Modeling
and Evaluation of Supplier Selection for Green Supply Chain using MCDA Techniques

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by

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A thesis submitted in partial fulfillment of the requirements for the degree of

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Abstract

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Purpose ─ The thesis purpose is to recommend a system for choosing the optimal suppliers for paint products in the UAE construction industries using Analytical Hierarchy Process (AHP) technique. In addition, the aim is to implement sensitivity analysis to verify the effectiveness and efficiency of the methodology.
Methodology ─ A general framework is performed to implement the model. The critical part of the framework is first to identify the criteria based on literature, subject matter experts, and present job knowledge. Second, perform a criteria pairwise comparison survey via experts and use the resulted data to rank the key criteria and sub criteria with the AHP method in Expert Choice™ software. Third, evaluate and rank the suppliers using the expert's comparison of the alternatives based on the sub criteria. Finally, deliver the model validation using sensitivity analysis.
Findings ─ Supplier A and Supplier B are the two highest-ranking suppliers with a weight of 0.398 and 0.267. As a result, the company may select those two suppliers. Sensitivity analysis demonstrates the impact on the suppliers' weights and ranking, when changing the weights of the main criteria and the sub criteria based on the target.
Practical Implications ─ The research contributes to supplier selection problem for paint product used in construction industry in the context of UAE. The proposed model offers green criteria for the supplier selection. Managers' will be more confident and their efforts will be reduced when performing the evaluation of suppliers and deciding the best suppliers by using the implemented model.
Originality/value ─ The general criteria provide a list of criteria that enables the decision makers to select from for supplier evaluation and selection. The demonstrated general framework can aid managers in making sure the judgement is consistent and provides guidelines for managers to select the optimal suppliers based on various factors.

Indexing Terms: Supplier Selection Process, Green Criteria, United Arab Emirates (UAE), Construction Industry, Paint Product, Analytical Hierarchy Process (AHP), Sensitivity Analysis

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Declaration and Copyright

Declaration

I declare that the work in this thesis was carried out in accordance with the regulations of Khalifa University of Science and Technology. The work is entirely my own except where indicated by special reference in the text. Any views expressed in the thesis are those of the author and in no way represent those of Khalifa University of Science and Technology. No part of the thesis has been presented to any other university for any degree.

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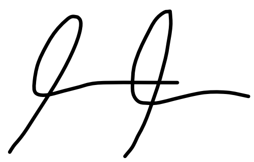
Author Signature: 

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Chapter 1 – Introduction

This section presents the types of supply chain, the importance of the procedure of selecting the suppliers for the Green Supply Chain, and possible approach to be used to model and analyze the research problem. It also presents the research challenges, objectives, and deliverables of the thesis proposal.

1.1 Background

As per data published by earth.org, one of the leading sources of environmental problems is a poor governance in the market place [37]. “Environment Protection” is the aim of countries worldwide to reduce the harmful impact of human activities on earth. A major contributor to this goal is encouraging organizations to provide their products and services in the most environmentally friendly possible way. Supply chain management infrastructure in companies that advocate green practices can go a long way in encouraging suppliers to adapt to environmental supply chain. Green Supply Chain incorporates green aspects with the aim to minimize harm on the environment. Various definition exists for the “Green Supply Chain Management” (GSCM) term. The most common definition is referring to the concept of successfully adding the green methods into the typical supply chain management. It consists of processes such as product design, selection of suppliers, selection and purchasing materials, product manufacturing, logistics, operation and end-of-life product management [33].

A traditional supply chain has its focus on constructing efficient systems for the flow of information and materials through the stages of production. In other words, it is a network of entities that involve product creation until product distribution and sale [33]. In a typical supply chain, organizations focus on the final product or service rather than the implementation process of that specific product or service. In terms of long environmental effects, the traditional supply chain does not consider the negative effects of their procedures and practices in the environment. It does not focus on criteria such as sources of energy, greenhouse gases, recycling materials, and resource types. On the other hand, green supply chain focus is on combining environmental criteria and the traditional processes of supply chain. Some of the environmental criteria are water conservation, energy consumption, usage of natural and renewable resources and environmental emission considerations. Practicing green supply chain in organizations leads to many advantages to the organization itself and mainly to the environment. Such enhancements are efficient waste management, improve emission controls, enhance management of change, increase organization reputation and improve customer satisfaction.

Supplier selection procedure (SS) significantly influences company's performance. As organizations strive to balance conflicting priorities to achieve competitive advantage, selecting the optimal number of suppliers requires careful consideration of various criteria that affects the organization and the management of supply chain. The decision maker must study, define and confirm the multi-conflicting green criteria, which will be used in the process of selecting the suppliers based on what suits the company's objectives and goals. In order to fulfil the company's requirements, the decision maker needs to incorporate quantitative and qualitative measures such as cost, quality performance, emission control, environmental policies, and on time delivery. Then, the decision maker must evaluate the trade-off between several criteria to get the optimal suppliers. As a result, the selecting suppliers' procedure is a multi-criteria decision-making and an important dilemma [34, 35].

It is essential to have the best in class suppliers capable and efficient in providing high quality of goods and services in a timely manner. Selecting the improper suppliers will lead to many drawbacks such as delay of the project, low quality of product/service, customer dissatisfaction, and reduction in the company's performance, profit margins and competiveness strategy. Consequently, the method of choosing suppliers is studied by using Multiple-Criteria Decision Making (MCDM) techniques. MCDM techniques aid the manager in analyzing and assessing the set of criteria to identify and rank suppliers that fit to the company's goals and requirements.

The process of selecting suppliers in environmental supply chain considers both the typical criteria and the environmental criteria such as value, CO_2 emission, service, and energy consumption. Achieving such process will become a significant milestone in developing a sustainable environmental as it will increase the company effectiveness and minimize the threats on the environment throughout the supply chain [3].

1.2 Factors and Barriers of the Green Supply Chain Management

In a company's journey to adopt green supply chain management procedures, they are faced with external and internal barriers that makes it very challenging to adhere to those procedures. On the other hand, factors also exist that will encourage and motivate companies to change their procedures to comply with green supply chain management. Understanding and balancing those factors and barriers will lead more companies taking the route of environmental supply chain.

The application of environmental practices derived from several external and internal factors. Some of the external factors include compliance to government regulation related to the environment, and pressure of the stakeholder, opponent, and end-client. The United Arab Emirates government provides strict policies and standards to be adhered by all the organizations to reduce the environmental impacts. The internal factors include green commitment, enhancement of organization repute and trademark, and access to foreign markets. Green implementation by organizations attracts investors and customers, which may lead to higher selling prices and hence higher organization revenue [47].

Incorporating Green practices in Supply Chain Management is important and provides a healthy environment, improves the industry reputation, increases customer satisfaction, and improves the financial vertical of a company.

In terms of environmental benefits, local companies will be able to contribute in reducing carbon emissions, reducing waste and preserving natural resources [33]. Therefore, performance of each element in the supply chain from suppliers, sub-suppliers and the clients affects the performance of a green supply chain drastically.

Firms may encounter a variety of external and internal constraints to implement environmental practices. Some of the external constraints include green professionals' absence, lack of green suppliers, strict stakeholder timelines and quotas, and absence of stakeholder engagement. The need of Subject Matter Experts (SME) in green industry is vital. To implement the green practices in organizations, they requires specific materials that are produced in an environmentally friendly manner, however, suppliers of such materials are few in the market. This limitation results in fear and hesitation of organizations to implement environmental practices. Moreover, the internal barriers include high implementation cost and lack of knowledge and awareness. Organizations face big challenge due to the additional cost occurrence from the green practices' implementation. The lack of understanding and mindfulness about the environmental importance and practices in the industries are the major barriers that prevent organizations to invest in implementing green practices [47].

The UAE's 2021 Vision aims of having "A green economy for sustainable development", where one of the actions is "Nurturing and sustainable environment for quality living" [44, 45]. This emphasizes the significance of having the organizations to include environmental protection as part of their vision and mission. In addition, adherence to the regulations set out by the government, and implement green practices.

1.3 Supplier Selection in Green Supply Chain

In this age of global competition, supplier selection process is an essential aspect in the development and accomplishment of any organization. An imperative supplier selection procedure plays an important role and significant influence on the environmental supply chain relationship and environmental supply chain management in the organization [2].

Optimal suppliers are those that meet the needs and obligations of the decision makers, which usually are providing the highest quality of services or products that adhere to the green regulations, have the reasonable prices, shorter lead duration and with the targeted quantities [1].

Single sourcing and multiple sourcing are two main kinds of selecting suppliers used by decision makers. Single sourcing is a type of supplier selection where only one supplier is chosen as an optimal supplier that can fulfil the entire organization's requirements [3]. Multiple sourcing is another type of supplier selection where several suppliers are chosen by the decision makers to fulfil the entire organization's demands. The decision makers allocate the quantity supplied or the service needs to be performed to each of the suppliers in order to have a balanced competitive network [3].

There are two types of procurement practices: “Reactive buying” and “Proactive buying”. Reactive buying is a type of purchase when a product/service is desired immediately without previous plan. Proactive buying is a type of planned purchase of a product/service by forecasting demands [3, 4]. Reactive buying limits information sharing and considers cost as its main priority [4]. The proactive buying focuses on considering various strategic matters in addition to the cost while choosing the suppliers to accomplish the organization’s long-term target [4]. Procurement is considered the leading management function in proactive buying, as it prefers multiple sourcing rather than single sourcing since it supports information and experience sharing and has negotiation opportunities [4]. Multiple sourcing is favored as it minimizes the supply and services uncertainty as it manages more than one supplier that offers higher volume demand flexibility and assurance of timely delivery [3, 4].

Identifying suitable suppliers for a fulfillment of demand depends on numerous factors that should be analyzed and evaluated. Supplier selection method is established on four stages as following [5]:

1- *Identification and selection of criteria*
2- *Determination of methods based on these criteria for the suppliers’ evaluation*
3- *Ranking the suppliers based on the evaluation results*
4- *Suppliers selection based on the highest ranking*

The supplier evaluation practice aim is to minimize risk, improve overall purchaser’s/service provider’s worth to ensure their commitment and assurance for a long-term business with the organization [1].

1.4 Issues and Solutions in Supplier Selection in Green Supply Chain

Making decision with respect to the best supplier of a certain product or service is critical, as it will affect the whole supply chain, from procuring raw materials to product distribution to end clients. Some of the organizations in the UAE focus on typical criteria, which is only economic based and fail to address environmental impacts too. In addition, they do not consider the priority of different criteria in the practice of making decision in selecting suppliers.

Due to the supplier selection issues, many researches have been conducted in this field of interest. Several decision models have been proposed in researches using various criteria. General decision models consist of mathematical models, analysis models, and artificial intelligence models [4, 7]. Each of those models consist of different techniques for implementing supplier selection problem. Chapter 2 will provide a literature review on the criteria and techniques for selecting suppliers in green supply chain.

Currently in the GSCM there is only one research with the application to UAE by Malik et al. [33] for finding the environmental supplier in the UAE health sector was observed. On the other hand, many researches have been done in other countries about the application of green supply chain. To close this gap, research must be conducted in the context of UAE to address the problem and forward the cause of green supply chain management. Applying green supply chains using multi-criterion decision-making techniques will help the industries in the UAE in the long-term development and growth. Therefore, it is vital to encourage companies operating in different sectors in the UAE to incorporate green/environmental mindset into their supply chain management.

The main aim of the proposed study is to apply the Analytical Hierarchy Process (AHP) to assess supplier selection considering green supply chain related criteria for the procurement of paint in the UAE construction industry. Paint is the most common product for all construction companies; therefore, it will aid the research in gathering a big sample base of surveys to be used in the AHP model and to enhance the accuracy and precision of the outcomes. Implementing the research on a commonly used product will lead in having a larger base of participants. As a result, making it a more beneficial reference in the topic of green supply chain. An extensively utilized MCDM method for choosing suppliers is the AHP method, which will be utilized in this research. AHP provides the ability to conduct supplier selection with quantitative and qualitative criteria [35]. This technique is based on conducting a comprehensive survey on the strengths and weaknesses of each supplier and comparing the suppliers based on the predefined criteria and sub-criteria to select the most efficient and effective supplier.

To have a robust supplier selection procedure with green related criteria is highly beneficial to the construction industry in the UAE, as they often deal with several suppliers providing different goods and services. Therefore, due to the expanding list of suppliers in the market, a method is required to assess how environmentally friendly their products/services and utilizing the results of the technique in their decision-making procedure. It is challenging to optimize their supply chain with a mindset of green supplier selection, thus decreasing the efficiency of the organization. Utilizing MCDM techniques will allow the decision makers in such companies to have a more comprehensive view of the supplier and make their decisions more informative thus more efficient. It will result in having a highly performed and eco-friendly industry, which will ultimately benefit the UAE growth.

1.5 Research Objectives and Deliverables

Research Objectives

1- Understand various MCDA techniques for supplier selection (SS) in a typical and environmental supply chain
2- Identify potential industries for which SS is applicable in UAE
3- Identify suitable techniques, model and solve SS
4- Offer interpretations of the model and validate with the data obtained to draw meaningful conclusions

Research Deliverables

1- Identify potential data sources in the UAE for various industry verticals
2- Conduct a detailed literature review for the process of selecting a supplier in a typical and green supply chain through utilizing MCDA techniques
3- Identify the limitations of MCDA techniques for SS in GSCM
4- Develop a general AHP framework for SS to be applied to construction industry
5- Solve, validate, and present the findings of a subset framework from the general AHP framework implemented on paint products related to construction industry

1.6 Conclusion

This chapter introduced the Green Supply Chain and an overview of selecting suppliers in Environmental Supply Chain. It presents the research objectives and deliverables, project plan, thesis possible approach, and research challenges that face in implementing the thesis. One important aspect that contributes to the success of any company performance is the supplier selection procedure. Integrating Green criteria in the decision-making leads to a healthy environment and reduces wasteful supply chain, boosts the industry image, and enhance customer satisfaction. Several external and internal factors lead to the attraction of industries to seek for implementing green practices. Besides, strict policies and standards set by the United Arab Emirates government and implemented by all organizations to reduce the environmental impacts. Businesses encounter variety of external and internal barriers that unpleasantly affect the green practices. Suitable suppliers' selection is significant as it plays a substantial role in sustaining a position in the international market. The proposed research main objective is to develop and apply MCDM techniques using AHP to evaluate the method of supplier selection with respect to environmental supply chain for paint products in the UAE construction industries. The remaining part of the thesis is structured as the following: chapter two will reviews previous researches on several techniques used in supplier selection procedures with typical criteria as well as sustainable criteria, chapter three provides the general framework of AHP for SS in green supply chain. Then chapter four presents the validation of the proposed method for paint product used in the UAE construction industry, chapter five presents the conclusion and discussion and finally chapter 6 proposes future work.

Chapter 2 – Literature Review

This section delivers a summary of literature on different techniques used in supplier selection problem, specifically on single or multiple multi-criterion decision making (MCDA) techniques. Chapter 2 is presented as three sections: Techniques used in supplier selection, MCDA methods for choosing suppliers in typical supply chain and environmental supply chain.

2.1 Techniques used in Supplier Selection

In the process of selecting the suppliers, determining the method for evaluating and analyzing the suppliers based on the chosen criteria is important. Different methods are used at the evaluation stage since it is difficult to find the best approach based on the selected criteria. Having an appropriate method to select the optimal suppliers that will meet the goals of the organization is the vital part in process of the supplier selection [2]. The models generally classified into two kinds, single model and integrated model. The single model includes the mathematics, analysis, and artificial intelligence that could be implemented for the single sourcing and the multiple sourcing [4, 7]. The integrated model compromises of two or more different single models combined. Choosing the right combination of multiple models addresses the limitations that is encountered in any single method and increases the accuracy of the model result. A detailed illustration of various single model is presented in figure 1 [4, 7].

The mathematical models permit the decision maker to convert the judgement into a mathematical function, which requires being either maximize or minimize. Analysis model mainly focus on the stochastic uncertainty in the supplier choice [8]. Artificial Intelligence models are computer-based methods where the decision maker uses historic data and experience to train and educate the systems to manage with the complication and uncertainties of the supplier selection process [8, 9]. Artificial intelligence algorithms can be utilized to provide analysis and decisions on new cases without the need for detailed supervision. Decision makers by utilizing artificial intelligence can produce better and more precise decisions in choosing the optimal supplier.

We briefly explain several popular methods below:

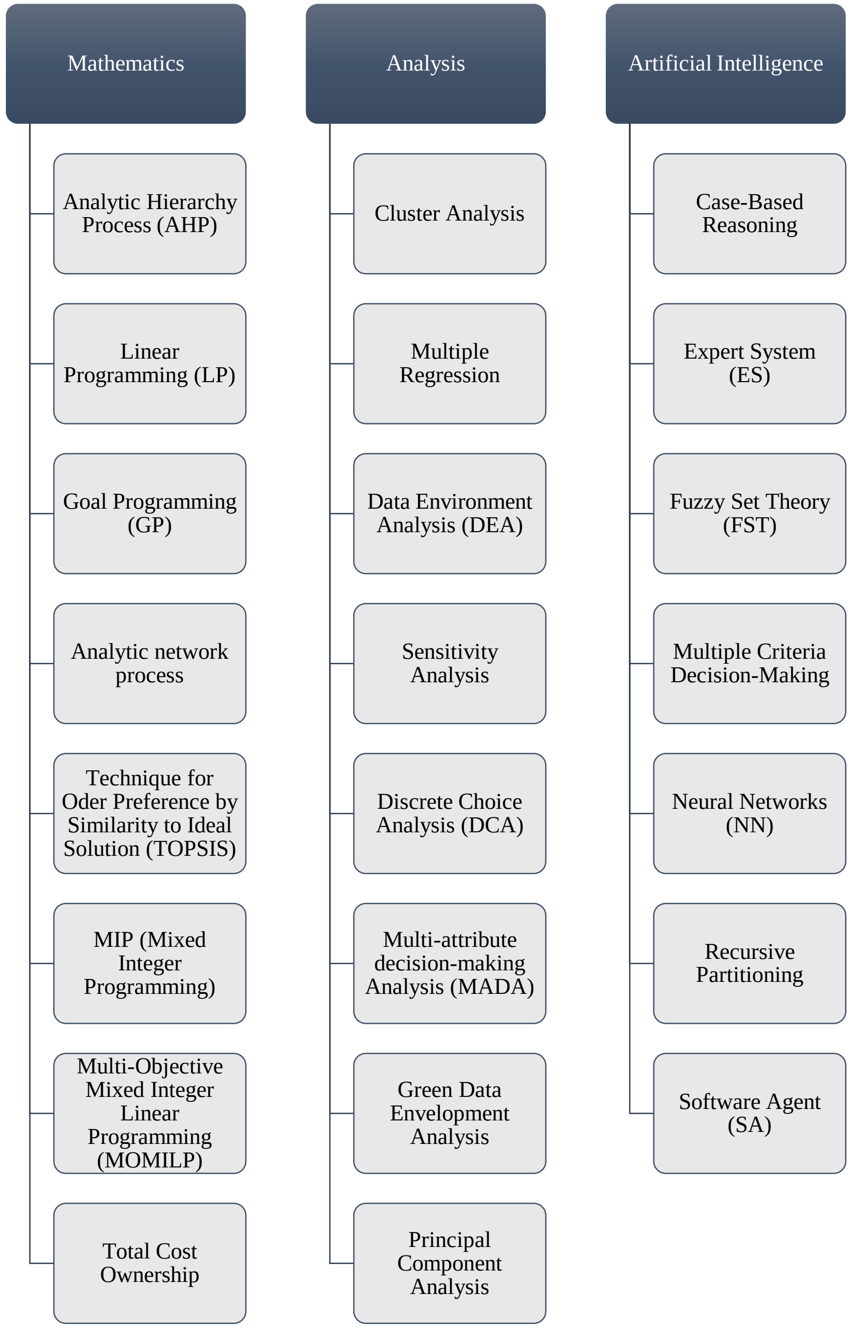

Figure 1: Single Model [4, 7]

- ***Analytic Hierarchy Process (AHP)***

Analytical Hierarchical Process is a structured technique that is a type of Multi-Criteria decision-making method, and it is required for analyzing and evaluating complex decisions that contain both qualitative and quantitative criteria that resulting in an overall ratio scales (weight) of the alternatives from the paired comparisons. AHP is simple to use, where it integrates several inputs from different decision makers [experts] to a combined outcome. Many decision makers rely on the AHP results. AHP allows the managers to organize the complex situations in a hierarchal form, which consists of, goals, criteria, and alternatives. AHP inputs are acquired either from tangible measurements or from individual judgement. As human judgement is not always reliable, AHP allows small inconsistency in the decision makers' evaluation. It includes a beneficial method for inspecting the consistency of the decision maker's judgement in order to lessen the prejudice in the procedure of the decision-making [6, 9]. Azimifard et al. [38] integrated AHP and TOPSIS for Iran's steel industry, along with sensitivity analysis to find the optimal suppliers. The four criteria used are emissions of CO_2, consumption of water, amount of employees, and distance between supplier country and the destination.

- ***Goal Programming (GP)***

Goal programming is a quantitative optimization technique that is an enhancement of linear programming with multi-conflicting goals and set of constraints. The method improves the quality of the decision-making approach of the users, helps of attaining the optimized use of resources, and helps reevaluate existing plans so that to adjust to changing conditions [40]. Diverse weights are allocated to every goal to indicate priority in the model. GP is a kind of the trendy Multi-Criteria Decision-Making technique. Goal programming achieves the best result that reaches as close as possible to every well-defined goals, while providing sufficient elasticity to the decision maker to put target levels on diverse criteria [6, 9]. There are several variants of GP models, such as Weighted, Lexicographic, Chebyshev, Fuzzy, Integer and Binary, and Fractional [41] The Weighted goal programming (WGP) enables direct trade-offs between all undesirable deviational variables by putting them in a weighted, normalized goal function. This technique is also called non pre-emptive goal programming. The main aim of this method is to reduce the weighted summation of whichever divergences of the objective functions from their own targets that is expressed as a linear programming problem. The lexicographic GP model is also called pre-emptive goal programming. It is a way to satisfy the goals by ranking them by priority levels and try to optimize one goal at a time, beginning with the goal with first priority then moving down through the low priority. Each priority level comprises of one or more undesired deviations that needed to be minimized [7]. Alegoz et al. [39] provided a hybrid technique for supplier selection and order allocation. In this method, first, the weights of the suppliers were obtained using qualitative criteria as an input to fuzzy TOPSIS technique, then the weights of quantitative criteria, the mathematical model objective, was obtained using the trapezoidal type-2 fuzzy AHP. Finally, the obtained suppliers weight and the quantitative criteria are used in the Goal Programming method to provide the optimal suppliers and allocation of orders for each supplier. In this paper, five different practical problems are applied to validate the proposed method's feasibility.

- ***Analytic Network Process (ANP)***

Analytic Network Process (ANP) is an extensive decision-making method that seizes the result of dependency and relationship between criteria [2]. It is a broad method of "Analytical Hierarchy Process (AHP)", which uses AHP as its starting point and include dependent relationships amongst decision-making elements and alternatives. As ANP takes into consideration the dependency between criteria, it provides more precise solutions for producing the criteria weights. It is modelled as a network structure, not as hierarchal structure as with the AHP [2,9]. Tavana et al. [42] integrated Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and Quality Function Deployment (QFD) to find the optimal suppliers for a dairy company. The research aim, first, to obtain the customer factors and sub-factors weights using the ANP technique. Then used the results of the ANP as input to the QFD to obtain the decision criteria weights. After that, the AHP approach is to order suppliers based on the weights of the decision criteria.

- ***Technique for Oder Preference by Similarity to Ideal Solution (TOPSIS)***

TOPSIS is a type of Multi-Criteria Decision-Making method that allows the decision makers to find the positive optimal result and negative optimal result. The concept of TOPSIS is to identify a best alternative that have the shortest distance from the positive optimal solution and the farthermost distance from the negative optimal solution [2, 9]. Tusnial et al. [43] presented an integrated Quality Function Deployment (QFD), Analytic Hierarchy Process (AHP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to implement a decision-making method for selecting suppliers for six suppliers of lithium-ion batteries.

- ***Cluster Analysis (CA)***

Cluster Analysis is a simple statistical technique that groups items based on set of scores into several clusters using classification algorithm. The cluster will contain items that have the least difference among them and will have the maximum differences concerning the items in other clusters. [8,9]. Che et al. [46] proposed a hybrid method that contains k-means, simulated annealing algorithm, the Taguchi method, and convergence factor particle swarm optimization to group the suppliers. The approach is implemented on computer screen module product of notebook computers and compared with other approaches to prove the model effectiveness.

- ***Data Envelopment Analysis (DEA)***

Data Envelopment Analysis is a classification algorithm that is used for evaluating and measuring decision alternative based on efficiency and effectiveness. Two sets of criteria, cost criteria as an input and benefit criteria as an output are used to evaluate the alternatives. The alternative efficiency is expressed as the below [8]:

$$\text{Alternative Efficiency} = \frac{\text{Weighted sum of its outputs}}{\text{Weighted sum of its inputs}} = \frac{\text{Performance of the supplier}}{\text{Costs of using the supplier}}$$

DEA technique assumes if an alternative provides a group of output criteria, which is not provided by others with the same group of input criteria, the alternative will have a relative efficiency of 100%. This technique finds the best satisfactory set of weights. For each alternative, it results in the group of weights that maximizes the proficiency rating of the alternative beside making its own and the other alternatives' rating always less than or equal to one. DEA method allows the decision maker to categorize the alternatives either efficient or inefficient [8,9]. He et al. [48] integrated all of Factor Analysis (FA), Data Envelopment Analysis (DEA), and Analytic Hierarchy Process (AHP) to evaluate, rank and find the best low-carbon suppliers. The proposed model is applied on seven cement suppliers.

- ***Neural Networks (NN)***

Neural Networks is dependent on artificial intelligence (AI) technology approaches that are developed similar to human judgment performance, which can manage better with the problem's complication and uncertainty than traditional methods [8]. In this technique, the manager is required to assess the alternative performance on every criterion and then the technique will use the past cases and the characteristics of the recent situation the decision-maker provided and will make the actual trade-off for the decision-maker [8]. Gegovska et al. [50] combined Fuzzy Multi-Criteria Decision-Making approaches and Artificial Neural Networks to obtain the optimal green supplier. The Fuzzy Multi-Criteria Decision-Making procedures consist of the Fuzzy Analytic Hierarchy Process, Fuzzy TOPSIS, and Fuzzy ELECTRE. The model applied to five suppliers with seven distinct criteria, which are quality, price, delivery, service, control the pollution, green product, and management of environmental aspects, to obtain the optimal green supplier.

2.2 MCDA for Supplier Selection in Supply Chain

In the literature, there are numerous articles that uses employs single or multiple MCDA methods for supplier assessment and selection process. A brief review of relevant articles was performed through evaluating criteria and their approaches:

Chang et al. [10] applied Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) approach for finding influential supplier selection criteria by evaluating supplier performance for the electronic industry. Yucenur [11] used and compared Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Analytical Network Process (FANP) for solving the issue in selecting suppliers in the textile industry. The hierarchy contains four criteria and 28 sub-criteria to find the comparative importance rating amongst the criteria for each of the approaches. Kokangul and Susuz [12] presented an integrated Analytical Hierarchy Process (AHP) and non-linear integer and multi-objective programming to find the optimal suppliers and to provide the finest demand amounts between them in the supplier selection problem for an automotive manufacturer firm. Two key criteria and 24 sub-criteria where utilized to analyze the eight suppliers. Chan and Kumar [13] applied a Fuzzy Extended Analytical Hierarchy Process (FEAHP) based methodology for selecting the best international supplier. Vinodh et al. [14] impelmented Fuzzy Analytic Network Process (FANP) approach encompassing 5 criteria and 16 sub-criteria for finding the optimal supplier for an Indian electronics switches manufacturing enterprise. Nguyen Thanh et al. [15] presented a Group Fuzzy Analytic Network Process (GFANP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods to select the best material supplier for Hochiminh City Open University. Four criteria were used for selecting the material supplier. Tahrir et al. [16] applied the Fuzzy Analytic Hierarchy Process (FAHP) method encompassing 6 criteria, 9 sub-criteria and 30 secondary sub-criteria in a steel manufacturing company in Malaysia for assessing and selecting the best supplier. Ku et al. [17] combined Analytic Hierarchy Process (FAHP) and Fuzzy Goal Programming (FGP) approaches for international supplier selection to find the priorities of the criteria for supplier selection and acquire the optimal order quantities for best-fitted suppliers based on company's strategies. Wang et al. [18] applied Analytical Hierarchy Process (AHP) method using 3 key criteria and 14 sub-criteria for selecting the optimal supplier. This results in to best three supplier selection criteria that are product quality, price/cost, and manufacturing capability. Similar to [18], Bayazit et al. [19] presented Analytical Hierarchy Process (AHP) for a Turkish construction company, AKG Construction Inc., along with sensitivity analysis to find the optimal suppliers. They used 3 criteria, 15 sub-criteria and 43 secondary sub criteria for the process of selecting suppliers. Raut et al. [20] combined Analytical Hierarchy Process (AHP) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) technique to get the most important criterion or the most significant criterion that affects other criteria. This aims to help the purchaser to focus in the most effective criterion and advise the suppliers to do the same in order to improve the performance.

Moreover, Nguyen et al. [21] applied Fuzzy Analytical Hierarchy Process (FAHP) method for ranking material supplier in Vietnam’s manufacture enterprises. Bayazit [22] applied Analytic Network Process (ANP) approach to evaluate multi-criteria supplier selection process that contain interdependencies. There were ten criteria, which are categorized into performance of the supplier and capability clusters of suppliers; and three suppliers. Hruška et al. [23] proposed Analytic Hierarchy Process (AHP) technique to get the optimal and suitable supplier out of three potential suppliers in a manufacturing company. Similar to

[23], Juliana et al. [24] applied Analytic Hierarchy Process (AHP) technique to aid the managers to find the best supplier of goods. Plebankiewicz et al. [25] compared two multi-criteria decision-making method, Fuzzy Analytical Hierarchy Process (FAHP) and Analytic Hierarchy Process (AHP), to evaluate three criteria and ten sub-criteria to get the optimal building material suppliers out of the ten suppliers. Ishizaka [26] compared Fuzzy logic, Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP), and Hybrid Fuzzy Analytic Hierarchy Process (H-FAHP) methods that compromises of four criteria, eight sub-criteria, and four sub-sub-criteria in order to find the best method that support decision makers in identifying a suitable supplier out of three suppliers. Jadidi et al. [27] implemented an enhanced multi-choice goal programming (MCGP) method to have a goal level for every objective: cost, rejects and lead-time, in a supplier selection issue. Jadidi et al. [28] developed a normalized goal programming (GP) method for two different situations: the fuzzy multi-objective optimization problem (MOOP) where the objectives weights are predetermined; and the crisp-MOOP where the objectives goals are predetermined in order achieve the desirable consistency between all objectives. The three objectives are the reduction of cost, rejects and lead-time. Chi et al. [29] integrated Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution method (TOPSIS) and Goal Programming (GP) in order to consider quantitative and qualitative methods to aid managers find the optimal suppliers based on certain criteria and targets for Casumina Rubber Company in Vietnam. Choudhary et al. [30] compared three types of goal programming (GP) approaches, preemptive GP, non-preemptive GP and weighted max–min fuzzy GP, in order to find in each replenishment period the best and optimal timings, lot-size to be acquired, supplier, and carrier. In addition, Yadav et al. [51] proposed a supplier selection approach for an automobile industry using the weight cum rating approach and AHP technique. The aim of this research is first to shortlist the suppliers, then to measure and find the optimal suppliers depending on the criteria provided from literature and case study. The main criteria are quality, price, delivery, service, long-term relationship, and flexibility. Then, a sensitivity analysis is implemented to analyze the change of the supplier's priority with respect to the weight modification of criteria or sub-criteria. To validate the model, a case study of an Indian automobile enterprise was implemented.

Furthermore, Yadav et al. [52] developed the supplier selection approach for the automobile industry in India under dynamic situations through the Fuzzy Analytical Hierarchy Process (FAHP) method. Six main criteria and 22 sub-criteria are selected from literature and the subject matter experts. The main criteria are quality, fee, delivery, service, long-term relationship, and flexibility. Su [53] proposed a framework using the Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) technique to define the criteria weights and to evaluate and select the optimal building material suppliers for an integrated construction group. Five key criteria and 19 sub-criteria are selected. Five main criteria include value, quality, service level, supplier qualification, and threat factors considered. Before determining the rank and finding the optimal building material suppliers using IFAHP, an algorithm is implemented for a non-consistency correction to reduce the time between the experts and decision-makers in adjustment and correction of Intuitionistic Fuzzy Preference Relations (IFPRs). A sensitivity analysis is implemented after the IFAHP to verify the efficiency of the suggested model. Basar et al. [56] used Fuzzy Analytical Hierarchical Process (FAHP) technique to investigate and evaluate the four suppliers' performance in the Turkish construction industry. Managers in the white goods sector in Turkey provided 3 key criteria and 11 sub-criteria that was used in the research. The criteria are features of the product, features of the supplier, and conditions of the delivery. Irmayanti [58] applied the Analytic Hierarchy Process (AHP) to evaluate and find the optimal suppliers of raw materials. The four criteria used in the research are brand, price, quality, delivery, and speed. Asadabadi et al. [59] compared the general form of Multi-Criteria Decision Making (MCDM) methods with the Analytic Hierarchy Process (AHP) by providing a simple evident example to showcase the reason for the intuitive decisions in the procedure of selecting suppliers preferred by the company's decision-makers. The research resulted that given the simple example, the general form of the MCDM method may infrequently outperform AHP. Based on this article, further studies should be performed to assure the company's decision-makers to use MCDM methods, such as AHP, are a reliable solution. Alkahtani et al. [61] implemented, analyzed and compared the Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP), and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS) for supplier selection process. The comparison of the three approaches is depending on the following criteria: agility during the decision process, computational complexity, number of criteria and alternative suppliers, and adequacy in supporting a group decision. Four key criteria and four sub-criteria with four suppliers were used in the research. The four criteria are performance of the supplier, performance of the product, performance of the service, and cost. The research concluded that AHP outperform F-TOPSIS and FAHP with respect to the computational complexity. Besides, F-TOPSIS method is well-matched with the assessment and selection of the optimal suppliers with respect to agility through the decision process, the amount of criteria and alternatives, and the sufficiency in helping a team decision. Hosseini et al. [63] recommended a combined ensemble as well as AHP method for resilient international plastic raw material supplier's selection for a manufacturer located in the United States. The purpose of the study is to discover the resilience criteria for supplier selection due to the urge need of resilient suppliers that can handle the disruptive event in the supply chain. Then to apply an advanced data-mining technique using ensemble methods that merge binomial logistics regression, classification and regression trees, and neural network to find the resilience value of each supplier and select the top five suppliers. After that to analyze the suppliers' performance, and to prioritize them using AHP method that consists of 2 key criteria and 12 sub-criteria. The two main criteria are the traditional criteria and the resilience criteria. The research data was collected via a questionnaire distributed among suppliers through procurement department.

Table 1 below summarizes the articles described above:

Table 1: Articles Summary

Reference No.	Author (Year)	Technique	Problem	Journal	Application
[10]	Chang et al.(2011)	Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL)	Finding influential criteria for selecting the suppliers	Expert Systems with Applications	Electronic industry
[11]	Yucenur (2011)	Fuzzy AHP and Fuzzy ANP	Solving multiple-criteria	Int J Adv Manuf Technol	Textile industry

			decision-making supplier selection problem in a international supply chain		
[12]	Kokangul and Susuz (2009)	Integrated AHP and non-linear integer and multi-objective programming	Find the optimal suppliers and to provide the finest order quantities between them in the supplier selection problem	Applied Mathematical Modelling	Automotive manufacturer firm
[13]	Chan and Kumar (2007)	Fuzzy extended AHP	Solving international supplier selection problem	Omega	Manufacturing company
[14]	Vinodh et al. (2011)	Fuzzy ANP	Finding the optimal supplier	Expert Systems with Applications	Indian electronics switches manufacturing company
[15]	Nguyen Thanh et al. (2017)	Integrated Group Fuzzy ANP and TOPSIS	Select the best material supplier	Key Engineering Materials	Hochiminh City Open University
[16]	Tahrir et al. (2014)	Fuzzy AHP	Assessing and selecting the best suppliers	Journal of Scientific Research and Reports	Steel manufacturing company in Malaysia
[17]	Ku et al. (2009)	Integrated Fuzzy AHP and Fuzzy GP	Conclude relative weights of supplier selection criteria and acquire the optimal order quantities for best-fitted suppliers	Quality & Quantity	Electrical and electronic manufacturer in Taiwan
[18]	Wang et al. (2018)	AHP	Identifying the best supplier	2018 IEEE International Conference on	-

				Advanced Manufacturing	
[19]	Bayazit et al. (2006)	AHP	Find the optimal suppliers	Journal of Systems Science and Systems Engineering	Turkish construction company, AKG Construction Inc.
[20]	Raut et al. (2011)	Integrated AHP and FDEMATEL	Find the most criterion that is important	International Journal of Business Innovation and Research	Manufacturing facility in India
[21]	Nguyen et al. (2018)	Fuzzy AHP	Ranking material supplier selection criteria	2018 IEEE 5th International Conference on Engineering Technologies and Applied Sciences	Vietnam’s construction companies
[22]	Bayazit (2006)	ANP	Evaluate multi-criteria supplier selection process	Benchmarking: An International Journal	-
[23]	Hruška et al. (2014)	AHP	Select the best and suitable supplier	TRANSPORT	Manufacturing company
[24]	Juliana et al. (2017)	AHP	Find the best supplier of goods	Scientific Journal of Informatics	Goods store
[25]	Plebankiewicz et al. (2016)	Fuzzy AHP and AHP	Find the best and optimal building material suppliers	Journal of Construction Engineering and Management	Large construction project
[26]	Ishizaka (2014)	Fuzzy logic, AHP, Fuzzy AHP, and Hybrid Fuzzy AHP	Find the best method that support decision makers in identifying a suitable supplier	International Journal of Integrated Supply Management	-
[27]	Jadidi et al. (2015)	Improved multi-choice goal programming (MCGP)	Propose an improved method for supplier	Applied Mathematical Modelling	-

			selection problem		
[28]	Jadidi et al. (2013)	Normalized GP	Propose a new normalized GP for a supplier selection problem and order allocation	International Journal of Production Economics	-
[29]	Chi et al. (2016)	Integrated AHP, TOPSIS and GP	Identify the optimal suppliers	MATEC Web of Conferences	Casumina Rubber company in Vietnam
[30]	Choudhary et al. (2014)	Preemptive GP, Non-Preemptive GP, and Weighted max–min fuzzy GP	Determine the best and optimal timings, lot-size to be acquired, supplier, and carrier	Computers & Industrial Engineering	-
[51]	Yadav et al. (2016)	Weight cum rating and AHP	Shortlist the suppliers, and identify the optimal suppliers	Journal of Modelling in Management	Indian automobile company
[52]	Yadav et al. (2015)	Fuzzy AHP	Develop a supplier selection model under dynamic situations	Benchmarking : An International Journal	Indian automobile company
[53]	Su (2020)	Intuitionistic Fuzzy AHP	Find the best and optimal building material suppliers	IEEE Access	Large-scale integrated construction Group
[56]	Basar et al. (2018)	Fuzzy AHP	Identify the optimal suppliers	Journal of Business and management	Turkish construction industry
[58]	Irmayanti (2020)	AHP	Evaluate and find the optimal suppliers of raw materials	IOP Conference Series: Materials Science and Engineering	-
[59]	Asadabadi et al. (2019)	AHP and general form of the MCDM	Showcase the reason for the intuitive decisions in the supplier	Cogent Engineering	-

			selection process preferred by the company's decision-makers rather than the MCDM approach		
[61]	Alkahtani et al. (2019)	AHP, Fuzzy AHP, and Fuzzy TOPSIS	Find the best method that support decision makers in identifying a suitable supplier	Advances in Mechanical Engineering	-
[63]	Hosseini et al. (2016)	Hybrid ensemble and AHP	Identify the optimal resilient international plastic raw material suppliers	Journal of Intelligent Manufacturing	U.S. based manufacturing company

2.3 MCDA for Supplier Selection in Green Supply Chain

In the recent years, green consideration and environmental awareness has obtained increased consideration between public, stakeholders and scholars towards environmental protection due to undesirable impacts of the industrial processes. Green Supply Chain Management (SCM) has come to be a significant problem for enterprises striving to achieve environmental sustainability. Thus, in the Supplier Selection Procedure, sustainability associated criteria was incorporated together with conventional criteria due to its long-term effects in environmental protection. This squarely puts the focus on companies to consider sustainability related criteria and green aspects in their suppliers' assessment procedure. In addition, to satisfy the green and social standards. Selected articles about sustainable criteria applied in multi-criterion decision-making (MCDM) procedures for environmental supplier selection process (GSSP) are briefly summarized.

Galankashi et al. [31] applied Nominal Group Technique (NGT) in order to find the interdependency level of the criterion and get the critical performance measures to be used in the Fuzzy Analytical Network Process (FANP). They used FANP to rank the most essential criteria and determine their importance level for the using in in the green supplier assessment and selection procedure for Small and Medium Enterprises (SMEs) in the electronic industry. This approach combines the classic and environmental supply chain performance measures with the process of selecting green suppliers. The main criteria selected in this article were value, quality, reputation, service and delivery, distance, green materials usage, emission level for air, level of waste, efficiency energy use and green design ability. Wang Chen et al. [32] integrated Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) in order to define the significant criteria weights and to assess and prioritize the optimal suppliers under ambiguous environment for Taiwanese optical prism (TOP) manufacturing entity in Luminance Enhancement Film (LEF) industry. Economic and environmental criteria were used for environmental supplier selection process. Those five criteria are price of the product, ISO quality system, lead-time, green technology and environmental certificate. Malik et al. [33] used Analytical Hierarchical Process (AHP) technique to investigate and evaluate the healthcare suppliers' environmental performance in the United Arab Emirates healthcare sector. The aim of this research is to determine an environmental benchmark applicable for the UAE healthcare. The selected expert team consists of two managers from the procurement department and three experts in the supply chain from each of the two public and three private hospitals. Eight key criteria and 27 sub-criteria used in the tool. The eight main criteria selected are Supplied Product Attributes (PA), Supplier Environmental Footprint (EF), Supplier Voluntary Certification (VC), Quality Assurance (QA), Supplier Resource Consumption (RC), Supplier Legal Compliance Competency (CC), Supplier Management Systems (MS) and Supplier Management Practices (MP). Chen et al. [7] adopted weighted goal programming (WGP) and preemptive goal programming (PGP) methods for global supplier selection for an automotive company in which eight main criteria including safety, quality, delivery, price, people, environment, cash flow, and risk factors are considered. The research aim is to find in an unpredictable disaster environment the optimal suppliers and appropriate supply locations in Asian region in order to have a resistant supply chain in an uncertain period of man-made or natural disasters. Wang et al. [54] implemented a supplier selection framework by integrating the Analytic Hierarchy Process (AHP) and Grey Relational

Analysis (GRA) technique to weight the criteria and prioritize the suppliers in the context of a resilient construction supply chain (RCSC). Integration of building information modeling (BIM) and a geographic information system (GIS) in an RCSC were adopted in the framework to provide clear information for the supply chain management. Five main criteria and 17 resilient sub-criteria are selected. This approach combines the classic and environmental supply chain performance measures into the supplier selection procedure. The main criteria were performance factors, flexibility, enterprise capacity, R&D, and green abilities. A sensitivity analysis is applied to the weightings given to each criterion after implementing the integrated model to analyze the resilience criteria that impact the priorities of suppliers the most.

Moreover, Jain et al. [55] integrated the Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) to define the significant criteria weights and to assess and find the optimal environmental headlamp suppliers for an Indian automobile company. Eight main criteria including Product Quality (PQ), Price/Cost (P/C), Quality of Relationship (QOR), Manufacturing Capability (MC), Warranty (W), On-time delivery (OTD), Environmental Performance (EP), and Brand name of the supplier (BNOS) are considered. Sensitivity analysis is implemented to validate the robustness of the approach. Pornsing et al. [57] implemented the Fuzzy Analytic Hierarchy Process (FAHP) method for the supplier selection process to rank and get the best Printed Circuit Board (PCB) suppliers for an electronic manufacturing services company. Nine criteria with five suppliers and three products types were used in the research. The nine criteria are technical ability, geography location, production flexibility, price, quality & warranty policy, delivery, economy and reliability, and green and social responsibility. Gupta et al. [64] proposed a joined Fuzzy Analytical Hierarchy Process (FAHP), Fuzzy Multi-Attributive Border Approximation Area Comparison (F-MABAC), Fuzzy Weighted Aggregated Sum-Product Assessment (F-WASPAS), and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS) models for environmental supplier selection process in the automotive industry in India. This technique combines the typical and environmental supply chain performance measures into the green process of selecting suppliers. The environmental criteria selected in this research were green management system, green brand, staff green related training, eco-design, control of the pollution, and consumption of the resource, while conventional criteria were cost, quality, and level of service. The article first obtained nine criteria from literature and experts, then, implemented the FAHP method to get the criteria's priority and choose the four criteria with the highest priority. After that, the criteria were inserted as an input for the further three approaches to find the optimal alternative. Sensitivity analysis is implemented to validate the effectiveness of the recommended method. Deshmukh et al. [65] implemented and compared Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (FAHP) methods to find the optimal green suppliers for plastic products manufacturing MSMEs in India. The conventional and environmental supplier evaluation criteria were combined in the study that contains 8 key criteria and 40 sub-criteria. The main criteria are service performance, cost, quality, environmental manufacturing management, delivery, risk, environmental performance assessment, and innovation and learning. The article outcome states that AHP and FAHP produces the same suppliers ranking. Lo et al. [66] combines Best-Worst Method (BWM), modified Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS), and Fuzzy Multi-Objective Linear Programming (F-MOLP) for environmental supplier selection and order allocation problem in an electronics company. The article provided 3 key criteria and 10 sub-criteria with six alternative suppliers. The main criteria compromise performance of the supplier, environmental protection, and supplier risk. The research aims to apply BWM to find the criteria weights, implements modified F-TOPSIS to obtain the suppliers ranking, carry out a sensitivity analysis to examine the robustness of the process, and F-MOLP to investigate the optimal order allocations.

Furthermore, Gao et al. [67] suggested a combination of consensus decision-making framework to find the optimal environmental supplier for electronics manufacturing. Mathiyazhagan et al. [68] used the Analytical Hierarchy Process (AHP) to assess and order green suppliers based on the fifteen environmental criteria for Indian automobile industry. The criteria are based on Management, Technology, Manufacturing, and Cost categories. Some of the environmental criteria are green safety certification, environmental fortification associate, green package, environmental-friendly substances, and to acquire the new environmentally friendly technology. Demir et al. [62] compared integrated approaches that solve an environmental supplier selection issue. The study was applied on a case study from the Paper factory located in Istanbul. The methods used in the research are the Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) method and Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) method to get the weights of the criteria, evaluate, rank, and find the optimal green supplier. Three main criteria comprising of supplier performance, environmental protection, and supplier risk. In addition, ten sub-criteria with three alternative green suppliers were used in this research. The research resulted in a slight difference in ranking between IF-AHP and IF-TOPSIS. Hamdan et al. [69] implemented a decision-making tool with respect to MATLAB software that combined the Analytic Hierarchy Process (AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS). AHP is used to allocate global weights to the traditional and green criteria, and F-TOPSIS to prioritize the suppliers based on the two types of criteria. Two optimization approaches, Multi-Period Bi-Objective and Multi-Objective Optimization are compared to find the best way to allocate orders. The proposed tool is applied to a case study from a facilities management company that is in the Gulf Cooperation Council region. The research result shows that both approaches had the same optimum solution. Therefore, the Bi-Objective model is preferred as it is better than multi-objective model as it is faster in the application.

Table 2 presents the summary of papers incorporating green criteria in supplier selection problem:

Table 2: Articles Summary including green criteria

Reference No.	Author	Technique	Problem	Journal	Application
[31]	Galankashi et al. (2015)	Fuzzy ANP	Determine the essential criteria importance level for the purpose of green supplier evaluation and selection	Procedia CIRP	Small and Medium Enterprises (SMEs) in the electronic industry
[32]	Wang Chen et al. (2016)	Integrated Fuzzy AHP and TOPSIS	Define the significant criteria weights and to	Mathematical Problems in Engineering	Taiwanese optical prism (TOP) manufacturing

			assess and prioritize the optimal suppliers under ambiguous environment		entity in Luminance Enhancement Film (LEF) industry
[33]	Malik et al. (2016)	AHP	Determine an environmental benchmark applicable for the UAE healthcare	Renewable and Sustainable Energy Reviews	United Arab Emirates healthcare sector
[7]	Chen et al. (2014)	Weighted GP and Preemptive GP	Find in an unpredictable disaster environment the optimal suppliers and appropriate supply locations in Asian region	Int J. Adv Manuf Technol	Automotive company
[54]	Wang et al. (2017)	AHP and GRA	Evaluate and find the optimal suppliers in the context of a resilient construction supply chain	Sustainability	Resilient Construction Company
[55]	Jain et al. (2018)	Fuzzy AHP and Fuzzy TOPSIS	Evaluate and rank the optimal environmental headlamp suppliers	Neural Computing and Applications	Indian automobile company
[57]	Pornsing et al. (2019)	Fuzzy AHP	Find the optimal Printed Circuit Board (PCB) suppliers	IEEE International Conference on Industrial Engineering and Applications (ICIEA)	Electronic manufacturing services company
[64]	Gupta et al. (2019)	Fuzzy AHP, Fuzzy MABAC, Fuzzy WASPAS,	Propose an integrated method for supplier	Computers & Industrial Engineering	Automotive industry in India

		and Fuzzy TOPSIS	selection problem		
[65]	Deshmukh et al. (2019)	AHP and Fuzzy AHP	Find the optimal green suppliers based on typical and green criteria	Proceedings of International Conference on Intelligent Manufacturing and Automation	Plastic products manufacturing MSMEs in India
[66]	Lo et al. (2018)	BWM, Fuzzy TOPSIS, Fuzzy MOLP	Propose a model for green supplier selection and order allocation problem	Journal of Cleaner Production	Electronics company
[67]	Gao et al. (2020)	Consensus decision making	Propose a group consensus decision-making framework by to find the optimal green supplier	Journal of Cleaner Production	Electronics manufacturing
[68]	Mathiyazhagan et al. (2018)	AHP	Evaluate and rank green suppliers based on environmental criteria	OPSEARCH	Indian automobile industry
[62]	Demir et al. (2020)	Intuitionistic Fuzzy AHP and Intuitionistic Fuzzy TOPSIS	Compare integrated approaches that solve a green supplier selection problem	International Conference on Intelligent and Fuzzy Systems	Paper factory located in Istanbul
[69]	Hamdan et al. (2017)	AHP and Fuzzy TOPSIS	Implement a decision-making tool to find optimal green suppliers and allocate orders to them.	Computers & Operations Research	Facilities management company located in Gulf Cooperation Council region

2.4 Conclusion

In this chapter, numerous methods were reviewed for the analysis and evaluation of suppliers and precisely on single or multiple multi-criterion decision making (MCDA) methods for supplier assessment and selection process using the conventional criteria and sustainable criteria. Having a proper strategy to choose the optimal suppliers that will meet the objective of the industry is the utmost dynamic part in process of selecting suppliers. The next chapter will provide the thesis contribution in this field and the general framework of the AHP technique for supplier selection procedure for environmental supply chain applied to construction industry. In addition, the process of developing a framework, choosing the criteria based on literature, consultation with subject matter experts and present job experience.

Chapter 3 – Methodology

This chapter provides the thesis primary contribution in terms of finding the optimal suppliers that meet the objective of the UAE construction industry for paint products considering green criteria. We present the general framework used in solving the problem. Besides, this chapter will provide the detailed flow for implementing the Analytical Hierarchy Process (AHP) technique using the chosen criteria from literature, subject matter experts, and the experience gained from the researcher's job. Chapter 3 presents two sections: General Framework, and Data Preparation.

3.1 General Framework

Supplier selection problem considering Green criteria is an important contribution to the policies and implementation of environmental goals by United Arab Emirates that requires more focus and research. This is important to enhance and introduce awareness for the industries to adopt and implement green criteria in the supplier selection procedures. The section introduces the general framework of the research implementation from the initial search for related articles and papers that explains similar problems to add value on the knowledge gained, until finding the best approach and implementing it on a real use case.

The general framework for the paint supplier selection comprises of three following phases as shown in Figure 2. The initial phase mainly consists of a literature review to gain insights about previous related work in other countries and specifically in the concerned country. The second phase, the modeling phase, is a critical part of the framework and the model implementation. Finally, the final phase consists of model validation, limitation, recommendations, and future works.

This research highlights three valuable contributions to the supplier selection process considering green criteria. First, the research highlights the significance of the issue of supplier selection, exclusively using MCDM. AHP method is applied in the construction industry and specifically to the product suppliers. This enables the decision-makers of the construction industry to have more confidence in the evaluation process. By having a simple methodology, it will reduce managers' efforts in having long discussion meetings for choosing the best suppliers based on various aspects and among a large number of suppliers. Also, AHP ensures that the evaluation of the decision-maker is consistent.

Second, incorporating environmental aspects as performance measures for the supplier selection process is a vital role since it adheres to the UAE vision for a sustainable environment. To the best of our knowledge, most construction companies in the UAE are using only typical criteria in their selection of suppliers, which will affect negatively the environment, the company's reputation, and customer satisfaction. Integrating green criteria plays an significant part in the company's achievement and the green environment. This study provides a list of key general criteria for construction industry in the context of UAE that the decision-maker can evaluate suppliers for any of their concerned products. Besides, the study also provides specifically chosen criteria from the provided general criteria for paint product that is used in the construction industry. Utilizing green criteria in the decision-making leads to a healthy environment, enhancement in the industry image, improvement in customer satisfaction, and ultimately contributes to sustainable development goals. Third, sensitivity analysis is implemented to aid the decision-makers to verify the proposed approach's robustness and effectiveness. It enables them to understand the impact of changing the criteria weights on the priorities of the suppliers.

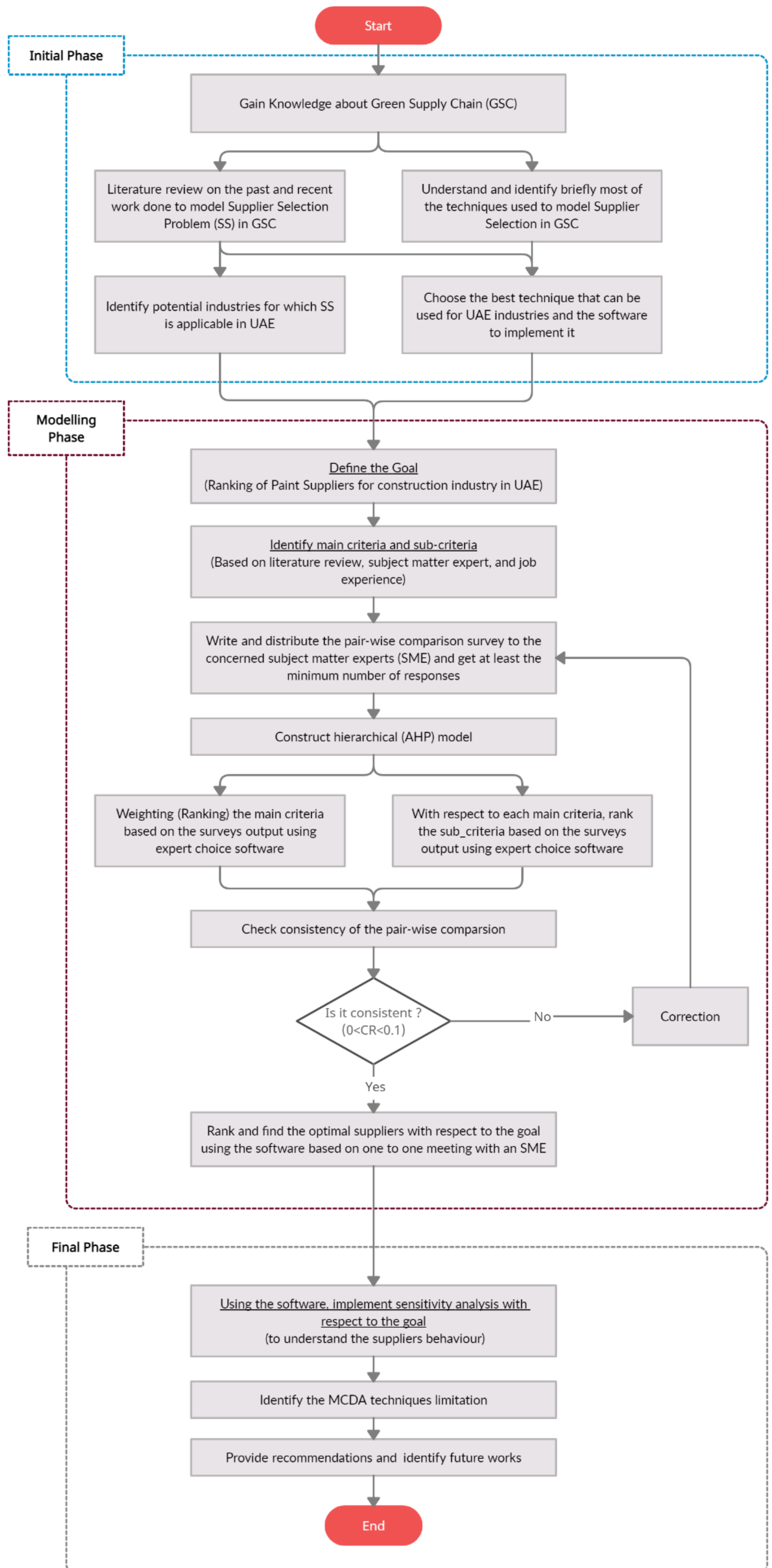

Figure 2: General Framework

3.1.1 Initial Phase

Having a clear understanding about the research topic is a vital factor that contributes to the achievement of the research implementation and validation. This phase helps to gain additional knowledge base of the research problem, which leads in having focus in the problem. It will enable the researcher to know different approaches that were implemented and the reason behind choosing the techniques. Finding articles that have investigated similar problems, supports in finding the best suitable techniques that can be implemented. In addition to support the research methodology.

Moreover, this phase permits the researcher to identify similar studies that has been implemented world-wide and specifically in the concerned country and understand the literature, and importantly the gaps in the research in order for it to be implemented in near future. Chapter 1 and chapter 2 in this research explained most of the findings of this initial phase in details.

Furthermore, based on the research conducted, it is evident that since the 1990's the UAE has taken important steps and implemented strategies aimed at environmental sustainability [70]. Such efforts have affected multiple industries, such as oil and gas, construction, transportation, water and electricity, and many others. In the construction industry, the UAE has issued green building regulations and specifications that aim to divert the focus of the producers to a more sentimentally efficient method of construction and resource utilization [70]. For instance, the use of water resource effectiveness, the regulation specifies exactly the construction design for water system must be like to the details of flow accepted per water outlets like sinks, basins, etc. Also, waste management of construction facilities is addressed to identify the types of waste and the proper methods to deals with each waste. These regulations affect significantly the supply chain of the construction industry in UAE by forcing suppliers to provide products that are compatible with the regulations as the demand increases, and forces contractors/producers to think and consider the consequences for violation of green regulation. Moreover, for cooling buildings the UAE is adopting the district cooling system (DCS) where central cooling system station distributes chilled air to multiple building and integrating smart control system and energy management systems to reduce wastage of energy thus being able to half-localized energy consumption in certain areas [70].

The oil and gas industry has increased efforts to reduce pollution and provide a green environment. Considerable efforts by UAE Government and ADNOC (UAE's national oil company) were dedicated to initiate and implement the Zero Flaring policy [70]. The gas byproduct from the extraction of oil is used efficiently in utilizing three methods gas injection, gas recovery, and gas exportation. ADNOC is abiding by strict quotas on gas flaring to ensure that no flaring is produced during the processing and refining of oil and gas [70]. Water waste is also efficiently managed to minimize the disposal and use the excess water in the inject wells and increase oil well pressure. Besides the distribution of the final product, that utilizes the latest technologies and strategies in transportation industry contributing to decreased pollution. Also, concerning the transportation industry, ADNOC gas processing and ADNOC Distribution are implementing cleaner fuel alternatives and providing the infrastructure for such fuel supply and distribution [70]. Thus, providing a critical step for greener supply chain in the oil and gas industry.

The UAE has also implemented efforts for making the agricultural sector and its supply chain efficient and green. In the barren and water-scarce environment of the UAE, many challenges are faced through the complete supply chain to produce food products. The number of farms in the UAE have increased from 4,000 in 1971 to 35,704 in 2011, with an area of 105,257 hectares [71]. This was due to major innovation in the supply chain of produce and agriculture industry. One such innovation is the Emirates Sustainable Agriculture Label that enables the produced product in the UAE to be identified and abide by the worldwide green regulations. Moreover, in the fishing industry, sustainable regulations were implemented to provide the necessary constraints to enable growth and minimize depletion of the fish resource in UAE waters [71]. There are several companies in UAE that specialize in waste management and enabling innovation in waste management efficiency to reduce pollution in the environment.

3.1.2 Modeling Phase

To have an effective and efficient supplier selection process with green related criteria is highly beneficial to UAE's construction industry, as they often deal with a several suppliers providing different goods and services. Therefore, due to the expanding list of suppliers in the market, a formal quantitative method is required to assess how environmentally-friendly their products/services are and utilizing the results of the method to make a decision on supplier selection. Exploiting MCDM techniques will allow the decision makers in such companies to have a more comprehensive view of the supplier and make their decisions more informative thus more efficient. This will result in the growth of a high performance and eco-friendly industry, growth for the construction industry, which will ultimately benefit sustainable development in UAE.

The research methodology used in this study is AHP technique to address the issue of choosing the suppliers for paint products used in construction industry**.** AHP is the simplest and extensively used approach that takes one or multiple decision makers pairwise comparisons evaluation of the criteria and the alternative suppliers as an input and outputs the overall suppliers' priority. AHP has many benefits such as it is produced from the subjective information, and numerical priorities [35]. This enables the decision makers to think inclusively, by assessing the suppliers' strengths and weaknesses and comparing the suppliers depending on certain criteria and sub-criteria, to select the best-fit suppliers effectively and efficiently [36].

AHP framework takes into account all phases in the supplier selection procedure starting from the goal of the problem, over the criteria formulation, potential suppliers' requirement, until ranking and selecting the competent supplier among the alternative suppliers available [57]. This section shows the AHP method that is consisted of several steps. First, create a hierarchical structure starting with a decision target, then key criteria and sub-criteria for assessing the alternatives, and, finally, alternatives for reaching the goal. Secondly, implement a pairwise comparison matrix for the key criteria and compute their priorities. Thirdly, implement a pairwise comparison matrix for the sub-criteria depending on the core criteria and compute their priorities. Fourthly, implement a pairwise comparison matrix for the alternatives based on the criteria and compute their priorities.

Determine the consistency to ensure all the subject matter expert decisions are consistent to have an accurate model. The consistency test is done for the pairwise comparison matrix of the core criteria, sub-criteria, and alternatives. After making sure that all the matrixes are consistent, and then the next step is to multiply each criteria priority with the associated suppliers' criteria priority, then sum them all to have the suppliers' priority and as a result, rank and find the optimal suppliers among them. The "Data Preparation" section will provide more details about the key criteria and sub-criteria description.

The pairwise comparison for the criteria, sub-criteria, and the suppliers are implemented based on Saaty scale. The definition of Saaty scale is demonstrated in the below Table 3 [55, 58].

Table 3: Saaty Scale

Scale	Definition	Explanation
1	Equal importance	Both factors have equal effect
3	Moderate importance	Rating and judgment moderately consider one factor over the other
5	Strong importance	Rating and judgment strongly consider one factor over the other
7	Very strong importance	Rating and judgment demonstrated the importance of one factor over the other
9	Extreme importance	Rating and judgment of one factor is evidently preferred over the other at the highest level of affirmation
2, 4, 6, 8	Intermediate importance	Intermediate rating if there are a hesitation value between two adjacent judgements

To implement the above steps, below are the details of the equations that clarifies the AHP methodology:

Step 1: Assuming there are ***n*** criteria to assess, then **Equation 1** presents the pairwise comparison matrix for the criteria [80, 55].

$$\boldsymbol{P}_{(n\,x\,n)} = \left[\boldsymbol{P}_{ij}\right] = \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{bmatrix}, \qquad \textbf{Equation 1}$$

$where\ \boldsymbol{P}_{ij}\ is\ the\ relative\ importance\ of\ criterion\ i\ with\ repect\ to\ criterion\ j,$

$\boldsymbol{n}\ is\ the\ amount\ of\ criteria\ considered\ in\ the\ evaluation,$

$\boldsymbol{P}_{ii} = 1\ \ and\ \boldsymbol{P}_{ji} = {}^{1}/_{P_{ij}}$

Step 2: Normalize the pairwise comparison matrix by dividing each relative importance (P_{ij}) with the total amount of P_{ij} of the same column inside the matrix. The following equations provides the implementation of the normalization [80, 55]:

Equation 2 *shows the normalization component:*

$$\boldsymbol{w}_{(1\,x\,n)} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{P}_{ij} = [\boldsymbol{w_1} \;\cdots\; \boldsymbol{w_n}], \qquad \mathbf{j = 1, \cdots, n} \qquad \textbf{Equation 2}$$

$where\ \boldsymbol{w_j}\ is\ the\ normalization\ component\ of\ the\ matix\ for\ the\ normalization$

Equation 3 *Normalize each column of P matrix with the assigned normalization component from equation 2:*

$$\boldsymbol{K}_{(n\,x\,n)} = {}^{\boldsymbol{P}_{(n\,x\,n)}}/_{\boldsymbol{w}_j} = \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{bmatrix} . \left[{}^{1}/_{\boldsymbol{w_1}} \cdots {}^{1}/_{\boldsymbol{w_n}}\right] = \begin{bmatrix} {}^{P_{11}}/_{\boldsymbol{w_1}} & \cdots & {}^{P_{1n}}/_{\boldsymbol{w_n}} \\ \vdots & \ddots & \vdots \\ {}^{P_{n1}}/_{\boldsymbol{w_1}} & \cdots & {}^{P_{nn}}/_{\boldsymbol{w_n}} \end{bmatrix}$$

$$= \begin{bmatrix} K_{11} & \cdots & K_{1n} \\ \vdots & \ddots & \vdots \\ K_{n1} & \cdots & K_{nn} \end{bmatrix}, \qquad \textbf{Equation 3}$$

$where\ \boldsymbol{K_{ij}}\ is\ the\ normalized\ matix$

Step 3: Average the normalized values through each row to get the criteria or sub-criteria or alternatives weights with respect to the criteria as per the below equation [80, 55]:

$$\boldsymbol{N}_{(n\,x\,1)} = {}^{\left(\sum_{j=1}^{n} \boldsymbol{K}_{ij}\right)}/_{\boldsymbol{n}} = \begin{bmatrix} {}^{P_{11}}/_{\boldsymbol{w_1}} & \cdots & {}^{P_{1n}}/_{\boldsymbol{w_n}} \\ \vdots & \ddots & \vdots \\ {}^{P_{n1}}/_{\boldsymbol{w_1}} & \cdots & {}^{P_{nn}}/_{\boldsymbol{w_n}} \end{bmatrix} . \begin{bmatrix} \mathbf{1} \\ \vdots \\ \mathbf{1} \end{bmatrix} . \boldsymbol{n}^{-\mathbf{1}}, \qquad \mathbf{i = 1, \cdots, n}$$

$$= \begin{bmatrix} {}^{\left(\sum_{j=1}^{n} \boldsymbol{K}_{1j}\right)}/_{\boldsymbol{n}} \\ \vdots \\ {}^{\left(\sum_{j=1}^{n} \boldsymbol{K}_{nj}\right)}/_{\boldsymbol{n}} \end{bmatrix} = \begin{bmatrix} N_1 \\ \vdots \\ N_n \end{bmatrix}, \qquad \textbf{Equation 4}$$

$where\ \boldsymbol{N_{ij}}\ is\ the\ matix\ that\ contains\ the\ normalized\ weights\ for\ the\ criteria$

Step 4**:** Check the pairwise comparison matrix consistency as per the below Equations. Note that the consistency ratio (CR) should be $CR < 0.1$ in order to have an acceptable pairwise comparison [80, 81].

Equation 5 *Sums the column vector* ***PN*** *elements to get the below maximum eigen value (*$\boldsymbol{\lambda_{max}}$*). Note that as the* $\boldsymbol{\lambda_{max}}$ *is closer to the number of criteria (****n****), the more consistent is the decision makers evaluation.*

$$\boldsymbol{\lambda_{max}} = \sum \boldsymbol{P}_{ij}\boldsymbol{N}_i = \sum \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{bmatrix} \times \begin{bmatrix} N_1 \\ \vdots \\ N_n \end{bmatrix} \qquad \textbf{Equation 5}$$

$where, \boldsymbol{\lambda_{max}}\ is\ the\ eigenvalue\ that\ is\ needed\ for\ the\ consistency\ index\ (CI)\ equation$

Equation 6 *to calculate the consistency index (CI) as the following:*

$$\mathbf{CI} = {(\lambda_{max} - n)}/{(n-1)} \qquad \textbf{Equation 6}$$

$where, \boldsymbol{CI}\ is\ the\ consistency\ index\ that\ is\ needed\ for\ the\ consistency\ ratio\ (CR)\ equation$

Equation 7 *to find the consistency ratio (CR) that is as follows:*

$$\mathbf{CR} = {CI}/{RI} \qquad \textbf{Equation 7}$$

$where, \boldsymbol{CR}\ is\ the\ consistency\ ratio,$

$\boldsymbol{CI}\ is\ the\ consistency\ index,$

$\boldsymbol{RI}\ is\ the\ random\ consistency\ index\ based\ on\ the\ number\ of\ criteria\ (n)\ that\ can\ be\ found\ from\ table\ 4$

Table 4: Random Consistency [80,81]

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Step 5: To find the overall consistency ratio, the below **Equation 8** is required [54].

$$\mathbf{CR}_{total} = {\sum_{i=1}^{n} N_i C_{ji}}/{\sum_{i=1}^{n} N_i\, RI_{ji}} \qquad \textbf{Equation 8}$$

$where, \mathbf{CR}_{total}\ is\ the\ overall\ consistency\ ratio\ of\ the\ AHP\ goal,$

$\boldsymbol{N_i}$ *is the primary criteria weights,*

$\boldsymbol{C_{ji}}$ *is the corresponding consistency ratio for the subcriteria (secondary crtieria),*

$\boldsymbol{RI_{ji}}$ *is the random consistency index for the corresponding subcriteria that can be shown in Table* 2

Step 6: After finding all the criteria, sub-criteria, and the suppliers' weights, then the following step is arranging all the priorities in a table form that is presented in Table 5. Then obtain the overall suppliers' priority generally by multiplying each associated criterion with the associated suppliers' criteria priority then summing them all together as per the below equations [51].

Table 5: Template structure

Goal	Supplier A	Supplier B	Supplier C
Main Criteria 1 (Weight value)			
1. *Secondary Criteria 1 (Weight value)*	Weight of supplier A with respect to sub criteria 1	Weight of supplier B with respect to sub criteria 1	Weight of supplier C with respect to sub criteria 1
2. *Secondary Criteria 1 (Weight value)*	Weight of supplier A with respect to sub criteria 2	Weight of supplier B with respect to sub criteria 2	Weight of supplier C with respect to sub criteria 2
Main Criteria 2 (Weight value)			
1. *Secondary Criteria 1 (Weight value)*	Weight of supplier A with respect to sub criteria 1	Weight of supplier B with respect to sub criteria 1	Weight of supplier C with respect to sub criteria 1

Equation 9 *calculate the suppliers* ($\boldsymbol{S_j}$) *second-level priorities based on the given sub-criteria as follows:*

$$\boldsymbol{S_j \text{ second level priority}} = \sum \{\left(Weight\ of\ \boldsymbol{S_j}\ with\ respect\ to\ subcriteria\ "\boldsymbol{C_i}"\right)\ x\ (Weight\ of\ "\boldsymbol{C_i}")\ \} \qquad \textbf{Equation 9}$$

Equation 10 *calculate the suppliers* ($\boldsymbol{S_j}$) *overall first-level priorities with respect to the given primary criteria as follows:*

$$\boldsymbol{S_j \text{ overall priority}} = \sum \{\left(Second\ level\ priority\ of\ \boldsymbol{S_j}\ with\ respect\ to\ primary\ criteria\ "\boldsymbol{C_i}"\right)\ x\ (Weight\ of\ "\boldsymbol{C_i}")\ \} \qquad \textbf{Equation 10}$$

3.1.3 Final Phase

Validating the research model result is a vital factor that contributes to the accomplishment of the research. A sensitivity analysis is applied to identify the impact on the alternatives' priorities when changing the weight of the key criteria or sub-criteria. Besides, the phase consists of result validation for the AHP model, the limitation that has been encountered, and the MCDM technique limitation. It provides recommendations for the construction industry to improve/develop a green supplier selection process and aid the company in increase awareness internally in the company to promote a green culture within all levels of the organization. Future research upon this work is recommended to improve and explore an option to address the limitations of the AHP modeling technique. For instance, a different method such as Fuzzy AHP, TOPSIS, and computational intelligence techniques can be implemented and compared to find the best model performance approach for the supplier selection problem. Moreover, social criteria can be added as performance measures of the supply chain to broaden the model to consider other factors that contribute to sustainable development. Chapter 4 and Chapter 5 will provide a detailed discussion about this phase.

3.2 Data Preparation

Research indicates that dedicating the achievement of any supply chain depends significantly on supplier selection [57]. It has a vital impact on the effectiveness of the supply chain. This section consists of two parts the "Theoretical Data Collection" and "Empirical Data Collection". The first section will discuss important decision variables, which are critical in evaluating the suppliers. It will help in ensuring precise analysis of the suppliers to achieve the best decisions. The second section will demonstrate the survey and interview that were applied for sample selection.

3.2.1 Theoretical Data Collection

Based on the literature review, collaboration with the subject matter expert, and the researcher's job experience, the study proposed a general four-level criteria system. In this context, includes ten main criteria, the second level consists of 47 sub-criteria, the third level has 18 sub-criteria, and the fourth level contains five sub-criteria. Those criteria consider the green supply chain aspects and they are common criteria that can be used in suppliers' selection for any product type in the construction industry. Note that the technical sub-criteria are not added in the general criteria for the supplier selection and should be added based on the product type and specification. The general criteria are shown in Table 6, and their description are elaborated into four tables: Table 6.1- 6.4.

In this study, the technical specification is considered for the paint product and its criteria has been provided by the subject matter expert based on his experience and his reference to Dubai Municipality Environmental Design Guide [77]. Some of the general criteria have been selected for the paint supplier selection method. The primary and sub criteria that are used for the paint suppliers selection in GSC are presented in Table 7 and the Technical Assessment / Product Specifications criteria (C10) details are provided in three tables: Table 7.1 – 7.3.

Some challenges were faced in initiating the survey. Those challenges are the COVID 19 pandemic, network security concerns, and the maximum duration of the survey, which played a major role in developing and structuring the survey. As a result, the paint criteria have been reduced to contain only the significant criteria based on the feedback of the SME, while the other remaining criteria is assumed to be full filled by all suppliers. This is implemented to obtain more responses for the request of fully completing the survey. The hierarchical system of the paint criteria is formed to display the selected criteria for the survey as shown in Figure 3. In this context, the main criteria include six criteria, the second level contains of 16 sub-criteria, and the third level has three sub-criteria.

Table 6: General Criteria

Level 1 – Main Criteria	Level 2 - Sub-Criteria	Level 3 - Sub-Criteria	Level 4 - Sub-Criteria
Green Design C1	Waste Management C11	Reduce C111	Appropriate Control of Toxic Wastes C1111
			Low Emission Materials (Low Pollution) C1112
			Compliance to Regulations on Exhaust Emissions C1113
		Reuse C112	Reuse Packing Material C1121
			Reduction of Reverse Logistic Quantity C1122
		Recycle C113	
		Remanufacturing and Disposal C114	

	Green Packaging C12	Reduce Packaging Material Usage C121	
		Better Space Utilization of the packaging C122	
	Waste Treatment C13		
Green Production C2	Environmental Emission C21		
	Water Conservation C22		
	Energy Consumption C23		
	Quality Assurance C24		
	Quantity Assurance and Availability C25		
	Product Storage C26		
	Quality of Service C27		
Green Operation C3	Adaption to Changes C31		
	Transportation C32	Flexibility C321	
		Number of Vehicles C322	
		Ways for Loading and Unloading C323	
		Delivery Duration C324	
		Delivery Reliability C325	
		Delivery Product Assurance C326	
		Delivery Location Assurance C327	
		Usage of Fuel-Efficient Vehicles C328	
Awareness and Development C4	Green Knowledge Transfer about Environmental Issues and Advice on Green Manufacturing Process C41		
	Supplier Awareness of their Partner Companies' Environmental Management C42		
	Supplier Awareness of their Companies' Environmental Management C43		
	Staff Training to Enhance Employee's Environmental Performance C44		
	Conduct Customer Opinion via Survey for Environmental Aspect C45		
	Investment and Resource Transfer C46		
	Green Expertise C47		
Business C5	Reputation and Organizational Performance C51	Experience and Capabilities in industry C511	
		Performance History of the Environmental Record C512	
		Green Market Share C513	
		Partnership with Green Organizations C514	
	Financial Strength and Position C52		
	Management Skills C53		
	Geographical Location C54		
	Technical Capability C55		

	Product Innovation Capability C56
	Green R&D Projects C57
	Market Strategy C58
Service C6	Long Term Relationship Potential C61
	Trust C62
	Response to complaints C63
	Warranty Support C64
	Repair and Maintenance Service C65
	Value Added Services C66
Resource Management C7	Local Sourcing C71
	Natural Resources C72
	Renewable Resources C73
	Resource Efficiency C74
Green Management C8	Adherence to Environmental Policies and Government Regulation C81
	ISO 14001 Certification C82
	ISO >14025 Certification C83
	Previous Violations of Environmental Permits C84
	Environmental Auditing C85
Cost Management C9	Cost Strategy C91
	Supplied Product Cost C92
	Component Disposal Cost C93
	Transportation Cost C94
	Cost Saving C95
Technical Assessment / Product Specifications C10	

Table 6.1: Level 1 - Main Criteria Definitions

Level 1 – Main Criteria	**Definition of the criteria**	**Relevant Literature**
Green Design C1	The design of the product that have minimal impact on the environment.	[72], [73]
Green Production C2	The production of the product that is friendly to the environment.	[36], [72], [75], [76], [User Defined]
Green Operation C3	Flexibility of the product in terms of ease of transportation and ability to change in major circumstance.	[36], [47], [User Defined]
Awareness and Development C4	The knowledge, expertise, and skills of the supplier and their employees.	[72], [33], [User Defined]
Business C5	The position of the company, including its strength and weakness and its performance.	[36], [74], [33], [User Defined]
Service C6	How well the service provided by the supplier.	[36], [Subject Matter Expert]
Resource Management C7	Availability of natural and renewable materials, and other assets of the supplier's organization.	[69], [33], [User Defined]
Green Management C8	Supplier complying with environmental policies and regulations as well as getting certificates related to the environment.	[72], [73], [74], [33], [47], [60]
Cost Management C9	Costs associated with the product.	[75], [Subject Matter Expert], [User Defined]

Technical Assessment / Product Specifications C10	Technical feasibility of the product.	[Subject Matter Expert]

Table 6.2: Level 2 - Sub Criteria Definitions

Level 2 – Sub Criteria	**Definition of the criteria**	**Relevant Literature**
Waste Management C11	Supplier management to waste from its establishment to its disposal to reduce harmful effects of waste on the health of the person, and the environment.	[72], [73]
Green Packaging C12	Supplier techniques in material usage and product packaging to minimize the packaging impact on the environment.	[72], [73]
Waste Treatment C13	Supplier practices to ensure the least possible environmental effect of waste.	[72]
Environmental Emission C21	Supplier practices for reducing the environmental effects, such as minimize CO_2 emission, water waste, and solid waste.	[User Defined]
Water Conservation C22	Supplier technique in preserving, managing of water resources.	[User Defined]
Energy Consumption C23	Supplier practices in reducing the consumption of energy.	[72]
Quality Assurance C24	Supplier practices in monitoring and evaluating the product cycle from its establishment until product delivery to customer (or also product disposal) to ensure meeting the quality standards.	[36]
Quantity Assurance and Availability C25	Supplier assurance to provide the required product quantity and the product availability if extra requirements required by customer.	[User Defined]
Product Storage C26	Supplier provides the best storing facility for the product as per the standards.	[76]
Quality of Service C27	Supplier quality of the service that will be provided for the purpose of the product.	[75]
Adaption to Changes C31	Supplier adaption to any kind of changes in ordering and delivery that can occur without advance knowledge such as Corona virus.	[User Defined]
Transportation C32	Supplier adherence to the customer's specific transportation requirements.	[36], [47], [User Defined]
Green Knowledge Transfer about Environmental Issues and Advice on Green Manufacturing Process C41	Supplier provides training awareness to their staff about environmental issues. Also, supplier provide advice internally to their company and externally to other companies on green manufacturing process.	[33]
Supplier Awareness of their partner companies' environmental management C42	Supplier consciousness of their partner companies' environmental management.	[72]
Supplier Awareness of their companies' environmental management C43	Supplier consciousness of their companies' environmental management	[72]
Staff Training to enhance employee's environmental performance C44	Supplier provides periodic trainings to increase their staff environmental awareness and enhance their environmental performance.	[33]
Conduct Customer Opinion via Survey for Environmental Aspect C45	Supplier customer opinion consideration about environmental aspect via conducting surveys.	[User Defined]
Investment and Resource Transfer C46	Supplier investment on green environment services and by selling different products,	[33]

	which is manufactured from environmentally friendly resources.	
Green Expertise C47	Supplier has staff that are expert and developers in environmental aspect.	[User Defined]
Reputation and Organizational Performance C51	Supplier's company growth, customers' order accumulation and organization goal achievement.	[33], [36]
Financial Strength and Position C52	The company financial statement for the last 4 years, and considering the industry, company objectives, time horizon and economic conditions.	[36]
Management Skills C53	Supplier's technical skills, analytical skills, decision-making skills, and communication skills.	[36]
Geographical Location C54	Suitability of supplier's geographical location.	[36]
Technical Capability C55	Supplier's technical capability.	[User Defined]
Product Innovation Capability C56	Supplier's capability for innovating products such as firm's design capability includes hardware, software, and knowledge	[36]
Green R&D Projects C57	Supplier's investment in research and development.	[33], [74]
Market Strategy C58	Supplier's market strategy applicability.	[Subject Matter Expert]
Long Term Relationship Potential C61	Supplier aims for strong and successful long-term relationship.	[36]
Trust C62	Supplier's relationship with the customer based on previous projects experience with the same supplier.	[Subject Matter Expert]
Response to Complaints C63	Supplier's speed of responses to complain and take actions to resolve it	[36]
Warranty Support C64	Period the warranty is valid.	[36]
Repair and Maintenance Service C65	Supplier's efficacy in repair and maintenance of the product.	[36]
Value Added Services C66	Supplier provides free services to the customer such as additional warranty or storage for additional time periods, or free delivery.	[Subject Matter Expert]
Local Sourcing C71	Supplier's ability to procure locally.	[User Defined]
Natural Resources C72	Supplier's usage of natural resources in manufacturing their product.	[User Defined]
Renewable Resources C73	Supplier's usage of renewable resources in manufacturing their product.	[User Defined]
Resource Efficiency C74	Supplier's adherence to resource consumption criteria according to the environmental policy.	[33], [69]
Adherence to Environmental Policies and Government Regulation C81	Supplier's adherence to environmental policies and government regulation.	[33], [72], [74]
ISO 14001 Certification C82	Supplier has a valid ISO 14001 certification that provide rules and framework for active environmental management system (EMS) that an industry follows, instead of creating an environmental performance requirement.	[73]
ISO >14025 Certification C83	Supplier has a valid ISO >14025 green product certification labels.	[60]
Previous Violations of environmental permits C84	Evaluation of supplier's previous environmental permits violations.	[33], [47]
Environmental Auditing C85	Supplier's implementation of robust auditing procedures to trace non-compliance	[47]

	with environmental activities at the organization and project levels.	
Cost Strategy C91	Supplier has cost strategy applicability and feasibility.	[Subject Matter Expert]
Supplied Product Cost C92	Cost provided by the supplier to purchase the supplied product.	[User Defined]
Component Disposal Cost C93	Cost provided by the supplier for end-of-life disposal of all/some of product components.	[User Defined]
Transportation Cost C94	Cost provided by the supplier to transport the supplied product.	[75]
Cost Saving C95	The total cost reduction from the procurement cost	[User Defined]

Table 6.3: Level 3 - Sub Criteria Definitions

Level 3 – Sub Criteria	**Definition of the criteria**	**Relevant Literature**
Reduce C111	Supplier reduce strategy to reduce the amount of product production/consumption.	[72], [73]
Reuse C112	Supplier reuse strategy to reuse the product and its components.	[72], [73]
Recycle C113	Suppliers recycle strategy to recycle the old product and its components.	[72], [73]
Remanufacturing and Disposal C114	Suppliers has a remanufacturing and disposal strategy for old product and its components.	[72], [73]
Reduce Packaging Material Usage C121	Supplier techniques used to reduce the materials usage for packaging.	[72], [73]
Better Space Utilization of the Packaging C122	Supplier practices for utilization of space in packages.	[72], [73]
Flexibility C321	Supplier flexibility to provide the product even if the product volume changes within any date and time in a short prior notice.	[36]
Number of Vehicles C322	Supplier flexibility in the number of vehicles to ship the product taking in consideration the space optimization.	[User Defined]
Ways for Loading and Unloading C323	Supplier technique and practices in loading and unloading the product.	[User Defined]
Delivery Duration C324	Supplier meeting the promised delivery time for the product.	[User Defined]
Delivery Reliability C325	Supplier reliability in number of delivery times for the product.	[User Defined]
Delivery Product Assurance C326	Supplier guarantee for the product availability and delivery on the agreed date and time with the required quantity.	[User Defined]
Delivery Location Assurance C327	Supplier guarantee for the product delivery on the agreed location.	[User Defined]
Usage of Fuel-Efficient Vehicles C328	Supplier uses fuel-efficient vehicles for product transportation.	[47]
Experience and Capabilities in Industry C511	Number of year's supplier has been in business and their capabilities in the industry.	[36]
Performance History of the Environmental Record C512	Evaluation of supplier's performance for their environmental record.	[33], [36]
Green Market Share C513	Supplier's green market share evaluation.	[33]
Partnership with Green Organizations C514	Supplier's assessment in their partnership with green organizations and the performance of those organizations.	[33]

Table 6.4: Level 4 - Sub Criteria Definitions

Level 4 – Sub Criteria	Definition of the criteria	Relevant Literature
Appropriate Control of Toxic Wastes C1111	Supplier control of the toxic wastes.	[72], [73]
Low Emission Materials C1112	Supplier usage of low pollution materials.	[72], [73]
Compliance to Regulations on Exhaust Emissions C1113	Supplier provides authentic documents that justify their compliance to regulations on exhaust emissions specifications.	[72], [73]
Reuse Packing Material C1121	Supplier techniques used in the reuse of the materials of the packaging.	[72], [73]
Reduction of Reverse Logistic Quantity C1122	Supplier strategy for reducing the unwanted/defective product/material.	[72], [73]

Table 7: Paint Criteria

Level 1 – Main Criteria	Level 2 - Sub-Criteria	Level 3 - Sub-Criteria	Level 4 - Sub-Criteria
Green Production C2	Environmental Emission C21		
	Energy Consumption C23		
	Quality Assurance C24		
	Quantity Assurance and Availability C25		
	Product Storage C26		
	Quality of Service C27		
Green Operation C3	Adaption to Changes C31		
	Transportation C32	Flexibility C321	
		Number of Vehicles C322	
		Ways for Loading and Unloading C323	
		Delivery Duration C324	
		Delivery Reliability C325	
		Delivery Product Assurance C326	
		Delivery Location Assurance C327	
		Usage of Fuel-Efficient Vehicles C328	
Awareness and Development C4	Green Knowledge Transfer about Environmental Issues and Advice on Green Manufacturing Process C41		
	Supplier Awareness of their Partner Companies' Environmental Management C42		
	Supplier Awareness of their Companies' Environmental Management C43		
	Staff Training to Enhance Employee's Environmental Performance C44		
	Conduct Customer Opinion via Survey for Environmental Aspect C45		
	Investment and Resource Transfer C46		
	Green Expertise C47		
Business C5	Reputation and Organizational Performance C51	Experience and Capabilities in industry C511	
		Performance History of the Environmental Record C512	
		Green Market Share C513	

		Partnership with Green Organizations C514	
	Financial Strength and Position C52		
	Management Skills C53		
	Geographical Location C54		
	Technical Capability C55		
	Product Innovation Capability C56		
	Green R&D Projects C57		
	Market Strategy C58		
Service C6	Long Term Relationship Potential C61		
	Trust C62		
	Response to Complaints C63		
	Warranty Support C64		
	Value Added Services C66		
Resource Management C7	Local Sourcing C71		
	Natural Resources C72		
	Renewable Resources C73		
	Resource Efficiency C74		
Green Management C8	Adherence to Environmental Policies and Government Regulation C81		
	ISO 14001 Certification C82		
	ISO >14025 Certification C83		
	Previous Violations of Environmental Permits C84		
	Environmental Auditing C85		
Cost Management C9	Cost Strategy C91		
	Supplied Product Cost C92		
	Component Disposal Cost C93		
	Transportation Cost C94		
	Cost Saving C95		
Technical Assessment / Product Specifications C10	Manufacturing Impacts (Raw Material) C101	White Pigment Content Specifications C1011	
		Titanium Dioxide TiO_2 Specification C1012	
	Technical Performance (Efficiency in use) C102	Spreading Rate Specifications C1021	
		Wet Scrub Resistance Specifications C1022	
	Emission Management C103	Emission During Use C1031	Volatile Organic Compounds (VOCs) Specifications C10311
			Indoor Air Quality Specifications C10312
			Heavy Metal Specifications C10313
			No Hazardous Substances Used C10314
			Formaldehydes Specifications C10315
			Light Reflective Value (Exterior Paint) Requirements C10316
			Solar Reflective Index (Exterior Paint of Roofing Surface) Requirements C10317
			Solar Reflective Index (Coating for Hardscapes) Requirements C10318
		Emission End of Life C1032	
		Manufacturer C1041	

	Product Details and Guide C104	Date of Manufacture C1042
		Usage Instructions C1043
		Written Storage Instructions C1044
	Product General Requirements C105	Water Resistance C1051
		Corrosion Resistance C1052
		Fungal Resistance C1053
		Alkali Resistance C1054
		Adhesion C1055
		Abrasion C1056
		Weathering C1057
		Water Vapor Penetrability C1058
		Crack Bridging C1059
		Wide Colour Selection C10510

Table 7.1: Paint Criteria - Level 2 - Sub Criteria Definitions

Level 2 – Sub Criteria	**Definition of the criteria**	**Relevant Literature**
Manufacturing Impacts (Raw Material) C101	Supplier compliance to the paint manufacturing impacts	[Subject Matter Expert]
Technical Performance (Efficiency in use) C102	Supplier compliance to the paint technical performance.	[Subject Matter Expert]
Emission Management C103	Supplier compliance to the emissions that occurs during the paint usage and at end of life.	[Subject Matter Expert]
Product Details and Guide C104	Supplier provides precise and accurate product details and guidance.	[Subject Matter Expert]
Product General Requirements C105	Supplier provides the required product general requirements.	[Subject Matter Expert]

Table 7.2: Paint Criteria - Level 3 - Sub Criteria Definitions

Level 3 – Sub Criteria	**Definition of the criteria**	**Relevant Literature**
White Pigment Content Specifications C1011	Supplier adherence to the amount of white pigments used for the coloring content of the paint.	[Subject Matter Expert]
Titanium Dioxide TiO_2 Specification C1012	Supplier adherence to the percentage of TiO_2 that is one of the chemical components of the paint.	[Subject Matter Expert]
Spreading Rate Specifications C1021	Supplier's adherence to the rate of paint spreading.	[Subject Matter Expert]
Wet Scrub Resistance Specifications C1022	Supplier's adherence to the resistance of the paint coat to the wet scrub according to its classification.	[Subject Matter Expert]
Emission During Use C1031	Supplier compliance to the emissions that occurs during the paint usage.	[Subject Matter Expert]
Emission End of Life C1032	Supplier compliance to the emissions that occurs at end-of-life the paint usage.	[Subject Matter Expert]
Manufacturer C1041	Supplier provides the manufacturer name and details.	[Subject Matter Expert]
Date of Manufacture C1042	Supplier provides the manufacturing date of the paint.	[Subject Matter Expert]
Usage Instructions C1043	Supplier provides guided instruction for the paint usage	[Subject Matter Expert]

Written Storage Instructions C1044	Supplier provides guided instruction for the storage of the paint	[Subject Matter Expert]
Water Resistance C1051	Supplier's adherence to the resistance of the paint coat toward water.	[Subject Matter Expert]
Corrosion Resistance C1052	Supplier's adherence to the resistance of the paint coat toward rust.	[Subject Matter Expert]
Fungal Resistance C1053	Supplier's adherence to the resistance of the paint coat toward fungal.	[Subject Matter Expert]
Alkali Resistance C1054	Supplier's adherence to the resistance of the paint coat toward alkali.	[Subject Matter Expert]
Adhesion C1055	Supplier's adherence to the paint coat adhesion.	[Subject Matter Expert]
Abrasion C1056	Supplier's adherence to the resistance of the paint coat toward abrasion (scratch).	[Subject Matter Expert]
Weathering C1057	Supplier compliance to the paint compatibility with low and high temperature of the weather.	[Subject Matter Expert]
Water Vapor Penetrability C1058	Supplier adherence to the paint capability for avoiding absorption of water vapor	[Subject Matter Expert]
Crack Bridging C1059	Supplier adherence to the paint high ability for avoiding cracks.	[Subject Matter Expert]
Wide Color Selection C10510	Supplier provides a wide range of color degrees for the paint.	[Subject Matter Expert]

Table 7.3: Paint Criteria - Level 4 - Sub Criteria Definitions

Level 4 – Sub Criteria	**Definition of the criteria**	**Relevant Literature**
Volatile Organic Compounds (VOCs) Specifications C10311	Supplier compliance to the amount of any volatile organic component boiling point less than 250 degree or semi-volatile organic components - boiling point between 250 and 400 degrees.	[Subject Matter Expert]
Indoor Air Quality Specifications C10312	Supplier should meet the standards of indoor air quality by undergoing paint testing. This requirement is restricted to the lightest colour paint within a series or, in tinting systems.	[Subject Matter Expert]
Heavy Metal Specifications C10313	Supplier compliance for not using the lead, heavy metals, or their compounds as an ingredient of the product.	[Subject Matter Expert]
No Hazardous Substances Used C10314	Supplier adherence for not using hazardous ingredients in the paint.	[Subject Matter Expert]
Formaldehydes Specifications C10315	Supplier compliance to the content amount of free Formaldehydes in the paint as per the standards.	[Subject Matter Expert]
Light Reflective Value (Exterior Paint) Requirements C10316	Supplier compliance to the paint appliance on a flat substrate such as wood, metal or plastic sheet or concrete surface with a minimum size of 150 x 150 mm. The thickness of applied paint shall be such that there is no transparency. This requirement is applicable only to exterior paints.	[Subject Matter Expert]
Solar Reflective Index - SRI (Exterior Paint of Roofing Surface) Requirements C10317	Supplier compliance to the paint appliance on a flat substrate such as wood, metal or plastic sheet or concrete surface with a minimum size of 150 x 150 mm. The thickness of applied paint shall be such that there is no transparency. This requirement is applicable to paints used in roofing surfaces.	[Subject Matter Expert]

Solar Reflective Index - SRI (Coating for Hardscapes) Requirements C10318	Supplier compliance to the paint appliance on a flat substrate such as wood, metal or plastic sheet or concrete surface with a minimum size of 150 x 150 mm and the SRI shall be within the specified limits. This requirement is applicable to paints or coatings applied on hardscapes.	[Subject Matter Expert]

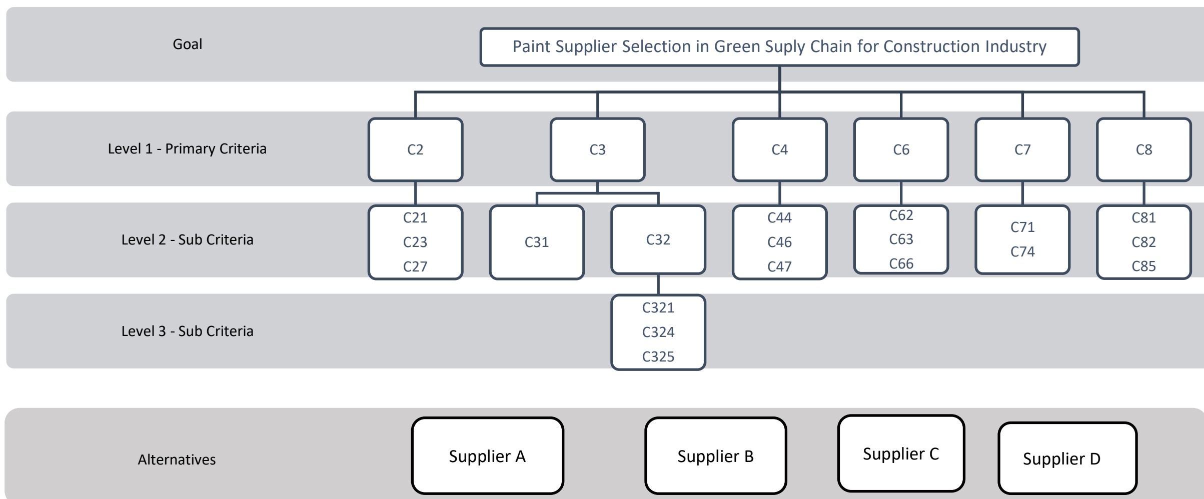

Figure 3: The hierarchical system of the Paint criteria that was used in the survey

3.2.2 Empirical Data Collection

Based on the research conducted, several industries were identified, such as infrastructure, construction, and renewable energy industries. However, the construction industry has been chosen for this research due to the following advantages: the diversity of activities and products dealt with by construction companies, the abundance of construction companies in the country due to high demand, and the relatively similar scope of activities among the companies makes them easier to compare and contrast. Furthermore, due to the researcher's former experience with construction companies and their activities.

A case study on the paint suppliers selection is performed by using the suggested framework. The paint product was chosen as all construction projects require this product and must procure it in high quantities. The product has been the focus of many researches for making it environmentally friendly and reduces harmful effects on the environment.

Besides, the construction companies are faced with a multitude of manufacturers to choose from and the green supplier selection can be illustrated clearly. As a result, the model can provide procedures for managers in UAE with insights into the numerous factors/criteria that need to be considered to efficiently rank and select suppliers based on the provided criteria for their organizations.

A survey was purposed to compute the relative importance of the criteria, and sub-criteria over another to formulate the AHP model. Also, several one-to-one meetings with the subject matter expert was conducted to compute the importance of the suppliers depending on the criteria to be utilized in the AHP model. SME's were requested to complete a pairwise comparison of the criteria depending on the importance scale displayed in Table 3. The preference of one criterion or supplier over another was defined based on the managers' experience. In the survey, first, the SME's compared the main criteria (level 1) based on the goal and subsequently compared level 2 sub-criteria with respect to the key criteria, and compared level 3 sub-criteria based on their associated level 2 sub-criteria. Finally, one construction company was supportive to use the researcher criteria and implement it in an RFQ (Request for Quotation) to paint suppliers then used the provided data to compare the supplier based on every sub-criterion.

Moreover, the actual survey implemented using Microsoft Forms and was sent to the companies located in UAE via email. The actual survey and the related email are shown in the Appendix. The survey consists of an introduction about the survey, definitions for all the criteria, 31 pairwise comparison questions, and surveyors' email accounts if they wish to have findings and results of the study. Moreover, to know the minimum number of surveys needed to be obtained, a sample size calculator was used [78] and provided that a minimum of 31 surveyors are required to have an accurate model. The survey duration from the start until the end of the survey was 99 days, which are between October 18th, 2020, and January 26th, 2020. As a result, out of 91 surveys mailed, 36 were accomplished. Ten companies deleted the email without opening it and 45 companies did not respond at all. The response rate was only 40%. The duration to complete the survey was assumed to be 15 minutes, however, the actual average time to complete it was 24:58 minutes. In this research, four suppliers based on company recommendations were considered for evaluation and ranking to find the optimal suppliers. Due to confidentiality, the generic names of these suppliers are used, such as “A”, “B”, “C” and “D” suppliers. The general supplier information can be shown in Table 8. The expert from the supported construction company sent for RFQ on February 3rd, 2021, and got replies from the paint suppliers on March 1st, 2021. Then a one-to-one meeting conducted with the associated SME to assess the suppliers depending on the sub-criteria.

Table 8: Suppliers Information

Supplier Code	Location	Product supplied	Established Year	Company Size
Supplier A	Mussafah / Abu Dhabi / Sharjah - UAE	Paint and building materials, electrical wiring materials, and off-shore and on-shore of oil and gas field equipment	1994	Large
Supplier B	Mussafah - Abu Dhabi - UAE	Paint and building materials, hardware, and safety materials	2008	Medium
Supplier C	Dubai / RAK -UAE	Paint and building materials, electrical products, industrial supplies and Consumables, and tiles and sanitary wares	2004	Large
Supplier D	Al Qouz -Dubai - UAE	Paint and building materials, hardware, electrical products, plumbing systems, sanitary, cement, steel, power tools, plywood & white wood, gypsum boards and gypsum related all materials, and water pumps and water proofing materials	2002	Medium

3.3 Conclusion

This chapter presents the general framework of AHP for SS in green supply chain. In addition, it demonstrates the AHP methodology in details, and defines the general criteria, the paint criteria that chosen based on literature, subject matter experts, and present job experience. The chapter provides the survey and interview details that was implemented for obtaining the required data. The next chapter will use the obtained data to implement the model in the AHP Expert Choice™ software, and provide the model validation using sensitivity analysis.

Chapter 4 – Validation

This chapter provides the model validation based on a data collected from a large-scale construction company in UAE that needs a paint supplier as a long-term partner. It represents the AHP Expert Choice^{TM} software results from the entered survey data based on the decision-makers' pairwise comparisons evaluation and the subject matter expert inputs about the supplier. It provides an analysis of the criteria priority and the suppliers ranking and a sensitivity analysis of the model. Chapter 4 presents two sections: Model Development, and Model Evaluation.

4.1 Model Development

Validating and verifying the AHP model against real data is a critical and important part of the framework. To conduct this task, decision-making software must be utilized. Decision-making software provide a tool for effective and efficient decision-making. Many tools exist for this purpose and each has its advantages and disadvantages. Such tools are Excel, Super Decision, Make It Rational, open-source packages, Expert Choice^{TM}, and implementation of an AHP package from scratch. The Expert Choice was chosen in this research since it is widely used in the other researches' implementation and is an excellent tool for such purpose. Its user interface is friendly and provides a provision for decision trees to be implemented professionally. The data analysis that the application provides and the presentation of the analysis as graphs and figures help convince the user and explain why certain decisions were taken. In this project, the expert choice will be utilized for the AHP supplier selection decision-making.

Constructing the AHP model in Expert Choice^{TM} consists of the following phases [79]: Structure, Measure, Synthesize, Allocate, Iterate, and Report. In the first phase, the research writes the goal of the use-case, structure the criteria and the sub-criteria that may have few levels, providing alternatives. In the second phase, pairwise relative comparisons of the components in the hierarchy are implemented. In the Synthesize phase, Expert Choice software implements the AHP method on the provided data and outputs the priorities for the criteria and the overall weights for the alternatives. In the fourth phase, it provides the user with resource alignment between the required benefits and the provided constraints of the alternatives. The user will provide several constraints such as cost, risks, and budget to determine the best alternatives combination that maximizes the shared benefit [79]. In the fifth phase, based on the analysis the decision and resource allocations can be iterated if required by going back to phase one. In the final phase, the report is generated.

Using the Expert Choice™, the hierarchal structure of the Paint criteria that was used in the survey were implemented based on Figure 3 and is shown as a Tree View pane on the left side of Figure 4. After the hierarchal structure is implemented, the 35 decision-makers

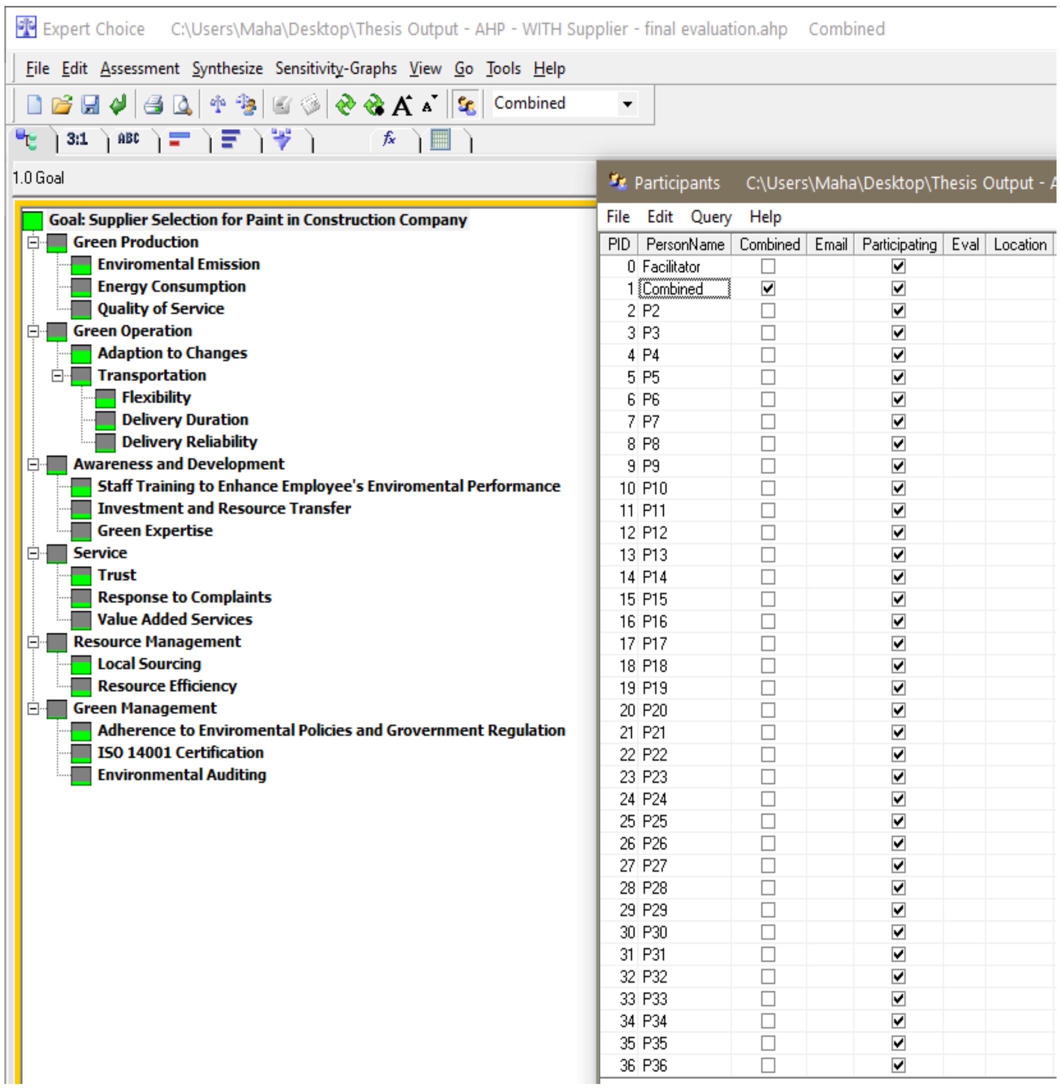

Figure 4: The hierarchal structure of the Paint criteria using the Expert Choice™ and the amount decision-makers implemented a pairwise comparison

and the researcher's input were inserted into the software. The 36 participants are shown on the right side of Figure 4.

Furthermore, all the judgments made by the decision-makers were combined for the pairwise comparison matrixes for the entire combinations of criteria and sub-criteria relationships. Those combined decision matrixes are presented in Figure 5. Besides, Figure 5 displays the consistency ratio (inconsistency) of the combined decision-makers' pairwise comparison. As per [83], the acceptable consistency ratio must be less than 10%, however, a consistency ratio of less than 20% is considered tolerable. This demonstrates that the inconsistency for the judgments based on all the main criteria were consistent.

	Green Production	Green Operation	Awareness and Development	Service	Resource M	Green Man
Green Production		2.26975	2.25954	4.24499	3.48025	2.5002
Green Operation			2.42781	3.54119	3.11137	2.43937
Awareness and Development				3.66532	4.90926	2.62515
Service					2.6865	2.46584
Resource Management						1.91289
Green Management	Incon: 0.09					

Compare the relative importance with respect to: Goal

	Enviromental Emission	Energy Consumption	Quality of Service
Enviromental Emission		2.48736	2.97104
Energy Consumption			2.30478
Quality of Service	Incon: 0.05		

Compare the relative importance with respect to: Green Production

	Adaption to Changes	Transportation
Adaption to Changes		2.46528
Transportation	Incon: 0.00	

Compare the relative importance with respect to: Green Operation

	Flexibility	Delivery Duration	Delivery Reliability
Flexibility		2.38901	2.36564
Delivery Duration			2.13167
Delivery Reliability	Incon: 0.06		

Compare the relative importance with respect to: Green Operation \ Transportation

	Staff Training to Enhance	Investment and Res	Green Expertise
Staff Training to Enhance Employee's Enviromental Performance		3.13882	2.39173
Investment and Resource Transfer			2.505
Green Expertise	Incon: 0.15		

Compare the relative importance with respect to: Awareness and Development

	Trust	Response to Complaints	Value Added Services
Trust		2.65872	4.25651
Response to Complaints			3.70766
Value Added Services	Incon: 0.08		

Compare the relative importance with respect to: Service

	Local Sourcing	Resource Efficiency
Local Sourcing		2.14815
Resource Efficiency	Incon: 0.00	

Compare the relative importance with respect to: Resource Management

	Adherence to Enviro	ISO 14001 Certification	Environmental A
Adherence to Enviromental Policies and Grovernment Regulation		2.5659	2.46756
ISO 14001 Certification			1.77831
Environmental Auditing	Incon: 0.04		

Compare the relative importance with respect to: Green Management

Figure 5: Pairwise comparison matrixes for criteria and sub-criteria relationships

The next step was deriving the local and the global weights of the criteria using the software. The local weights refer to the relative weights of the criteria with respect to the prior hierarchical level, while global weights represent the relative weights of the criteria based on the target [82]. The local weights add up to one under each parent's criteria, while the global weights of all the criteria under the parent's criteria add up to their parent's criteria weight. The global weights add up to one under the goal. Both weights for the entire criteria are shown in Table 9. It shows the highest three ranks among the main criteria are "Green Production" with a priority of 0.326, "Green Operation" with a priority of 0.242, and "Awareness and Development" with a priority of 0.199. Also, the highest three ranks from the sub-criteria with respect to the goal are "Environmental Emission" with a global priority of 0.184, "Adaption to Changes" with a global priority of 0.172, and "Staff Training to Enhance Employee's Environmental Performance" with a global priority of 0.113.

Table 9: Priority and Ranking of the criteria

Level 1 – Main Criteria	Local (L) and Global (G) Weights	Ranking of the Main Criteria with respect to the goal	Level 2 - Sub-Criteria	Local (L) and Global (G) Weights	Level 3 - Sub-Criteria	Local (L) and Global (G) Weights	Ranking of the Sub-Criteria with respect to the goal
Green Production C2	L:0.326 & G:0.326	1	**Environmental Emission C21**	L:0.565 & G:0.184			1
			Energy Consumption C23	L:0.283 & G:0.092			4
			Quality of Service C27	L:0.153 & G:0.050			7
Green Operation C3	L:0.242 & G:0.242	2	**Adaption to Changes C31**	L:0.711 & G:0.172			2
			Transportation C32	L:0.289 & G:0.070	Flexibility C321	L:0.535 & G:0.037	5
					Delivery Duration C324	L:0.289 & G:0.020	
					Delivery Reliability C325	L:0.175 & G:0.012	
Awareness and Development C4	L:0.199 & G:0.199	3	**Staff Training to Enhance Employee's Environmental Performance C44**	L:0.570 & G:0.113			3
			Investment and Resource Transfer C46	L:0.270 & G:0.054			8
			Green Expertise C47	L:0.160 & G:0.032			11
Service C6	L:0.098 & G:0.098	4	Trust C62	L:0.597 & G:0.059			6
			Response to Complaints C63	L:0.297 & G:0.029			12
			Value Added Services C66	L:0.106 & G:0.010			16
Resource Management C7	L:0.068 & G:0.068	5	Local Sourcing C71	L:0.682 & G:0.046			9
			Resource Efficiency C74	L:0.318 & G:0.021			13
Green Management C8	L:0.068 & G:0.068	5	Adherence to Environmental Policies and Government Regulation C81	L:0.553 & G:0.038			10
			ISO 14001 Certification C82	L:0.265 & G:0.018			14

	Environmental Auditing C85	L:0.183 & G:0.012	15

Furthermore, the subject matter expert (SME) pairwise comparison for the four suppliers depending on the sub-criteria was inserted in the Expert Choice™. The pairwise decision matrixes and the Consistency Ratio (inconsistency) for those matrixes are shown in Figure 6. This shows that the consistency ratio of all the pairwise comparisons is less than 10%, so, the SME's judgment is consistent. Table 10 provides the order of the suppliers with respect of the sub-criteria. It shows that Supplier A has the highest ranking out of the eighteen criteria compared to the other three suppliers. This states that Supplier A has the highest priority and then comes Supplier B as the second-highest priority, which is higher than the other remaining suppliers by six sub-criteria. Lastly, Supplier C ranked third and

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	1.0	1.0
Supplier B			1.0	1.0
Supplier C				1.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Green Production \ Environmental Emission

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	1.0	1.0
Supplier B			1.0	1.0
Supplier C				1.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Green Production \ Energy Consumption

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		7.0	1.0	9.0
Supplier B			6.0	5.0
Supplier C				8.0
Supplier D	Incon: 0.09			

Compare the relative importance with respect to: Green Production \ Quality of Service

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		6.0	6.0	9.0
Supplier B			1.0	6.0
Supplier C				6.0
Supplier D	Incon: 0.09			

Compare the relative importance with respect to: Green Operation \ Adaption to Changes

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		6.0	1.0	6.0
Supplier B			6.0	1.0
Supplier C				6.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Green Operation \ Transportation \ Flexibility

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		5.0	4.0	9.0
Supplier B			1.0	5.0
Supplier C				5.0
Supplier D	Incon: 0.04			

Compare the relative importance with respect to: Green Operation \ Transportation \ Delivery Duration

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	5.0	5.0
Supplier B			5.0	5.0
Supplier C				1.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Green Operation \ Transportation \ Delivery Reliability

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		4.0	6.0	5.0
Supplier B			8.0	9.0
Supplier C				3.0
Supplier D	Incon: 0.10			

Compare the relative importance with respect to: Awareness and Development \ Staff Training to Enhance Employee's Environmental Performance

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	1.0	1.0
Supplier B			1.0	1.0
Supplier C				1.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Awareness and Development \ Investment and Resource Transfer

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		4.0	6.0	4.0
Supplier B			9.0	6.0
Supplier C				3.0
Supplier D	Incon: 0.07			

Compare the relative importance with respect to: Awareness and Development \ Green Expertise

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		4.0	7.0	9.0
Supplier B			4.0	6.0
Supplier C				4.0
Supplier D	Incon: 0.09			

Compare the relative importance with respect to: Service \ Trust

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		6.0	1.0	6.0
Supplier B			6.0	1.0
Supplier C				6.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Service \ Response to Complaints

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		9.0	5.0	9.0
Supplier B			6.0	1.0
Supplier C				7.0
Supplier D	Incon: 0.08			

Compare the relative importance with respect to: Service \ Value Added Services

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	1.0	1.0
Supplier B			1.0	1.0
Supplier C				1.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Resource Management \ Local Sourcing

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	1.0	1.0
Supplier B			1.0	1.0
Supplier C				1.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Resource Management \ Resource Efficiency

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		4.0	6.0	6.0
Supplier B			4.0	5.0
Supplier C				1.0
Supplier D	Incon: 0.06			

Compare the relative importance with respect to: Green Management \ Adherence to Environmental Policies and Government Regulation

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		4.0	6.0	6.0
Supplier B			4.0	4.0
Supplier C				1.0
Supplier D	Incon: 0.05			

Compare the relative importance with respect to: Green Management \ ISO 1400 1Certification

	Supplier A	Supplier B	Supplier C	Supplier D
Supplier A		1.0	1.0	9.0
Supplier B			1.0	9.0
Supplier C				9.0
Supplier D	Incon: 0.00			

Compare the relative importance with respect to: Green Management \ Environmental Auditing

Figure 6: Pairwise comparison matrixes for alternatives based on the sub-criteria

was higher than Supplier D by nine sub-criteria. After obtaining the criteria, sub-criteria, and the suppliers' priorities, these resulted priorities were synthesized with respect to the goal to provide the suppliers' overall priorities and ranking. Figure 7 provides the suppliers' scores, which are produced as an outcome of the process of selecting suppliers. It presents the overall inconsistency of 0.07, which shows that the overall decision maker's judgment is consistent. Distributive synthesis mode in Expert Choice™ has been used instead of the Ideal mode since more than one supplier will be chosen as per the subject matter expert feedback. Based on the provided outcome, the two highest-ranking suppliers are Supplier A that scored the highest ranking of 0.398, and Supplier B that is the second highest ranking of 0.267. Supplier D has the lowest score of 0.134, while Supplier C has a score of 0.202. Hence, the company may select those two suppliers. Moreover, it noticeable that the score difference between the highest and lowest ranking suppliers is 66% higher. Consequently, significant variation in decision maker's evaluation can change the final ranking. However, slight variations in their decision can change the ranking between Supplier B and Supplier C, since their score difference is 24.3%. As stated earlier, the supplier's priority based on each sub-criterion varies depending on the decision maker's judgment; therefore, it shows that the overall highest score of the supplier does not need to have a high score in all the sub-criterion. As a result, sensitivity analysis is required to present the change in supplier ranking based on the main criteria.

Table 10: Priorities for Criteria and Suppliers

Goal	**Criteria Priority**	**Supplier A**	**Supplier B**	**Supplier C**	**Supplier D**	**Consistency Ratio**
Green Production - C2	0.326					
Environmental Emission - *C21*	0.565	0.250	0.250	0.250	0.250	0
Energy Consumption - *C23*	0.283	0.250	0.250	0.250	0.250	0
Quality of Service - *C27*	0.153	0.448	0.099	0.415	0.038	0.09
Green Operation - C3	0.242					
Adaption to Changes - *C31*	0.711	0.661	0.150	0.150	0.038	0.09
Transportation - *C32*	0.289					
Flexibility - C321	0.535	0.429	0.071	0.429	0.071	0
Delivery Duration - C324	0.289	0.617	0.166	0.173	0.044	0.04
Delivery Reliability - C325	0.175	0.417	0.417	0.083	0.083	0
Awareness and Development - C4	0.199					
Staff Training to Enhance Employee's Environmental Performance - *C44*	0.570	0.249	0.629	0.045	0.078	0.10
Investment and Resource Transfer - *C46*	0.270	0.250	0.250	0.250	0.250	0
Green Expertise - *C47*	0.160	0.249	0.614	0.044	0.093	0.07
Service - C6	0.098					

Trust *- C62*	0.597	0.620	0.242	0.096	0.041	0.09
Response to Complaints *- C63*	0.297	0.429	0.071	0.429	0.071	0
Value Added Services *- C66*	0.106	0.657	0.051	0.243	0.049	0.08
Resource Management - C7	0.068					
Local Sourcing *- C71*	0.682	0.250	0.250	0.250	0.250	0
Resource Efficiency *- C74*	0.318	0.250	0.250	0.250	0.250	0
Green Management - C8	0.068					
Adherence to Environmental Policies and Government Regulation *- C81*	0.553	0.600	0.255	0.074	0.071	0.06
ISO 14001 Certification *- C82*	0.265	0.604	0.243	0.076	0.076	0.05
Environmental Auditing *- C85*	0.183	0.321	0.321	0.321	0.036	0

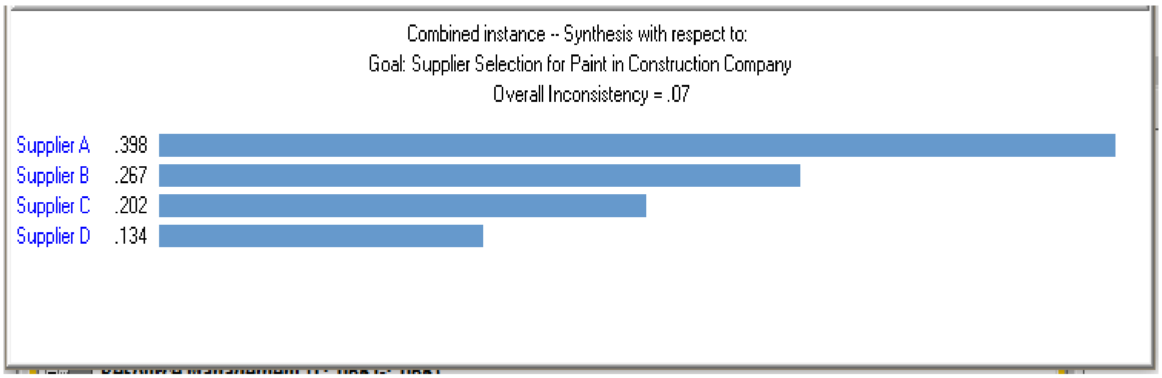

Figure 7: Synthesis with respect to goal that provides the supplier's score

4.2 Model Evaluation

This section demonstrates the sensitivity analysis of the AHP model using the AHP Expert Choice™ software. The aim of this evaluation is to recognize the impact of altering the key criteria with respect to the goal on the suppliers' weights and to test the model robustness. In addition, as the model consists of three levels, sensitivity analysis can be implemented on the sub-criteria with respect to the target. The Expert choice software provides five forms of sensitivity analysis, which are performance sensitivity, dynamic sensitivity, gradient sensitivity, head-to-head sensitivity, and two-dimensional sensitivity [51].

Performance sensitivity graph depending on the target is presented in Figure 8. It is shown that Supplier A has the highest weight based on four criteria, which is, Green Production, Green Operation, Service and Green Management criteria. Also, it has lower priority than Supplier B with respect to Awareness and Development criteria and same priority as all suppliers with respect to Resource Management. Therefore, in a different scenario where

Awareness and Development criteria will be a significant criterion and increased up to 0.50, Supplier B will have the highest ranking instead of Supplier A. Supplier B has the highest weight based on one criterion that is Awareness and Development criteria. It has lower weight than Supplier A and Supplier C with respect to Green Production, Green Operation, and Service criteria, while has higher priority than Supplier C and Supplier D with respect to Green Management. In another scenario where Green Production, Green Operation, or Service criteria will be a significant criterion and increased up to 0.75, Supplier C will have higher ranking than Supplier B. Supplier C ranks the lowest based on Awareness and Development criteria and second-least priority ranking derived from Green Management criteria. When Awareness and Development criteria becomes the most significant criterion and increased up to 0.90, Supplier D will have a higher ranking than Supplier C. Supplier D has the lowest priority based on four criteria, that is, Green Production, Green Operation, Service and Green Management criteria.

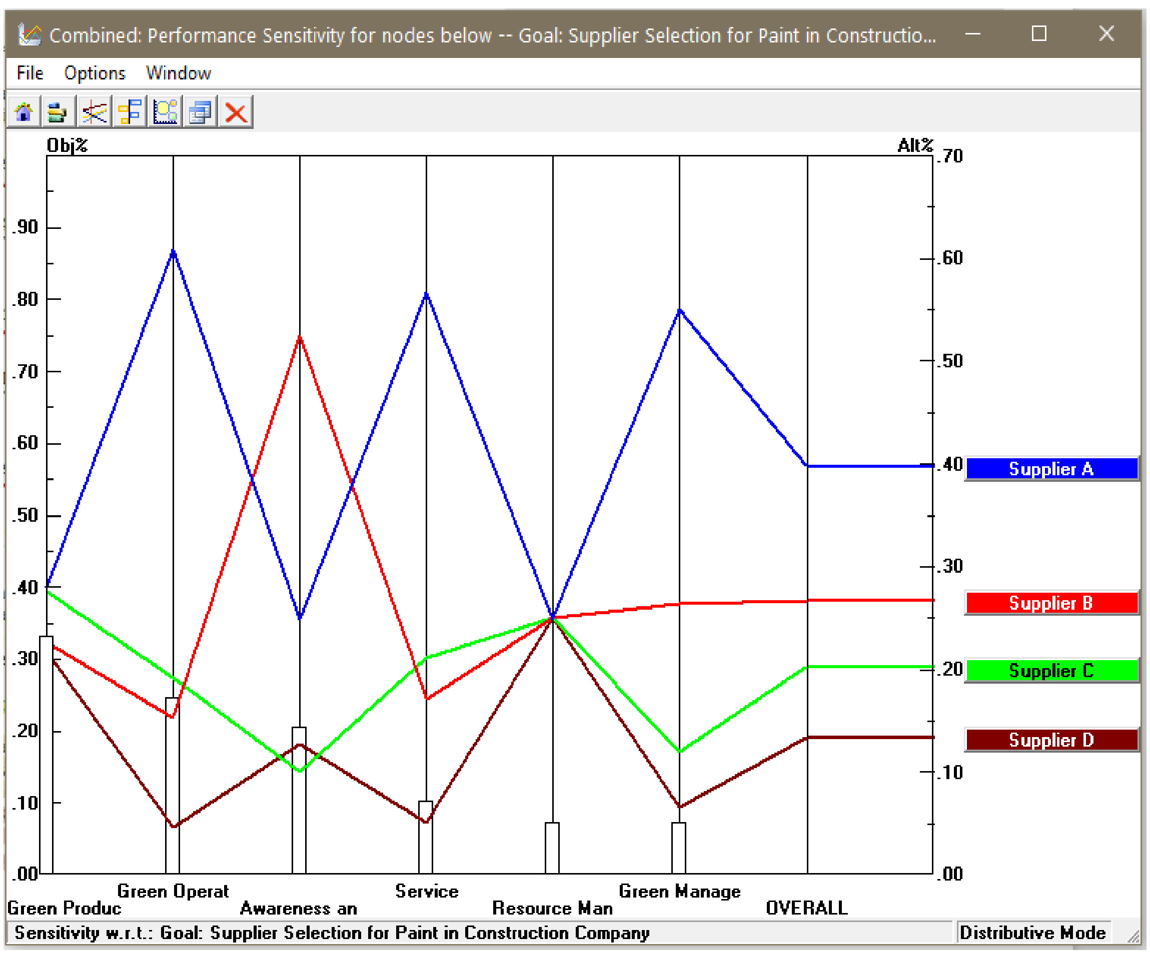

Figure 8: Performance Sensitivity based on the target

Moreover, analysis is executed by modifying the weight of each key criterion and few of the sub-criterion as shown below using performance sensitivity and dynamic sensitivity graph:

1- **Sensitivity analysis based on Green Production:**

The suppliers' ranking will alter from Supplier (A, B, C, D) to Supplier (A, C, B, D) when Green Production is 75%, Green Operation is 8.9%, Awareness and Development is 7.4%, Service is 3.6%, Resource Management is 2.5%, and Green Management is 2.5% as shown in Figure 9.

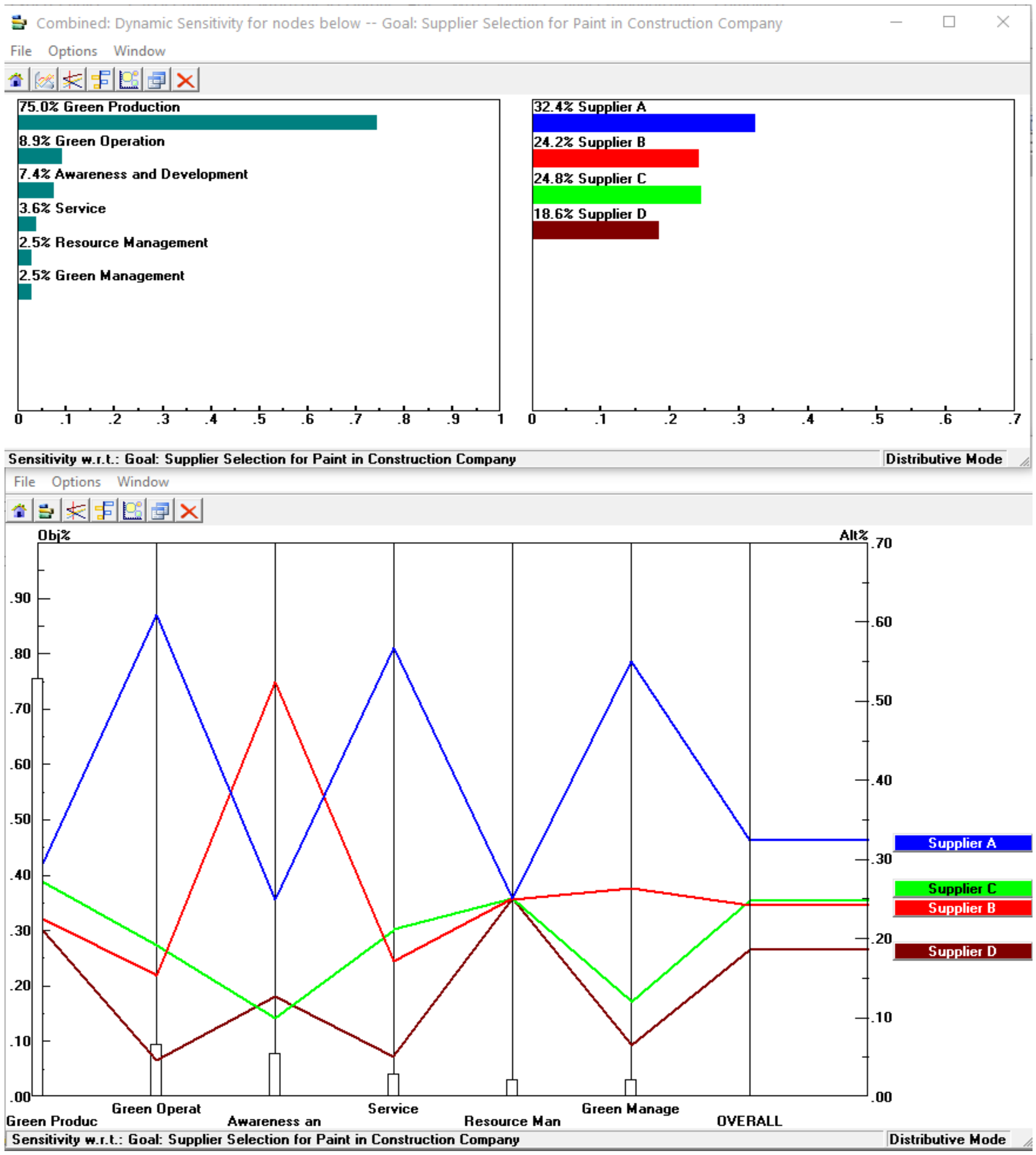

Figure 9: Sensitivity analysis by adjusting the Green Production weights upward

If the Green Production criteria priority value decreased to 5%, the suppliers' ranking will not change and will stay as Supplier (A, B, C, D). As presented in Figure 10, Green Operation is 34%, Awareness and Development is 28%, Service is 13.8%, Resource Management is 9.5%, and Green Management is 9.6%.

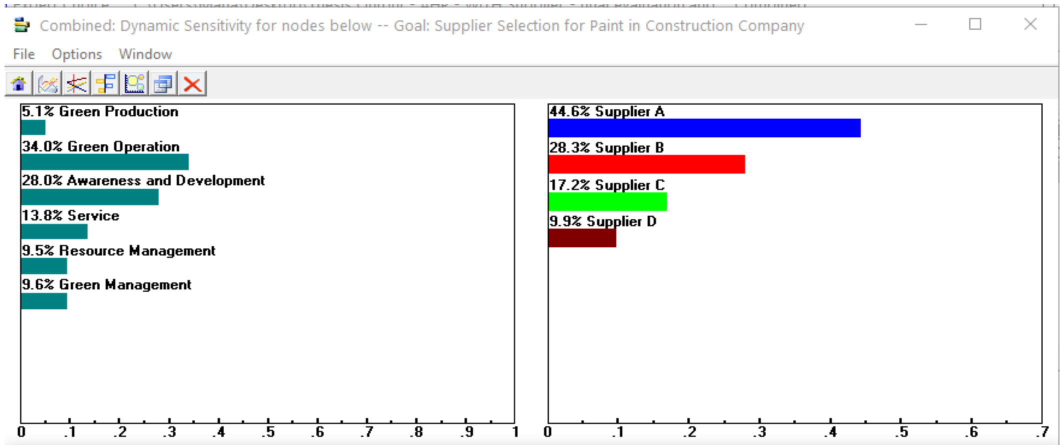

Figure 10: Sensitivity analysis by adjusting the Green Production weights downward

2- **Sensitivity analysis based on Green Operation:**

The order of the suppliers will alter from Supplier (A, B, C, D) to Supplier (A, C, B, D) when Green Production is 8.6%, Green Operation is 80%, Awareness and Development is 5.2%, Service is 2.6%, Resource Management is 1.8%, and Green Management is 1.8% as shown in Figure 11.

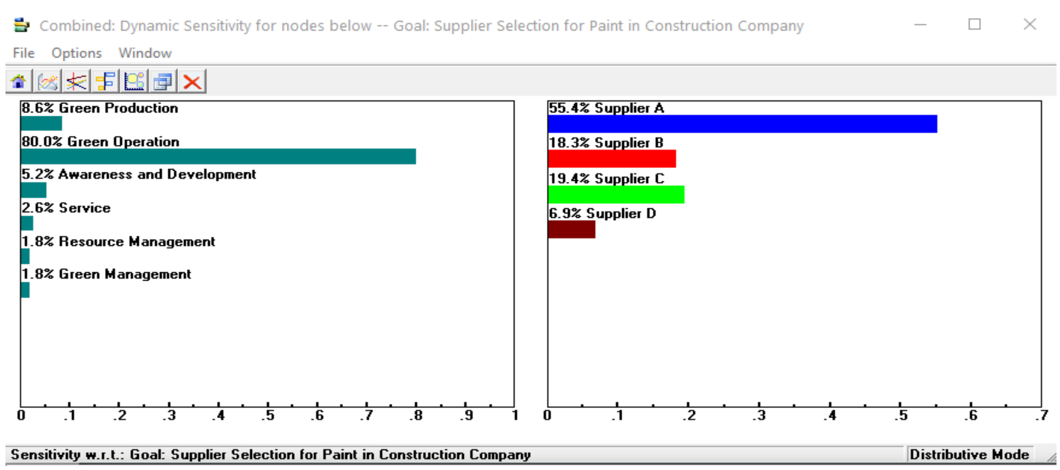

Figure 11: Sensitivity analysis by adjusting the Green Operation weights upward

Besides, if the Green Operation criteria priority value decreased to 4.9%, the supplier ranking will not change and will stay as Supplier (A, B, C, D). As presented in Figure 12, Green Production is 40.8%, Awareness and Development is 25%, Service is 12.3%, Resource Management is 8.5%, and Green Management is 8.5%.

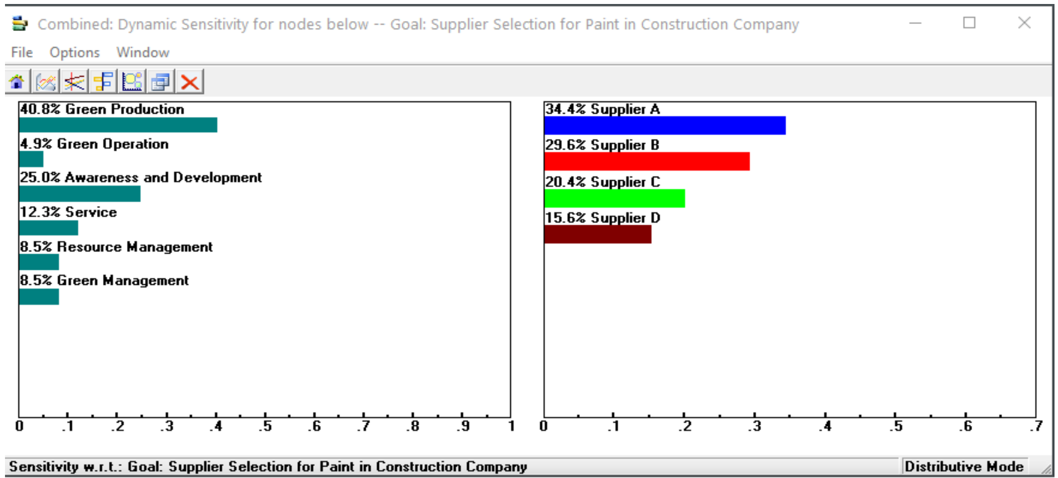

Figure 12: Sensitivity analysis by adjusting the Green Operation weights downward

3- **Sensitivity analysis based on Awareness and Development:**

The order of the suppliers will amend from Supplier (A, B, C, D) to Supplier (B, A, D, C) when Green Production is 6.1%, Green Operation is 4.5%, Awareness and Development is 85%, Service is 1.8%, Resource Management is 1.3%, and Green Management is 1.3% as shown in Figure 13.

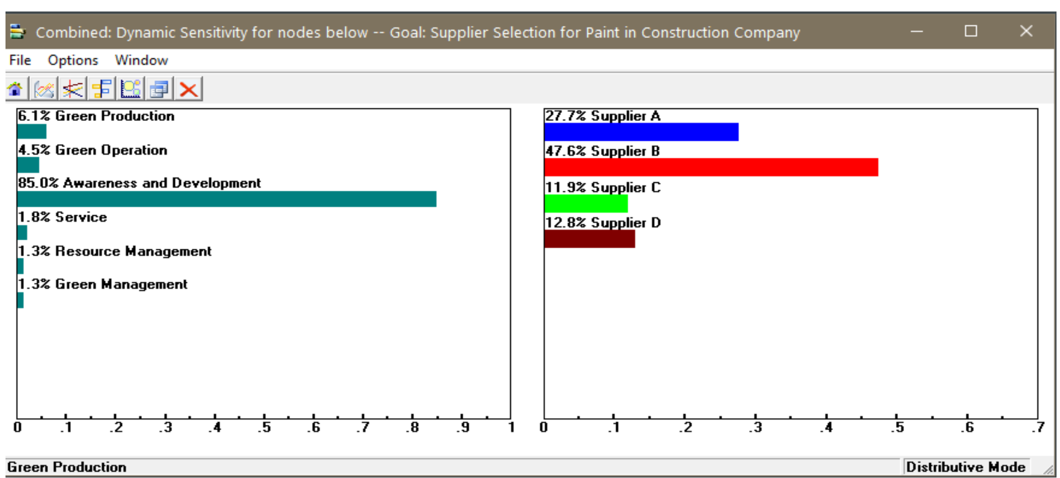

Figure 13: Sensitivity analysis by adjusting the Awareness and Development weights upward

In addition, if the Awareness and Development criteria priority value decreased to 4.1%, the supplier ranking will change from Supplier (A, B, C, D) to Supplier (A, C, B, D). As it is shown in Figure 14, Green Production is 39%, Green Operation is 28.9%, Service is 11.8%, Resource Management is 8.1%, and Green Management is 8.1%.

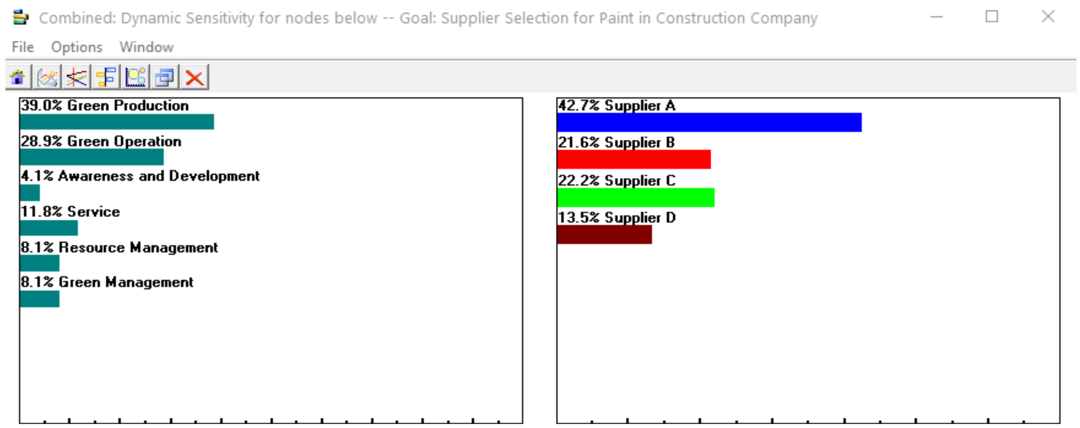

Figure 14: Sensitivity analysis by adjusting the Awareness and Development downward

4- **Sensitivity analysis based on Service:**

The order of the suppliers will vary from Supplier (A, B, C, D) to Supplier (A, C, B, D) when Green Production is 7.3%, Green Operation is 5.4%, Awareness and Development is 4.4%, Service is 79.9%, Resource Management is 1.5%, and Green Management is 1.5% as shown in Figure 15.

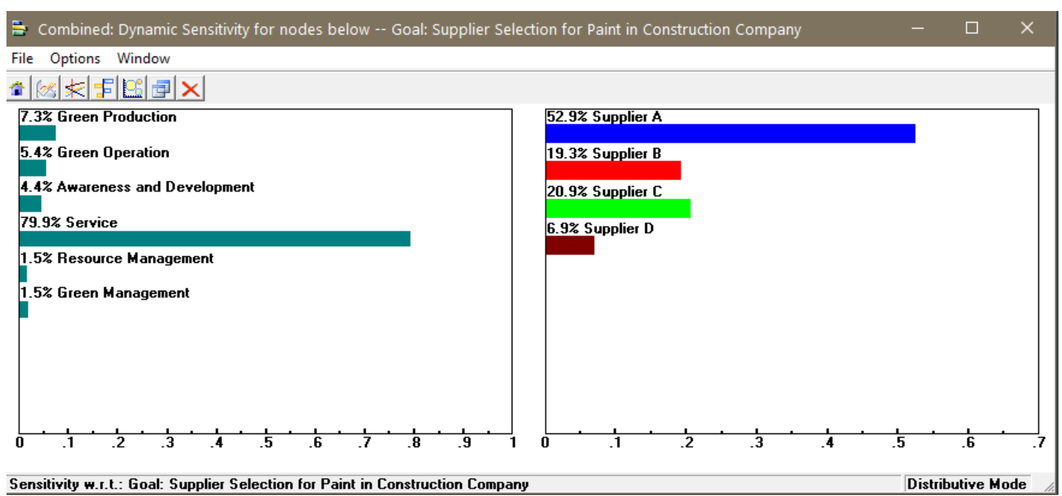

Figure 15: Sensitivity analysis by adjusting the Service upward

If the Service criteria priority value decreased to 5.1%, the supplier ranking will not change and will stay as Supplier (A, B, C, D). As it is shown in Figure 16, Green Production is 34.3%, Green Operation is 25.4%, Awareness and Development is 21%, Resource Management is 7.1%, and Green Management is 7.2%.

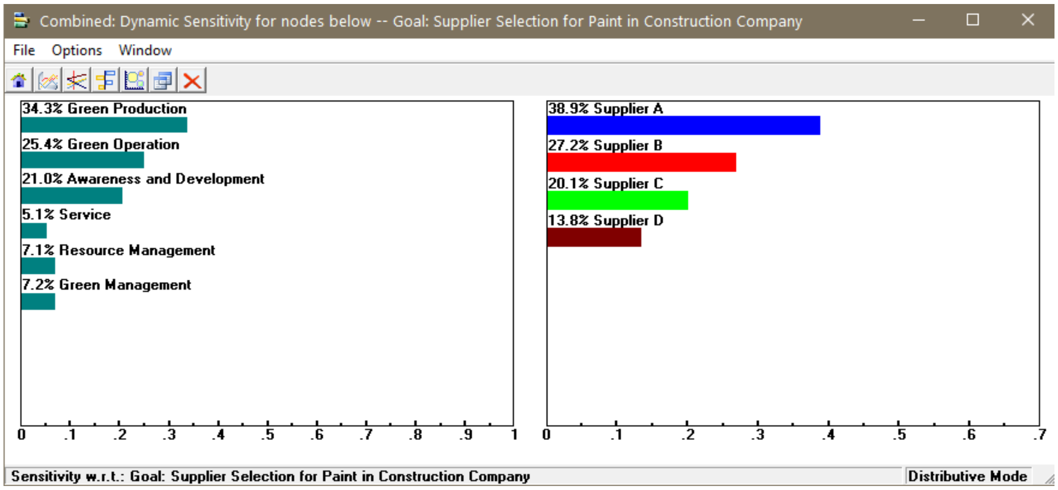

Figure 16: Sensitivity analysis by adjusting the Service downward

5- **Sensitivity analysis based on Resource Management:**

The suppliers ranking will remain the same irrespective of any change in Resource Management criteria weight since the ranking is robust.

6- **Sensitivity analysis based on Green Management:**

The suppliers ranking will remain the same irrespective of any change in Green Management criteria weight.

7- **Sensitivity analysis based on Green Production/Quality of Service:**

The order of the suppliers will vary from Supplier (A, B, C, D) to Supplier (A, C, B, D) when Environmental Emission is 7.8%, Energy Consumption is 3.9%, and Quality of Service is 88.4% as shown in Figure 17.

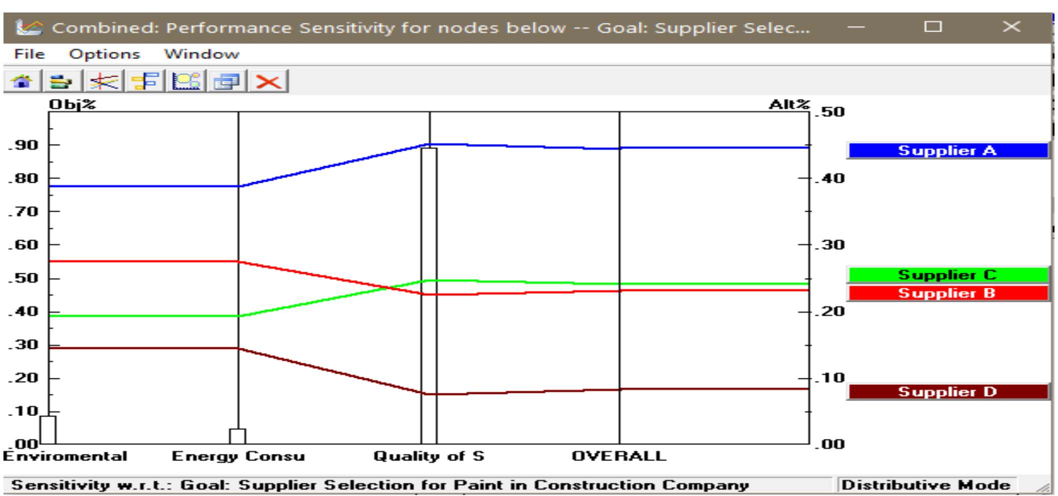

Figure 17: Sensitivity analysis by adjusting the Green Production/Quality of Service weights upward

If the Quality of Service criteria priority value decreased to 5.2%, the supplier ranking will not change and will stay as Supplier (A, B, C, D). As it is presented in Figure 18, Environmental Emission is 63.2% and Energy Consumption is 31.6%.

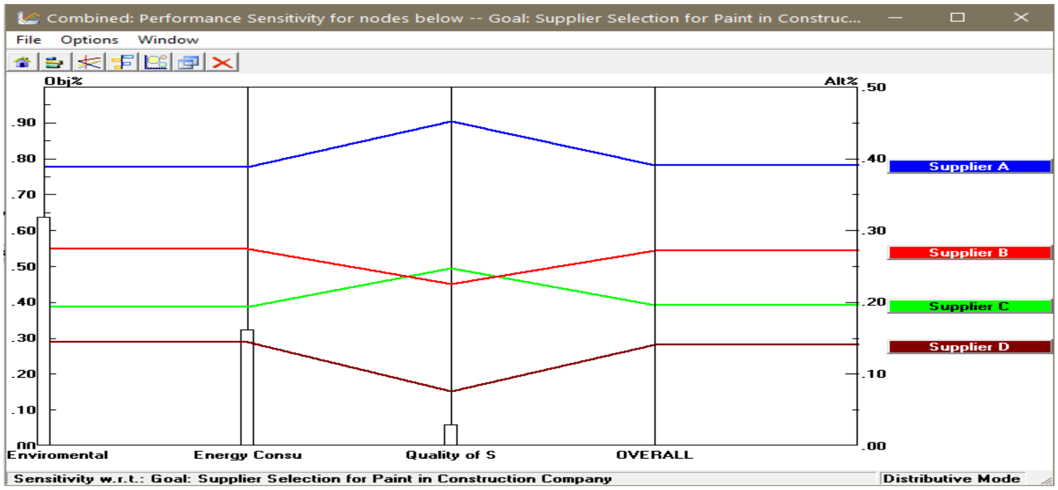

Figure 18: Sensitivity analysis by adjusting the Green Production/Quality of Service weight downward

8- **Sensitivity analysis based on Awareness and Development /Investment and Resource Transfer:**

The ranking of the suppliers will change from Supplier (A, B, C, D) to Supplier (A, C, B, D) when Staff Training to Enhance Employee's Environmental Performance is 10.8%, Investment and Resource Transfer is 86.2%, and Green Expertise is 3% as shown in Figure 19.

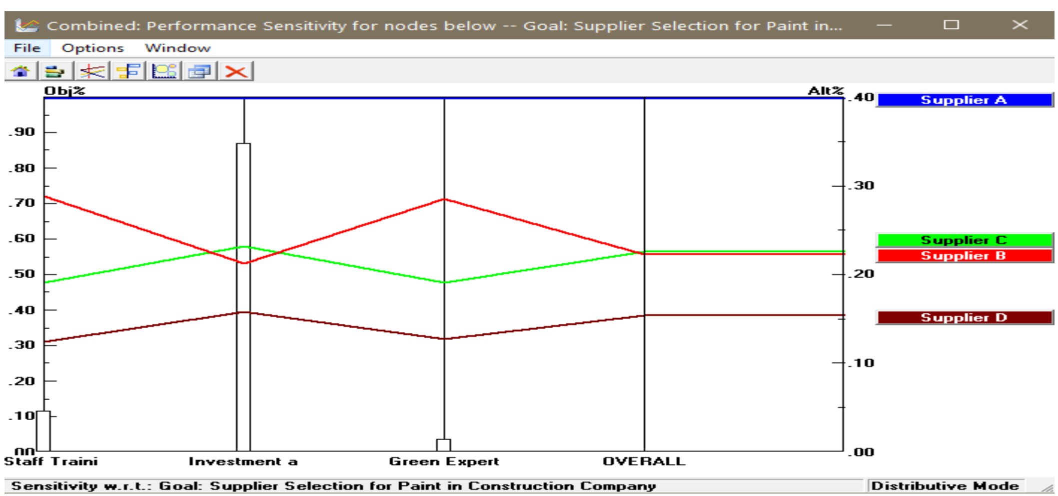

Figure 19: Sensitivity analysis by adjusting the Awareness and Development /Investment and Resource Transfer

In addition, if the Investment and Resource Transfer criteria priority value decreased to 5.2%, the supplier ranking will not change and will stay as Supplier (A, B, C, D).

4.3 Conclusion

In this chapter, the AHP model is implemented for supplier selection problem in UAE construction industry considering green criteria validated its robustness using sensitivity analysis in the AHP Expert Choice™ software. Sensitivity analysis is implemented to recognize the change of suppliers' priority when altering the main criteria and sub-criteria based on the goal: Supplier Selection of Paint in Construction Industry. The next chapter will provide thesis conclusions, limitations, MCDM technique limitation, recommendations, and future research.

Chapter 5 – Conclusion

This chapter provides the research limitations, the future works, and the study conclusion. It demonstrate the challenges that has been encountered and the works that can be implemented in the near future. It demonstrates how to overcome the limitation, to further validate the proposed framework, and enhance the research model. Chapter 5 presents two sections: Conclusion of the Study, and Limitations and Future Works of the Study.

5.1 Conclusion of the Study

The vision of the UAE in the year 2021 is to have a green economy for sustainable development. Thus, the organizations, operating in the United Arab Emirates (UAE), is required to adopt green strategies in their decision-making processes [44, 45]. The prupose of this proposed research is to provide a process for evaluating the supplier selection in green supply chain for UAE industries. In this highly competitive market, the organization's success depends highly on its ability to make informative and efficient decisions, and this can be achieved by using MCDM techniques. During the course of this research, multiple MCDM techniques were studied and evaluated to obtain the best suitable approach to solve the supplier selection problem. The decision making model selected must also integrate environmental criteria into the process. As a result of the study, the Analytic Hierarchy Process (AHP) technique was adopted for the following advantages:

- Deal with small sample sizes
- Many software available adopt this method
- Easy to implement
- Easy to translate the data into a presentable form via a hierarchical structure

The proposed model focused on the UAE's construction industry in general and the paint suppliers in particular as an example that represents the procedure and framework.

To the best of our knowledge, the UAE construction sector is still using traditional modes of supplier selection, focusing on typical criteria such as cost and lead-time. These methods do not take into consideration the impact on the environment. The aim here is to provide a model and an example to the implementation of supplier selection using green criteria. In the long run, this will results in are more sustainable environment, and will be in line with the UAE's vision. The study implemented a general four-level criteria system, which are shared criteria that can be used in suppliers' selection for any kind of product in the construction industry. The first level includes the main ten criteria, the second includes 47 sub-criteria, the third level contains 18 sub-criteria, and the fourth level consists of five sub-criteria. The general criteria provides managers a list of criteria to select from depending on their requirements. Moreover, a specific criteria system was proposed for the purpose of the selection of paint suppliers in Green Supply Chain. Besides, the main criteria include six criteria, the second level consists of 16 sub-criteria, and the third level has three sub-criteria that are structured in hierarchical system shown in Figure 3.

A use case in a construction company has been applied to the proposed model to find the optimal paint suppliers. Providing real life data to support the thesis was a crucial step. This was done by implementing Saaty scale on a survey that was distributed to representatives of the construction industry in the market. The results were then compiled in the practical and efficient Expert Choice^{TM} software. Expert Choice^{TM} software makes the implementation of the AHP easier and provides the results in a more useful presentation to aid decision makers. The consistency rate of the decision maker's judgment demonstrated that the evaluation is consistent. As a result, Supplier A and Supplier B are the two highest-score suppliers of 0.398 and 0.267 respectively, while Supplier C and Supplier D are the lowest-ranking suppliers. Moreover, the model robustness is validated using the sensitivity analysis by altering the main criteria and sub criteria based on the target of the suppliers' ranking. It revealed that as some of the criteria weights has high effects on the suppliers ranking when they are modified significantly, while other criteria does not have high impact and the ranking of suppliers stayed robust. Using the implemented model, managers in UAE will be able to decide the optimal suppliers as well as minimize their effort while evaluating and ranking the suppliers. It will also make the managers more confident. The general framework offers the managers instructions that will help them to select the best suppliers with defined criteria and ensure that their evaluation is reliable.

This research addresses three main contributions to the supplier selection process while incorporating green criteria. First, the proposed method is implemented in the construction industry located in the UAE, mainly for the product suppliers. It helps the managers, who are the decision makers of the construction company, to be more confident in their judgment while evaluating the suppliers. This method will lessen the effort and time the managers will take in discussing and evaluating the suppliers using the defined criteria. It will enable them to narrow the large number of suppliers effectively and quickly. Second, adding environmental criteria as a key measure to select the supplier is critical because it is consistent with the UAE vision for a sustainable environment. This study offers general criteria for the construction industry, in the UAE, whereby the decision-maker will be able to assess suppliers for specific products. The research demonstrates specific criteria for the paint product that is used in the construction industry. Third, sensitivity analysis is applied to aid the decision-makers to ensure that the proposed model is robust.

5.2 Limitation and Future Works of the Study

In performing the proposed model, various limitations has been encountered. Many sectors were approached to provide the required data; however, few industries provided positive reply with minimum amount resources. Due to the minimum resources provided, a survey was constructed to get the required data. Moreover, anonymous online feedback for the survey was required in order to get the maximum number of expert participant in the construction industry to provide their judgement. This is because few were willing to provide their feedback publically, while others required it to be an anonymous feedback. As a result of the maximum required duration of the survey, which is 15 minutes, the number of question were reduced to meet the requirements. The result of the survey shows that 36 were completed out of 91 surveys mailed due to several factors, including COVID 19 pandemic and network security concerns.

These research findings were based on only one case study of a construction industry, and precisely only one subject matter expert is involved in the supplier evaluation, which requires carefulness in result analysis and interpretation. Based on my knowledge, most of the construction companies does not consider the importance of incorporating green criteria in their supplier selection, as a result, suppliers' focus mainly in the typical criteria that are used by the companies for evaluation.

Implementing a green supply chain under the AHP methodology is possible as illustrated by the research conclusions. The widespread implementation of such models will result in benefiting the industry, the environment, and country as a whole. Considering both, the environmental and financial aspect in the processes of supplier selection is imperative. It is therefore recommended for major and influential companies to take the initiative and implement change from the top i.e. managerial level. Furthermore, it is advised to provide internal awareness within organizations to introduce a green mindset and a green cultural outlook to supply chain management. Thus, this will help in making future decisions to greener outcomes. The system implemented and the methods utilized in this research provide guidance for companies that are welling to adopt green supply chain methodologies. In order to systematize the process of the supplier selection within an organization, it is recommended to implement the proposed framework for supplier selection in the business management software or enterprise resource management.

Future work is recommended to overcome the challenges and the limitations, and validate, improve and enhance the model. First, as the amount of criteria or the amount of decision makers for supplier evaluation rises, the AHP methodology cannot function efficiently that leads to inaccurate results. Implementing and comparing different methods such as Fuzzy AHP, TOPSIS, and computational intelligence techniques can be beneficial in finding the best approach for the supplier selection problem. Second, incorporating social criteria as a performance measures in the research criteria. This will enable the construction industry to have a sustainable supply chain. Third, engaging and involving different companies in the research to get the best and accurate model that represents the problem. For instance, this can be done by involving the university upper management in being engaged in collaborating with companies to obtain the required data that can be provided. Fourth, the study can be extended to add more survey samples, and additional subject matter experts to evaluate the suppliers for model validation. However, this can increase the computational complexities. Fifth, different products related to the construction industry can be examined to verify the model efficiency and effectiveness. Sixth, study, inspect, and analyze how the proposed criteria have either negative or positive impact on some key aspects such as cost, reputation, and market visibility. Seventh, the chosen problem for this research is based on the context of a specific country, and a further study will be necessary to inspect if the outcome can be extended to other Arab countries' construction industry.

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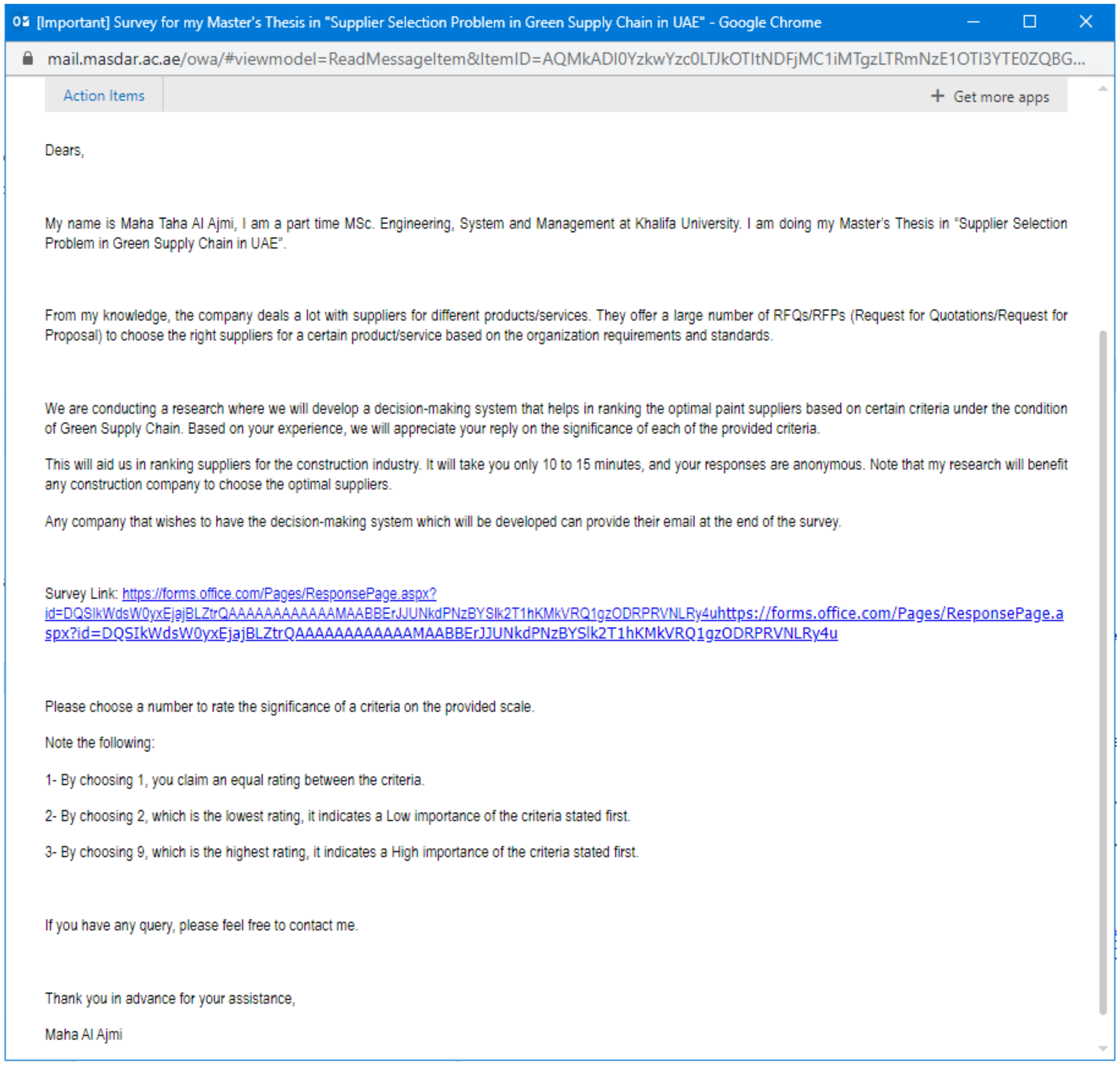
Appendix A - Survey Email



[Important] Survey for my Master's Thesis in "Supplier Selection Problem in Green Supply Chain in UAE" - Google Chrome

mail.masdar.ac.ae/owa/#viewmodel=ReadMessageItem&ItemID=AQMkADI0YzkwYzc0LTJkOTItNDFjMC1iMTgzLTRmNzE1OTI3YTE0ZQBG...

Action Items

\+ Get more apps

Dears,

My name is Maha Taha Al Ajmi, I am a part time MSc. Engineering, System and Management at Khalifa University. I am doing my Master's Thesis in "Supplier Selection Problem in Green Supply Chain in UAE".

From my knowledge, the company deals a lot with suppliers for different products/services. They offer a large number of RFQs/RFPs (Request for Quotations/Request for Proposal) to choose the right suppliers for a certain product/service based on the organization requirements and standards.

We are conducting a research where we will develop a decision-making system that helps in ranking the optimal paint suppliers based on certain criteria under the condition of Green Supply Chain. Based on your experience, we will appreciate your reply on the significance of each of the provided criteria.

This will aid us in ranking suppliers for the construction industry. It will take you only 10 to 15 minutes, and your responses are anonymous. Note that my research will benefit any construction company to choose the optimal suppliers.

Any company that wishes to have the decision-making system which will be developed can provide their email at the end of the survey.

Survey Link: https://forms.office.com/Pages/ResponsePage.aspx?id=DQSIkWdsW0yxEjajBLZtrQAAAAAAAAAAAAMAABBErJJUNkdPNzBYSlk2T1hKMkVRQ1gzODRPRVNLRy4uhttps://forms.office.com/Pages/ResponsePage.aspx?id=DQSIkWdsW0yxEjajBLZtrQAAAAAAAAAAAAMAABBErJJUNkdPNzBYSlk2T1hKMkVRQ1gzODRPRVNLRy4u

Please choose a number to rate the significance of a criteria on the provided scale.

Note the following:

1- By choosing 1, you claim an equal rating between the criteria.

2- By choosing 2, which is the lowest rating, it indicates a Low importance of the criteria stated first.

3- By choosing 9, which is the highest rating, it indicates a High importance of the criteria stated first.

If you have any query, please feel free to contact me.

Thank you in advance for your assistance,

Maha Al Ajmi

Figure 20: Survey Email

Appendix B - Survey Template

The following shows the survey template:

Criteria Importance for Supplier Selection Problem in Green Supply Chain in UAE

We are conducting a research where we will develop a decision-making system that helps in ranking the optimal paint suppliers based on certain criteria under the condition of Green Supply chain. Based on your experience, we will appreciate your reply on the significance of each of the provided criteria. This will aid us in ranking suppliers for the construction industry. It will take you only 10 to 15 minutes, and your responses are anonymous. Note that my research will benefit any construction company to choose the optimal suppliers. Any company that wishes to have the decision-making system, which will be developed, can provide their email at the end of the survey.

Please choose a number to rate the significance of a criterion on the provided scale.

Note the following:

1- By choosing 1, you claim an equal rating between the criteria.

2- By choosing 2, which is the lowest rating, it indicates a Low importance of the criteria stated first.

3- By choosing 9, which is the highest rating, it indicates a High importance of the criteria stated first.

<u>Six major criteria will be rated</u>

1- **Green Production:** The production of the product that is friendly to the environment.

2- **Green Operation:** Flexibility of the product in terms of ease of transportation and ability to change in major circumstance.

3- **Awareness and Development:** The knowledge, expertise, and skills of the supplier and their employees.

4- **Service:** The service provided by the supplier.

5- **Resource Management:** Availability of natural and renewable materials, and other assets of the supplier's organization.

6- **Green Management:** Supplier complying with environmental policies and regulations as well as getting certificates relate to the environment.

1. Green Production - Green Operation

   1 2 3 4 5 6 7 8 9

2. Green Production - Awareness and Development

   1 2 3 4 5 6 7 8 9

3. Green Production – Service

   1 2 3 4 5 6 7 8 9

4. Green Production - Resource Management

   1 2 3 4 5 6 7 8 9

5. Green Production - Green Management

   1 2 3 4 5 6 7 8 9

6. Green Operation - Awareness and Development

   1 2 3 4 5 6 7 8 9

7. Green Operation – Service

   1 2 3 4 5 6 7 8 9

8. Green Operation - Resource Management

   1 2 3 4 5 6 7 8 9

9. Green Operation - Green Management

   1 2 3 4 5 6 7 8 9

10. Awareness and Development – Service

    1 2 3 4 5 6 7 8 9

11. Awareness and Development - Resource Management

    1 2 3 4 5 6 7 8 9

12. Awareness and Development - Green Management

    1 2 3 4 5 6 7 8 9

13. Service - Resource Management

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

14. Service - Green Management

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

15. Resource Management - Green Management

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

Three sub-criteria will be rated with respect to "Green Production" criteria

1- **Environmental Emission:** Supplier practices for reducing the environmental effects, such as minimize Carbon Dioxide (CO_2) emission, wastewater, and solid waste.

2- **Energy Consumption:** Supplier practices in reducing the consumption of energy.

3- **Quality of service:** Supplier quality of the service that will be provided for the purpose of the product.

16. Environmental Emission - Energy Consumption

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

17. Environmental Emission - Quality of service

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

18. Energy Consumption - Quality of service

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

Two sub-criteria will be rated with respect to “Green Operation” criteria

1- **Adaption to changes:** Suppliers adaption to any kind of changes in ordering and delivery that can occur without advance knowledge such as Corona virus.

2- **Transportation:** Supplier adherence to the customer’s specific transportation requirements.

19. Adaption to changes – Transportation

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

Three sub-criteria will be rated with respect to “Transportation” criteria

1. **Flexibility:** Supplier flexibility to provide the product even if the product volume changes within any date and time and short prior notice.

2. **Delivery Duration:** Supplier meeting the promised delivery time for the product.

3. **Delivery Reliability:** Supplier reliability in product delivery times.

20. Flexibility - Delivery Duration

1 2 3 4 5 6 7 8 9

21. Flexibility - Delivery Reliability

1 2 3 4 5 6 7 8 9

22. Delivery Duration - Delivery Reliability

1 2 3 4 5 6 7 8 9

Three sub-criteria will be rated with respect to “Awareness and Development” criteria

1. **Staff Training to enhance employee’s environmental performance:** Supplier provide periodic trainings to increase their staff environmental awareness and enhance their environmental performance.

2. **Investment and Resource Transfer:** Supplier investment on green environment services and by selling different products, which is manufactured from environmentally friendly resources.

3. **Green Expertise:** Supplier provide the list of expertise in environmental aspect.

23. Staff Training to enhance employee’s environmental performance - Investment and Resource Transfer

1 2 3 4 5 6 7 8 9

24. Staff Training to enhance employee’s environmental performance - Green Expertise

1 2 3 4 5 6 7 8 9

25. Investment and Resource Transfer - Green Expertise

1 2 3 4 5 6 7 8 9

Three sub-criteria will be rated with respect to “Service” criteria

1. **Trust:** Supplier’s relationship with the customer based on previous projects experience with the same supplier.

2. **Response to complaints**: How fast supplier responds to complaint and take actions to resolve it.

3. **Value Added Services:** Supplier provides free services to the customer such as additional warranty or storage for additional periods, or free delivery.

26. Trust - Response to complaints

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

27. Trust - Value Added Services

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

28. Response to complaints - Value Added Services

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

Two sub-criteria will be rated with respect to “Resource Management” criteria

1. **Local Sourcing:** Supplier’s ability to procure locally.

2. **Resource Efficiency:** Supplier’s adherence to resource consumption criteria according to stated environmental policy.

29. Local Sourcing - Resource Efficiency:

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

Three sub-criteria will be rated with respect to “Green Management” criteria

1. **Adherence to Environmental Policies and Government Regulation:** Supplier’s adherence to environmental policies and government regulation.

2**. ISO 14001 Certification:** Supplier has a valid ISO 14001 certification that provide rules and framework for active environmental management system (EMS) that an industry follows.

3. **Environmental Auditing:** Suppliers implementation of robust auditing procedures to trace noncompliance with environmental activities at the organization and project levels.

30. Adherence to Environmental Policies and Government Regulation - ISO 14001 Certification

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

31. Adherence to Environmental Policies and Government Regulation - Environmental Auditing

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

32. ISO 14001 Certification - Environmental Auditing

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

<u>Providing your email (Optional)</u>

33. If you wish to have the decision-making system which will be developed please provide your email

Enter your answer