selected marine areas for possible site selection by the decision making groups denoted as: Area 1, and Area 2. Each site is investigated by using Graphic Information Systems (GIS) to obtain the yield evaluations with and without fish farms. GIS is software that allows for combining data from a geographic illustration to obtain new perspective and inform decision making.

Resources (R)	HerringDay, HerringNight, Lobster, Scallops, Urchins
Habitat (H)	Rockweed, SaltMarshes, CurrentFlow, BottomStructure
Effluents (E)	Coastal-based pollution; MarineActivity pollution; Natural pollutants
Activities (A)	HerringWeir, FishFarms, LobsterTraps, ScallopDrags, UrchinDrags, Recreational

Table 6.1: Sub-criteria table for each criterion.

The sub-criteria for each criterion are given in Table 6.1 below. Chemical A, B, and C are used for describing the Effluents in this thesis.

As a result, there are two selected marine areas for possible site selection by the decision making groups denoted as: Area 1, and Area 2. Each site's ecosystem impacts are evaluated along the 18 dimensions of the decision hierarchy sub-criteria using GIS (Zhao et al 2005) to obtain the ecosystem yield evaluations with and without fish farms. The site alternatives evaluations are fixed for all decision makers. The inputs for criteria (Level I), and sub-criteria (Level II) for each decision makers are stored in the appendices (see Appendix C, D, E, F, G, and H).

6.1. Case Study Inputs

As input, AHP uses the judgments of the decision makers about the criteria, sub-criteria, and evaluation of the decision makers. The inputs of the decision makers for the aqua culture case study were obtained through web-based application developed as a prototype as presented in Chapter 5 above. The decision makers entered their preferences in a table for

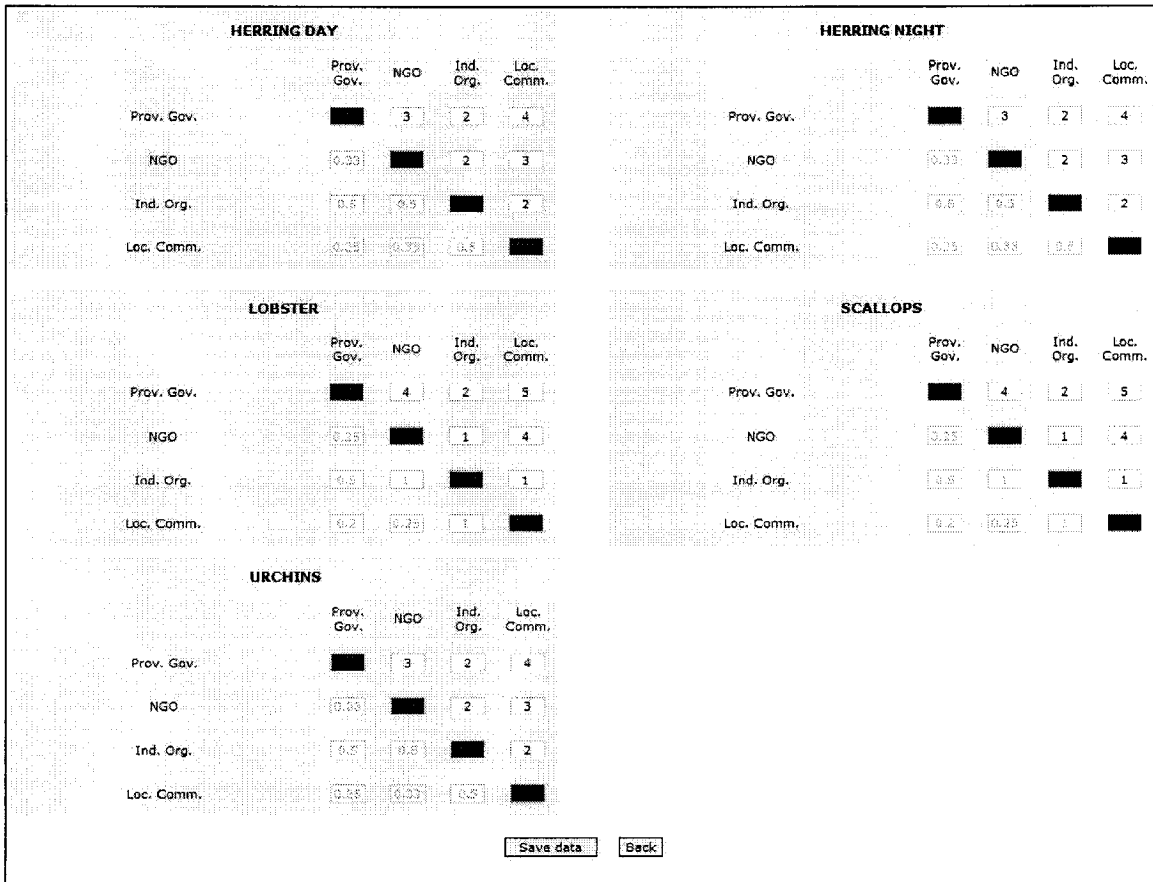


Figure 6.5: Screen dumps for the inputs of evaluation of the decision making groups for the Federal Scientists with respect sub-criteria under the Resources.

The below two figures (Figure 6.6, Figure 6.7) show the key questions with relevant answers and the selected method once the key questions answered appropriately.

First figure (Figure 6.6) shows the key questions for method selection for selecting the most appropriate fish farm for the Aqua Case Study. The below questions were answered based on two tables (Table 4.10.1, and Table 4.10.2) which was explained in Section 4.10. Those tables assist the decision analyst to answer each question appropriately. The first table (Table 4.10.1) shows the strength and the weakness of the methods, and the second table (Table 4.10.2) analyses the link between the input/output, and the needs of the decision makers. The decision analyst answers each question based on these info in order to select the most suitable method for the case study. The conceptualization of method selection diagram (Figure 5.3) was stored in the database of the prototype web-based tool. By answering each question with 'Yes' or 'No', the tool eliminates some of the methods. At the end of the questionnaire, there will be only one method left which would be the most suitable method.

Second figure (Figure 6.7) shows the most appropriate method as Group Evaluation method for the Aquaculture Case Study to evaluate four possible fish sites in the Grand Manan Island area of Atlantic Canada.

Model conceptualization [LogOut](#)

Model conceptualization

Answer the next questionnaire to evaluate the methodology needed to perform the matrix calculation.

Information Content: Are the decision makers generally certain about the information content of the decision or there should the information on comparisons be considered as vague or uncertain?

Yes
 No

Decision Makers Evaluation: Is it possible for the decision makers to evaluate each other? ?

Yes
 No

Scale of Measure: Are the units in the criteria/sub-criteria of the decision hierarchy the same? Can we combine those units? Can we assume that regardless of the units, we can treat all the units as one?

Yes
 No

Decision Makers' Equities: Is there at least one member of the decision making group who is weighted the same or more than the others?

Yes
 No

Input Combination: Is combining the assign weights/inputs necessary?

Yes
 No

Figure 6.6: Screen dumps of the questions for the Conceptualization of Model Selection for the Aquaculture Case Study.

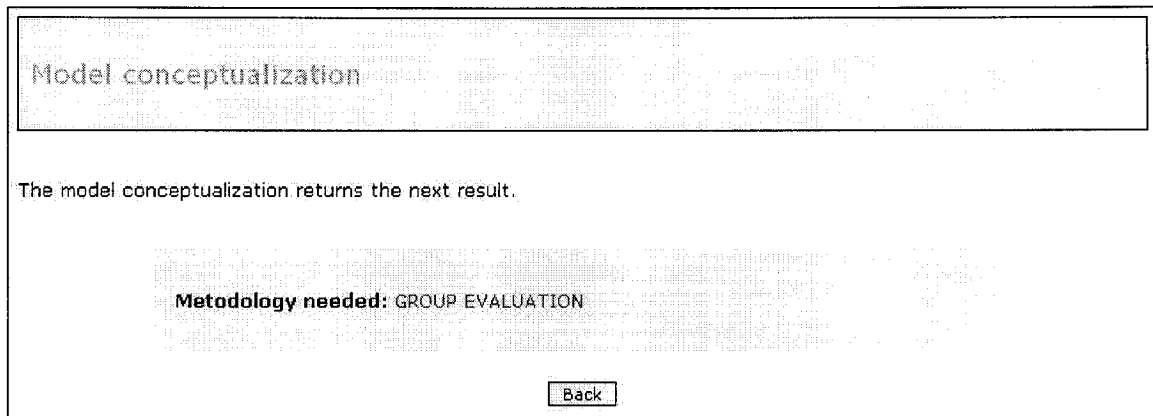


Figure 6.7: Screen dumps of the selected method for the Aquaculture Case Study.

6.2. Case Study Analysis and Results

In this chapter, the description of the decision makers to the characteristics of the method critiques (see Chapter 3) and the comparisons (see Chapter 4) is investigated and the link between decision makers and the methods is also provided.

The overall duration of the evaluation of criteria, sub-criteria and decision makers input data collection was exhaustive for all methods and was quite a long process. The following tables show the outputs obtained using the web-based tool developed as a prototype for the case study and the Group Evaluation results since the prototype web-based tool shows that the most appropriate method is the Group Evaluation method. The complete data set of data for all methods provided in the appendices (Appendix C, D, E, F, G, and H). In the tables below it is noted that: FS is Federal Scientists, PG is Provincial Governments, NGO is Non-Governmental Organizations, IO is Industrial Organizations, and LC is Local Communities decision makers.

Criteria	FS	PG	NGO	IO	LC	Priority	Scaled Priority
Resources	0.383	0.289	0.388	0.384	0.289	0.355	0.341
Habitat	0.314	0.176	0.369	0.19	0.271	0.276	0.265
Effluents	0.174	0.09	0.086	0.088	0.087	0.131	0.125
Activities	0.129	0.445	0.156	0.338	0.354	0.281	0.270
Total	<i>1</i>	<i>1</i>	<i>1</i>	<i>1</i>	<i>1</i>	<i>1.043</i>	<i>1</i>

Table 6.3.1: Pairwise comparison matrix, overall priority and scaled priority of the criteria in Level I for five decision making groups.

The above table, Table 6.3.1, shows the individual AHP priorities and the overall AHP Combined priority of the criteria. For example, according to the Federal Scientists, Resources is the highest criterion with 0.383 among the other criteria. However, according to the Local Communities, Activities is the highest criterion with 0.354. Overall scaled

priority shows that Resources is the highest criterion with 0.341 among the other criteria in Level1. Activities criterion is the second criterion with 0.27, Habitat is the third highest criterion with 0.265, and Effluents is the lowest weighted criterion with 0.125, overall.

Table 6.3.2 shows the priority matrix of the criteria for all the decision makers. The complete data priorities matrices for all the other decision makers are found in the appendices (Appendix C, D, E, F, G, and H).

	Resources	Habitat	Effluents	Activities
Federal Scientists	0.514	0.486	0.494	0.365
Prov.Gov.	0.230	0.216	0.229	0.288
NGO	0.097	0.121	0.125	0.069
Ind.Org.	0.088	0.089	0.053	0.180
Local Comm.	0.071	0.087	0.099	0.097

Table 6.3.2: Priorities of the decision making groups with respect to Criteria.

The above table (Table 6.3.2) shows the priorities of each decision making groups with respect to each criterion. This table was conducted by combining four pairwise comparison matrices which each one provides the priorities of the decision making groups with respect to each criterion.

To see the complete data with the matrices of criteria, see Appendix I, and the respective Tables (Table I.1.2, Table I.1.3, Table I.1.4, and Table I.1.5).

Following table shows the scaled priority matrix of the alternatives with respect to criteria for the Federal Scientists (see Appendix F, F.2). For the complete data priorities matrices for the other decision makers, see Appendix I.

Federal Scientists	Resources	Habitat	Effluents	Activities
A1FF	0.109	0.499	0.261	0.196
A2FF	0.401	0.00002	0.239	0.324
A1NoFF	0.093	0.500	0.261	0.155
A2NoFF	0.399	0.0001	0.239	0.325

Table 6.3.3: Alternatives priority matrix of each criterion for the Federal Scientists.

The above table shows the priority of the criteria (Level I) for Federal Scientists. For example, according to Federal Scientists, A2FF is the best alternative with 0.399 with respect to Resources; A1FF is the best alternative with 0.499 with respect to Habitat etc.

	Criteria				Priority	Ranking
	0.341	0.265	0.125	0.270		
	Resources	Habitat	Effluents	Activities		
A1FF	0.103	0.499	0.253	0.179	0.2470	3
A2FF	0.405	0.000	0.247	0.342	0.2610	1
A1NoFF	0.088	0.500	0.253	0.138	0.2311	4
A2NoFF	0.404	0.001	0.247	0.342	0.2608	2

Table 6.3.4: Alternatives pairwise comparison matrix and overall result for selecting the best alternative in Group Evaluation.

The above table shows the overall ranking and priority for selecting the best alternative, A2FF (Area 2 with Fish Farm). According to the decision maker groups, Area 2 with Fish Farm (A2FF) is the “best”, highest ranking site location for the Fish Farms with 0.261. Area 2 without Fish Farm (A2NoFF) is very close to the Group Evaluation highest ranking site with 0.2608. The below table was obtained through the web-based tool developed as a prototype to show the overall results.

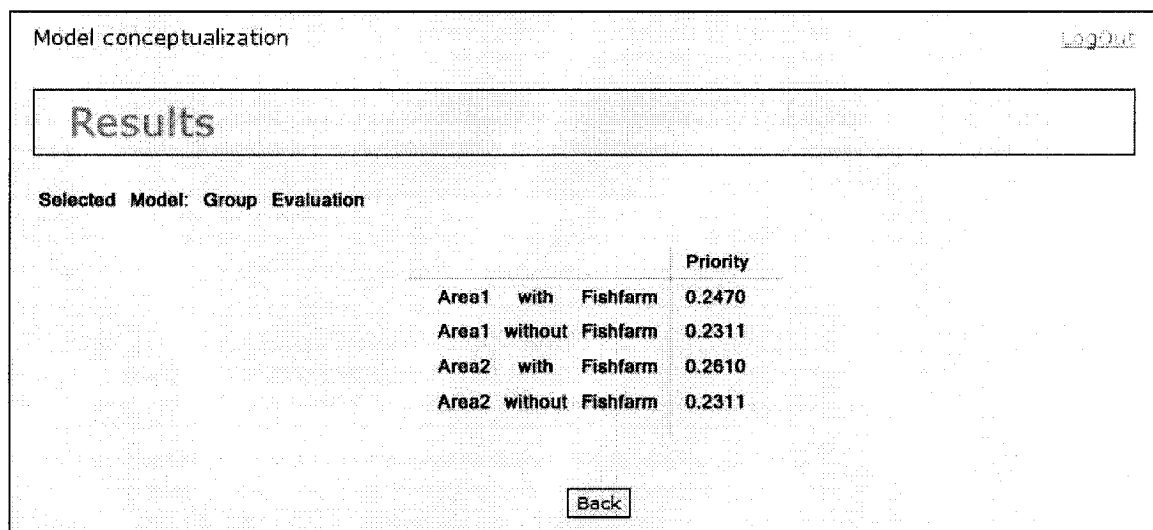


Figure 6.8: Screen dumps of the results for the Aquaculture Case Study.

7 Conclusions and Future Research Construction

This section summarizes the main conclusions of the multicriteria group decision making methods and the case study that focused on the coastal zone of Grand Manan Island, New Brunswick situated in the Bay of Fundy. Finally, limitations and suggestions about possible areas of future research constructions are presented.

7.1 Conclusions

The objective of this research is to investigate and analyze the multicriteria group decision making methods and how to determine and apply the most preferred group decision making method in the case study. The research described within this study has two main aims:

- 1) to analyze multi-criteria group decision making methods by implementing on an illustrative problem (see Chapter 4) in order to be able to determine the most preferred method
- 2) to develop a web-based tool as a prototype for the case study to help the decision analysis to select the most suitable method and then provide a result based on the chosen method

The assessment of suitable method is an important aspect of the investigations. In order to find the most suitable method, the research conducted for this thesis set out to investigate how each method is used in order to identify their potential problems in terms of weakness and strengths that is based on the decision makers and the illustrative problem. However, as established in the literature review presented in Chapter 2, there are number of methods that can be applied to multi-criteria group decision making problems. The literature on the multi-criteria group decision making methods has been adequately and systemically reviewed. The methods used in this study have been reviewed to determine how those methods may influence decision makers.

The overall objective is to gather methodologies from the theory of multi-criteria decision making, with emphasis on group decision making. As a result, followings have become a direct guide to analyze multi-criteria group decision making methods in this thesis:

- i) understanding the rationality of the decision makers,
- ii) considering uncertainty in data inputs issues on the decision makers' preferences,
- iii) evaluating the other decision makers,
- iv) developing the approaches of the decision makers to particular situations,
- v) and finally differentiating different types of problems which requires a number of specifications/restrictions

In Chapter 3, each method has been reviewed based on their use in group decision making. The attributes of the methods have been underlined and has been inspected (see Chapter 4). The main purpose is to expose decision makers to a comprehensive and consistent overall

evaluation of different methods and tools for decision support in a group setting. At the end of the analysis of each method, critiques have been presented to help us to build the web-based tool as a prototype.

In Chapter 4, the factors of the methods that used in Chapter 3 about the attributes of the methods have been inspected. Each method has been applied to the same specific problem in order to illustrate and to demonstrate a practical case of multi-criteria problem solving with group decision making. This illustration assists in defining a framework for application of the methods generally. Comparison of the methods table (Table 4.10.1) shows the strength and the weakness of each method. Process flow table (Table 4.10.2) shows influence of the decision makers with respect to given methodology, input requirements, process, and the results. As a result of a consistent support of those two tables (Table 4.10.1, Table 4.10.2) blended in a harmony, the web-based tool as a prototype has been constructed (see Chapter 5).

It has been highlighted that the prototype web-based tool is very useful in managing the large data for group analysis. Decision makers enter their pairwise comparisons through the prototype tool and the inputs are stored in the database. Chapter 5 focuses on the web-based tool as a prototype which is used not only to enter and store the data, and to calculate the results for different methods, but also to explore the problem content and the applicability of the different group decision making methods. After the decision makers securely enter the system and provide their judgments for the criteria, sub-criteria and the decision makers, the decision analyst answers the key questions (Figure 5.5) to conceptualize of the method selection. The web-based tool developed as a prototype then evaluates the most suitable method and provides the results based on the selected method.

7.2 Contributions of the Thesis

The specific contributions of the research presented in this thesis can be viewed in the following areas:

- 1) Analytical development work
 - a. Examine multi-criteria decision making methods, and review literature for resolution of differences in group preferences
 - b. Compare and contrast the use of the group decision making methods and discuss the effect of those methods
- 2) Practical applied work
 - a. Build a web-based tool as a prototype for multi-criteria group decision making and test the capabilities of the methods
 - b. Apply the tool to the specific application in marine ecosystem decision making for aquaculture siting and evaluation and selection of coastal marine aquaculture sites.

Before development of the prototype web-based tool and the case study was begun, extensive analytical work was investigated to provide a solid foundation for the current research. This included a broad-based literature review of group decision making methods using AHP and their applications as well as web-based tools. It has been found that group decision making applications of the tools on the internet are used generally for a fixed problem or fixed methodology. This thesis has developed an analysis of group decision making methods with another perspective: the input/output correlation and their link with a case study or any given problem. The analytical review assists in developing, functionality for practical applied work.

The analytical work shows that demonstration of the framework for the case study used in this thesis is feasible. The link between the input/output and the needs of the decision makers underlined in analytical work has been analyzed in order to develop the web-based tool as a prototype. However, successful adoption of the suitable method requires very specific information: what the case study data requirements are; how the decision makers are influenced by the other decision makers; and, how uncertainty in inputs affects the results. The results of this research are a contribution towards improving the capability of the web-based tool as a prototype by offering the most suitable method to support decision makers in their understanding of the group decision making process.

While the case study focused on where to locate an aquaculture site in the marine environment, the research tool will also be useful for any multi-criteria group decision making problem.

7.3 Limitations

This thesis mainly intended for investigating and analyzing the multicriteria group decision making methods in order to select the most appropriate group decision making method for selecting an aquaculture site in the marine environment of Grand Manan Island, New Brunswick situated in the Bay of Fundy.

Due to the original case study and time restrictions, the web-based tool has been developed as a prototype to satisfy the marine environment demands only. Therefore the aquaculture site was the main focus of this study. Nevertheless, the structure of the thesis allows the prototype web-based tool to be used in any other group decision making fields once the tool is built dynamically.

For the case study, there are three members in each of the five decision making groups so that there are 15 people in total to evaluate criteria, sub-criteria and the decision makers in this study. Considering the overall comparisons, there many matrices to built and evaluate. For this large data set, it is unavoidable to have some inconsistency. For the case study, over 500 input matrices were required. Among these data, only a couple of matrices indicated substantial inconsistency. It was judged that the inputs would not affect the overall results.

7.4 Future Research

The multi-disciplinary approach to make strategic decisions presented in this thesis is an attempt to offer ideas for identifying future research areas for improvement of the current study. During the study, possible future research activities were identified for further investigations, as described below.

- 1) Extension of the prototype model web-based tool
- 2) Purpose and effective use of alternative MCDM methods

Future work will require more enhancements into the web-based application by identifying a wider selection of methods through the web-based tool to improve the case studies. To satisfy the decision makers with different needs, future work will need to focus on developing the current tool to provide complete requirements for decision makers and the methods. Currently, the requirements added by the decision analyst directly for only the aquaculture site case study used in this thesis. Further research also needs to investigate how decision makers can provide additional info about the problem context and group decision making aspects without specifying directly these requirements. Therefore, to make the extension system more useful, more information about the decision makers needs to be collected through the web-based tool, processed, and integrated with the requirements of the methods. To evaluate the results, feedback also needs to be obtained from the decision makers. Besides defining their needs and requirements, decision makers will also be able to define their own components and sub-components.

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APPENDIX A

Pairwise Comparison Inputs – Illustrative Example

The tables in this appendix contain the decision makers' individual alternative ratings, by criterion. The possible ratings are between 1 and where 1 indicates Equal Importance, and 9 indicates Extreme Importance. In this appendix, there are individual pairwise comparison input for criteria and decision makers.

A.1. Criteria and sub-criteria tables for AHP inputs

CEO:

Criteria	Visibility	Accessibility	Traffic	Convenience	Priority
Visibility	1	3	2	2	0.398
Accessibility	-	1	1/4	1/4	0.085
Traffic	-	-	1	1/2	0.218
Convenience	-	-	-	1	0.299

Table A.1.1: Criteria pairwise comparison matrix and priority by the CEO in AHP.

Visibility	Location1	Location2	Location3	Priority
Location1	1	1/3	1/4	0.123
Location2	-	1	1/2	0.320
Location3	-	-	1	0.557

Table A.1.2: Alternatives pairwise comparison matrix and priority with respect to Visibility by the CEO in AHP.

Accessibility	Location1	Location2	Location3	Priority
Location1	1	3	4	0.608
Location2	-	1	3	0.272
Location3	-	-	1	0.120

Table A.1.3: Alternatives pairwise comparison matrix and priority with respect to Accessibility by the CEO in AHP.

Traffic	Location1	Location2	Location3	Priority
Location1	1	3	5	0.619
Location2	-	1	4	0.284
Location3	-	-	1	0.096

Table A.1.4: Alternatives pairwise comparison matrix and priority with respect to Traffic by the CEO in AHP.

Convenience	Location1	Location2	Location3	Priority
Location1	1	1/3	4	0.265
Location2	-	1	7	0.656
Location3	-	-	1	0.080

Table A.1.5: Alternatives pairwise comparison matrix and priority with respect to Convenience by the CEO in AHP.

CFO

Criteria	Visibility	Access.	Traffic	Convenience	Priority
Visibility	1	3	4	4	0.503
Accessibility	-	1	3	4	0.273
Traffic	-	-	1	3	0.145
Convenience	-	-	-	1	0.079

Table A.1.6: Criteria pairwise comparison matrix and priority by the CFO in AHP.

Visibility	Location1	Location2	Location3	Priority
Location1	1	1/4	1/5	0.096
Location2	-	1	1/3	0.284
Location3	-	-	1	0.619

Table A.1.7: Alternatives pairwise comparison matrix and priority with respect to Visibility by the CFO in AHP.

Accessibility	Location1	Location2	Location3	Priority
Location1	1	1/6	1/4	0.113
Location2	-	1	1/3	0.347
Location3	-	-	1	0.540

Table A.1.8: Alternatives pairwise comparison matrix and priority with respect to Accessibility by the CFO in AHP.

Traffic	Location1	Location2	Location3	Priority
Location1	1	1/4	1/5	0.096
Location2	-	1	1/3	0.284
Location3	-	-	1	0.619

Table A.1.9: Alternatives pairwise comparison matrix and priority with respect to Traffic by the CFO in AHP.

Convenience	Location1	Location2	Location3	Priority
Location1	1	4	2	0.530
Location2	-	1	5	0.320
Location3	-	-	1	0.150

Table A.1.10: Alternatives pairwise comparison matrix and priority with respect to Convenience by the CFO in AHP.

CIO

Criteria	Visibility	Access.	Traffic	Convenience	Priority
Visibility	1	2	1/3	1/3	0.145
Access.	1/2	1	1/4	1/3	0.098
Traffic	3	4	1	1/2	0.327
Convenience	3	3	2	1	0.430

Table A.1.11: Criteria pairwise comparison matrix and priority by the CIO in AHP.

Visibility	Location1	Location2	Location3	Priority
Location1	1	6	3	0.656
Location2	-	1	2	0.193
Location3	-	-	1	0.152

Table A.1.12: Alternatives pairwise comparison matrix and priority with respect to Visibility by the CIO in AHP.

Accessibility	Location1	Location2	Location3	Priority
Location1	1	1/3	1/3	0.142
Location2	-	1	1/2	0.334
Location3	-	-	1	0.525

Table A.1.13: Alternatives pairwise comparison matrix and priority with respect to Accessibility by the CIO in AHP.

Traffic	Location1	Location2	Location3	Priority
Location1	1	5	5	0.703
Location2	-	1	1/2	0.115
Location3	-	-	1	0.182

Table A.1.14: Alternatives pairwise comparison matrix and priority with respect to Traffic by the CIO in AHP.

Convenience	Location1	Location2	Location3	Priority
Location1	1	1/4	6	0.334
Location2	-	1	2	0.523
Location3	-	-	1	0.143

Table A.1.15: Alternatives pairwise comparison matrix and priority with respect to Convenience by the CIO in AHP.

A.2. Criteria and sub-criteria tables for AHP Combined inputs

Criteria	Visibility	Accessibility	Traffic	Convenience	Priority
Visibility	1.00	2.62	1.39	1.39	0.357
Accessibility	0.38	1.00	0.57	0.69	0.149
Traffic	0.72	1.75	1.00	0.91	0.247
Convenience	0.72	1.44	1.10	1.00	0.247

Table A.2.1: Criteria pairwise comparison matrix and priority with in AHP Combined.

Visibility	Location1	Location2	Location3	Priority
Location1	1.00	0.79	0.53	0.242
Location2	1.26	1.00	0.69	0.308
Location3	1.88	1.44	1.00	0.450

Table A.2.2: Alternatives pairwise comparison matrix and priority with respect to Visibility in AHP Combined.

Accessibility	Location1	Location2	Location3	Priority
Location1	1.00	0.55	0.76	0.246
Location2	1.82	1.00	0.79	0.369
Location3	1.31	1.26	1.00	0.386

Table A.2.3: Alternatives pairwise comparison matrix and priority with respect to Accessibility in AHP Combined.

Traffic	Location1	Location2	Location3	Priority
Location1	1.00	1.55	1.71	0.449
Location2	0.64	1.00	0.87	0.268
Location3	0.58	1.14	1.00	0.284

Table A.2.4: Alternatives pairwise comparison matrix and priority with respect to Traffic in AHP Combined.

Convenience	Location1	Location2	Location3	Priority
Location1	1.00	0.69	3.63	0.380
Location2	1.44	1.00	4.12	0.506
Location3	0.28	0.24	1.00	0.114

Table A.2.5: Alternatives pairwise comparison matrix and priority with respect to Convenience in AHP Combined.

A.3. Criteria tables for WSM inputs

In the following table, inputs are collected by using AHP given in Appendix A1.

	CEO	CFO	CIO
Location1	0.315	0.135	0.483
Location2	0.408	0.304	0.323
Location3	0.277	0.561	0.194

Table A.3.1: Alternatives pairwise comparison matrices and priorities for overall by CEO, CFO, and CIO.

In the following table, inputs are collected by using Group Evaluation given in Appendix A5.

	Priority
CEO	0.622
CFO	0.218
CIO	0.160

Table A.3.2: DMs self-evaluation pairwise comparison matrix and overall priority for Group Evaluation.

A.4. Criteria tables for WPM inputs

In the AHP method, each decision maker has preference with respect to criteria. Inputs for the criteria and sub-criteria are already collected by using Group Evaluation method below (Appendix A5).

	Priority
CEO	0.622
CFO	0.218
CIO	0.160

Table A.4.1: DMs self-evaluation pairwise comparison matrix and overall priority for Group Evaluation.

A.5. Criteria and sub-criteria tables for Group Evaluation inputs

Visibility	CEO	CFO	CIO	Priority
CEO	1	5	8	0.711
CFO	-	1	5	0.223
CIO	-	-	1	0.066

Table A.5.1: DMs pairwise comparison matrix with respect to Visibility.

Accessibility	CEO	CFO	CIO	Priority
CEO	1	2	7	0.580
CFO	-	1	6	0.350
CIO	-	-	1	0.070

Table A.5.2: DMs pairwise comparison matrix with respect to Accessibility.

Traffic	CEO	CFO	CIO	Priority
CEO	1	2	4	0.557
CFO	-	1	3	0.320
CIO	-	-	1	0.123

Table A.5.3: DMs pairwise comparison matrix with respect to Traffic.

Convenience	CEO	CFO	CIO	Priority
CEO	1	4	2	0.557
CFO	-	1	1/3	0.123
CIO	-	-	1	0.320

Table A.5.4: DMs pairwise comparison matrix with respect to Convenience.

	Priority
CEO	0.622
CFO	0.218
CIO	0.160

Table A.5.6: DMs self-evaluation pairwise comparison matrix and overall priority for Group Evaluation.

Table A.5.6, is derived by using the criteria priorities for each decision makers in the AHP (Appendix A1), and the decision makers' priorities (Appendix A5) with respect to each criterion in the Group Evaluation. In order to calculate the overall priority of each decision maker, the priority of the selected decision maker is multiplied by the relative priority of the criterion made by the same decision maker. The sum of the entries is stored as the overall priority of the selected decision maker.

A.6. Criteria and sub-criteria tables for Fuzzy AHP inputs

CEO

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	2	3	4	1	2	3	1	2	3
Access.	1/4	1/3	1/2	1	1	1	1/5	1/4	1/3	1/5	1/4	1/3
Traffic	1/3	1/2	1	3	4	5	1	1	1	1/3	1/2	1
Conv.	1/3	1/2	1	3	4	5	1	2	3	1	1	1

Table A.6.1: Criteria fuzzy pairwise comparison matrixes by CEO for Fuzzy AHP.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/4	1/3	1/2	1/5	1/4	1/3
Location2	2	3	4	1	1	1	1/3	1/2	1
Location3	3	4	5	1	2	3	1	1	1

Table A.6.2: Alternatives fuzzy pairwise comparison matrixes with respect to Visibility by CEO for Fuzzy AHP.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	2	3	4	3	4	5
Location2	1/4	1/3	1/2	1	1	1	2	3	4
Location3	1/5	1/4	1/3	1/4	1/3	1/2	1	1	1

Table A.6.3: Alternatives fuzzy pairwise comparison matrixes with respect to Accessibility by CEO for Fuzzy AHP.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	2	3	4	4	5	6
Location2	1/4	1/3	1/2	1	1	1	3	4	5
Location3	1/6	1/5	1/4	1/5	1/4	1/3	1	1	1

Table A.6.4: Alternatives fuzzy pairwise comparison with respect to Traffic for the CEO for Fuzzy AHP.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/4	1/3	1/2	3	4	5
Location2	2	3	4	1	1	1	6	7	8
Location3	1/5	1/4	1/3	1/8	1/7	1/6	1	1	1

Table A.6.5: Alternatives fuzzy pairwise comparison matrixes with respect to Convenience by CEO for Fuzzy AHP.

CFO

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	2	3	4	3	4	5	3	4	5
Access.	1/4	1/3	1/2	1	1	1	2	3	4	3	4	5
Traffic	1/5	1/4	1/3	1/4	1/3	1/2	1	1	1	2	3	4
Conv.	1/5	1/4	1/3	1/5	1/4	1/3	1/4	1/3	1/2	1	1	1

Table A.6.6: Criteria fuzzy pairwise comparison matrixes for the CFO in Fuzzy AHP.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/5	1/4	1/3	1/6	1/5	1/4
Location2	3	4	5	1	1	1	1/4	1/3	1/2
Location3	4	5	6	2	3	4	1	1	1

Table A.6.7: Alternatives fuzzy pairwise comparison matrixes with respect to Visibility for the CFO in Fuzzy AHP.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/7	1/6	1/5	1/4	1/3	1/2
Location2	5	6	7	1	1	1	1/4	1/3	1/2
Location3	2	3	4	2	3	4	1	1	1

Table A.6.8: Alternatives fuzzy pairwise comparison matrixes with respect to Accessibility for the CFO in Fuzzy AHP.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/5	1/4	1/3	1/6	1/5	1/4
Location2	3	4	5	1	1	1	1/4	1/3	1/2
Location3	4	5	6	2	3	4	1	1	1

Table A.6.9: Alternatives fuzzy pairwise comparison with respect to Traffic for the CFO in Fuzzy AHP.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	3	4	5	1	2	3
Location2	1/5	1/4	1/3	1	1	1	4	5	6
Location3	1/3	1/2	1	1/6	1/5	1/4	1	1	1

Table A.6.10: Alternatives fuzzy pairwise comparison matrixes with respect to Convenience for the CFO in Fuzzy AHP.

CIO

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	1	2	3	1/4	1/3	1/2	1/4	1/3	1/2
Access.	1/3	1/2	1	1	1	1	1/5	1/4	1/4	1/4	1/3	1/2
Traffic	2	3	4	4	4	5	1	1	1	1/3	1/2	1
Conv.	2	3	4	2	3	4	1	2	3	1	1	1

Table 4.6.11: Criteria fuzzy pairwise comparison matrixes for the CIO in Fuzzy AHP.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	5	6	7	2	3	4
Location2	1/7	1/6	1/5	1	1	1	1	2	3
Location3	1/4	1/3	1/2	1/3	1/2	1	1	1	1

Table A.6.12: Alternatives fuzzy pairwise comparison matrixes with respect to Visibility for the CIO in Fuzzy AHP.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/4	1/3	1/2	1/4	1/3	1/2
Location2	2	3	4	1	1	1	1/3	1/2	1
Location3	2	3	4	1	2	3	1	1	1

Table A.6.13: Alternatives fuzzy pairwise comparison matrixes with respect to Accessibility for the CIO in Fuzzy AHP.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	4	5	6	4	5	6
Location2	1/6	1/5	1/4	1	1	1	1/3	1/2	1
Location3	1/6	1/5	1/4	1	2	3	1	1	1

Table 4.6.14: Alternatives fuzzy pairwise comparison with respect to Traffic for the CIO.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1/5	1/4	1/3	5	6	7
Location2	3	4	5	1	1	1	1	2	3
Location3	1/7	1/6	1/5	1/3	1/2	1	1	1	1

Table A.6.15: Alternatives fuzzy pairwise comparison matrixes with respect to Convenience for the CIO in Fuzzy AHP.

A.7. Criteria and sub-criteria tables for Fuzzy AHP Combined inputs

Criteria	Visibility			Accessibility			Traffic			Convenience		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	1.59	2.62	3.63	0.91	1.39	1.96	0.91	1.39	1.96
Access.	0.28	0.38	0.63	1	1	1	0.43	0.57	0.69	0.53	0.69	0.94
Traffic	0.51	0.72	1.10	1.44	1.75	2.32	1	1	1	0.61	0.91	1.59
Conv.	0.51	0.72	1.10	1.06	1.44	1.88	0.63	1.10	1.65	1	1	1

Table A.7.1: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to criteria in Fuzzy AHP Combined.

Accessibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.22	1.82	2.42	1.84	2.46	3.11
Location2	2.03	2.50	3.01	1	1	1	1.27	1.89	2.56
Location3	0.95	1.40	1.87	0.91	1.38	1.89	1	1	1

Table A.7.2: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Accessibility in Fuzzy AHP Combined.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.55	0.68	0.89	0.31	0.42	0.55
Location2	2.10	3.03	3.97	1	1	1	0.35	0.56	1.02
Location3	3.04	3.98	4.92	1.17	2.12	3.09	1	1	1

Table A.7.3: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Visibility in Fuzzy AHP Combined.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.17	1.55	2.00	1.39	1.71	2.08
Location2	0.50	0.64	0.85	1	1	1	0.63	0.87	1.36
Location3	0.48	0.58	0.72	0.74	1.14	1.59	1	1	1

Table A.7.4: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Traffic in Fuzzy AHP Combined.

Convenience	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.57	0.75	0.99	3.39	4.39	5.39
Location2	2.10	2.98	3.87	1	1	1	4.15	5.15	6.15
Location3	0.19	0.25	0.37	0.19	0.26	0.44	1	1	1

Table A.7.5: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Convenience in Fuzzy AHP Combined.

A.8. Criteria and sub-criteria tables for Fuzzy AHP Group inputs

Criteria	Visibility			Access.			Traffic			Conv.		
	L	M	H	L	M	H	L	M	H	L	M	H
Visibility	1	1	1	1.59	2.62	3.63	0.91	1.39	1.96	0.91	1.39	1.96
Access.	0.28	0.38	0.63	1	1	1	0.43	0.57	0.69	0.53	0.69	0.94
Traffic	0.51	0.72	1.10	1.44	1.75	2.32	1	1	1	0.61	0.91	1.59
Conv.	0.51	0.72	1.10	1.06	1.44	1.88	0.63	1.10	1.65	1	1	1

Table A.8.1: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Criteria in Fuzzy AHP Group.

Access.	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.23	1.82	2.43	1.85	2.46	3.11
Location2	2.03	2.50	3.02	1	1	1	1.27	1.89	2.57
Location3	0.96	1.40	1.87	0.91	1.38	1.90	1	1	1

Table A.8.2: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Accessibility in Fuzzy AHP Group.

Visibility	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.55	0.69	0.89	0.31	0.42	0.56
Location2	2.10	3.04	3.97	1	1	1	0.36	0.56	1.02
Location3	3.04	3.98	4.93	1.18	2.12	3.09	1	1	1

Table A.8.3: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Visibility in Fuzzy AHP Group.

Traffic	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	1.67	2.36	3.07	2.77	3.46	4.16
Location2	1.12	1.49	1.91	1	1	1	1.79	2.40	3.07
Location3	1.39	1.74	2.09	0.87	1.35	1.83	1	1	1

Table A.8.4: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Traffic in Fuzzy AHP Group.

Conv.	Location1			Location2			Location3		
	L	M	H	L	M	H	L	M	H
Location1	1	1	1	0.57	0.76	1.00	3.40	4.40	5.40
Location2	2.10	2.98	3.87	1	1	1	4.15	5.15	6.15
Location3	0.20	0.25	0.37	0.20	0.26	0.44	1	1	1

Table A.8.5: Fuzzy numbers in the pairwise comparison for ranking the alternatives with respect to Convenience in Fuzzy AHP Group.

APPENDIX B

Results – Illustrative Example

The tables in this section contain the results for different methods for the illustrative problem (see Chapter 4). The overall priority provides a ranking for the alternatives.

B.1. Criteria tables for AHP results

	Priority		
	CEO	CFO	CIO
Location1	0.315	0.135	0.483
Location2	0.408	0.304	0.323
Location3	0.277	0.561	0.194

Table B.1.1: Alternatives pairwise comparison matrix and priorities for overall by CEO, CFO, and CIO in AHP.

B.2. Criteria tables for AHP Combined results

	Overall Priority
Location1	0.328
Location2	0.356
Location3	0.316

Table B.2.1: Overall priority matrix for selecting the best location in AHP Combined.

B.3. Criteria tables for WPM results

CEO	Criteria							
(	0.398	0.085	0.218	0.299)			
	Visib.	Access.	Traffic	Conv.				Priority
Loc.1	0.123	0.608	0.619	0.265	=>	R(Location1/Location2)=		0.660
Loc.2	0.320	0.272	0.284	0.656	=>	R(Location1/Location3)=		1.349
Loc.3	0.557	0.120	0.096	0.080	=>	R(Location2/Location3)=		2.043

Table B.3.1: Alternatives pairwise comparison matrix and priority by CEO in WPM.

B.4. Criteria tables for Group Evaluation results

	CEO	CFO	CIO	Priority	Scaled Priority
Visibility	0.398	0.503	0.145	0.405	0.376
Accessibility	0.085	0.273	0.098	0.152	0.141
Traffic	0.218	0.145	0.327	0.208	0.193
Convenience	0.299	0.079	0.430	0.314	0.291
	<i>1</i>	<i>1</i>	<i>1</i>	<i>1.078</i>	<i>1</i>

Table B.4.1: Criteria pairwise comparison matrix and priority in Group Evaluation.

	(	0.376	0.141	0.193	0.291)
	Visibility	Accessibility	Traffic	Convenience	Priority	
Location1	0.152	0.402	0.462	0.320	0.296	
Location2	0.304	0.303	0.263	0.572	0.474	
Location3	0.544	0.295	0.274	0.109	0.330	

Table B.4.2: Alternatives pairwise comparison matrix and priority in Group Evaluation.

B.5. Criteria tables for Fuzzy AHP results

Criteria		Low	Mode	High	Normalized Matrix		
Visibility	v1	1.190	1.860	2.450	0.133	0.17	0.204
Access.	v2	0.320	0.380	0.490	0.071	0.091	0.115
Traffic	v3	0.760	1.000	1.500	0.036	0.046	0.058
Convenience	v4	1.000	1.410	1.970	0.020	0.024	0.031
		<i>3.270</i>	<i>4.660</i>	<i>6.400</i>	<i>15.510</i>		

Table B.5.1: Criteria fuzzy normalized matrix for the CEO in Fuzzy AHP.

Visibility		Low	Mode	High	Normalized Matrix		
Location1	v1	0.370	0.440	0.550	0.034	0.040	0.051
Location2	v2	0.870	1.140	1.590	0.080	0.105	0.146
Location3	v3	1.440	2.000	2.470	0.133	0.184	0.227
		<i>2.680</i>	<i>3.580</i>	<i>4.600</i>	<i>10.870</i>		

Table B.5.2: Alternatives fuzzy normalized matrix with respect to Visibility for CEO in Fuzzy AHP.

Accessibility		Low	Mode	High	Normalized Matrix		
Location1	v1	1.820	2.290	2.710	0.162	0.204	0.242
Location2	v2	0.790	1.000	1.260	0.071	0.089	0.112
Location3	v3	0.370	0.440	0.550	0.033	0.039	0.049
		2.980	3.730	4.520	11.230		

Table B.5.3: Alternatives fuzzy normalized matrix with respect to Accessibility for CEO in Fuzzy AHP.

Traffic		Low	Mode	High	Normalized Matrix		
Location1	v1	2.000	2.470	2.880	0.169	0.208	0.244
Location2	v2	0.910	1.100	1.360	0.077	0.093	0.115
Location3	v3	0.320	0.370	0.440	0.027	0.031	0.037
		3.230	3.940	4.680	11.840		

Table B.5.4: Alternatives fuzzy normalized matrix with respect to Traffic for CEO in Fuzzy AHP.

Convenience		Low	Mode	High	Normalized Matrix		
Location1	v1	0.910	1.100	1.360	0.072	0.087	0.108
Location2	v2	2.290	2.760	3.170	0.182	0.219	0.252
Location3	v3	0.290	0.330	0.380	0.023	0.026	0.030
		3.490	4.190	4.910	12.590		

Table B.5.5: Alternatives fuzzy normalized matrix with respect to Convenience for CEO in Fuzzy AHP.

Criteria		Low	Mode	High	Normalized Matrix		
Visibility	v1	2.060	2.630	3.160	0.133	0.170	0.204
Access.	v2	1.110	1.410	1.780	0.071	0.091	0.115
Traffic	v3	0.560	0.710	0.900	0.036	0.046	0.058
Convenience	v4	0.320	0.380	0.490	0.020	0.024	0.031
		4.050	5.130	6.330	15.510		

Table B.5.6: Criteria fuzzy normalized matrix for the CFO in Fuzzy AHP.

Visibility		Low	Mode	High	Normalized Matrix		
Location1	v1	0.320	0.370	0.440	0.027	0.031	0.037
Location2	v2	0.910	1.100	1.360	0.077	0.093	0.115
Location3	v3	2.000	2.470	2.880	0.169	0.208	0.244
		3.230	3.940	4.680	11.840		

Table B.5.7: Alternatives fuzzy normalized matrix with respect to Visibility for the CFO in Fuzzy AHP.

Accessibility		Low	Mode	High	Normalized Matrix		
Location1	v1	0.330	0.380	0.460	0.029	0.034	0.041
Location2	v2	1.080	1.260	1.520	0.096	0.112	0.135
Location3	v3	1.590	2.080	2.520	0.142	0.185	0.225
		2.990	3.720	4.500	11.220		

Table B.5.8: Alternatives fuzzy normalized matrix with respect to Accessibility for the CFO in Fuzzy AHP.

Traffic		Low	Mode	High	Normalized Matrix		
Location1	v1	0.320	0.370	0.440	0.027	0.031	0.037
Location2	v2	0.910	1.100	1.360	0.077	0.093	0.115
Location3	v3	2.000	2.470	2.880	0.169	0.208	0.244
		3.230	3.940	4.680	11.840		

Table B.5.9: Alternatives fuzzy normalized matrix with respect to Traffic for the CFO in Fuzzy AHP.

Convenience		Low	Mode	High	Normalized Matrix		
Location1	v1	1.440	2.000	2.470	0.135	0.188	0.232
Location2	v2	0.930	1.080	1.260	0.087	0.101	0.118
Location3	v3	0.380	0.460	0.630	0.036	0.044	0.059
		2.750	3.540	4.360	10.650		

Table B.5.10: Alternatives fuzzy normalized matrix with respect to Convenience for the CFO in Fuzzy AHP.

Criteria		Low	Mode	High		Normalized Matrix		
Visibility	v1	0.500	0.690	0.930		0.034	0.047	0.064
Access.	v2	0.360	0.450	0.590		0.025	0.031	0.041
Traffic	v3	1.280	1.570	2.11		0.088	0.107	0.145
Convenience	v4	1.410	2.060	2.630		0.097	0.141	0.180
		3.550	4.760	6.270	14.590			

Table B.5.11: Criteria fuzzy normalized matrix for the CIO in Fuzzy AHP.

Visibility		Low	Mode	High		Normalized Matrix		
Location1	v1	2.150	2.620	3.040		0.185	0.225	0.261
Location2	v2	0.520	0.690	0.840		0.045	0.060	0.072
Location3	v3	0.440	0.550	0.790		0.037	0.047	0.068
		3.110	3.860	4.670	11.650			

Table B.5.12: Alternatives fuzzy normalized matrix with respect to Visibility for the CIO in Fuzzy AHP.

Accessibility		Low	Mode	High		Normalized Matrix		
Location1	v1	0.400	0.480	0.630		0.038	0.046	0.060
Location2	v2	0.870	1.140	1.590		0.083	0.109	0.151
Location3	v3	1.260	1.820	2.290		0.120	0.173	0.218
		2.530	3.440	4.510	10.480			

Table B.5.13: Alternatives fuzzy normalized matrix with respect to Accessibility for the CIO in Fuzzy AHP.

Traffic		Low	Mode	High		Normalized Matrix		
Location1	v1	2.520	2.920	3.300		0.203	0.235	0.266
Location2	v2	0.380	0.460	0.630		0.031	0.037	0.051
Location3	v3	0.550	0.740	0.910		0.044	0.059	0.073
		3.450	4.120	4.840	12.420			

Table B.5.14: Alternatives fuzzy normalized matrix with respect to Traffic for the CIO in Fuzzy AHP.

Convenience		Low	Mode	High	Normalized Matrix		
Location1	v1	1.000	1.140	1.330	0.093	0.106	0.123
Location2	v2	1.440	2.000	2.470	0.134	0.186	0.229
Location3	v3	0.360	0.440	0.580	0.034	0.041	0.054
		2.800	3.580	4.380	10.760		

Table B.5.15: Alternatives fuzzy normalized matrix with respect to Convenience for the CIO in Fuzzy AHP.

	CEO			CFO			CIO		
	Low	Mode	High	Low	Mode	High	Low	Mode	High
Loc.1	0.020	0.034	0.057	0.008	0.012	0.018	0.038	0.064	0.099
Loc.2	0.025	0.044	0.075	0.021	0.031	0.047	0.010	0.016	0.028
Loc.3	0.015	0.030	0.048	0.021	0.033	0.049	0.008	0.014	0.024

Table B.5.16: Alternatives overall priority matrices for all the decision makers in Fuzzy AHP.

B.6. Criteria and sub-criteria tables for Fuzzy AHP Combined results

Criteria		Low	Mode	High	Normalized Matrix		
Visibility	v1	1.320	1.870	2.380	0.088	0.125	0.159
Access.	v2	0.580	0.730	0.940	0.039	0.049	0.062
Traffic	v3	0.830	1.080	1.490	0.055	0.072	0.099
Convenience	v4	0.880	1.240	1.660	0.059	0.083	0.111
		3.610	4.910	6.460	14.980		

Table B.6.1: Criteria fuzzy normalized matrix in Fuzzy AHP Combined.

Visibility		Low	Mode	High	Normalized Matrix		
Location1	v1	0.560	0.660	0.790	0.050	0.060	0.070
Location2	v2	0.910	1.190	1.590	0.080	0.100	0.140
Location3	v3	1.530	2.040	2.480	0.130	0.170	0.210
		3.000	3.890	4.860	11.750		

Table B.6.2: Alternatives fuzzy normalized matrix for with respect to Visibility in Fuzzy AHP Combined.

Accessibility		Low	Mode	High	Normalized Matrix		
Location1	v1	1.310	1.650	1.960	0.100	0.120	0.140
Location2	v2	1.370	1.680	1.980	0.100	0.120	0.140
Location3	v3	0.960	1.250	1.530	0.070	0.090	0.110
		3.640	4.580	5.470	22.140		

Table B.6.3: Alternatives fuzzy normalized matrix for with respect to Accessibility in Fuzzy AHP Combined.

Traffic		Low	Mode	High	Normalized Matrix		
Location1	v1	1.670	2.020	2.340	0.110	0.140	0.160
Location2	v2	1.260	1.530	1.800	0.090	0.100	0.120
Location3	v3	1.070	1.330	1.570	0.070	0.090	0.110
		4.000	4.880	5.710	14.590		

Table B.6.4: Alternatives fuzzy normalized matrix for with respect to Traffic in Fuzzy AHP Combined.

Convenience		Low	Mode	High	Normalized Matrix		
Location1	v1	1.250	1.490	1.750	0.090	0.110	0.130
Location2	v2	2.060	2.490	2.880	0.160	0.190	0.220
Location3	v3	0.340	0.410	0.550	0.030	0.030	0.040
		3.650	4.390	5.180	13.220		

Table B.6.5: Alternatives fuzzy normalized matrix for with respect to Convenience in Fuzzy AHP Combined.

	Low	Mode	High
Location1	0.022	0.035	0.056
Location2	0.023	0.038	0.062
Location3	0.020	0.034	0.056

Table B.6.6: Alternatives priority matrix with three possible outcomes in Fuzzy AHP Combined.

B.7. Criteria and sub-criteria tables for Fuzzy AHP Group results

		Low	Mode	High	Normalized Matrix		
Visibility	v1	1.070	1.500	1.930	0.083	0.117	0.150
Accessibility	v2	0.500	0.620	0.800	0.039	0.049	0.062
Traffic	v3	0.820	1.030	1.420	0.064	0.080	0.110
Convenience	v4	0.760	1.030	1.360	0.059	0.080	0.106
		<i>3.150</i>	<i>4.180</i>	<i>5.510</i>	<i>12.840</i>		

Table B.7.1: Criteria fuzzy normalized matrix in Fuzzy AHP Group.

	Low	Mode	High
Location1	0.021	0.033	0.051
Location2	0.025	0.041	0.066
Location3	0.020	0.034	0.055

Table B.7.2: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes in Fuzzy AHP Group.

APPENDIX C

Pairwise Comparisons Group Evaluation Inputs and Alternatives Data Grid Values – Case Study

The tables in this appendix are related to the Case Study on aquaculture site selection. The tables contain the decision makers' individual pairwise comparisons by criterion and for evaluating other decision makers. Data grid values for each of the fish farm sites are also provided. The possible ratings are between 1 and where 1 indicates Equal Importance, and 9 indicates Extreme Importance. In this appendix, there are individual pairwise comparison input for criteria and decision makers.

This section has mainly two parts:

- Part 1) comparison of the decision makers - Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities - with respect to criteria and sub-criteria.
- Part 2) the input of the four alternatives which is the same for every decision making group. The following tables in this section provide pairwise comparisons of all the decision makers. Individual pairwise comparisons of the decision makers are gathered in the same table in order to reduce the number of pages.

Part 1. The possible ratings are between 1 and where 1 indicates Equal Importance, and 9 that indicates Extreme Importance. The tables in the first part of this section contain the decision makers' ratings for the other decision makers with respect to criteria and sub-criteria. For example, in the following table, Table C.1.1, every decision maker's judgments with respect to Resources are provided. The digits 4,6,3 in the second cell of the first row represent the pairwise comparisons of Federal Scientists (Fed.Sc.) to Provincial Government (P.G.) for NGO, Industrial Organizations (I.O.), and Local Communities (L.C.) respectively.

Pairwise comparisons of the decision makers with respect to Resources and sub-components under Resources.

RESOURCES	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	4,6,3	6,7,4	4,6,5	4,3,7
P.G.	-	1	3,4,3	2,3,5	4,3,3
NGO	-	-	1	2,1,1/2	3,1/2,2
I.O.	-	-	-	1	2,1/3,2
L.C.	-	-	-	-	1

Table C.1.1: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Resources.

Herr.Day	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,3	5,6,4	3,6,4	5,3,6
P.G.	-	1	3,3,2	2,3,2	4,2,2
NGO	-	-	1	2,1/3,1	3,1,1
I.O.	-	-	-	1	2,2,1/2
L.C.	-	-	-	-	1

Table C.1.2: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Herring Day.

Herr.Night	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,3	5,6,4	3,6,4	5,3,6
P.G.	-	1	3,3,2	2,3,2	4,2,2
NGO	-	-	1	2,1/3,1	3,1,1
I.O.	-	-	-	1	2,2,1/3
L.C.	-	-	-	-	1

Table C.1.3: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Herring Night.

Lobster	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	4,6,3	6,7,5	4,6,4	5,3,7
P.G.	-	1	4,4,3	2,5,3	5,3,3
NGO	-	-	1	1,1/4,1/2	4,1/2,1/2
I.O.	-	-	-	1	1,2,1/3
L.C.	-	-	-	-	1

Table C.1.4: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Lobster.

Scallops	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	4,7,3	5,8,5	4,6,4	4,3,8
P.G.	-	1	4,5,3	2,5,3	5,3,3
NGO	-	-	1	1,1/5,1/2	4,1/2,1/3
I.O.	-	-	-	1	1,3,1/3
L.C.	-	-	-	-	1

Table C.1.5: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Scallops.

Urchins	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,2	5,6,3	4,5,2	4,3,6
P.G.	-	1	3,3,2	2,3,2	4,2,2
NGO	-	-	1	2,1/4,1/2	3,1/2,1
I.O.	-	-	-	1	2,2,1/3
L.C.	-	-	-	-	1

Table C.1.6: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Urchins.

Pairwise comparisons of the decision makers with respect to Habitat and sub-components under Habitat.

HABITAT	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	5,3,3	7,4,5	3,5,3	7,3,3
P.G.	-	1	1,4,3	2,2,4	2,3,3
NGO	-	-	1	3,3,1	2,1,1
I.O.	-	-	-	1	1,1/3,2
L.C.	-	-	-	-	1

Table C.1.7: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Habitat.

Rockweed	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,3	4,7,4	3,4,2	3,2,7
P.G.	-	1	1,4,3	2,3,2	2,2,3
NGO	-	-	1	3,1/2,2	2,1,1
I.O.	-	-	-	1	1,2,1/2
L.C.	-	-	-	-	1

Table C.1.8: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Rockweed.

SaltMarches	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	2,4,1	3,5,2	2,4,3	2,2,5
P.G.	-	1	1/2,3,2	3,4,2	1,2,2
NGO	-	-	1	3,2,3	1,2,2
I.O.	-	-	-	1	1/2,1/2,1/3
L.C.	-	-	-	-	1

Table C.1.9: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Salt Marches.

Current Flow	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	5,5,3	2,7,3	1,5,3	3,4,7
P.G.	-	1	1,4,2	2,2,2	2,1,3
NGO	-	-	1	3,2,2	2,2,1
I.O.	-	-	-	1	1,2,1
L.C.	-	-	-	-	1

Table C.1.10: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Current Flow.

Bottom Structure	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,3	2,7,3	1,3,3	3,3,7
P.G.	-	1	1,4,1	2,2,1	2,1,3
NGO	-	-	1	3,2,1	2,2,1
I.O.	-	-	-	1	1,3,1
L.C.	-	-	-	-	1

Table C.1.11: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Bottom Structure.

Pairwise comparisons of the decision makers with respect to Effluents and sub-components under Effluents.

EFFLUENTS	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	5,3,3	7,5,3	7,6,5	7,3,3
P.G.	-	1	1/3,5,4	2,5,4	1,5,3
NGO	-	-	1	4,3,3	2,1,2
I.O.	-	-	-	1	1/2,1/3,1/3
L.C.	-	-	-	-	1

Table C.1.12: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Effluents.

ChemicalA	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,3,3	3,3,3	5,7,3	3,3,3
P.G.	-	1	1,3,4	1,5,5	1,3,3
NGO	-	-	1	1,4,3	1,3,1
I.O.	-	-	-	1	1,1/3,1/3
L.C.	-	-	-	-	1

Table C.1.13: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to ChemicalA.

ChemicalB	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,3	3,7,3	3,3,3	3,3,7
P.G.	-	1	1/4,5,3	3,3,3	2,4,5
NGO	-	-	1	5,4,3	3,3,1
I.O.	-	-	-	1	1/2,1/3,1/2
L.C.	-	-	-	-	1

Table C.1.14: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to ChemicalB.

ChemicalC	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,4,3	3,5,2	5,3,2	3,3,5
P.G.	-	1	1/2,4,3	2,2,2	2,2,4
NGO	-	-	1	3,3,2	2,2,1
I.O.	-	-	-	1	1/2,1/3,1/3
L.C.	-	-	-	-	1

Table C.1.15: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to ChemicalC.

Pairwise comparisons of the decision makers with respect to Activities and sub-components under Activities.

ACTIVITIES	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,1,3	5,3,3	1/3,5,1/3	5,3,2
P.G.	-	1	3,4,4	2,2,4	3,5,3
NGO	-	-	1	1/2,1/5,1/5	1,1/3,1/3
I.O.	-	-	-	1	3,1/3,3
L.C.	-	-	-	-	1

Table C.1.16: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Activities.

HerringWeir	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,1	2,7,2	1/3,4,1/3	1,2,5
P.G.	-	1	3,3,3	1,4,2	2,3,3
NGO	-	-	1	1/3,1/4,1/4	1,1/3,1/3
I.O.	-	-	-	1	3,2,1/2
L.C.	-	-	-	-	1

Table C.1.17: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Herring Weir.

FishFarms	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	2,2,1/2	3,5,3	1/4,4,1/2	2,2,3
P.G.	-	1	4,5,4	2,5,3	3,3,5
NGO	-	-	1	1/4,1/6,1/4	1,1/3,1
I.O.	-	-	-	1	3,3,1/3
L.C.	-	-	-	-	1

Table C.1.18: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Fish Farms.

LobsterTraps	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,2	2,7,4	1/3,5,1/2	2,3,5
P.G.	-	1	3,3,3	1,4,2	2,3,3
NGO	-	-	1	1/3,1/5,1/5	1,1/2,1/3
I.O.	-	-	-	1	3,3,1/3
L.C.	-	-	-	-	1

Table C.1.19: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Lobster Traps.

Scallops Drags	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	3,5,2	2,7,3	1/3,5,1/3	2,3,5
P.G.	-	1	3,3,2	1,4,2	2,3,3
NGO	-	-	1	1/3,1/5,1/5	1,1/2,1/3
I.O.	-	-	-	1	3,2,1/3
L.C.	-	-	-	-	1

Table C.1.20: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Scallop Drags.

Urchins Drags	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	2,5,2	3,7,3	1/3,4,1/2	1,2,5
P.G.	-	1	3,3,2	1,3,2	2,2,3
NGO	-	-	1	1/3,1/4,1/4	1,1/2,1/3
I.O.	-	-	-	1	3,2,1/2
L.C.	-	-	-	-	1

Table C.1.21: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Urchins Drags.

Recreational	Fed.Sc.	P.G.	NGO	I.O.	L.C.
Fed.Sc.	1	1,2,1	1/2,3,2	1/2,4,1	1/2,2,2
P.G.	-	1	1,2,5	1,5,3	1/3,1,1
NGO	-	-	1	2,3,3	1/2,1/2,1
I.O.	-	-	-	1	1/3,1/2,1/3
L.C.	-	-	-	-	1

Table C.1.22: Comparison of Decision Makers for Federal Scientists, Provincial Government, NGO, Industrial Organizations, and Local Communities with respect to Recreational.

Part 2. This section contains a data grid for alternatives with respect to sub-criteria and it's the same for every decision making group. The alternatives are: Alternative 1 with Fish Farm (A1FF), Alternative 2 with Fish Farm (A2FF), Alternative 1 without Fish Farm (A1NoFF), and Alternative 2 without Fish Farm (A2NoFF).

	R1	R2	R3	R4	R5	H1	H2	H3	H4	E1	E2	E3	A1	A2	A3	A4	A5	A6
A1FF	0	0	0	0.403	0.086	0.735	0.739	0.777	0.133	0	1	0.972	0	0.771	0	0.431	0	0
A2FF	0	1	1	0.006	0	0	0	0	0	1	1E-08	5E-09	0.879	0.023	1	0	0.098	1
A1 NoFF	0	0	0	0.305	0.132	0.739	0.739	0.777	0.133	1E-09	1	0.972	1	0	0	0.431	3E-06	0
A2 NoFF	0	1	0.999	0	0.001	0.003	0	0	2E-08	1	0	0	0.926	0	1	1E-07	0.098	1

Table C.2.1.: Data grid for alternatives with respect to sub-criteria for all the decision makers.

APPENDIX D

Pairwise Comparison Inputs for NGO and Results – Case Study

The tables in this appendix contain the NGO's individual ratings (inputs) for the case study, including: (1) criteria and sub-criteria of the decision hierarchy in AHP Combined inputs; (2) alternatives; (3) fuzzy AHP Combined inputs; and (4) the methods results.

Note that the pairwise comparisons of the decision makers' on each other with respect to criteria and sub-criteria are in Appendix C, Part 1. The possible ratings are between 1 and 9 where 1 indicates Equal Importance, and 9 indicates Extreme Importance. Combined results are the results for 3 NGO's.

D.1. AHP Combined Input: Criteria and sub-criteria pairwise comparison matrix for NGO. Following matrices were conducted by applying geometric mean to each individual AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities	Priority
Resources	1	1	4.309	2.759	0.388
Habitat	-	1	3.915	2.466	0.369
Effluents	-	-	1	0.481	0.086
Activities	-	-	-	1	0.156

Table D.1.1: Criteria pairwise comparison matrix and priority for NGO in AHP Combined.

Resources	Herr.Day	Herr.Night	Lobster	Scal.	Urch.	Priority
Herr.Day	1	1	1.710	2.154	2.714	0.293
Herr.Night	-	1	1.710	2.154	2.714	0.293
Lobster	-	-	1	1.260	1.587	0.171
Scal.	-	-	-	1	1.260	0.136
Urch.	-	-	-	-	1	0.108

Table D.1.2: Sub-criterion pairwise comparison matrix and priority with respect to Resources for NGO in AHP Combined.

Habitat	Rock.	S.March.	C.Flow	B.Struc.	Priority
Rock.	1	0.843	2.154	1.260	0.299
S.March.	-	1	1.710	1.442	0.316
C.Flow	-	-	1	0.874	0.170
B.Struc.	-	-	-	1	0.215

Table D.1.3: Sub-criterion pairwise comparison matrix and priority with respect to Habitat for NGO in AHP Combined.

Effluents	ChemicalA	ChemicalB	ChemicalC	Priority
Ch.A	1	2.154	2.759	0.541
Ch.B	-	1	1.817	0.283
Ch.C	-	-	1	0.175

Table D.1.4: Sub-criterion pairwise comparison matrix and priority with respect to Effluents for NGO in AHP Combined.

Activities	Herr.W.	FishF.	L.Traps	S.Drags	U.Drags	Recr.	Priority
Herr.W.	1	2.466	1.260	3.476	3.476	1.587	0.298
FishF.	-	1	0.481	1.494	1.494	0.693	0.140
L.Traps	-	-	1	2.289	1.587	0.874	0.196
S.Drags	-	-	-	1	1	0.511	0.081
U.Drags	-	-	-	-	1	0.511	0.095
Recr.	-	-	-	-	-	1	0.190

Table D.1.5: Sub-criterion pairwise comparison matrix and priority with respect to Activities for NGO in AHP Combined.

D.2. Alternatives Input: Comparison and priority of the alternatives with respect to criteria for NGO. Individual rankings are stored in Appendix C.

Abbreviations:

- A1FF : Alternative1 with FishFarm
- A2FF : Alternative2 with FishFarm
- A1NoFF : Alternative1 without FishFarm
- A2NoFF : Alternative2 without FishFarm

Criteria	Resources	Habitat	Effluents	Activities	Priority
A1FF	0.061	0.499	0.228	0.143	0.217
A2FF	0.443	0.001	0.272	0.660	0.270
A1NoFF	0.053	0.500	0.228	0.333	0.241
A2NoFF	0.443	0.001	0.272	0.671	0.272

Table D.2.1: Alternatives priority matrix and priority with respect to Criteria for NGO.

D.3. Fuzzy AHP Combined Input: Comparison of Decision Makers for NGO with respect to criteria and sub-criteria under the same source.

Following matrices were conducted by applying geometric mean to each individual fuzzy AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities
Resources	1	1	3.037	2.290
Habitat	1	1	2.714	2
Effluents	0.183	0.232	1	0.330
Activities	0.315	0.362	0.347	1

Table D.3.1: Criteria pairwise comparison matrices for NGO in Fuzzy AHP Combined.

Resources	Herring Day	Herring Night	Lobster	Scallops	Urchins
Herr.Day	1	1	1.590	2.150	2.290
Herr.Night	1	1	1.590	2.150	2.290
Lobster	0.550	0.580	1	1.260	1.440
Scal.	0.380	0.460	0.690	1	1
Urch.	0.320	0.370	0.580	0.690	1

Table D.3.2: Sub-criterion pairwise comparison matrices with respect to Resources for NGO in Fuzzy AHP Combined.

Habitat	Rockweed	Salt Marches	Current Flow	Bottom Structure
Rockw.	1	0.840	2.150	1
S.March.	1	1	1.710	1.260
C.Flow	0.380	0.550	1	0.630
B.Struc.	0.690	0.630	1.140	1

Table D.3.3: Sub-criterion pairwise comparison matrices with respect to Habitat for NGO in Fuzzy AHP Combined.

Effluents	ChemicalA		ChemicalB		ChemicalC			
ChemicalA	1	1	1.590	2.150	2.620	2.290	2.760	3.170
ChemicalB	0.380	0.460	1	1	1	1.260	1.820	2.290
ChemicalC	0.310	0.360	0.440	0.550	0.790	1	1	1

Table D.3.4: Sub-criterion pairwise comparison matrices with respect to Effluents for NGO in Fuzzy AHP Combined.

Activities	Herring Weirs		Fish Farms		Lobster Traps		Scallop Drags		Urchin Drags		Recreation				
Herr.W.	1	1	2	2.470	2.880	1	1.260	1.440	2.290	3.480	4.580	1.440	1.590	1.710	
FishF.	0.350	0.410	0.500	1	1	0.630	0.690	0.790	1.590	2.150	2.620	1	1.490	2.080	
L.Traps	0.870	1.140	1.590	1.260	1.440	1	1	1.820	2.880	3.910	1.440	1.590	1.710	1.140	
S.Drags	0.220	0.290	0.440	0.380	0.460	0.630	0.260	0.350	1	1	1	1	1	0.400	
U.Drags	0.220	0.290	0.440	0.480	0.670	1	0.580	0.630	1	1	1	1	1	0.400	
Recr.	0.580	0.630	0.690	1.260	1.440	1.590	0.870	1.140	1.590	1.390	1.960	2.880	1.390	1.960	2.880

Table D.3.5: Sub-criterion pairwise comparison matrices with respect to Activities for NGO in Fuzzy AHP Combined.

D.4. Results: This section contains output results for the 3 NGO's in AHP, AHP Combined, WSM, WPM, and Fuzzy AHP Combined.

AHP Output for NGO:

	Priority		
	NGO1	NGO2	NGO3
A1FF	0.262	0.225	0.222
A2FF	0.231	0.270	0.273
A1NoFF	0.275	0.235	0.231
A2NoFF	0.232	0.271	0.274

Table D.4.1: Alternatives priority matrix for the three NGO's in AHP.

According to NGO1, A1NoFF has the highest priority with 0.275 over the other alternatives. According to NGO2, A2NoFF has the highest priority with 0.271 over the other alternatives. Also, A2FF is the closest one with 0.270. According to NGO3, A2NoFF has the highest priority with 0.274 over the other alternatives. Also, A2FF is the closest one with 0.273.

AHP Combined and WSM Output:

WSM is calculated by equally weighting the output of three NGO.

	Overall Priority	
	AHP Combined	WSM
A1FF	0.222	0.240
A2FF	0.265	0.253
A1NoFF	0.246	0.2536
A2NoFF	0.267	0.2537

Table D.4.2: Alternatives overall priority matrix for the three NGO's in AHP Combined, and WSM.

A2NoFF has the highest priority with 0.67 over the other alternatives in AHP Combined. A2NoFF also has the highest priority with 0.2537 in WSM. It is noted that A1NoFF is the closest with 0.2536 in WSM.

WPM Output:

	0.388	0.369	0.086	0.156		
	Resources	Habitat	Effluents	Activities		
A1FF	0.061	0.499	0.228	0.079	==>	R(A1FF/A2FF)= 13.979
A2FF	0.443	0.0001	0.272	0.365	==>	R(A1FF/A1NoFF)= 0.924
A1NoFF	0.053	0.500	0.228	0.184	==>	R(A1FF/A2NoFF)= 3.865
A2NoFF	0.443	0.001	0.272	0.371	==>	R(A2FF/A1NoFF)= 0.066
						R(A2FF/A2NoFF)= 0.276
						R(A1NoFF/A2NoFF)= 4.184

Table D.4.3: Alternatives pairwise comparison matrix and priority for overall by the NGO in WPM.

A1FF over A2FF is 13.979 indicates that A1FF is much greater than A2FF, and A1FF over A1NoFF is 0.924 indicates that A1NoFF is greater than A1FF. Comparison of A1NoFF with A2FF and A2NoFF also show that A1NoFF has higher priority over those two alternatives. As a result, A1NoFF has the highest priority over all the alternatives in WPM method.

Fuzzy AHP Combined Output:

Criteria						Normalized Matrix
Resources	v1	1.530	1.841	2.140		0.120 0.130 0.140
Habitat	v2	0.810	0.993	1.180		0.110 0.120 0.130
Effluents	v3	0.390	0.468	0.610		0.020 0.020 0.030
Activities	v4	0.980	1.169	1.350		0.050 0.060 0.070
		3.720	4.470	5.290	13.500	

Table D.4.4: Criteria fuzzy normalized matrix for the three NGO's in Fuzzy AHP Combined.

	<u>Low</u>	<u>Mode</u>	<u>High</u>
A1FF	0.070	0.090	0.100
A2FF	0.080	0.100	0.120
A1NoFF	0.040	0.080	0.090
A2NoFF	0.030	0.100	0.120

Table D.4.5: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes for the three NGO's in Fuzzy AHP Combined.

APPENDIX E

Pairwise Comparisons Inputs for Industrial Organizations and Results – Case Study

The tables in this section contain the representatives of Industrial Organizations' individual ratings (inputs) for: (1) criteria and sub-criteria of the decision hierarchy in AHP Combined inputs; (2) alternatives; (3) fuzzy AHP Combined inputs; and (4) the methods results.

The tables in this section contain the representatives Industrial Organizations' individual ratings (inputs) for criteria, sub-criteria, and the results. Note that the pairwise comparisons of the decision makers' on each other with respect to criteria and sub-criteria are in Appendix C. The possible ratings are between 1 and where 1 indicates Equal Importance, and 9 indicates Extreme Importance.

Combined results are the results for 3 representatives of Industrial Organizations.

E.1. AHP Combined Input: Criteria and sub-criteria pairwise comparison matrix for Industrial Organizations. Following matrices were conducted by applying geometric mean to each individual AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities	Priority
Resources	1	1.442	1.817	3.107	0.383
Habitat	-	1	1.817	2.884	0.314
Effluents	-	-	1	1.101	0.174
Activities	-	-	-	1	0.129

Table E.1.1: Criteria pairwise comparison matrix and priority for Industrial Organizations in AHP Combined.

Resources	Herr.Day	Herr.Night	Lobster	Scal.	Urch.	Priority
Herr.Day	1	0.794	0.362	0.382	0.437	0.098
Herr.Night	-	1	0.405	0.415	0.500	0.115
Lobster	-	-	1	0.585	1.817	0.267
Scal.	-	-	-	1	1.913	0.330
Urch.	-	-	-	-	1	0.191

Table E.1.2: Sub-criterion pairwise comparison matrix and priority with respect to Resources for Industrial Organizations in AHP Combined.

Habitat	Rock.	S.March.	C.Flow	B.Struc.	Priority
Rock.	1	2	0.500	0.333	0.171
S.March.	-	1	0.500	0.333	0.120
C.Flow	-	-	1	0.500	0.260
B.Struc.	-	-	-	1	0.450

Table E.1.3: Sub-criterion pairwise comparison matrix and priority with respect to Habitat for Industrial Organizations in AHP Combined.

Effluents	Ch.A	Ch.B	Ch.C	Priority
Ch.A	1	2	3	0.539
Ch.B	-	1	2	0.297
Ch.C	-	-	1	0.164

Table E.1.4: Sub-criterion pairwise comparison matrix and priority with respect to Effluents for Industrial Organizations in AHP Combined.

Activities	Herr.W.	FishF.	L.Traps	S.Drags	U.Drags	Recr.	Priority
Herr.W.	1	0.362	0.415	0.464	0.550	1.710	0.100
FishF.	-	1	1.587	1.260	1.817	0.481	0.220
L.Traps	-	-	1	1.442	1.710	2.904	0.229
S.Drags	-	-	-	1	1.357	1.651	0.175
U.Drags	-	-	-	-	1	1.442	0.138
Recr.	-	-	-	-	-	1	0.138

Table E.1.5: Sub-criterion pairwise comparison matrix and priority with respect to Activities for Industrial Organizations in AHP Combined.

E.2. Alternatives Input: Comparison, priority and scaled priority of the alternatives with respect to criteria for Industrial Organizations. Individual rankings are stored in AppendixC.

Abbreviations:

A1FF: Alternative1 with FishFarm, A2FF: Alternative2 with FishFarm

A1NoFF: Alternative1 without FishFarm, A2NoFF: Alternative2 without FishFarm

Criteria	Resources	Habitat	Effluents	Activities	Priority	Scaled Priority
A1FF	0.143	0.499	0.229	0.245	0.263	0.263
A2FF	0.369	0.002	0.271	0.473	0.247	0.247
A1NoFF	0.121	0.500	0.229	0.175	0.245	0.245
A2NoFF	0.367	0.001	0.271	0.473	0.246	0.246

Table E.2.1: Alternatives priority matrix, priority, and scaled priority with respect to Criteria for Industrial Organizations.

E.3. Fuzzy AHP Combined Input: Comparison of Decision Makers for Industrial Organizations with respect to criteria and sub-criteria under the same source.

Following matrices were conducted by applying geometric mean to each individual fuzzy AHP matrix under the same source.

Criteria	Resources		Habitat		Effluents		Activities	
Resources	1	1	3.107	3.476	3.826	3.175	4.481	5.451
Habitat	0.261	0.288	0.322	1	1	2	3.107	4.16
Effluents	0.183	0.223	0.315	0.240	0.322	0.500	1	1
Activities	1.140	1.440	1.747	1.260	1.610	2	2.290	3.107

Table E.3.1: Criteria pairwise comparison matrices for Industrial Organizations in Fuzzy AHP Combined.

Resources	Herring Day		Herring Night		Lobster		Scallops		Urchins	
Herr.Day	1	1	0.690	0.790	1	0.310	0.360	0.440	0.330	0.380
Herr.Night	1.260	1.440	1	1	1	0.350	0.440	0.460	0.350	0.410
Lobster	2.290	2.760	2.150	2.290	2.880	1	1	1	0.550	0.580
Scal.	2	2.620	3	1.820	2.410	2.880	1.590	1.710	1.820	1
Urch.	1.710	2.290	2.760	1.440	2	2.470	0.440	0.550	0.790	0.500

Table E.3.2: Sub-criterion pairwise comparison matrices with respect to Resources for Ind. Organizations in Fuzzy AHP Combined

Habitat	Rockweed		Salt Marches		Current Flow		Bottom Structure	
Rockw.	1	1	1.590	2.150	2.620	0.870	1.140	1.590
S.March.	0.380	0.460	0.630	1	1	0.440	0.550	0.790
C.Flow	0.630	0.870	1.140	1.260	1.820	2.290	1	1
B.Struc.	1.260	1.440	1.590	1.590	2.080	2.520	1.260	1.820

Table E.3.3: Sub-criterion pairwise comparison matrices with respect to Habitat for Ind. Organizations in Fuzzy AHP Combined.

	ChemicalA		ChemicalB		ChemicalC	
Effluents						
ChemicalA	1	1	1.260	1.820	2.290	2.470
ChemicalB	0.440	0.550	0.790	1	1	1.260
ChemicalC	0.350	0.410	0.500	0.440	0.790	1

Table E.3.4: Sub-criterion pairwise comparison matrices with respect to Effluents for Industrial Organizations in Fuzzy AHP Combined.

	Herring Weirs		Fish Farms		Lobster Traps		Scallop Drags		Urchin Drags		Recreation						
Activities																	
Herr.W.	1	1	0.315	0.362	0.437	0.347	0.415	0.550	0.382	0.464	0.630	0.437	0.550	0.794	1.260	1.710	2.289
FishF.	2.289	2.759	3.175	1	1	1	1.587	2.080	1	1.260	1.442	1.260	1.817	2.289	0.397	0.481	0.630
L.Traps	1.817	2.410	2.884	0.481	0.630	1	1	1	1.260	1.442	1.587	1.587	1.710	1.817	2.289	2.904	4.000
S.Drags	1.587	2.154	2.621	0.693	0.794	1	0.630	0.693	0.794	1	1	1.101	1.357	1.817	1.101	1.651	2.520
U.Drags	1.260	1.817	2.289	0.437	0.550	0.794	0.550	0.585	0.630	0.550	0.737	0.909	1	1	1.260	1.442	1.587
Recr.	0.437	0.585	0.794	1.587	2.080	2.520	0.250	0.344	0.437	0.397	0.606	0.909	0.630	0.693	0.794	1	1

Table E.3.5: Sub-criterion pairwise comparison matrices with respect to Activities for Industrial Organizations in Fuzzy AHP Combined.

E.4. Results: This section contains output results for the 3 members of Industrial Organizations in AHP, AHP Combined, WSM, WPM, and Fuzzy AHP Combined.

AHP Output for Industrial Organizations:

	Priority I.O.1	Priority I.O.2	Priority I.O.3
A1FF	0.234	0.212	0.239
A2FF	0.297	0.290	0.287
A1NoFF	0.174	0.209	0.187
A2NoFF	0.295	0.289	0.286

Table E.4.1: Alternatives priority matrix for the three representatives of Industrial Organizations in AHP.

According to the first representative of Industrial Organizations, A2FF has the highest priority with 0.297 over the other alternatives. Also, A2NoFF is the closest one to the A2FF with 0.295. According to the second representative of the Industrial Organizations, A2FF has the highest priority with 0.290 over the other alternatives. Also, A2NoFF is the closest one to the A2FF with 0.289. According to third representative of the Industrial Organizations, A2FF has the highest priority with 0.287 over the other alternatives. Also, A2NoFF is the closest one to A2FF with 0.287.

AHP Combined and WSM Output:

WSM is calculated by equally weighting the output of three representatives of Industrial Organizations.

	Overall Priority	
	AHP Combined	WSM
A1FF	0.270	0.275
A2FF	0.238	0.233
A1NoFF	0.254	0.260
A2NoFF	0.238	0.233

Table E.4.2: Alternatives overall priority matrix for Industrial Organizations in AHP Combined, and WSM.

A1FF has the highest priority with 0.270 over the other alternatives in AHP Combined. A1FF also has the highest priority with 0.275 in WSM.

WPM Output:

	0.383	0.314	0.174	0.129		
	Resources	Habitat	Effluents	Activities		
A1FF	0.143	0.499	0.229	0.179	==>	R(A1FF/A2FF)= 15.374
A2FF	0.369	0.000	0.271	0.346	==>	R(A1FF/A1NoFF)= 1.114
A1NoFF	0.121	0.500	0.229	0.128	==>	R(A1FF/A2NoFF)= 5.174
A2NoFF	0.367	0.001	0.271	0.346	==>	R(A2FF/A1NoFF)= 0.072
						R(A2FF/A2NoFF)= 0.336
						R(A1NoFF/A2NoFF)= 4.642

Table E.4.3: Alternatives pairwise comparison matrix and overall priority for Industrial Organizations in WPM.

A1FF over A2FF is 15.374 indicates that A1FF is much more greater than A2FF, and A1FF over A1NoFF is 1.114 indicates that A1FF is greater than A1NoFF. Comparison of A1FF to A2NoFF also shows that A1FF is greater than A2NoFF with 5.174. As a result, A1FF has the highest priority over all the alternatives in WPM method.

Fuzzy AHP Combined Output:

Criteria						Normalized Matrix		
Resources	v1	1.800	1.966	2.100		0.110	0.140	0.160
Habitat	v2	1.660	1.834	1.980		0.060	0.070	0.090
Effluents	v3	0.280	0.324	0.400		0.030	0.030	0.050
Activities	v4	0.750	0.857	0.980		0.070	0.090	0.100
		4.490	4.980	5.460	14.900			

Table E.4.4: Criteria fuzzy normalized matrix for the three representatives in Industrial Organizations in Fuzzy AHP Combined.

	Low	Mode	High
A1FF	0.070	0.080	0.090
A2FF	0.090	0.100	0.110
A1NoFF	0.030	0.090	0.100
A2NoFF	0.020	0.100	0.110

Table E.4.5: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes for the three representatives Industrial Organizations in Fuzzy AHP Combined.

APPENDIX F

Pairwise Comparisons Inputs for Federal Scientists and Results – Case Study

The tables in this section contain the Federal Scientists' individual ratings (inputs) for: (1) criteria and sub-criteria of the decision hierarchy in AHP Combined inputs; (2) alternatives; (3) fuzzy AHP Combined inputs; and (4) the methods results.

The tables in this section contain the Federal Scientists' individual ratings (inputs) for criteria, sub-criteria, and the results. Note that the pairwise comparisons of the decision makers' on each other with respect to criteria and sub-criteria are in Appendix C. The possible ratings are between 1 and where 1 indicates Equal Importance, and 9 indicates Extreme Importance.

Combined results are the results for 3 members in Federal Scientists.

F.1. AHP Combined Input: Criteria and sub-criteria pairwise comparison matrix for Federal Scientists. Following matrices were conducted by applying geometric mean to each individual AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities	Priority
Resources	1	1.442	1.817	3.107	0.383
Habitat	-	1	1.817	2.884	0.314
Effluents	-	-	1	1.101	0.174
Attivities	-	-	-	1	0.129

Table F.1.1: Criteria pairwise comparison matrix and priority for Federal Scientists in AHP Combined.

Resources	Herr.Day	Herr.Night	Lobster	Scal.	Urch.	Priority
Herr.Day	1	1	0.693	0.693	1	0.170
Herr.Night	-	1	0.693	0.693	1	0.170
Lobster	-	-	1	1	1.442	0.245
Scal.	-	-	-	1	1.442	0.245
Urch.	-	-	-	-	1	0.170

Table F.1.2: Sub-criterion comparison matrix and priority with respect to Resources for Federal Scientists in AHP Combined.

Habitat	Rock.	S.March.	C.Flow	B.Struc.	Priority
Rock.	1	1.442	0.550	0.630	0.200
S.March.	-	1	0.481	0.550	0.156
C.Flow	-	-	1	1.260	0.351
B.Struc.	-	-	-	1	0.292

Table F.1.3: Sub-criterion pairwise comparison matrix and priority with respect to Habitat for Federal Scientists in AHP Combined.

Effluents	Ch.A	Ch.B	Ch.C	Priority
Ch.A	1	1.442	2.466	0.475
Ch.B	-	1	1.817	0.336
Ch.C	-	-	1	0.189

Table F.1.4: Sub-criterion pairwise comparison matrix and priority with respect to Effluents for Federal Scientists in AHP Combined.

Activities	Herr.W.	FishF.	L.Traps	S.Drags	U.Drags	Recr.	Priority
Herr.W.	1	0.500	0.874	1.101	1.101	2	0.163
FishF.	-	1	2.080	2.080	2.080	2	0.287
L.Traps	-	-	1	1.442	1.442	1	0.163
S.Drags	-	-	-	1	1	0.928	0.128
U.Drags	-	-	-	-	1	0.928	0.128
Recr.	-	-	-	-	-	1	0.131

Table F.1.5: Sub-criterion pairwise comparison matrix and priority with respect to Activities for Federal Scientists in AHP Combined.

F.2. Alternatives Input: Comparison and priority of the alternatives with respect to criteria for Federal Scientists. Individual rankings are stored in Appendix C.

Abbreviations:

- A1FF : Alternative1 with FishFarm
- A2FF : Alternative2 with FishFarm
- A1NoFF : Alternative1 without FishFarm
- A2NoFF : Alternative2 without FishFarm

Criteria	Resources	Habitat	Effluents	Activities	Priority
A1FF	0.109	0.499	0.261	0.277	0.266
A2FF	0.400	0.000	0.239	0.456	0.241
A1NoFF	0.093	0.500	0.261	0.218	0.252
A2NoFF	0.398	0.001	0.239	0.457	0.241

Table F.2.1: Alternatives priorities with respect to Criteria for Federal Scientists.

F.3. Fuzzy AHP Input: Comparison of Decision Makers for Federal Scientists with respect to criteria and sub-criteria under the same source.

Following matrices were conducted by applying geometric mean to each individual fuzzy AHP matrix under the same source.

Criteria	Resources		Habitat		Effluents		Activities				
Res.	1	1	1.260	1.442	1.587	1.260	1.817	2.289	2	3.110	4.160
Hab.	0.630	0.693	0.794	1	1	1.260	1.817	2.289	1.820	2.880	3.910
Eff.	0.437	0.550	0.794	0.437	0.550	0.794	1	1	0.630	1.100	1.650
Act.	0.240	0.320	0.500	0.260	0.350	0.550	0.610	0.910	1.587	1	1

Table F.3.1: Criteria pairwise comparison matrices for Federal Scientists in Fuzzy AHP Combined.

Resources	Herring Day		Herring Night		Lobster		Scallops		Urchins					
Herr.Day	1	1	1	1	0.630	0.693	0.794	0.630	0.693	0.794	1	1		
Herr.Night	1	1	1	1	0.630	0.693	0.794	0.630	0.693	0.794	1	1		
Lobster	1.260	1.442	1.587	1.260	1.442	1.587	1	1	1	1	1.260	1.442	1.587	
Scal.	1.260	1.442	1.587	1.260	1.442	1.587	1	1	1	1	1.260	1.442	1.587	
Urch.	1	1	1	1	1	1	0.630	0.693	0.794	0.630	0.693	0.794	1	1

Table F.3.2: Sub-criterion pairwise comparison matrices with respect to Resources for Federal Scientists in Fuzzy AHP Combined.

Habitat	Rockweed		Salt Marches		Current Flow		Bottom Structure					
Rockw.	1	1	1.260	1.442	1.587	0.437	0.550	0.794	0.481	0.630	1	
S.March.	0.630	0.693	0.794	1	1	0.397	0.481	0.630	0.437	0.550	0.794	
C.Flow	1.260	1.817	2.289	1.587	2.080	2.520	1	1	1	1	1.260	1.442
B.Struc.	1	1.587	2.080	1.260	1.817	2.289	0.693	0.794	1	1	1	1

Table F.3.3: Sub-criterion pairwise comparison matrices with respect to Habitat for Federal Scientists in Fuzzy AHP Combined.

Effluents	ChemicalA		ChemicalB		ChemicalC		
ChemicalA	1	1	0.870	1.440	2.290	2	2.880
ChemicalB	0.440	0.690	1	1	1	1.260	2.290
ChemicalC	0.350	0.410	0.440	0.550	0.790	1	1

Table F.3.4: Sub-criterion pairwise comparison matrices with respect to Effluents for Federal Scientists in Fuzzy AHP Combined.

Activities	Herring Weirs	Fish Farms	Lobster Traps	Scallop Drags	Urchin Drags	Recreation
Herr.W.	1	0.405	0.630	0.909	0.909	1.442
FishF.	1.442	1	1.587	1.587	1.587	2
L.Traps	0.874	0.397	1	1.260	1.260	1.186
S.Drags	0.737	0.397	0.630	1	1	1.077
U.Drags	0.737	0.397	0.630	1	1	1.077
Recr.	0.405	0.342	0.843	0.928	1.077	1

Table F.3.5: Sub-criterion pairwise comparison matrices with respect to Activities for Federal Scientists in Fuzzy AHP Combined.

F.4. Results: This section contains output results for the 3 members of Federal Scientists in AHP, AHP Combined, WSM, WPM, and Fuzzy AHP Combined.

AHP Output for Federal Scientists:

	Priority		
	F.Sci.1	F.Sci.2	F.Sci.3
A1FF	0.287	0.231	0.3001
A2FF	0.226	0.273	0.199
A1NoFF	0.262	0.224	0.3020
A2NoFF	0.225	0.272	0.199

Table F.4.1: Alternatives priority matrix for the three members of Federal Scientists in AHP.

According to the first member of Federal Scientists, A1FF has the highest priority with 0.287 over the other alternatives. According to the second member of the Federal Scientists, A2FF has the highest priority with 0.273 over the other alternatives. Also, A2NoFF is the closest one to the A2FF with 0.272. According to third member of the Federal Scientists, A1NoFF has the highest priority with 0.3020 over the other alternatives. Also, A1FF is the closest one to A1NoFF with 0.3001.

AHP Combined and WSM Output:

WSM is calculated by equally weighting the output of three members of Federal Scientists.

	Overall Priority	
	AHP Combined	WSM
A1FF	0.265	0.269
A2FF	0.241	0.237
A1NoFF	0.253	0.258
A2NoFF	0.241	0.236

Table F.4.2: Alternatives overall priority matrix for the Federal Scientists in AHP Combined, and WSM.

A1FF has the highest priority with 0.265 over the other alternatives in AHP Combined. A1FF also has the highest priority with 0.269 in WSM.

WPM Output:

	0.383	0.314	0.174	0.129		
	Resources	Habitat	Effluents	Activities		
A1FF	0.109	0.499	0.261	0.196	==>	R(A1FF/A2FF)= 14.424
A2FF	0.400	0.000	0.239	0.324	==>	R(A1FF/A1NoFF)= 1.093
A1NoFF	0.093	0.500	0.261	0.155	==>	R(A1FF/A2NoFF)= 4.849
A2NoFF	0.398	0.001	0.239	0.325	==>	R(A2FF/A1NoFF)= 0.076
						R(A2FF/A2NoFF)= 0.336
						R(A1NoFF/A2NoFF)= 4.437

Table F.4.3: Alternatives pairwise comparison matrix and priority for overall by the Federal Scientists in WPM.

A1FF over A2FF is 14.424 indicates that A1FF is much greater than A2FF, and A1FF over A1NoFF is 1.093 indicates that A1FF is greater than A1NoFF. Comparison of A1FF to A2NoFF also shows that A1FF is greater than A2NoFF. As a result, A1FF has the highest priority over all the alternatives in WPM method.

Fuzzy AHP Combined Output:

Criteria					Normalized Matrix		
Resources	v1	1.387	1.733	2.010	0.105	0.131	0.152
Habitat	v2	1.066	1.324	1.564	0.081	0.100	0.118
Effluents	v3	0.593	0.735	0.925	0.045	0.055	0.070
Activities	v4	0.461	0.593	0.852	0.035	0.045	0.064
		3.507	4.385	5.350	13.242		

Table F.4.4: Criteria fuzzy normalized matrix for three members in Federal Scientists in Fuzzy AHP Combined.

	Low	Mode	High
A1FF	0.073	0.091	0.111
A2FF	0.068	0.086	0.107
A1NoFF	0.022	0.086	0.105
A2NoFF	0.014	0.086	0.107

Table F.4.5: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes for three members in Federal Scientists in Fuzzy AHP Combined.

APPENDIX G

Pairwise Comparisons Inputs for Local Communities and Results – Case Study

The tables in this section contain the Local Communities' individual ratings (inputs) for: (1) criteria and sub-criteria of the decision hierarchy in AHP Combined inputs; (2) alternatives; (3) fuzzy AHP Combined inputs; and (4) the methods results.

Note that the pairwise comparisons of the decision makers' on each other with respect to criteria and sub-criteria are in Appendix C, Part1. The possible ratings are between 1 and 9 where 1 indicates Equal Importance, and 9 indicates Extreme Importance. Combined results are the results for 3 leaders in Local Communities.

G.1. AHP Combined Input: Criteria and sub-criteria pairwise comparison matrix for Local Communities. Following matrices were conducted by applying geometric mean to each individual AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities	Priority
Resources	1	1	3.915	0.737	0.289
Habitat	-	1	3.107	0.737	0.271
Effluents	-	-	1	0.281	0.087
Activities	-	-	-	1	0.354

Table G.1.1: Criteria pairwise comparison matrix and priority for Local Communities in AHP Combined.

Resources	Herr.Day	Herr.Night	Lobster	Scal.	Urch.	Priority
Herr.Day	1	1	1.442	2.154	2.080	0.271
Herr.Night	-	1	1.442	2.154	1.817	0.265
Lobster	-	-	1	1.260	2.289	0.199
Scal.	-	-	-	1	2.289	0.158
Urch.	-	-	-	-	1	0.107

Table G.1.2: Sub-criterion pairwise comparison matrix and priority with respect to Resources for Local Communities in AHP Combined.

Habitat	Rock.	S.March.	C.Flow	B.Struc.	Priority
Rock.	1	0.737	1.817	1.817	0.306
S.March.	-	1	1.260	1.260	0.297
C.Flow	-	-	1	0.794	0.187
B.Struc.	-	-	-	1	0.210

Table G.1.3: Sub-criterion pairwise comparison matrix and priority with respect to Habitat for Local Communities in AHP Combined.

Effluents	Ch.A	Ch.B	Ch.C	Priority
Ch.A	1	1.817	2.154	0.494
Ch.B	-	1	1.442	0.291
Ch.C	-	-	1	0.215

Table G.1.4: Sub-criterion pairwise comparison matrix and priority with respect to Effluents for Local Communities in AHP Combined.

Activities	Herr.W.	FishF.	L.Traps	S.Drags	U.Drags	Recr.	Priority
Herr.W.	1	1.817	0.794	2.154	2.924	0.333	0.182
FishF.	-	1	1.587	2.884	3.107	0.333	0.184
L.Traps	-	-	1	1.587	2.466	0.333	0.153
S.Drags	-	-	-	1	1.260	0.333	0.090
U.Drags	-	-	-	-	1	0.333	0.073
Recr.	-	-	-	-	-	1	0.317

Table G.1.5: Sub-criterion pairwise comparison matrix and priority with respect to Activities for Local Communities in AHP Combined.

G.2. Alternatives Input: Comparison, priority and scaled priority of the alternatives with respect to criteria for Local Communities. Individual rankings are stored in Appendix C.

Abbreviations:

- A1FF : Alternative1 with FishFarm
- A2FF : Alternative2 with FishFarm
- A1NoFF : Alternative1 without FishFarm
- A2NoFF : Alternative2 without FishFarm

Criteria	Resources	Habitat	Effluents	Activities	Priority
A1FF	0.069	0.499	0.251	0.181	0.231
A2FF	0.437	0.002	0.249	0.642	0.266
A1NoFF	0.059	0.500	0.251	0.221	0.235
A2NoFF	0.436	0.001	0.249	0.646	0.267

Table G.2.1: Alternatives priority matrix and priority with respect to Criteria for Local Communities.

G.3. Fuzzy AHP Input: Comparison of Decision Makers for Local Communities with respect to criteria and sub-criteria under the same source.

Following matrices were conducted by applying geometric mean to each individual fuzzy AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities
Res.	1	1	2.714	0.550
Hab.	0.693	1	2	0.550
Eff.	0.199	0.368	1	0.220
Act.	1.100	1.817	3.560	1

Table G.3.1: Criteria pairwise comparison matrices for Local Communities in Fuzzy AHP Combined.

Resources	Herring Day	Herring Night	Lobster	Scallops	Urchins
Herr.Day	1	1	1.260	1.587	1.587
Herr.Night	1	1	1.260	1.587	1.260
Lobster	0.630	0.693	1	1	1.817
Scal.	0.382	0.464	0.585	1	1.817
Urch.	0.397	0.481	0.368	0.437	1

Table G.3.2: Sub-criterion pairwise comparison matrices with respect to Resources for Local Communities in Fuzzy AHP Combined.

Habitat	Rockweed	Salt Marches	Current Flow	Bottom Structure
Rockw.	1	0.550	1.260	1.260
S.March.	1.101	1	0.794	0.794
C.Flow	0.437	0.550	1	0.693
B.Struc.	0.437	0.550	1	1

Table G.3.3: Sub-criterion pairwise comparison matrices with respect to Habitat for Local Communities in Fuzzy AHP Combined.

G.4. Results: This section contains output results for the 3 leaders of Local Communities in AHP, AHP Combined, WSM, WPM, Fuzzy AHP Combined.

AHP Output for Local Communities:

	Priority		
	NGO1	NGO1	NGO1
A1FF	0.145	0.212	0.285
A2FF	0.339	0.2867	0.214
A1NoFF	0.175	0.214	0.286
A2NoFF	0.341	0.2872	0.215

Table G.4.1: Alternatives priority for the three leaders of Local Communities in AHP.

According to the first leader of Local Communities, A2NoFF has the highest priority with 0.341 over the other alternatives. Also, A2FF is the closest one to the A2NoFF with 0.339. According to the second leader of the Local Communities, A2NoFF has the highest priority with 0.2872 over the other alternatives. Also, A2FF is the closest one to the A2NoFF with 0.2867. According to the third leader of the Local Communities, A1NoFF has the highest priority with 0.286 over the other alternatives. Also, A1FF is the closest one to A1NoFF with 0.285.

AHP Combined and WSM Output:

WSM is calculated by equally weighting the output of three leaders of Local Communities.

	Overall Priority	
	AHP Combined	WSM
A1FF	0.194	0.215
A2FF	0.301	0.2820
A1NoFF	0.203	0.220
A2NoFF	0.302	0.2828

Table G.4.2: Alternatives overall priority matrix for the three leaders of Local Communities in AHP Combined, and WSM.

A2NoFF has the highest priority with 0.302 over the other alternatives in AHP Combined. A2NoFF also has the highest priority with 0.2828 in WSM. Also, A2FF is the closest one to the A2NoFF in WSM with 0.2820.

WPM Output:

	0.289	0.271	0.087	0.354		
	Resources	Habitat	Effluents	Activities		
A1FF	0.069	0.499	0.251	0.107	==>	R(A1FF/A2FF)= 5.505
A2FF	0.437	0.000	0.249	0.380	==>	R(A1FF/A1NoFF)= 0.974
A1NoFF	0.059	0.500	0.251	0.131	==>	R(A1FF/A2NoFF)= 2.139
A2NoFF	0.436	0.001	0.249	0.382	==>	R(A2FF/A1NoFF)= 0.177
						R(A2FF/A2NoFF)= 0.389
						R(A1NoFF/A2NoFF)= 2.195

Table G.4.3: Alternatives pairwise comparison matrix and priority for overall by the Local Communities in WPM.

A1FF over A2FF is 5.505 indicates that A1FF is much greater than A2FF, and A1FF over A1NoFF is 0.974 indicates that A1NoFF is greater than A1FF. Comparison of A1NoFF to A2NoFF also shows that A1NoFF is greater than A2NoFF with 2.195. Comparison of A2FF to A1NoFF is 0.177 shows that A1NoFF is greater than A2FF. As a result, A1NoFF has the highest priority over all the alternatives in WPM method.

Fuzzy AHP Combined Output:

Criteria						Normalized Matrix		
Resources	v1	1.027	1.323	1.631		0.077	0.099	0.122
Habitat	v2	1.036	1.396	1.701		0.078	0.105	0.127
Effluents	v3	0.347	0.432	0.602		0.026	0.032	0.045
Activities	v4	1.026	1.251	1.580		0.077	0.094	0.118
		3.436	4.404	5.515	13.354			

Table G.4.4: Criteria fuzzy normalized matrix for three leaders of Local Communities in Fuzzy AHP Combined.

	Low	Mode	High
A1FF	0.064	0.084	0.105
A2FF	0.089	0.111	0.141
A1NoFF	0.040	0.087	0.108
A2NoFF	0.033	0.112	0.141

Table G.4.5: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes for three leaders of Local Communities in Fuzzy AHP Combined.

APPENDIX H

Pairwise Comparisons Inputs for Provincial Governments and Results – Case Study

The tables in this section contain the Provincial Governments' individual ratings (inputs) for: (1) criteria and sub-criteria of the decision hierarchy in AHP Combined inputs; (2) alternatives; (3) fuzzy AHP Combined inputs; and (4) the methods results.

Note that the pairwise comparisons of the decision makers' on each other with respect to criteria and sub-criteria are in Appendix C. The possible ratings are between 1 and where 1 indicates Equal Importance, and 9 indicates Extreme Importance. Combined results are the results for 3 managers in Provincial Governments.

H.1. AHP Combined Input: Criteria and sub-criteria pairwise comparison matrix for Provincial Governments. Following matrices were conducted by applying geometric mean to each individual AHP matrix under the same source.

Criteria	Resources	Habitat	Effluents	Activities	Priority
Resources	1	2.714	2.621	0.481	0.289
Habitat	-	1	2.621	0.437	0.176
Effluents	-	-	1	0.228	0.090
Attivities	-	-	-	1	0.445

Table H.1.1: Criteria pairwise comparison matrix and priority for Provincial Governments in AHP Combined.

Resources	Herr.Day	Herr.Night	Lobster	Scal.	Urch.	Priority
Herr.Day	1	0.794	0.464	0.523	0.693	0.126
Herr.Night	-	1	0.464	0.659	0.874	0.152
Lobster	-	-	1	1	2.289	0.303
Scal.	-	-	-	1	1.710	0.260
Urch.	-	-	-	-	1	0.159

Table H.1.2: Sub-criterion pairwise comparison matrix and priority with respect to Resources for Provincial Governments in AHP Combined.

Habitat	Rock.	S.March.	C.Flow	B.Struc.	Priority
Rock.	1	1	2.289	1.442	0.315
S.March.	-	1	2.621	1.651	0.337
C.Flow	-	-	1	1.442	0.170
B.Struc.	-	-	-	1	0.177

Table H.1.3: Sub-criterion pairwise comparison matrix and priority with respect to Habitat for Provincial Governments in AHP Combined.

Effluents	Ch.A	Ch.B	Ch.C	Priority
Ch.A	1	1.817	2.154	0.494
Ch.B	-	1	1.442	0.291
Ch.C	-	-	1	0.215

Table H.1.4: Sub-criterion pairwise comparison matrix and priority with respect to Effluents for Provincial Governments in AHP Combined.

Activities	Herr.W.	FishF.	L.Traps	S.Drags	U.Drags	Recr.	Priority
Herr.W.	1	0.362	0.550	0.585	0.874	0.457	0.088
FishF.	-	1	1.817	2.884	2.884	1	0.273
L.Traps	-	-	1	1	2.289	0.737	0.162
S.Drags	-	-	-	1	2.714	0.500	0.149
U.Drags	-	-	-	-	1	1	0.122
Recr.	-	-	-	-	-	1	0.206

Table H.1.5: Sub-criterion pairwise comparison matrix and priority with respect to Activities for Provincial Governments in AHP Combined.

H.2. Alternatives Input: Comparison, priority and scaled priority of the alternatives with respect to criteria for Provincial Governments. Individual rankings are stored in Appendix C.

Abbreviations:

- A1FF : Alternative1 with FishFarm
- A2FF : Alternative2 with FishFarm
- A1NoFF : Alternative1 without FishFarm
- A2NoFF : Alternative2 without FishFarm

Criteria	Resources	Habitat	Effluents	Activities	Priority
A1FF	0.105	0.499	0.251	0.275	0.265
A2FF	0.404	0.002	0.249	0.463	0.249
A1NoFF	0.089	0.500	0.251	0.152	0.238
A2NoFF	0.403	0.001	0.249	0.461	0.248

Table H.2.1: Alternatives priorities with respect to Criteria for Provincial Governments.

H.3. Fuzzy AHP Input: Comparison of Decision Makers for Provincial Governments with respect to criteria and sub-criteria under the same source.

Following matrices were conducted by applying geometric mean to each individual fuzzy AHP matrix under the same source.

Criteria	Resources		Habitat		Effluents		Activities		
Resources	1	1	2.289	2.714	3.107	1.587	3.634	0.400	0.630
Habitat	0.322	0.368	0.437	1	1	1.587	3.634	0.300	0.440
Effluents	0.275	0.382	0.630	0.275	0.630	1	1	0.180	0.230
Activities	1.590	2.080	2.520	1.260	2.290	3.300	5.518	1	1

Table H.3.1: Criteria pairwise comparison matrices for Provincial Governments in Fuzzy AHP Combined.

Resources	Herring Day		Herring Night		Lobster		Scallops		Urchins	
Herr.Day	1	1	0.693	0.794	1	0.382	0.464	0.630	0.347	0.523
Herr.Night	1	1.260	1.442	1	1	0.382	0.464	0.630	0.500	0.659
Lobster	1.587	2.154	2.621	1.587	2.154	2.621	1	1	1	1
Scal.	1.260	1.913	2.884	1.260	1.518	2	1	1	1	1
Urch.	0.874	1.442	2.289	0.874	1.145	1.587	0.368	0.437	0.550	0.909

Table H.3.2: Sub-criterion pairwise comparison matrices with respect to Resources for Prov. Governments in Fuzzy AHP Combined

Habitat	Rockweed		Salt Marches		Current Flow		Bottom Structure	
Rockw.	1	1	1	1	1	1.260	2.289	3.302
S.March.	1	1	1	1	1	1.587	2.621	3.634
C.Flow	0.303	0.437	0.794	0.275	0.382	0.630	1	1
B.Struc.	0.437	0.693	1.145	0.397	0.606	0.909	0.630	0.693

Table H.3.3: Sub-criterion pairwise comparison matrices with respect to Habitat for Prov. Governments in Fuzzy AHP Combined.

Effluents	ChemicalA			ChemicalB			ChemicalC		
ChemicalA	1	1	1	1.260	1.817	2.289	1.587	2.154	2.621
ChemicalB	0.437	0.550	0.794	1	1	1	1.260	1.442	1.587
ChemicalC	0.382	0.464	0.630	0.630	0.693	0.794	1	1	1

Table H.3.4: Sub-criterion pairwise comparison matrices with respect to Effluents for Prov. Governments in Fuzzy AHP Combined.

Activities	Herring Weirs	Fish Farms	Lobster Traps	Scallop Drags	Urchin Drags	Recreation
Herr.W.	1	0.315	0.362	0.437	0.437	0.550
FishF.	2.289	2.759	3.175	1	1	1
L.Traps	1.260	1.817	2.289	0.437	0.550	0.794
S.Drags	1.101	1.710	2.621	1.260	1.817	2.289
U.Drags	0.737	1.145	1.587	1	1	1
Recr.	1.587	2.190	3.175	0.368	0.437	0.550
				0.928	1.357	1.817

Table H.3.5: Sub-criterion pairwise comparison matrices with respect to Activities for Prov. Governments in Fuzzy AHP Combined.

H.4. Results: This section contains output results for the 3 managers of Provincial Governments in AHP, AHP Combined, WSM, WPM, and Fuzzy AHP Combined.

AHP Output for Provincial Governments:

	Priority		
	P.G.1	P.G.2	P.G.3
A1FF	0.229	0.206	0.240
A2FF	0.302	0.294	0.286
A1NoFF	0.168	0.205	0.188
A2NoFF	0.301	0.295	0.285

Table H.4.1: Alternatives priority matrix for the three managers of Provincial Governments in AHP.

According to the first manager of Provincial Governments, A2FF has the highest priority with 0.302 over the other alternatives. Also, A2NoFF is the closest one to the A2NoFF with 0.301. According to the second manager of the Provincial Governments, A2NoFF has the highest priority with 0.295 over the other alternatives. Also, A2FF is the closest one to the A2NoFF with 0.294. According to the third manager of the Provincial Governments, A2FF has the highest priority with 0.286 over the other alternatives. Also, A2NoFF is the closest one to A1NoFF with 0.285.

AHP Combined and WSM Output:

WSM is calculated by equally weighting the output of three managers of Provincial Governments.

	Overall Priority	
	AHP Combined	WSM
A1FF	0.227	0.231
A2FF	0.299	0.292
A1NoFF	0.176	0.186
A2NoFF	0.298	0.291

Table H.4.2: Alternatives overall priority matrix for the three managers of Provincial Governments in AHP Combined, and WSM.

A2FF has the highest priority with 0.299 over the other alternatives in AHP Combined. Also, A2NoFF is the closest one to the A2FF in AHP Combined with 0.298. A2FF also has the highest priority with 0.292 in WSM. Also, A2NoFF is the closest one to the A2FF in WSM with 0.2908.

WPM Output:

	0.289	0.176	0.090	0.445		
	Resources	Habitat	Effluents	Activities		
A1FF	0.105	0.499	0.251	0.203	==>	R(A1FF/A2FF)= 3.065
A2FF	0.404	0.000	0.249	0.343	==>	R(A1FF/A1NoFF)= 1.364
A1NoFF	0.089	0.500	0.251	0.113	==>	R(A1FF/A2NoFF)= 1.668
A2NoFF	0.403	0.001	0.249	0.341	==>	R(A2FF/A1NoFF)= 0.445
						R(A2FF/A2NoFF)= 0.544
						R(A1NoFF/A2NoFF)= 1.223

Table H.4.3: Alternatives pairwise comparison matrix and priority for overall by the Provincial Governments in WPM.

A1FF over A2FF is 3.065 indicates that A1FF is greater than A2FF, and A1FF over A1NoFF is 1.364 indicates that A1NoFF is greater than A1FF. Comparison of A1FF to A2NoFF also shows that A1FF is greater than A2NoFF with 1.668. As a result, A1NoFF has the highest priority over all the alternatives in WPM method.

Fuzzy AHP Combined Output:

Criteria						Normalized Matrix		
Resources	v1	1.066	1.318	1.564		0.077	0.095	0.112
Habitat	v2	0.645	0.829	1.080		0.046	0.060	0.078
Effluents	v3	0.359	0.454	0.656		0.026	0.033	0.047
Activities	v4	1.495	2.016	2.448		0.107	0.145	0.176
		3.564	4.617	5.748	13.929			

Table H.4.4: Criteria fuzzy normalized matrix for the three managers of Provincial Governments in Fuzzy AHP Combined.

	Low	Mode	High
A1FF	0.067	0.088	0.111
A2FF	0.087	0.113	0.138
A1NoFF	0.056	0.068	0.087
A2NoFF	0.043	0.113	0.138

Table H.4.5: Alternatives priority fuzzy numbers in the pairwise comparison with three possible outcomes in Fuzzy AHP Combined.

APPENDIX I

Overall Results of the Case Study for the Selected Method

The tables in this section contain the results for the selected method, Group Evaluation. Web-based tool provides this selected method by answering the key questions and report only the overall result. The other tables are added to show how the overall result table is obtained.

	Fed.S.	PG	NGO	IO	LC	Overall	Scaled Overall
Resources	0.383	0.289	0.388	0.384	0.289	0.355	0.341
Habitat	0.314	0.176	0.369	0.190	0.271	0.276	0.265
Effluents	0.174	0.090	0.086	0.088	0.087	0.131	0.125
Activities	0.129	0.445	0.156	0.338	0.354	0.281	0.270
	<i>1</i>	<i>1</i>	<i>1</i>	<i>1</i>	<i>1</i>	<i>1.043</i>	<i>1</i>

Table I.1.1: Pairwise comparison matrix, overall priority and scaled priority of the criteria in Level1 for five decision making groups.

The above table shows the AHP combined priority by using geometric mean for each decision making group. For example, the first column (Fed.S.) in the above table was conducted from the Federal Scientists' AHP Combined input (see Appendix F, Table F.1.1). The other columns were also conducted from other appendices by using the same approach.

Resources	Fed.S.	P.G.	NGO	I.O.	L.C.	Priority
Fed.S.	1	4.330	5.670	5	4.670	0.514
P.G.	0.230	1	3.330	3.330	3.330	0.230
NGO	0.180	0.300	1	1.170	1.830	0.097
I.O.	0.200	0.300	0.860	1	1.440	0.088
L.C.	0.210	0.300	0.550	0.690	1	0.071
	<i>1.821</i>	<i>6.233</i>	<i>11.402</i>	<i>11.192</i>	<i>12.277</i>	<i>1</i>

Table I.1.2: Pairwise comparison matrix and overall priority of the decision making groups with respect to Resources.

The above table shows the pairwise comparison and priority of the decision making groups with respect to Resources. Federal Scientists have the highest priority over the other decision making groups with 0.514.

Habitat	Fed.S.	P.G.	NGO	I.O.	L.C.	Priority
Fed.S.	1	3.670	5.330	3.670	4.330	0.486
P.G.	0.270	1	2.670	2.670	2.670	0.216
NGO	0.190	0.380	1	2.330	1.330	0.121
I.O.	0.270	0.380	0.430	1	1.110	0.089
L.C.	0.230	0.380	0.750	0.900	1	0.087
	<i>1.963</i>	<i>5.791</i>	<i>10.178</i>	<i>10.566</i>	<i>10.444</i>	<i>1</i>

Table I.1.3: Pairwise comparison matrix and overall priority of the decision making groups with respect to Habitat.

The above table shows the pairwise comparison and priority of the decision making groups with respect to Habitat. Federal Scientists have the highest priority over the other decision making groups with 0.486.

Effluents	Fed.S.	P.G.	NGO	I.O.	L.C.	Priority
Fed.S.	1	3.670	5	6	4.330	0.494
P.G.	0.270	1	3.110	3.670	3	0.229
NGO	0.200	0.320	1	3.330	1.670	0.125
I.O.	0.170	0.270	0.30	1	0.390	0.053
L.C.	0.230	0.330	0.60	2.570	1	0.099
	<i>1.870</i>	<i>5.594</i>	<i>10.011</i>	<i>16.571</i>	<i>10.388</i>	<i>1</i>

Table I.1.4: Pairwise comparison matrix and overall priority of the decision making groups with respect to Effluents.

The above table shows the pairwise comparison and priority of the decision making groups with respect to Effluents. Federal Scientists have the highest priority over the other decision making groups with 0.494.

Activities	Fed.S.	P.G.	NGO	I.O.	L.C.	Priority
Fed.S.	1	2.330	3.670	1.890	3.330	0.365
P.G.	0.430	1	3.670	2.670	3.670	0.288
NGO	0.270	0.270	1	0.300	0.560	0.069
I.O.	0.530	0.380	3.330	1	2.110	0.180
L.C.	0.300	0.270	1.800	0.470	1	0.097
	<i>2.530</i>	<i>4.253</i>	<i>13.466</i>	<i>6.329</i>	<i>10.667</i>	<i>1</i>

Table I.1.5: Pairwise comparison matrix and overall priority of the decision making groups with respect to Activities.

The above table shows the pairwise comparison and priority of the decision making groups with respect to Activities. Federal Scientists have the highest priority over the other decision making groups with 0.365.

Fed.Sci.	R	H	E	A
A1FF	0.109	0.499	0.261	0.196
A2FF	0.400	0.000	0.239	0.324
A1NoFF	0.093	0.500	0.261	0.155
A2NoFF	0.398	0.001	0.239	0.325

Table I.1.6: Alternatives pairwise comparison matrix of criteria for the Federal Scientists.

The above table shows the priority of the criteria (Level I) for Federal Scientists. For example, according to Federal Scientists, A2FF is the best alternative with 0.399 with respect to Resources, A1FF is the best alternative with 0.499 with respect to Habitat etc.

Prov.Gv.	R	H	E	A
A1FF	0.105	0.499	0.251	0.203
A2FF	0.404	0.000	0.249	0.343
A1NoFF	0.089	0.500	0.251	0.113
A2NoFF	0.403	0.001	0.249	0.341

Table I.1.7: Alternatives pairwise comparison matrix of criteria for the Provincial Governments.

The above table shows the priority of the criteria (Level I) for Provincial Governments. For example, according to Provincial Governments, A2FF is the best alternative with 0.404 with respect to Resources, A1FF is the best alternative with 0.499 with respect to Habitat etc.

Ind.Org.	R	H	E	A
A1FF	0.143	0.499	0.246	0.179
A2FF	0.369	0.000	0.254	0.346
A1NoFF	0.121	0.500	0.246	0.128
A2NoFF	0.367	0.001	0.254	0.346

Table I.1.8: Alternatives pairwise comparison matrix of criteria for the Industrial Organizations

The above table shows the priority of the criteria (Level I) for Industrial Organizations. For example, according to Industrial Organizations, A2FF is the best alternative with 0.368 with respect to Resources, A1FF is the best alternative with 0.499 with respect to Habitat etc.

Loc.Com.	R	H	E	A
A1FF	0.069	0.499	0.251	0.107
A2FF	0.437	0.000	0.249	0.380
A1NoFF	0.059	0.500	0.251	0.131
A2NoFF	0.436	0.001	0.249	0.382

Table I.1.9: Alternatives pairwise comparison matrix of criteria for the Local Communities

The above table shows the priority of the criteria (Level I) for Local Communities. For example, according to Local Communities, A2FF is the best alternative with 0.436 with respect to Resources, A1FF is the best alternative with 0.499 with respect to Habitat etc.

NGO	R	H	E	A
A1FF	0.061	0.499	0.228	0.079
A2FF	0.443	0.000	0.272	0.365
A1NoFF	0.053	0.500	0.228	0.184
A2NoFF	0.443	0.001	0.272	0.371

Table I.1.10: Alternatives pairwise comparison matrix of criteria for the NGO

The above table shows the priority of the criteria (Level I) for NGO. For example, according to NGO, A2FF is the best alternative with 0.443 with respect to Resources, A1FF is the best alternative with 0.499 with respect to Habitat etc.

	(	0.341	0.265	0.125	0.270)	
		Resources	Habitat	Effluents	Activities		Priority
A1FF		0.103	0.499	0.253	0.179		0.2470
A2FF		0.405	0.000	0.247	0.342		0.2610
A1NoFF		0.088	0.500	0.253	0.138		0.2311
A2NoFF		0.404	0.001	0.247	0.342		0.2608

Table I.1.11: Alternatives pairwise comparison matrix and overall result for selecting the best alternative

The above table shows the overall ranking and priority for selecting the best alternative. According to decision maker groups, Alternative 2 with Fish Farm (A2FF) is the best site location for the Fish Farms with 0.261. Alternative 2 without Fish Farm (A2NoFF) is the closest site to the selected site with 0.2608.

APPENDIX J

PHP and JavaScript Codes Used in the Web-Based Tool for the Aqua Case Study

This appendix contains the summary of the Php and JavaScript codes for the web-based tool for the Aqua Case Study. Due to the large number of size of the complete codes, this appendix provides only a short summary and the number of lines for each code session. Complete codes are available if requested.

The codes used for the web-based tool are structured as follows:

1. Login: Admin, and Decision Makers
2. Matrix Entries and Calculation
3. Resources
4. Habitat
5. Effluents
6. Activities
7. Evaluation of Decision Makers
8. Data Grid
9. Questionnaire and Result

1. Login: Admin, and Decision Makers:

This section summarizes the codes that have been used for the web-based tool to create login page for the decision makers and the admin. Each decision maker has a unique username and a password that have been given by the Administrator to enter the system in order to enter their pairwise comparisons. Once a decision makers attempts to enter the system by providing the username and the password, the system starts the inquisition process. If the username and the password are validated by the system, then the decision maker will be able to enter or modify pairwise comparisons. Same process is used for the Administrator as well. The Administrator provides the username and the password to enter the system. Once the inquisition process is done, and the username and the password that have been provided by the Administrator are validated, the Administrator then will be able to access the system. Decision makers can only access to their own pairwise comparisons matrices; however, the Administrator, is able to access all the decision makers judgments, geometric mean calculation matrices, *Questionnaire* page, and the *Result*. There are three types of codes used to login: 1) Index2 – login page to enter the system for the decision makers; 2) Index – login page to enter the system for the Administrator; and 3) Logout – log out page for the Administrator and the decision maker leaving the system.

Index2 – login page to enter the system for the decision makers.

Number of lines of code: 59

Login – login page to enter the system for the Administrator.

Number of lines of code: 280

Log Out – log out page for the Administrator and the decision makers.

Number of lines of code: 78

2. Matrix Entries and Calculation:

This section summarizes the codes that have been used for the web-based tool to create matrices. The codes in this section define, differentiate and create different types of matrices such as criteria, sub-criteria, and evaluation of the decision makers that are created by different groups or group members. Decision makers enter their pairwise comparisons in the given matrix for only two elements at a time. However, the reciprocals are evaluated automatically once the values entered by the decision makers. Once all the values are entered by the decision makers, they are stored in the database. Those values are then used for different methodology depending on the needs of the decision makers and the requirement of the methods. There is one type codes used for creating, storing, calculating the different matrices for the different decision makers, or decision maker groups: *Matrix*.

Matrix – to create, modify, store the matrices for each criterion, sub-criterion, evaluation of the decision makers, and alternatives for different decision maker group members, and groups.

Number of lines of code: 857

3. Resources:

This section summarizes the codes that have been used for the web-based tool to create matrices for the criterion, Resources, and the sub-criteria under the Resources. There are two types of codes used for creating the matrices for Resources: 1) to enter the pairwise comparisons by the decision makers (Resources); and 2) to compute the geometric mean of the pairwise comparisons for each group (Resourcesx)

Resources – to enter the pairwise comparisons.

Number of lines of code: 543

Resourcesx – to compute the geometric mean.

Number of lines of code: 502

4. Habitat:

This section summarizes the codes that have been used for the web-based tool to create matrices for the criterion, Habitat, and the sub-criteria under the Habitat. There are two types of codes used for creating the matrices for Habitat: 1) to enter the pairwise comparisons by the decision makers (Habitat); and 2) to compute the geometric mean of the pairwise comparisons for each group (Habitatx)

Habitat – to enter the pairwise comparisons.

Number of lines of code: 489

Habitatx – to compute the geometric mean.

Number of lines of code: 454

5. Effluents:

This section summarizes the codes that have been used for the web-based tool to create matrices for the criterion, Effluents, and the sub-criteria under the Effluents. There are two types of codes used for creating the matrices for Effluents: 1) to enter the pairwise comparisons by the decision makers (Effluents); and 2) to compute the geometric mean of the pairwise comparisons for each group (Effluentsx)

Effluents – to enter the pairwise comparisons.

Number of lines of code: 438

Effluentsx – to compute the geometric mean.

Number of lines of code: 396

6. Activities:

This section summarizes the codes that have been used for the web-based tool to create matrices for the criterion, Activities, and the sub-criteria under the Activities. There are two types of codes used for creating the matrices for Activities: 1) to enter the pairwise comparisons by the decision makers (Activities); and 2) to compute the geometric mean of the pairwise comparisons for each group (Activitiesx)

Activities – to enter the pairwise comparisons.

Number of lines of code: 572

Activitiesx – to compute the geometric mean.

Number of lines of code: 542

7. Evaluation of Decision Makers :

This section summarizes the codes that have been used for the web-based tool to create matrices for the evaluation of the decision makers with respect to criteria, and sub-criteria. There are two types of codes used for creating the matrices for Evaluation: 1) to enter the pairwise comparisons for evaluation of the decision makers by the decision makers (Evaluation); and 2) to compute the geometric mean of the Evaluation matrices with respect to criteria, and sub-criteria (Evaluationx)

Evaluation – to enter the pairwise comparisons to evaluate the decision makers.

Number of lines of code: 511

Evaluationx – to compute the geometric mean of the evaluation matrices.

Number of lines of code: 456

8. Data Grid:

This section summarizes the *Date Grid* codes that have been used for the web-based tool to create matrices for the alternatives. There are two types of codes used for creating the

matrices for the *Data Grid*: 1) to enter the data grid for the alternatives (Data Grid); and 2) to save the entered the data grid successfully for all the decision makers (Data Gridx)

Data Grid – to enter the data grid for the alternatives for all the decision makers.

Number of lines of code: 230

Data Gridx – to save the data grid successfully for all the decision makers.

Number of lines of code: 456

9. Questionnaire and Result:

This section summarizes *the Questionnaire, and theResult* codes that have been used for the web-based tool to define the most appropriate methodology that will be used for the case study. There are a number of key questions prepared to analyze the methods and the needs of the decision makers. Once the Administrator answers the key questions, the system provides the most appropriate methodology. The result will be provided once the Administrator clicks on the *Calculate* button after the appropriate methodology is selected. There are two types of codes used for answering the key questions and obtaining the selected methodology: 1) to answer the key questions (Questionnaire); and 2) to provide the most appropriate methodology based on the answered key questions (QResult).

Questionnaire – to answer the key questions by the Administrator.

Number of lines of code: 230

QResult – to provide the most appropriate methodology.

Number of lines of code: 130