AN INTEGRATION OF RANK ORDER CENTROID, MODIFIED ANALYTICAL HIERARCHY PROCESS AND 0-1 INTEGER PROGRAMMING IN SOLVING A FACILITY LOCATION PROBLEM

MOHAMMED AHMED SALEM BALHUWAISL

DOCTOR OF PHILOSOPHY

UNIVERSITI UTARA MALAYSIA

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Abstrak

Daerah Hadhramout merupakan pengeluar utama kurma di Republik Yaman. Walaupun pengeluaran kurma tinggi dari segi kuantiti mahupun kualiti, kerugian perniagaan sangat tinggi. Keadaan ini diburukkan lagi dengan aktiviti pasaran gelap yang berleluasa. Baru-baru ini, kerajaan Yaman telah menyatakan persetujuan tentang pentingnya pembinaan satu kilang pembungkusan kurma sebagai satu penyelesaian kepada masalah-masalah tersebut. Oleh itu, kajian ini bertujuan untuk mengenal pasti lokasi terbaik di antara tujuh daerah yang mengeluarkan kurma di Hadhramout. Pilihan dibuat berdasarkan sebelas kriteria yang dikenal pasti oleh beberapa wakil pekebun dan majlis tempatan. Kriteria tersebut ialah pertumbuhan pasaran, jarak dengan pasaran, jarak dengan bahan mentah, buruh, iklim buruh, pembekal, komuniti, kos pengangkutan, faktor alam sekitar, kos pengeluaran, dan kos pembinaan kilang. Darjah kepentingan dan pemberat sepadan bagi setiap kriterion dikira menggunakan dua pendekatan, iaitu Proses Hierarki Analitik (AHP) dan Sentroid Tertib Pangkat (ROC). Dalam memanfaatkan AHP, sedikit pengubahsuaian telah dilaksanakan pada langkah perbandingan berpasangan yang menghapuskan masalah ketidaktekalan yang dihadapi dalam peraturan perbandingan berpasangan pada AHP piawai. Begitu juga yang dilakukan dalam menggunakan ROC yang mana teknik penormalan telah dicadangkan untuk menyelesaikan masalah pemberian pemberat pada kriteria yang mempunyai aras keutamaan yang sama, yang tidak dijelaskan atau dinyatakan dalam ROC piawai. Kedua-dua kaedah yang dimanfaatkan menyatakan pembekal merupakan kriterion paling penting, manakala komuniti dianggap kriterion paling tidak penting dalam memutuskan lokasi akhir kilang kurma. Menggabungkan pemberat kriteria dengan beberapa kekangan keras dan lembut yang perlu dipenuhi oleh lokasi, lokasi akhir ditentukan dengan menggunakan tiga model matematik, iaitu, ROC digabungkan dengan model pengaturcaraan integer 0-1, AHP digabungkan dengan model pengaturcaraan integer 0-1, dan purata ROC dan AHP digabungkan dengan model pengaturcaraan integer 0-1. Ketiga-tiga model menghasilkan keputusan yang sama; Doean ialah lokasi terbaik. Keputusan kajian ini jika dilaksanakan, diharap dapat membantu kerajaan Yaman dalam usaha mereka untuk memajukan pengurusan kurma di Hadhramout.

Kata Kunci: Proses Hierarki Analitik, Sentroid Tertib Pangkat, model pengaturcaraan integer 0-1, lokasi kemudahan

Abstract

Hadhramout province is the major producer of dates in The Republic of Yemen. Despite producing substantial quantity and quality of dates, the business losses are still high. The situation worsens with the widespread of the black market activities. Recently, the Yemeni government has issued an agreement stating the importance of building a date palm packaging factory as a resolution to the problems. Hence, this study aims to identify the best location for a date palm packaging factory among the seven districts which produce most of the date palm supplies in Hadhramout. The selection was based on eleven criteria identified by several representatives from the farmers and the local councils. These criteria were market growth, proximity to the markets, proximity to the raw materials, labor, labor climate, suppliers, community, transportation cost, environmental factors, production cost, and factory set up cost. The level of importance and the respective weight of each criterion were calculated using two different approaches, namely, Analytic Hierarchy Process (AHP) and Rank Order Centroid (ROC). In applying AHP, a slight modification was made in the pairwise comparison exercises that eliminated the inconsistency problem faced by the standard AHP pairwise comparison procedure. Likewise, in applying ROC, a normalization technique was proposed to tackle the problem of assigning weights to criteria having the same priority level, which was neither clarified nor available in the standard ROC. Both proposed techniques revealed that suppliers were the most important criterion, while community was regarded to be the least important criterion in deciding the final location for the date palm factory. Combining the criteria weights together with several hard and soft constraints that were required to be satisfied by the location, the final location was determined using three different mathematical models, namely, the ROC combined with 0-1 integer programming model, the AHP combined with 0-1 integer programming model, and the mean of ROC and AHP combined with 0-1 integer programming model. The three models produced the same result; Doean was the best location. The result of this study, if implemented, would hopefully help the Yemeni government in their effort to improve the production as well as the management of the date palm tree in Hadhramout.

Keywords: Analytic Hierarchy Process, Rank Order Centroid, 0-1 integer programming model, Facility location.

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List of Abbreviations

AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
CI	Inconsistency Index
CR	Consistency Ratio
DEA	Data Envelopment Analysis
FL	Facility location
GCI	Geometric Consistency Index
GP	Goal Programming
ILP	Integer Linear Programming
LP	Linear Programming
MILP	Mixed Integer Linear Programming
MEW	Multiplicative Exponential Weighting
MCDM	Multi Criteria Decision Making
OR	operations research
QFD	Quality Function Deployment
ROC	Rank Order Centroid
RS	Rank Sum
RR	Reciprocal the Ranks
SWOT	Strengths, Weaknesses, Opportunities, Threats
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
0-1 IP	0-1 Integer Programming

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CHAPTER ONE

INTRODUCTION

This chapter begins with a brief overview of the background of the facility location problem. This is followed by the statement of the problem, objectives and research questions, scope of the study, and contribution of the study.The chapter concludes with a brief statement on the organization of this entire thesis.

1.1 Facility Location Problem

Facility location, also known as location analysis, is a branch of operations research and computational geometry. It concerns itself with mathematical modeling and solution of problems about optimal placement of facilities in order to select the best solution. In particular, facility location is a cycle of processes. It starts with the planning stage and ends with a selection that implies options presuming the existence of different alternatives for analysis by the decision makers. Meanwhile, every alternative has its own characteristics and facilities.

Determining a final site selection in a facility location problem is an important task as the site selection is directly linked to many warehouse systems, inventory control and handling activities, as well as customers and suppliers. A good location offers a strategic advantage against competitors. As an example, locating more outlets ensures accessibility and the offering of better services to potential customers over short distances (Jayaraman, 1998, and Ghosh 2009).

Locating facilities to serve customers has been a serious problem in operations research, computer science, and business applications (Kumral, 2004). Variations of this problem have been viewed in pattern recognition, geographical information system, location science, and statistics (Drezner, 1995; Hurtado and Toussaint, 2000). In terms of practical applications, facility location problems occur in planning and stationing service centers encompassing airports (Korpela et al., 2002), post offices (Hurtado and Toussaint, 2000), hospitals (Drezner, 1995), fire stations (Okabe et al., 1992), waste disposal sites (Aupperle and Keil, 1989) and merchandise distribution centers (Batta et al., 1989).

It is very important to realize that making strategic decisions, such as identifying a location for a certain project, business, or organization, implicate organization in extended years. The location must be identified correctly to make sure no change is later necessary. This explains that identifying the best location of such projects is not easy. It involves the uncertainty of the future, complexity and conflicting factors linked to the site selection problem, and constraints and restrictions of resources to produce a site. In response to this, in every situation, management's location decision reflects a specific strategy (Krajewski and Ritzman, 1993).

The above situations are being faced in Yemen. The government encounters several problems regarding the selection of the best location among the available options in Hadhramout, in the agriculture and industrial sectors, since every option has its own characteristics and facilities. In particular, one of the most important problems in manufacturing that the government is trying to solve is to find the location for date palm packaging. In this regard, the Yemeni government has made several attempts to solve the problem. It is important because the industry represents one of the most important national products (Obad et al., 2003; Ministry of Agriculture and Irrigation, 2009).

1.1.1 Facility Location Problem in Hadhramout

Yemen is situated in Western Asia and to the South of the Arabian Peninsula, as portrayed in Figure (1.1). Its covers an area of about 527,970 km^2. Yemen has many products, and one of the most important products is the date palm. Many of the provinces in Yemen produce the date palm, such as Marib, Alhodeidah, Almahrah, Shabowa, and Hadhramout. Table (1.1) provides the statistics of the date palm production in tons and the area of land covered for production in hectares for each province.

Table 1.1Theproduction area and production in Yemen

Province name	**Dates area (Hectare)**	**Production (Ton)**
Marib	25	130
Alhodeidah	4150	17058
Almahrah	19	98
Shabowa	150	450
Hadhramout	11452	48912
Total	15796	66648

Source: Ministry of Agriculture and Irrigation, statistical report, 2011

It is noted from Table 1.1 that theHadhramout province is the largest area in Yemen producing date palm. In addition, it has the highest production compared to the other provinces.

Figure 1.1: The location of Yemen and the provinces that produce the date palm trees

Hadhramout is considered as having one of the most fertile grounds in Yemen, and in the region. The current study focuses on Hadhramout province since it is the major producer of date palm in Yemen compared to other provinces. The Hadhramout province has 30 districts. Its covers an area of about 193032 km^2. The production of date palm in Hadramout province also spreads across several districts, such as Sah, Seyoun, Tareem, Shabam, Alqaten, Doean, and Wadi Alaeen and Horah as illustrated in Figure 1.2.

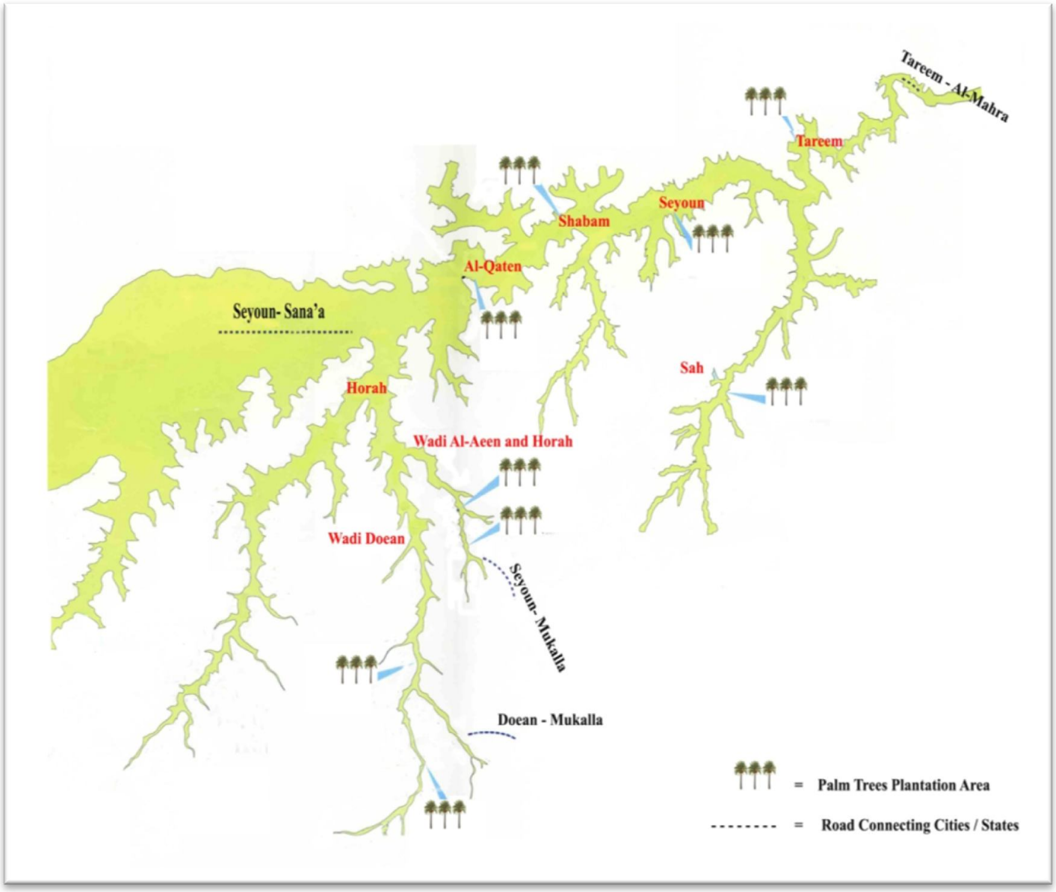

Figure 1.2 Districts in Hadhramout province that produce the date palm trees

The production of date palm in tons and the area of land covered for production in hectares for each district are provided in Table 1.2.

Table 1.2 Total area and production in each district in Hadhramout

District name	Dates area (hectare)	Production (Ton)
Sah	1803	8420
Seyoun	1432	5695
Tareem	1571	7202
Shabam	1382	4791
Alqaten	1425	6197
Doean	1662	7987
Wadi Alaeen and Horah	1421	7326
Others	756	1294
Total	11452	48012

Source: Ministry of Agriculture and Irrigation, statistical report, 2011

Hadhramout produces date palm in considerable quantity and quality and it has a long history of palm dates' cultivation. There are about 4,680,000 date palm trees, scattered around the regions of Seyoun, Sah, Shabam, Tareem, Wadi Al-Aeen and Horah, Al-Qaten, and Doean. Seventy-five percent of those trees are productive. There are some significant efforts exerted by Yemeni researchers to enhance the production of the dates in the south region. However, the product quantity is still low, the field and post-harvest losses are high and the date products and by-products' utilization still need improvements (Al-Katheri, 2000).

As a real-world case in Hadhramout, there was a small mobile date factory in Seyoun district. Dates were bought from farmers with low prices (below the factory rate) during 1994-2006. This situation did not continue for very long because it was not profitable for the farmers. Another reason that contributed to the collapse of that factory was the postponements of payment to farmers, making farmers feel reluctant to sell. As a result, the farmers sold their dates in black markets that offered high prices with immediate payments (Bameftah et al., 2005).

Recently, the Yemeni government issued an agreement, stating the importance of building a date palm factory, and explaining how this step can contribute towards improving the production of the date palm trees in the region, particularly in Hadhramout. Hadhramout was singled out since it has the most fertile grounds in the region.

Based on the situations as described in the previous paragraph, this study believes that the agreement for the setting up of a factory to mobilize and manage date products in Hadhramout is indeed very timely. Among the functions of the factory include purchasing the production of the dates from the local farmers and then mobilizing the products through proper packaging and selling the finished product to the domestic and international markets. Proper implementation, planning and operations will improve the production of the date palm trees in Yemen and lead to the growth and expansion of the date palm industry in the future. In other words, if the farmers get benefits from this factory, the farmers will then plant more date palm trees and when the date palm trees increase, it can be expected that the production of date palm will increase as well. Since the agreement to establish the date palm factory exists, the immediate issue now is for the government to determine the best location for establishing the factory, from among the alternative locations available in Hadhramout (Obad et al., 2003, and Ministry of Agriculture and Irrigation, 2009).

Several empirical studies have evidenced that the identified location problems discussed above are influenced by several criteria as shown in the next section.

1.1.2 Criteria in Facility Location Problem

Literature on facility location, has documented that several criteria, directly or indirectly, influence facility location selection. The global location factors, among others, include government stability (Bertolini and Bevilacqua, 2006), government regulations (Badri,1999; Radcliffe and Schniederjans, 2003), political and economic systems, exchange rates, culture, climate (Yang and Lee, 1997; Liu, 2000), export and import regulations, tariffs and duties, raw material availability (Yang and Lee, 1997; Liu, 2000), availability of suppliers (Chan et al., 2001; Drezner and Wesolowsky, 2002; Chu and Chu, 2000; Berman et al., 2005; Berman and Parkan, 1981; Kim et al., 2005), transportation and distribution systems (Yang and Lee, 1997; Liu, 2000), labor force (Pscheco and Casado, 2004; Yang and Lee, 1997; Liu, 2000), available technology, technical expertise, cross-border trade regulations and group trade agreements. Meanwhile, the factors for the selection of the region, city or country include labor (Pscheco and Casado, 2004; Yang and Lee, 1997; Liu, 2000), proximity to customers, number of customers (Min and Melachrinoudis, 2001), construction costs, land costs (Caballero et al., 2005; Drezner and Wesolowsky, 2002; Klose and Gortz, 2005; Min and Melachrinoudis, 2001), availability of modes and quality of transportation (Yang and Lee, 1997; and Liu, 2000), transportation costs (Caballero et al., 2005; Drezner and Wesolowsky, 2002;

Klose and Gortz, 2005; Min and Melachrinoudis, 2001), local business regulations (Badri,1999; Radcliffe and Schniederjans, 2003), business climate (Yang and Lee, 1997; Liu, 2000), tax regulations financial services (Badri,1999; Radcliffe and Schniederjans, 2003), incentive packages applied to that region and labor-force education, are both critical and important in facility location selection. Based on the factors listed, it is clear that there is a need in location problem approaches, to concentrate on the combination of qualitative and quantitative factors (see section 2.1.3). The factors, which affect the facility location, may be grouped into categories as outlined in Table 1.3.

Table 1.3Categories of criteria for facility location problem

Category	**Criteria**
Process input	Raw material, Personnel, Transportation of raw material, workforce availability, Availability of water and power, road-rails.
Process output	Market nearness.
Process characteristics	Environmental factors such as pollution, noise, etc., weather (in case of knitting industry), Level of humidity and seasons, rainfall.
Personal Preference	Preference of executives or entrepreneur.
Govt. Policy	Tax exemption, Legal requirement, Incentives, Availability of loan/land.
Local conditions	Community culture and attribute, Past history of industry located in the area, Incidence of labor unrest in the area, Political interference.
Cost factors	Cost of land, Cost of transportation, wages of unskilled and skilled labor.
Competition	Location of other industries in the area, Market forces for competition.
Intangible factors	International consideration, room for expansion and growth, school, churches, medical facilities, recreational facilities.

The criteria mentioned above are related to many types of problems; however, the criteria for the selection of location for the date palm packaging factory should come from the list above since some or all of the above mentioned criteria may be relevant.

At the same time, new criteria that are unique to Yemen and the city of Hadhramout must also be identified and included if necessary, to ensure the accuracy of the location selection.

However, not all the criteria selected are equally important. Therefore, the determination of the level of importance and the ranking of the criteria should also be given attention. The decision makers need to rank the criteria used for the selected decision to become accurate.

Other than the selection and the ranking of criteria, the determination of the final location will also depend on the objective(s) to be achieved in solving the problem. The related objectives of solving the facility location problem are explained in the next section.

1.1.3 Objective Function(s) in Facility Location Problem

The goal of the facility location problem is to determine the placement for one or more new facilities, subject to various constraints, so as to achieve some objective, typically associated with cost. Usually, the interest is in placing the facilities with respect to the locations of assets of existing entities, which sometimes are called "fixed points." However, there are instances when the selection of the new facilities with respect to each other is also of importance. Several studies have been carried out in solving several facility location objectives. For e.g., Sambola et al. (2005) solved the facility location problem by minimizing the sum of the set up costs plus the routing costs, and Eitzen et al. (2005) solved their facility location problem by optimizing overall product mix for a dairy company. Another facility location problem was solved by minimizing the costs of human resources needed in a mail processing center by Judice et al., (2005), while Wasner and Zapfel (2004) solved their problem by determining the number, locations of hubs and depots and their assigned service areas, as well as the routes between demand points and consolidation points.

Other researchers solved the location problem by designing an outbound supply chain network, which considered lead times, location of distribution facilities and choice of transportation mode (Eskigun et al., 2005). In addition Boland et al. (2005) solved their problem byminimizing the sum of the orders over the number of zones that need to be visited to pick each other. Wang and Regan (2000) solved the facility location problem by developing vehicle assignment for a local truckload pickup and delivery and minimizing total transportation costs by fixing fleet size. In the same vein, Korpela and Lehmusvaara (1999), and Korpela et al., (2001a, 2002) resolved a trucking terminal site location problem which resulted in maximizing customers' satisfaction.

In addition, Malladi and Min (2005) solved a facility location problem by choosing the best high-speed Internet access technology for each rural community based on cost, quality, and speed. By the same token, Cebi and Bayraktar (2003) and Ghodsypour and Obrien (1998) proposed a solution for selecting the best set of suppliers for a particular type of raw material, and to identify the amount of raw materials to be bought from the suppliers. Further, Guo and He (1999), Badri (1999), and Badri; (2001) worked on selecting the best combination of alternatives based on the resource restriction (budget and country restriction of products from locations to distribution centers). Partovi (2006) found a solution for selecting facility locations for companies manufacturing digital mass measurement weighted products for industrial use.

It can be concluded that the previous studies have utilized either one objective function or several objective functions in order to solve their facility location problems. Thus, there is a need to also justify the suitability of whether to use one objective or several objective functions in determining the date palm factory location in Yemen.

As a summary, the objective (s) to be achieved and the combination of criteria to be applied must be embedded in a model that can be solved using several facility location techniques as portrayed in the next section.

1.1.4 Facility Location Problem in Terms of Techniques

Several facility location techniques have been applied to solve the facility location problem. These include criteria rank models, location selection models and location selection integration models.

The criteria rank models are normally used to solve the facility location problems when it is difficult to model the problem mathematically. The possible approaches to be applied in solving the facility location problem, among others, are the scoring model (Taylor, 2004, and Stevenson and Ozgur, 2007), Analytic Hierarchy Process (AHP) (Ho, 2007; Liu et al., 2008; Bhutta and Huq, 2002; Rafikul Islam and Shuib, 2005; Rafikul Islam, 2007; Van Den Honert and Lootsma, 1996; Mohd Armi et al., 2007), ELECTRE III (Li and Wang, 2007), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Isiklar and Buyukozkan, 2006).

The techniques applied above can also be used to rank and give weight to the criteria used in order to know the priority or level of preference of each criterion in determining the location selection. However, rank-based weight methods can also be used to rank the criteria tosolve the facility location criteria. Some of the techniques include the Rank Order Centroid (ROC) (Barron and Barrett, 1996; Jia et al., 1997; Roberts and Goodwin, 2003), Rank Sum (RS) (Barron and Barrett, 1996; Lin et al., 2004; Roberts and Goodwin, 2003), and Reciprocal of the Ranks (RR) (Barron and Barrett, 1996).

In situations where the facility location problem can be modelled mathematically using proper mathematical functions, several location selection techniques have been applied,such as Linear Programming (LP) (Sambola et al., 2005; Eitzen, et al., 2005), Mixed Integer Linear Programming (MILP) (Judice et al., 2005; Wasner and Zapfel, 2004), Integer Linear Programming (ILP) (Eskigun et al., 2005; Boland et al., 2005), and Goal Programming (GP) (Trivedi, 1981; Musa and Saxena, 1984; Berrada, et al, 1996; Moored et al., 1978 Charles et., 1984; Schniederjans et al., 1982) .

However, in some situations, using different approaches (criteria rank models as well as location selection models) may result indifferent locations being selected as the final solution. Some researchers introduced a hybrid or combination of a few existing techniques with the hope of obtaining a more convincing result. Most of the integral models applied to select the best solution integrated AHP with the mathematical programming methods, comprising MILP (Korpela and Lehmusvaara, 1999; Korpela et al., 2001a; Korpela et al., 2002; Crary et al., 2002; Malladi and Min, 2005; Stannard and Zahir, 2006), ILP (Malczewski et al., 1997;

Braglia et al., 2001; Akgunduz et al., 2002; Cebi and Bayraktar, 2003; Kearns, 2004; Ozdemir and Gasimov, 2004), LP (Ghodsypour and Obrien, 1998; Saaty et al., 2003; Lee and Hsu, 2004), GP (Schniederjans and Garvin, 1997; Kwak and Lee, 1998; Radasch and Kwak, 1998; Badri, 1999; Guo and He, 1999; Kim et al., 1999; Lee and Kwak, 1999; Zhou et al., 2000; Badri, 2001; Kwak and Lee, 2002; Radclife and Schniederjans, 2003; Wang et al., 2004; Yurdakul, 2004; Kwak et al., 2005; Bertolini and Bevilacqua, 2006), Quality Function Deployment (QFD) (Koksal and Egitman, 1998; Lam and Zhao, 1998; Partovi, 1999; Partovi and Epperly, 1999; Zakarian and Kusiak, 1999; Chuang, 2001; Hsiao, 2002; Kwongand Bai, 2002; Madu et al., 2002; Partovi and Corredoira, 2002; Myint, 2003; Bhattacharya et al., 2005; Partovi, 2006; Hanumaiah et al., 2006), Meta-heuristics, Strengths, Weaknesses, Opportunities, Threats (SWOT) (Chang and Lo, 2001; Kuo et al., 2002; Chan and Chung, 2004a; Chan et al., 2004; Chan and Chung, 2004b; Chan et al., 2005; Chan and Chung, 2005; Chan et al., 2006), and Data Envelopment Analysis (DEA) (Kurttila et al., 2000; Kajanus et al., 2004; Shrestha et al., 2004; Masozera et al., 2006; Shinno et al., 2006).

To summarize, from the suggested models mentioned above, AHP seems to be the choice for most researchers to be used in either weighting or ranking the criteria, as well as in the final location selection process. The advantage of AHP over other techniques is that the AHP technique applies pairwise comparisons between criteria or two decision elements at a time (Rafikul Islam and Shuib, 2005) which makes the allocation of weights and the ranking of criteria more believable. In addition, the AHP method is also fit for group decision making (Van Den Hornert and Lootsma, 1996).

1.1.5 Analytic Hierarchy Process Technique and its Consistency

The Analytic Hierarchy Process (AHP) is defined as a mathematical technique developed by Saaty in the 1970s. This technique is used for complex multi-criteria decision making (Saaty 1980, 1990, 1994).It makes it easier for decision makers to reduce the uncertainty involved with many kinds of concerns, including applications in group decision making (Saaty et al., 2008), in fields such as government (Syamsuddin and Hwang, 2009), business (Kumar et al., 2009), industry (Burdurlu and Ejder, 2003), healthcare (Liberatore and Nydick, 2008), and education (Liberatore and Nydick, 1997). The AHP is carried out in six steps (Saaty and Vargas, 2001, and Taylor, 2010):

- Step 1: the problem is decomposed into a hierarchy of goals, criteria, sub-criteria and alternatives. This is the most creative and important part of decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. Hierarchy indicates a relationship between elements of one level with those of the level immediately below. This relationship percolates down to the lowest levels of the hierarchy, and in this manner, every element is connected to every other one, at least in an indirect manner. Saaty suggests that a useful way to structure the hierarchy is to work down from the goal as far as one can and then work up from the alternative until the levels of the two processes are linked in such a way as to make comparisons possible.
- Step 2: data are collected from experts or decision makers corresponding to the hierarchy structure, in the pairwise comparisons of alternatives on a qualitative scale as described in Table 2.1.

- Step 3: the pairwise comparisons of various criteria generated at step 2 are organized into a square matrix. The diagonal elements of the matrix are 1. The criterion in the *i*th row is better than criterion in the *j*th column if the value of element (*i, j*) is more than 1; otherwise the criterion in the *j*th column is better than that in the *i*th row. The (*j, i*) element of the matrix is the reciprocal of the (*i, j*) element.
- Step 4: the principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized eigenvector are termed weights with respect to the criteria or sub-criteria and rating with respect to the alternatives.
- Step 5: the consistency of the matrix of order *n* is evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level, then answers to comparisons may be re-examined. The consistency index (*CI)*, is calculated as $CI = (\lambda_{max} - n)/(n-1)$ where λ_{max} is the maximum eigenvalue of the judgment matrix. This *CI* can be compared with that of a random matrix, *RI*. The ratio derived, *CI* / *RI*, is termed consistency ratio (*CR)*. Saaty suggests the value of *CR* should be less than 0.1.
- Step 6: the rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings. The AHP produces weight values for each alternative based

on the judged importance of one alternative over another with respect to a common criterion (Bhushan and Rai, 2004).

The Inconsistency Index (*CI*) measures the degree of inconsistency before computing the weights based on pairwise judgments. Perfect consistency implies a value of zero. However, as human beings, we are often biased and inconsistent in making subjective judgments. Consequently, perfect consistency does not exist which in turn, may lead us to accept some inconsistency up to a certain degree.

In pairwise comparison method, the consistency test is performed to ensure that the decision maker is being neither random nor illogical in his or her pairwise comparisons (Xu et al, 2008).

Literatures have revealed three common approaches to measure consistency. These include Consistency Ratio (CR) by (Saaty, 1980), the Geometric Consistency Index (GCI) (Aguaron and Moreno-Jimenez, 2003), and Harmonic Consistency Index by Stein and Mizzi (2006) and Zeshui (2004) (see section 2.2.2.2).

1.2 Problem Statement

The facility location problem is still very much researched because of several issues. One issue in particular is the selection of criteria to be used. Specifically, different locations have different criteria and selecting the criteria is very important in determining the suitable location. It is worth mentioning that for the problem studied in this thesis, before selecting the best location of the date palm factory, several problems related to the location selection were considered. First, the evaluation of the criteria in which there are various criteria available to solve the facility location problem as mentioned in section 1.1.2. However, there were some undetermined aspects, such as whether the criteria were enough to solve the current problem, which criteria from the available criteria were suitable for the current study, and which criteria were more important for this identified problem; and second, having evaluated the criteria, the problem of selecting the appropriate technique to measure the rank and weight of the criteria as discussed in section 1.1.4. It is worth highlighting that AHP and ROC are two suitable techniques to measure the rank and weight of the criteria. In this case, the ROC computes the weight according to the ranking of the criteria given by the evaluators, while AHP computes the weight according to the pairwise comparison between the criteria by the evaluators.

However, a problem may occur with ROC when the decision makers give the same order or rank to two different criteria. When this happens, the sum of the weights of all the criteria is not equal to one. Meanwhile, the AHP technique may have a problem in terms of consistency in pairwise comparisons done by evaluators which, up to now, has not been solved. Usually, when this occurs, the evaluators are either requested to redo the pairwise comparisons or the evaluators' inputs are excluded from the analysis. In the former case, when the evaluators redo the pairwise comparison, the original thought or preference is disturbed. Hence the result might be distorted. As for the latter, if there are many evaluators, deleting a few inconsistent evaluators may not affect the result that much. However, if there are only a few evaluators involved, the deletion of inconsistent evaluators is not an option. In terms of the results, it is not guaranteed whether the AHP and ROC give the same weight for the criteria.

Finally, after solving the evolution and ranking the criteria, the decision on the location has to be made. There are many models available to refer to in choosing the location as elaborated in Section 1.1.4. The researcher is of the view that the use of 0-1 integer programming mathematical model is appropriate in selecting the suitable location because only one location should be selected (Tamiz et al., 2002).

1.3 Objectives of the Study

The objectives of this study are outlined to solve the identified problems and to answer the research questions. Hence, this study aims to achieve the following objectives.

- To identify the criteria for selecting the best location for the date palm packaging factory.
- To propose the techniques for ranking the criteria
- To formulate an approach to reduce inconsistency in pairwise comparisons
- To rank the criteria.
- To propose the models for selecting the best location
- To determine the best location of the date palm packaging factory based on the criteria.

1.4 Scope of the Study

This study seeks to find a solution for a facility location problem that exists within Hadhramout province, Yemen. Firstly, to solve a facility location problem in Hadhramout, seven districts in Hadhramout (Sah, Seyoun, Tareem, Shabam, Al-qaten, Doean, and Wadi Al-Aeen and Horah) which are deemed as potential locations for the date palm packaging factory were chosen by the government in Yemen because these districts produce the most raw dates.

Secondly, although there are many criteria that can be used to determine the final location of the palm dates packaging factory, only eleven most prominent criteria were chosen. The number of criteria should not be too many to avoid confusions among evaluators particularly when applying the AHP (Saaty, 1980).

1.5 Contribution of the Study

This study is important because it can substantially increase the focus of the Yemeni government on the production of the date palms in recent years as a national resource. Similarly, topics relating to facility location problem are determined to be significantly important to the sustainability of the Yemeni economy, local farmers, and the labor force. More importantly, research on facility location problem is important, particularly because findings stemming from this research will contribute to the operations research (OR) literature on both the theoretical and practical aspects.

1.5.1 Theoretical Aspect

Three models of facility location problem are investigated and evaluated in deciding on the location in which the factory should be built. The models are the ROC combined with the 0-1 IP, the AHP combined with 0-1 IP, and the mean of weights ofthe ROC and the AHP combined with the 0-1 IP. Based on the works available in the literatures, no previous empirical study has been found which examined the ROC in the facility location problem. Also, no previous study has been found which combined the ROC with the 0-1 IP in the facility location problem and no previous study has combined the mean of the ROC and the AHP with the 0-1 IP.

In the AHP, a new approach is introduced in doing the pairwise comparison that can guarantee the consistency all the time. In addition, the ROC model is applied in this study to weight the criteria with an emphasis given to the evaluator that provides the same rank for more than one criterion.

1.5.2 Practical Aspect

This study is expected to have the following several practical contributions:

1.5.2.1 Benefits of the Study

This study benefits, in general, the researchers working in the OR field, by supporting the implementation of the recent agreement issued by the Yemeni government, as to the importance of building a date palm packaging factory and how this step can contribute to improving the production of the date palm trees in the region. This is because if the farmers get benefits from this factory, the farmers will then plant more date palm trees and when the date palm trees increase, normally the production of date palm will increase as well. Since the agreement of establishing the date palm packaging factory exists, the most significant issue the government should take into consideration is to determine the best location for establishing the factory, from among the alternative locations available in Seyoun, Sah, Shabam, Trareem, Wadi Al-Aeen and Horahh, Al-Qaten, and Doean.

1.5.2.2 Facility Location Problem in Yemen

This study intensifies our understanding of the facility location problem in Yemen. With a little knowledge about this area, this research provides a basis for further study and provides insight into the unknown areas in the Middle East.

1.5.2.3 Facility Location Problem Criteria

This study investigates information regarding factors that determine the facility location problem, with new insights devoted to newly introduced variables. Furthermore, investors who intend to venture into date palm manufacturing would benefit from an increased understanding of the facility location problem in the Yemeni context. This opportunity would help them to assess the factors influencing the facility location problem. Further, the factory will enhance the date palm trees' production leading to farmers' better living conditions. It will also provide jobs for the unemployed. Hence, hundreds of white and blue-collar workers can have an opportunity to work in the factory.

Besides, this study provides insights into facility location issues in Yemen. These insights are beneficial to the policy makers. They would be able to decide on the solutions of the "what", "when", and "how" facility location problems in Yemen.

1.5.2.4 Researchers and Academic Community

This study is also within the interest of researchers and academic community due to lack of systematic research that has addressed the issues of facility location problem in Yemen. In response to that, this study provides substantial information about issues in the Yemeni market, as a basis for future research.

This study differs from the prior research conducted in the facility location problem in several aspects. It investigates and produces empirical evidence showing the facility location problem in Yemen, in which literatures reveal that empirical studies examining the facility location problem in Yemen have not been carried out.

1.6 Thesis Organization

In this thesis, a facility location problem is presented. The main contribution is the formulation of an approach to reduce inconsistency in pairwise comparison in the AHP model and the tie in criteria ranking in the ROC model. Then, we introduce an integration of the ROC-0-1 IP, the AHP-0-1 IP, and the ROC and the AHP-0-1 IP models to choose one final location from several locations to build date palm packaging factory in Yemen.

This chapter firstly, reviews the general introduction of facility location problem by explaining the criteria, objectives, and techniques used in facility location problem, followed by the AHP and inconsistency models. The second part explains the statement of the problem, objectives of the study, scope of the study, contribution of the study, and finally, the report organization. The next chapter reviews the classification of facility location problem, the models, objectives, and techniques. This is followed by the introduction of the multiple criteria decision making (MCDM) which is explained in two parts: identification and evaluation of the criteria. Chapter two closes with a discussion on the impact of the criteria to this study. Chapter Three continues by reviewing the literatures of some available techniques to solve the date palm packaging factory problem. Chapter Four explains how the data for this study were collected, as well as the method used in the analysis of the data. Later, data analysis and discussions of the results are provided in Chapter Five. Finally, Chapter Six concludes the study by addressing several recommendations. It also discusses the possible extensions of the study and scope for further investigation.

CHAPTER TWO

IDENTIFICATION OF CRITERIA AND THE EVALUATION TECHNIQUES IN FACILITY LOCATION PROBLEMS

This chapter is divided into two main sections. The first section elaborates in detail on the objectives and criteria used in solving facility location problems. The second section discusses several suitable techniques that are being applied in solving the facility location problems. The chapter concludes with a summary and justifications for the adoption of suitable techniques in weighting the criteria in solving the facility location problems as the theoretical basis for this study.

2.1 Classification of Facility Location Models, Objectives and Criteria Used

The classification of facility location problem is discussed in three parts: the facility location models, facility location objectives, and the criteria used in facility location problem.

2.1.1 Facility Location Models

The goal of the facility location problem is to determine the placement for one or more new facilities, subject to various constraints, so as to achieve some objective, typically associated with costs. Usually, the interest is in placing the facilities with respect to location of asset of existing entities, sometimes called “fixed points”. Literatures reveal a number of models in solving problems related to facility location. Among the most applied models include the Covering Model, the P-center Model, and the P-median Model. The major difference that sets these three models apart is in the objective function used in each model.

Covering Models aim at minimizing the facility quantity while providing coverage to all demand nodes or maximizing the coverage, provided the facility quantity is pre-specified (Chung, 1986). In contrast, the P-center Models aim at minimizing the maximum distance (or travel time) between the demand nodes and facilities (Chen and Handler, 1993). They are often used to optimize the locations of facilities in the public sector such as hospitals, post-offices, and fire stations. Meanwhile, the P-median models attempt to minimize the sum of distance (or average distance) between the demand nodes and their nearest facilities (Rosing et al., 1979). Companies in the private sector often utilize P-median models to make facility distribution plans so as to improve their competitive edge**.**

2.1.2 Objective Functions Used in Facility Location Problems

Different objective functions have been utilized to solve different facility location problems. Farahani and Hekmatfar (2009), for example, stated that the location models have been deployed in various applications, including in locating warehouses so that the mean time to market is minimized. Sambola et al. (2005), Wang and Regan (2000), and Judice et al. (2005) solved a manufacturing facility location problem to minimize the costs. Meanwhile, Eitzen et al. (2005) solved a business facility location problem to optimize the overall product mix for a dairy company. Korpela and Lehmusvaara (1999), Korpela et al., (2001a), and Korpela et al. (2002) solved a trucking terminal site location problem to maximize customers' satisfaction. Similarly, Cebi and Bayraktar (2003) and Ghodsypour and Obrien (1998) chose the best set of suppliers for a particular type of raw materials. Further, Badri (1999), Badri (2001), and Guo and He (1999) solved a service facility location problem to choose the best combination of alternatives.

Regardless of what facility location model is selected and the objective function(s) applied, the final location selection may also depend on the criteria used.

2.1.3 Criteria Used in Facility Location Problems

The opinions of decision makers are represented by appropriate criteria which are sufficient for making comparisons. A criterion measures how effective and sufficient the rules or judgments are in testing the acceptability that justify the reasons and support for analysis (Drobne and Lisec, 2009). Criteria can be classified into quantifiable and non-quantifiable criteria with respective objective and subjective traits. Further, they can be described as the attributes of an alternative within the multi-criteria decision making (MCDM). In short, the criteria, attributes, objectives, and goals are often used in place of others to point out an assessment references.

Researchers on the facility location problems have been using several criteria to determine the best location under investigation. The following sub-sections discuss the most suitable criteria used in solving a facility location problem.

2.1.3.1 Cost

Cost is a very significant criterion related to facility location problems. In particular, labor cost, land cost, and transportation cost are among the concerns.

i. Labor Cost

Labor cost comprises wages and non-wages benefits, like contributions to medical plans, vacation time and pay, and pension schemes. They vary by industry, country, and region and in unionized and non-unionized sectors. Tremendous differences in labor costs can be seen between countries with high wages like developed countries and less developed countries, like China and India. Nevertheless, the labor costs can also vary within any particular country (Marianov and ReVelle, 1992; Yang and Lee, 1997; Ishizaka and Labib, 2011; Ozkan et al., 2011).

ii. Land Cost

Suburban land and building are generally available at a lower cost per square feet and there is room to expand due to higher land availabilities in suburban areas. In addition, the redevelopment within cities requires costs. In fact, development in cities and redevelopment cost within the city core is very expensive (Mohammed, 2005; Caballero et al., 2005; Tahriri et al., 2008; Ishizaka and Labib, 2011).

iii. Transportation Cost

For warehousing and distribution operations, transportation cost is extremely important. With a warehouse nearby, many firms can hold inventory closer to customer, thus reducing delivery time and transportation cost and promote sales. But the transportation cost increase if they are far from the warehouses. In addition the transportation costs will increase if the production to be transferred is heavy. Hence, transportation cost re determined by: (1) the physical characteristics, such as the value and quantity of the products; and (2) by freight rates (Alakil, 2003; Klose and Gortz, 2005; Ozkan et al., 2011).

iv. Other Costs

The finished products need to be distributed to the markets, which incur distribution costs. Locations near to the inputs incur lower procurement costs, while locations near to the markets incur lower distribution costs. While the transportation costs comprise direct freight charges, transfer costs refer to both direct costs and indirect costs, such as insurance costs and losses resulting from damage in transit, construction costs, and utilities costs (telephone, energy, and water) (Min and Melachrinoudis, 2001; Drezner and Wesolowsky, 2002; Hwang et al., 2005; Ariffi et al., 2008).

2.1.3.2 Labor Availability

The most important factor in most firms in deciding the locations for their factories is labor. For most firms, high quality labor is important because the firms value the labor output per dollar. Productivity can decrease if certain types of labor are in short supply. This happens in the event of increasing costs required to pay for the available labor, the labor hired from other areas, or the use of less productive labor that is available locally (Dumais et al., 1997; Yang and Lee, 1997; Liu, 2000; Fulton and Paul, 2001; Pscheco and Casado, 2004; Ozkan et al., 2011).

2.1.3.3 Proximity to Market

Proximity to markets is another criterion affecting the selection of locations and is subject to infrastructure and transportation merits on some special attentions. Firms need to move their products, either goods or services, to the market. Hence, different modes of transportations are utilized. In this regard, locating near markets is particularly important in case the final goods are bulky or heavy and outbound transportation rates are high (Hansen et al., 1997; Liu, 2000; Min and Melachrinoudis, 2001; Ozkan et al., 2011).

2.1.3.4 Proximity to Raw Materials

Raw material is another important criterion in selecting locations. Firms producing goods, and even firms providing services, need various materials to develop products that they can sell. Some firms need to be located close to the source of their raw materials. Some firms need natural resources such as lumber (Yang and Lee, 1997; Liu, 2000; Ozkan et al., 2011; Maidamisa et al., 2012).

2.1.3.5 Proximity of Resources to Suppliers

Sometimes, the raw materials cannot be obtained from the location. Therefore, the resources need to be nearer to the location so that suppliers can have access to them. Suppliers and resourcesin many companies and plants supply parts to other facilities or rely on other facilities for management and staff support. These require frequent coordination and communication, which can become more difficult as distance increases (Berman and Parkan, 1981; Chu and Chu, 2000; Chan et al., 2001; Drezner and Wesolowsky, 2002; Berman et al., 2005; Kim et al., 2005).

2.1.3.6 Proximity to Customers

Location is a key factor in determining how conveniently customers can carry on their business with a firm. Thus, the influence of location on revenues tends to be the dominant factor. The factory should seek another location if the customer's proximity is inadequate because the key is proximity to customer who will patronize the facility and seek its services (Berman and parkan, 1981; Chu and Chu, 2000; Chan et al., 2001; Drezner and Wesolowsky, 2002; Berman et al., 2005; Kim et al., 2005).

2.1.3.7 Land Availability

Another criterion is land, the demand for it being dependent on the type of firm. Manufacturing firms need more space and tend to prefer suburban locations where the land is relatively less expensive and less difficult to develop. In contrast, warehousing and distribution firms need to be close to interstate highways (Yang and Lee, 1997; Bernnan et al., 1999; Ozkan et al., 2011).

2.1.3.8 Capital

Capital is one of the conditions considered for a location. It is important to distinguish the physiology of fixed capital in buildings and equipment from financial capital. Fixed capital costs, like building and construction costs vary from region to region. Besides, buildings can also be rented and existing plants can be expanded. Financial capital is highly mobile and does not influence decisions very much (Yang and Lee, 1997; Bernnan et al., 1999; Ozkan et al., 2011).

2.1.3.9 Community Infrastructure and Amenity

Community infrastructure and amenity or quality of life is an important criterion as all manufacturing activities require access to the community infrastructure, most notably economic overhead capital, such as roads, railways, port facilities, power lines, and service facilities. Besides, social overhead capital, such as schools, universities, and hospitals, low crime rate, and a clean environment is also important. These criteria also need to be considered by location decisions as infrastructure is enormously expensive to build. For most manufacturing activities, the existing stock of infrastructure provides is physically restrictive for growth of industries. An existing infrastructure does not cause industry to occur (Eberts, 1991; Fisher, 1997; Pscheco and Casado, 2004; Ozkan et al., 2011).

2.1.3.10 Government Regulation

Regulations protect the health and safety of a community, and help maintain the quality of life. However, simplified bureaucracies and straightforward regulations can help firms react quickly in a competitive marketplace (Jaffe et al., 1995; Tannewald, 1997; Goodstein, 1999).

2.1.3.11 Other Criteria

Besides the criteria explained in the previous subsections, other criteria may need to be considered, including room for expansion, construction costs, accessibility to multiple modes of transportation, the cost of shuffling people and materials between plants, insurance cost, competition from other firms for the workforce, local ordinances (such as pollution or noise control regulations), (Drezner, 1995), community attitudes, climate, culture (MacCormack, 1994), taxes (Buss, 1999; Helms, 1985; Phillips et al, 1995; Wasylenko, 1997), incentives and enterprise zones (Bartik, 1994; Buss, 1999; Engberg and Robert, 1999), etc.

All or some of the criteria mentioned in the previous paragraphs can be embedded either as part of the objective function(s) or as constraints in the model. Facility location is obviously a MCDM problem because in the facility location problem, there are many facilities to be chosen and many criteria to be evaluated to select the best location. The criteria should be evaluated by the decision maker(s) to select the best solution (Yang and Lee, 1997).

2.2 Multiple Criteria Decision Making

Multiple criteria decision making (MCDM) is a sub-discipline of operations research that explicitly considers multiple criteria in decision making environments. It refers to making decisions in the presence of multiple, usually conflicting criteria. The problems of MCDM can be broadly classified into two categories: multiple attribute decision making (MADM), and multiple objective decision making (MODM) (Saaty, 1988; Xu et al., 2006). The major difference between the two classes lies in the existence of predetermined alternatives. MODM deals with optimization problems, in which several objective functions should be satisfied, while MADM is associated with the problems in which alternatives have been predetermined. In other words, MADM involves making preference decisions (evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting attributes. It is widely used for real world problems (Xu et al., 2006).

Facility location problem can be classified as a MADM model since the location selection is done after evaluating a finite set of alternatives with respect to multiple criteria. The main purpose in most MADM problems is to measure the overall preference values of the alternatives on some permissible scale. Alternatives are generally first evaluated explicitly with respect to each of the criteria to obtain some sort of criterion-specific priority scores which are then aggregated into overall preference values. These criterion-specific scores and overall values may be in ordinal, interval or ratio scales (Bhushan and Rai, 2004).

While ordinal scales on the overall preference values are sufficient if only the best alternative needs to be selected, interval scales are used in multi-attribute utility theory (MAUT) function models. Meanwhile, ratio scales are assumed in the AHP. In terms of the differences, the interval scales have measurements which are in equal distance from each other. This means the interval is a measurement where the difference between two values is meaningful and follows a linear scale. Interval data is continuous data where differences are interpretable, ordered, and constant, but there is no 'natural' zero (0). In contrast, ratio scales include an absolute 0 measurement, which signifies the point when the characteristic being measured vanishes. In addition, ratio is the relation in degree or number between two similar things or a relationship between two quantities, which are ordered, constant, and with natural 0. Ratio data is interpretable and could be a natural 0. This explains that the interval and ratio scales are almost similar, but ratio scales must be measurable at a 0starting point (Grabish, 1996; Cho et al., 1998).

To solve a facility location problem as a part of MADM, there are three main stages: the first stage deals with the identification of the suitable criteria and the location alternatives by the evaluators; the second stage involves evaluating the criteria by finding the weights of the criteria; and the third stage requires the selection of the best solution by combining the weights of the criteria and the values of the criteria to get the overall score of the alternatives or options in context of the location. The first two stages are described further in the following sections, while the third stage is elaborated in Chapter Three.

2.2.1 Identification of the Criteria

The relevant criteria to be used vary, depending on the nature and type of the location problem. The criteria may come from those criteria discussed in Section 2.1.3, as well as from new criteria that are unique and only applicable to a particular location problem. As an illustration, Aida Mauziah (2004) listed proximity to the mosque as one of the criteria to determine the location for a new housing project. This criterion has not been found in any other studies, but was included in her study since the criterion was appropriate in that particular context.

2.2.2 Evaluation of the Criteria

Many different methods have been proposed for assessing criteria weights which are then used explicitly to aggregate criterion-specific priority scores. These approaches can be classified into subjective approaches and objective approaches, depending on the information provided (Ma et al., 1999; Xu, 2004; Kong and Liu, 2005; Abbas et al., 2011). The subjective approaches select weights based on preference information of attributes given by the decision matrix (M) while, the objective approaches determine weights based on the objective information (Ma et al., 1999).

Weights determined by subjective approaches reflect the subjective judgment or intuition of the decision maker (DM), but analytical results or rankings of alternatives based on the weights can be influenced by the DM due to his/her lack of expertise, intuition, past data, experiences, knowledge, and facts. Various subjective approaches have been proposed, such as ratio method, rating method, tradeoff analysis, swing method, ranking methods, and pairwise comparison method (Ma et al., 1999; Xu, 2004).

Meanwhile, objective approaches often determine weights by solving mathematical models without any consideration of the decision maker's preference. Since the problem to be solved in this study focuses on the subjective approaches, several previous related researches regarding these approaches are discussed in the following sub-sections. Among the suitable techniques are ranking techniques, pairwise comparison techniques, and a few other techniques.

2.2.2.1 Ranking Methods

Ranking methods, compared to other methods of human judgments, are very reliable and make it easy and simple to assign weight relatively (Eckernrode, 1965; Johnson &Huber, 1977). The requirement is that for decision making, the levels of factors have to be in order of preference from the most to least preferred factors or making a pair of the most preferred factor level as a choice. Accordingly, Barron and Barrett (1996) addressed three popular weighting formulas for ranking order, known as Reciprocal of the Ranks (RR), Rank Order Centroid (ROC), and Rank Sum (RS). For every rank-based method, suppose there are *n* criteria to be evaluated. Accordingly, let w_i be the weight of a criterion which is ranked at *i*th position. Then, the formula of (*RS*) method is stated in Equation 2.1.

$$w_i(RS) = \frac{2(n+1-r_i)}{n(n+1)}, i = 1, 2, \dots, n \qquad (2.1)$$

Where, w_i is the weight of criterion *i*, *n* is the number of criteria, and r_i is the rank of criterion *i*. for example, suppose there are 5 criteria, then the weights can be calculated as follows:

w_1= 2(5+1-1)/5(6) = 10/30 = 0.33, w_2 = 2(5+1-2)/5(6) = 8/30 = 0.27

w_3 = 2(5+1-3)/5(6) = 6/30 = 0.20, w_4 = 2(5+1-4)/5(6) = 4/30 = 0.13

w_5 = 2(5+1-5)/5(6) = 2/30 = 0.07.

The formula of RR method is given in Equation 2.2.

$$w_i(RR) = \frac{\frac{1}{r_i}}{\sum_{i=1}^{n}\frac{1}{r_i}}, i = 1, 2, \dots, n \qquad (2.2)$$

As an illustration, suppose there are 5 criteria, then the weights can be calculated as follows

w_1 = (1/1)/(1+1/2 +1/3 +1/4 +1/5) = 1/2.25 = 0.44

w_2 = (1/2)/ (1+1/2 +1/3 +1/4 +1/5) =0.5/ 2.25 = 0.22

w_3 = (1/3)/ (1+1/2 +1/3 +1/4 +1/5) = 0.33/ 2.25 = 0.15

w_4 = (¼)/(1+1/2 +1/3 +1/4 +1/5) = 0.25/ 2.25 = 0.11

w_5= (1/5)/ (1+1/2 +1/3 +1/4 +1/5) = 0.2/2.25 = 0.09

The ROC method can be computed by averaging the corresponding coordinates of the defining vertices (Barron & Barrett, 1996). They apply the ROC to identify approximate weights in decision making process. Specifically, the formula of ROC method is given as in Equation 2.3:

$$w_i(ROC) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{r_i}, i = 1, 2, \ldots, n \quad (2.3)$$

For example, suppose there are 5 criteria, then the weights can be calculated as follows

w_1 = 1/5 (1+1/2 +1/3 +1/4 +1/5) = 0.46,

w_2 = 1/5 (1/2 +1/3 +1/4 +1/5) = 0.26, w_3 = 1/5 (1/3 +1/4 +1/5) = 0.16,

w_4 = 1/5 (1/4 +1/5) = 0.09, w_5 = 1/5 (1/5) = 0.04.

The sum of the five criteria equal 1, $w_1+w_2+w_3+w_4+w_5$ = 1or$\sum_{i=1}^{5} w_i$=1. In a case where the total weight given to a group of attributes equals 1, it implies that $\sum_i^n$

w_i=1,w_i=1, i = 1, 2,…,n. which also means that the number of criteria to be ranked has limits.

Barron and Barrett (1996) state that ROC is more accurate than the other rank-based formulae; because the ROC formula generalizes to incorporate both forms of information, i.e., about attribute weights and partial rank order information, as well. Furthermore, ROC- based analysis is so straightforward and efficacious, as it provides an appropriate implementation tool (Roberts & Goodwin, 2003; Maznah Mat Kasim, 2008).

2.2.2.2 Pairwise Comparison Method

Pairwise comparison generally refers to any process of comparing entities in pairs to judge which of each entity is preferred, or has a greater amount of some quantitative property (Saaty, 1999). In the 1970s, Saaty came up with pairwise comparison which has generally been employed in tackling problems associated with MADM (Yeh et al., 1998; Eshlaghy and Farokhi, 2011). The method is capable of dealing with subjectivities in a numerical form as well as putting a given set of items' attributes in order form. The method has to pair one item with another item in a given set of items in a pairwise comparison matrix (Saaty, 1990). As a consequence, a structurally-based reciprocal pairwise comparison matrix having a subjective scale ranging from one to nine is called Saaty's rating scale. Table 2.1 exhibits the rating scale values that stand for the degree of priority or preference.

On the other hand, this approach is not effective when the number of pairwise comparisons to be made becomes very large and doubles the tasks. To solve this limitation, Saaty suggests that the criteria to be used should not exceed nine (Saaty, 1995).Analytical Hierarchy Process (AHP) (Saaty, 1970, 1990, 2008) and Analytical Network Process (ANP) (Bayazit, 2006; and Percin, 2008) are among the techniques that use pairwise comparison.

The AHP technique is one of the pairwise techniques used in this study. It has been modified to guarantee consistency at all times. The technique is used because it is a powerful and flexible decision making process to help people set priorities and make the best decisions when both qualitative and quantitative aspects of a decision are considered (Saaty, 1994).

i. Definition and History of AHP

The concept of AHP was developed, among other theorists, by Thomas Saaty, an American mathematician working at the University of Pittsburgh in 1977, and has been extensively studied and refined since then. The AHP is an approach in making decisions that involves structuring multiple choice criteria into a hierarchy. It involves assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining the overall ranking of the alternatives (Saaty, 1994).

The AHP is another method to address the MCDM problem. It is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It has been utilized in various applications in group decision making. In current practice, it is used around the world in a wide variety of decision making situations and fields, including government, business, industry, healthcare, and education(Saaty,2008).

ii. The Usage of AHP in Terms of Criteria Weighting and Inconsistency

Saaty (2008) points out that it is necessary for the decisions to be decomposed into steps for it to be made in a well-planned way for priorities generation. The steps are as follows: (1) the problem and knowledge are defined and determined respectively;(2) decisions are structured in an order of importance from the highest to the lowest with respect to the decision's goal; then a wider view of the objective via the intermediate level (a criteria which the next element depends upon) to the bottom level often known as a set of alternatives is formulated; (3) the construction of pairwise comparison matrices in which the individual element at the higher level is employed to distinguish the element that follows it in the next level; and (4) the priorities are obtained from the comparisons to weight the priorities that follow in the next level. These steps are repeated for each of the elements.

In making comparisons, a scale of numbers is needed that indicates the number of times an element is more important or dominant over the others with respect to the criterion or property. In addition, it is subject to what they are compared to by using Saaty's Pairwise comparisons of the level of importance between decision elements as outlined in Table 2.1 (Taylor, 2010).

Table 2.1 Preference scale for pairwise comparisons

***Preference Level**	**Numeric Value**
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

*Preference level can also be replaced by importance level, significance level, or any other appropriate levels.

All the data collected from the respondents according to the scale are transferred into a matrix form. The comparison matrix is manipulated mathematically to determine the weights of the criteria w_j, $j = 1,\ldots,m$. Accordingly, the pairwise comparisons matrix should be formed as shown in Equation 2.4,

$$D = \begin{bmatrix} 1 & y_{12} & \cdots & y_{1m} \\ y_{21} & 1 & \cdots & y_{2m} \\ \vdots & \vdots & & \vdots \\ y_{i1} & y_{i2} & \cdots & y_{im} \\ \vdots & \vdots & & \vdots \\ y_{m1} & y_{m2} & \cdots & 1 \end{bmatrix} \qquad (2.4)$$

Where y_{ij} is the pairwise comparison value. For example, y_{12} means the level of preference of criterion 1 over criterion 2.

The priorities of the pairwise comparison matrix then need to be determined. The values obtained in the matrix are according to the crisp AHP scale. After the matrix is obtained, the elements are summed in each column. Then, each element in the pairwise comparison matrix is divided by the values in the total column. Next, the average of the element in each row is computed. The average provides the priorities for the criteria.

Then, the consistency for each criterion is computed. Chapter Four (Section 4.3.4.2) elaborates in detail about the steps, with real examples using the collected data.

iii. Consistency in AHP

In AHP, the idea of consistency is also considered important. The term ‘consistency’ refers to the extent of maintenance of the perceived association between existing elements in the pairwise comparison. This is necessary because comparisons made without consistency could lead to lack of understanding on the path of respondents with respect to the distinctions in the choices provided or the relative significance of the compared elements could not be properly evaluated .Besides, consistency could also be affected in case the information regarding the compared criteria and the concentration during the process of judgment are lacking (Ta and Har, 2000).

As there is a difficulty in ensuring consistency when dealing with pairwise comparisons, several studies have suggested some alternatives. Saaty (1980) suggests that especially for cases involving qualitative attributes; *CR* can be lowered down to between 0.1 and 0.2. However, in so doing, the credibility of the logic becomes less solid. Meanwhile, in cases involving many variables, *CR* can easily exceed 0.2.

In the event of manipulating some of Saaty’s arithmetic operations, Lamata and Pelaez (2002) suggest a method for improving the consistency of judgments. Unfortunately, the method somehow alters the logic presented by Saaty, in spite of the fact that the method has managed to reduce inconsistent judgment. The

Geometric Consistency Index (GCR) was introduced by Aguaron and Moreno-Jimenez (2003). It replaces the CR, which was later confirmed by Saaty himself as being a valid replacement for the arithmetic operations. However, the issue of the original consistency is still unresolved, since Aguaron and Moreno-Jimerez simply introduced a new formula to calculate the consistency in which the pairwise comparison approach was not improved.

Consequently, several studies have ignored conducting pairwise comparison entirely. In this regard, some studies applied simpler approaches, such as simple scoring model (Stevenson and Ozgur, 2007), rank method (Roberts & Goodwin, 2003), ELECTRE III technique (Li and Wang, 2007), and ROC (Roberts and Goodwin, 2003). However, these techniques have been criticized as lacking good features that appear in AHP, especially those related to the pairwise comparison.

Zeshui (2004) proves that the consistency of the weighted geometric mean for complex judgment matrix is acceptable on condition all judgment matrices for the same problem are of acceptable consistency. Accordingly, Zeshui introduced a new formula to calculate consistency. However, the study has not improved the pairwise comparison approach. In geometric mean approach, it is supposed that there exits more than one respondent. Hence, their judgment should be aggregated to get a single value. Therefore, the geometric mean approach is applicable. Theoretically, in geometric mean computing, the weight (w_j) given by each respondent is multiplied and squared by the number of respondents (Zahir, 1999). Stein and Mizzi (2006) outline how the new consistency measure harmonizes the variations in the consistency index with change in any matrix element. This index has been developed to produce numerical values similar to the standard consistency index. But it is easier to compute and can interpret new properties of the column that contains the sums of reciprocal matrices obtained.

iv. Strengths and Weaknesses of the AHP

All methods of modeling have their own strengths and weaknesses. Therefore, in MCDM, there have been debates concerning the strengths and weaknesses of the AHP by the specialists. Among the strengths are:

- AHP is very flexible, able to check inconsistencies in pairwise comparisons and possesses intuitive appeal to the decision makers (Ramanathan, 2001). Data imputation is also easy and direct.
- It is good at decomposing a decision problem into various parts by giving the criteria order of arrangement which clearly defines the importance of each element (Macharis et al., 2004).
- AHP is capable of capturing the objective as well as the subjective assessment measures.
- AHP lessens the biasness in making decisions by offering a checking mechanism for the consistency of the assessment measures, as well as evaluation alternatives.
- It also estimates the geometric mean of each pairwise comparison and by so doing, buttresses the decision made in group via consensus (Zahir, 1999).
- AHP has the advantage of deriving scales in the absence of ordinary measures and thus assists in modeling in risky and uncertain situations (Millet and Wedley, 2002).

In terms of limitations, AHP is vague in the following aspects:

- Irregularities have been noticed in ranking when AHP method or its variants are employed. There is likelihood of having rank reversal in a case where a sample of an existing choice is included in the alternative set under assessment. According to Triantaphyllou (2001), rank reversal is unlikely given that a multiplicative AHP's variant is employed. This is in line with Belton (1986) and Belton and Gear (1997), who note that a basic concern in the ranking reversals of AHP lie in how to interpret the weights of criteria. In addition, some variants of AHP and the AHP itself are still regarded to be more dependable in the MCDM methodology.
- The AHP is aggregation of an additive form and accordingly, it has aggregation problem. The aggregation problem in this case is the occurrence of compensation taking place between good scores and bad scores. The former is on some criteria while the latter is on other criteria. As a consequence of such aggregation, essential information is likely to be lost.
- Decision problems are broken down into various sub-systems in AHP. This means a large number of pairwise comparisons are required to be completed within and between the sub-systems. The problem in this process is that pairwise comparisons to be done could be very large i.e. (n $(n-1)/2$), which consumes a sufficient amount of time to work (Macharis et al., 2004).
- AHP is also weak in allowing the employment of 9-point scale. In that case, it becomes problematic for decision makers to differentiate among them or point out which alternative is more important by six or seven times compared to another. In addition, AHP is incapable of coping with the scenario where

alternative Y is 25 times more important than alternative Z (Murphy, 1993; Belton & Gear, 1983; Belton, 1986). As a result of analysis on the scale's limitations, Hajkowicz et al., (2000) propose that the scale needs appropriate modification.

v. Other Related Studies about AHP Scale

In addition to Saaty's scale, there are two other scales available to obtain the pairwise comparison matrix. The scales are named Lootsma and Fuzzy.

- **Lootsma Scale**

Lootsma scale is a specific geometric scale. It has a fixed scale parameter (u = 2 or 4) and the number of gradations (m = 7 or 9). However, the parameter should not be fixed since a particular problem has its own optimal parameter. Besides, the upper bound of the Lootsma scale is 8, 16, 64, or 256. When the upper bound is 64 or 256, Saaty's homogencity axiom will be severely violated.

- **Fuzzy Scale**

In fuzzy AHP scale, the linguistic variables are used to compare the relative importance between any two dimensions. These linguistic variables with 9-point scale can compare nicely. Further, the comparative ratings can be represented in trapezoidal fuzzy numbers (Zheng et al., 2012). The main difference between crisp and fuzzy is in the scales which are selected by the evaluators. Specifically, the evaluators in crisp AHP are required to compare between each of the two criteria by selecting exactly one number from 1 to 9. In contrast, in fuzzy AHP, the evaluators are required to compare between each of the two criteria in words, or in linguistic expression to obtain the matrix comparison. In addition, the important point is that if the information evaluations are certain, crisp method should be preferred; if the information evaluations are not certain, fuzzy method should be preferred. However, its usage is time consuming because it involves a lot of mathematical calculations. Based on the descriptions in the previous paragraphs, this study deduces that Saaty's scales are suitable for adaptation into this study. This is because the evaluators involved in this study are those who have experience in the location facility. Hence, it is assumed that they are confident and certain in evaluating the criteria.

vii. Applications of AHP in Terms of Weighting the Criteria

Several applications have used the AHP technique for decision making purposes in most sectors. It can be seen in logistics (Korpela et al., 2002; Cebi and Bayraktar, 2003; Chan and Chung, 2005; Chan et al., 2004, 2005, 2006; Wang et al., 2006; Mahmoodzadeh et al., 2007; Ariffi et al., 2008; Tahriri et al., 2008). In a study by Chan et al., (2004, 2005), the AHP method was used to weight the criteria. The only difference is the assessment criteria. Besides total cost, two new criteria were used to measure the fitness of the solutions: total lead time and tardiness. Meanwhile, Chan et al., (2006) viewed the same problem and used the same method as Chan and Chung (2005). The only difference is the assessment criteria applied in the AHP method. Besides total cost, total lead time, and tardiness, effectiveness of capacity utilization was also viewed. This criterion was already suggested in their brier papers, including Chan and Chung (2004a, b), Chan et al., (2004, and 2005).

Also, AHP has been used in the manufacturing sector (Yurdakul, 2004; Bertolini and Bevilacqua, 2006; Ertay et al., 2006; MohdArmi et al., 2007; Ishizaka and Labib, 2011; Ozkan et al., 2011). In Yurdakul (2004) for instance, the AHP was applied in solving a computer integrated manufacturing technology selection to get the relative importance of weightings of alternative technologies, with respect to four criteria: innovation, customization, product proliferation, and price reduction. In another situation, Bertolini and Bevilacqua (2006) applied the AHP to assess the maintenance alternatives with respect to three criteria: occurrence, severity, and detestability.

The AHP has also been used in the agriculture sector (Gua and He, 1999; Shrestha et al., 2004; Maidamisa et al., 2012).Gua and He (1999) used the AHP to assess the relative importance of weightings of various harvesting measures for optimizing the grain harvesting and post-harvesting system in China. In addition, Shrestha et al., (2004) applied the AHP to identify the relative importance of weightings of the individual SWOT factors. The AHP weightings were done with respect to the key stakeholders, including research specialists, large landholders, and small landholders in solving factor evaluation in silvopasture adoption.

In yet another set of applications, Malczewski et al., (1997), Kurttila et al., (2000), and Masozera et al., (2006) utilized the AHP in the environmental sector. Kurttila et al., (2000) suggested the AHP method to assist the decision making in a Finnish forestry. There were two alternatives faced by the forestry: (i) make a commitment to move to certified forestry; (ii) stay in timber-production-oriented forestry. The AHP was then applied to identify the relative importance of weightings of the SWOT group. Masozera et al., (2006) used the same method to evaluate the suitability of community-based management method to the Nyungwe Forest Reserve in Rwanda.

Meanwhile, Schniederjans and Garvin (1997), Saaty et al., (2003), and Kearns (2004) proved the effectiveness of the AHP in the business sector. Saaty et al., (2003) analysed the resource allocation problem in two merging companies. Tangible and intangible resources were allocated to proper management areas so that positive synergistic effects might be generated. The AHP was applied to get the relative importance of weightings of alternative management areas, such as markets, innovation, and cost reduction.

The potential of the AHP in the education sector was proven by Kwak and Lee (1998), Koksal and Egitman (1998), Lam and Zhao (1998), and Ozdemir and Gasimov (2004). Ozdemir and Gasimov (2004) developed a binary nonlinear programming model with multiple objectives for the faculty course assignment problem. Because of the complicated model, they decreased the multiple objective functions to a single objective function. The AHP was applied to identify the relative importance of weightings of the objectives or the preferences of instructors and administrators.

The AHP has also been utilized in the military (Kim et al., 1999; Partovi and Epperly, 1999; Crary et al., 2002). Crary et al., (2002) for example, applied the AHP to find the relative importance of weightings of alternative ships with respect to various missions in the US Navy.

The AHP was also used to solve government sector problems (Rafikul Islam and Shuib, 2005; Malladi and Min, 2005; Stannard and Zahir, 2006; Liu et al., 2008). Stannard and Zahir (2006) applied the AHP method to search for optimal allocation of a limited number of aircrafts among a group of airlift users with varying levels of priority and length of usage. The AHP was applied to find the relative importance of weightings of alternative tasks of airlift users in advance. The evaluation criteria comprised system training value, user category, and effective use of the aircraft.

The AHP was used in the marketing sector (Radasch and Kwak, 1998; Badri, 2001; Zhou et al., 2000). Radasch and Kwak (1998) used the AHP method to assist the offset planning. The AHP was applied to assess the relative importance of weightings of alternative offset suggestions with regards to four criteria: economic, social, political, and company.

The AHP has also been applied in the healthcare sector (Lee and Kwak, 1999; Wang et al., 2004; Chan and Chang, 2004a, b; Chan et al., 2004). Kwak and Lee (2002) applied the AHP method on the resource allocation problem in the health-care system. They applied the AHP to identify the priority ranking of the goals in the GP model. The assessment criteria consisted effectiveness, care delivery, partnership, competitiveness, and cost.

Finally, the AHP has also penetrated the service sector (Badri, 2001, Korpela et al., 2001a). Badri (2001) used the AHP method to design quality control systems in the service-based organizations. AHP was applied to get the relative importance of weightings of alternative customer data collection methods with respect to several service quality criteria, including responsiveness, assurance, reliability, empathy, and tangibles.

As a conclusion, the AHP has been applied in most of the fields as described above. Thus, the AHP can also be applied to solve the date palm packaging factory problem.

2.2.2.3 Other Criteria Evaluation Techniques

Besides the MCDM techniques available for assisting in making decisions as discussed in the previous sub-sections, there are also other potential approaches. Hence, the following paragraphs briefly explain about them:

i. Ratio Methods

In this method, decision makers are required to rank the necessary attributes first with respect to their priority by giving a weight of ten to attributes having least significance while all others are given a multiple of ten (Al-Kloub et al., 1997); the next is to aggregate and normalize the criteria scores in order to realize their weights.

ii. Rating Methods

One other way to bring out the relative weights is by using the methods of rating. These methods are of two forms, i.e., the method of point allocation and the method of direct rating (Saeid et al., 2011).

(a) Point Allocation Method

In point allocation, a hypothetical fixed number of points is allocated by the decision makers ranging from zero to 100. The points are then applied among the attributes to indicate their degree of significance relatively. Any attribute having the maximum points is considered the best and thus more important than others in relative terms. The sum of the weights of all the attributes must be 100. The normalization of the method is easy.

(b) Direct Rating Method

This method is used to relatively bring out the weights with the use of the experts' judgments (Poyhonen and Hamalaien, 2001). The method offers an essential scale made for the decision makers to give relative criterion weight (Wagholikar, 2007; Waghlikar and Deer, 2007). In this case, the criterion ranging from zero to one can be rated directly by the decision makers without the requirement to normalize, and the range of selection is divided into various linguistic variables. An example of the scales in this method is exhibited in Table 2.2.

Table 2.2 Importance scale of information evolution using direct rating

	Extremely	0.0
	Highly	0.1
The criteria is less importance	Very	0.2
	Strongly	0.3
	Moderately	0.4
	Equally	0.5
	Moderately	0.6
	Strongly	0.7
The criteria is more importance	Very	0.8
	Highly	0.9
	Extremely	1.0

iii. Tradeoff Analysis

With respect to the way of doing tradeoff analysis, decision makers assess pairs of alternatives by comparison of each pair of the attributes (Al-Kloub et al., 1997; Yeh et al., 1998). While one alternative has the best and the worst result on the first and second attribute respectively, the others have the worst and best on the first and second attribute respectively. The selection of the alternative preferred from two choices indicates the more important attribute decided by the decision makers. Nonetheless, this procedure is problematic since the method presumes the determination of attributes on a continuous scale (Poyhonen and Hamalainen, 2001).

iv. Swing Method

Another method which can be employed to weight attributes is the swing method. It possesses its principal within which essential metric varies from its best to worst level. The attribute having the highest priority is given 100 points and is considered the most important metric. After that, values of less than 100 points are assigned to other metrics, showing the relative significance of their variations concerning the most significant metric (Srivastava et al., 1995). The experts' judgment and intuition are used to accord values to these metrics. Having completed the assigning of values to all the respective metrics, then the weights' values are normalized in which the criteria's total value must sum up to one.

Based on the discussions in the previous paragraphs, it is obvious that all the methods are very subjective and the outcomes of the judgment strongly depend on the understanding of the methods, as well as the background of the evaluators (Hardman and Macchi, 2003).

2.3 Discussion and Summary

In this Chapter, the related location criteria are compiled. Besides, the MCDM technique is also discussed. After taking into consideration the advantages and disadvantages of the identified techniques from previous studies, this study deduces that the ROC is appropriate for selecting the weight of the criteria (Barron & Barrett, 1996). The ROC-based analysis is so straightforward and efficacious; it presents a proper implementation tool. Indeed, the decision based on ROC weights is easier to justify, useful, usable, and has efficacious weights, whose average performance is excellent in absolute terms. Hence, the ROC is used to rank each criterion by the respondents.

On the other hand, the AHP technique which uses Saaty's scale is also appropriate for this study. The AHP is a proper method for comparing two decision elements at a time (Rafikul Islam and Shuib, 2005), with some modification that can always guarantee the consistency. Thus, it is used for comparing criteria, and subsequently, for allocating weights. In addition, the AHP method is fit for group decision making (Van Den Hornert and Lootsma, 1996). The discussions in this chapter set the foundation for selecting the best solution, particularly in facility location problem, which is discussed in detail in the next chapter.

CHAPTER THREE

SINGLE AND INTEGRATED SELECTION MODELS

As previously mentioned in Chapter 2, once the criteria have been identified and the weights of those criteria are determined, the process of selecting the best solution is ready to be carried out. This Chapter focuses on the selection models. It contains two main sections: the first section begins with single selection models, followed by integrated selection models; and ends with the summary of the Chapter.

3.1 Single Selection Models

There are suitable techniques available to solve the multi-criteria problems in terms of selecting the best solution. Among the most popular are Technique to Order Preference by Similarity to Ideal Solution (TOPSIS), Analytical Network Process (ANP), and the scoring model. Besides that, the Elimination and Choice Translating Reality (ELECTRE) technique and Analytic Hierarchy Process (AHP) are also discussed.

3.1.1 Technique for Order Preference by Similarity to Ideal Solution

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was first proposed by Hwang and Yoon and has been widely used in practice (Hwang & Yoon, 1981). TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative-ideal solution. Then, the method chooses an alternative with the maximum similarity to the positive-ideal solution (Wang and Chang, 2007). It is based on selecting the best alternative having the shortest distance to the positive ideal solution and the farthest distance from the negative ideal solution. The positive ideal solution is the solution that maximizes the benefit criteria and also minimizes the total cost; whereas, the negative ideal solution is the solution that minimizes the benefit criteria and maximizes the total cost (Wang and Elhag, 2006). In TOPSIS, the best alternative selected has a maximum value of relative closeness to the ideal solution with the intention to minimize the distance from the ideal solution and to maximize the distance from the negative ideal solution (Isiklar and Buyukokan, 2006).

The main advantages of using TOPSIS method lies in its operations. Particularly, its logic is rational and understandable. The computation processes are straightforward, the concept permits the pursuit of best alternatives criterion depicted in a simple mathematical calculation and the important weights are incorporated in the comparison procedures. Due to this, decision making for selection of suitable stakeholders is of special importance (Zaeri et al., 2011). However, TOPSIS still suffers from ranking abnormality. Some proposals have been presented to avoid this issue. Bari and Leung (2007) propose an iterative approach for application of TOPSIS for network selection problem. Generally, most studies follow the steps outlined by Chen (2000):

- First step: Convert decision matrix with m alternatives and n criteria to a dimensionless matrix (x_{ij} is the value of ith alternative in jth criteria),
- Second step: Obtain a weighted normalized decision matrix,
- Third step: Determine the positive ideal solution (A*) and negative ideal solution (A-).
- Fourth step: Calculate Euclidean distance from ith alternative to positive ideal solution and negative ideal solution.

- Fifth step: Calculate, C_i * the relative closeness to the ideal solution.
- Sixth step: Rank the alternatives in descending order of C_i * or select alternatives with maximum value of C_i, where$i=1,\ldots, m$.

3.1.2 The Analytical Network Process

The Analytical Network Process **(**ANP) is a general theory of relative measurement used to derive composite priority ratio scales from individual ratio scales. It represents a relative measurement of the influence of elements that interact with respect to the control criteria. Through its super matrix whose elements are themselves matrices of column priorities, the ANP captures the outcome of dependence and feedback within and between clusters of elements (Saaty, 1999).

It is a more general form of AHP used in multi-criteria decision analysis. AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while the ANP structures it as a network. Both of them use a pairwise comparison system to measure the weights of the components of the structure. Finally, it ranks the alternatives in the decision. However, the ANP method has not received due attention because of the linear structure applied in traditional method and its ability to deal with feedback (Bayazit, 2006; Percin, 2008).

The benefits of the ANP model are: (1) it allows assessing the consistency of the judgments, which is not possible to evaluate with methods that assign weights by consensus; and (2) it facilitates the process of assigning weights by splitting the problem into smaller parts, which allows the decision makers to review and refine the decision structure. On the other hand, the disadvantage of the ANP model is that it requires filling in a lot of questionnaires (Lesmes et al., 2009). ANP involves the following steps:

- Determine the control hierarchies, including their criteria for comparing the components of the system and their sub-criteria for comparing the elements of the system.
- Number and arrange the clusters and their elements in a convenient way to determine the clusters of the system, with their elements for each control criterion or sub-criterion, to better organize the development of the model.
- Determine the approach to follow in the analysis of each cluster or element, whether as being influenced by other clusters and elements, or influencing other clusters and elements with respect to a criterion.
- Construct a three column table placing each cluster label in the middle column for each control criterion.
- Perform paired comparisons on the clusters as they influence each cluster and on those that it influences, with respect to the criterion for each entry in the constructed table.
- Perform paired comparisons on the elements within the clusters themselves according to their influence on each element in another cluster they are connected to.
- Construct the super matrix for each control criterion by laying out the clusters in the order they are numbered and all the elements in each cluster, both vertically on the left and horizontally at the top.

- Compute the limiting priorities of each super matrix according to whether it is reducible or not.
- Synthesize the limiting priorities by weighting each limiting super matrix by the weight of its control criterion and adding the resulting super matrix.
- Repeat the synthesis for each of four control hierarchies: one for benefits, one for costs, a third for opportunities, and fourth for risks.
- Synthesize the results from the four control hierarchies by multiplying the benefits by the opportunities and dividing by the costs multiplied by the risks. Then, read-off the highest priority alternative or desired mix of alternatives.

3.1.3 Scoring Model Technique

The scoring model resembles the process of AHP (Taylor, 2004), in a sense that this model is the same as the simple average method. In many areas, scoring models are largely employed to choose the best alternative based on many selection criteria. Kim et al. (2002) utilized the model in the insurance sector, while Schreiner (2000) utilized it in the banking sector. Stevenson and Ozgur (2007) view the scoring model as a technique of multiplying criteria which is subjective in nature, but which allows the decision makers to give weights to the criterion one by one. This expresses the significance of the criterion and the alternative decision on the criterion is also rated one by one. In this situation, scoring model is equal to any simple average method.

There are several advantages in using scoring model. This method is simple and easy to understand. It can give direct reflection of managerial policies and is easily adapted to accommodate changes. On the other hand, there are several disadvantages, such as scores may not directly represent the value or utility. Also, the elements or the values in the decision matrix are assumed to be independent. In addition, the unweighted scoring models assume equal importance of all criteria which is not true in real applications. The steps in this model include:

i. Once a selection problem has been recognized, a list of criteria to be taken into consideration is developed.
ii. Weights are given to the criterion one by one.
iii. Recognize the alternative decisions and with respect to each criterion, score the alternative decisions one by one.
iv. For each of the alternative decisions, make a computation of the factor score.
v. Finally, the best decision goes for the highest weighted score.

3.1.4 The ELECTRE Technique

This technique was originally named in French language as *Elimination EtChoixTraduisant La REalite*, and pioneered by Bernard Roy (1968, 1990), in response to insufficiencies of the available decision making solution methods at that time. Roy's original idea was to include uncertain nature of decision making by incorporating the concepts of indifference and preference. This philosophy, based on the concept of outranking, was well clarified in Roy (1993, 1996), and has become a foundation of other versions of ELECTRE, ELECTRE I, II, III, IV and TRI. Even though these different versions are built on the same foundation, they differ both operationally, and in the context of the decision making problems. More specifically, ELECTRE I is formatted as selection model, ELECTRE TRI for solving assignment problems; while ELECTRE II, III and IV are for ranking purposes. Moreover, ELECTRE III is younger than ELECTRE II (Roy, 1990; Vanderpooten, 1990), and

ELECTRE III is used when it is possible and desirable to determine the relative importance of criteria, whereas, ELECTRE IV is applicable when this quantification of the weights of criteria is not possible (Buchanan et al., 1999).

ELECTRE III has a few disadvantages. For example, it suffers difficulty in ranking process, which forces additional threshold measures (Li and Wang, 2007). Moreover, the performance level of alternatives depends on the measure of this threshold for which there exists no "correct" value. Li and Wang (2007) add that the normal ranking method also suffers from incomplete ranking result. Consequently, they proposed an optimized ELECTRE approach by presenting three definitions: concordance credibility degree, discordance credibility degree and net credibility degree.

3.1.5 AHP Technique

Chapter two in Section 2.2.2.2 outlines that AHP has four steps, which are decomposing, weighing, evaluating, and selecting. The last step is to select the best alternative or option. It can be done by performing the pairwise comparison between the alternatives in terms of each criterion. Then, numbers of the matrices will be obtained equal to the number of the criteria. The results obtained in each matrix, show the score for each alternative in each criteria; then all results from each alternative matrix in one matrix and the final weight for each criteria obtained from the weighting criteria step are presented as discussed in Section 2.2.2.2. Then, each criterion is multiplied with the weight for each alternative. Further, these products are added together and this score weight represents the overall score of the alternative. So the ranks of the alternative are given according to these scores, in which the highest weight is ranked the first.

AHP aims at qualifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision makers, and stresses the importance of the intuitive judgments of the decision makers, as well as the consistency of the comparison of alternatives in the decision-making process. Since a decision maker bases judgment on knowledge and experience, and then makes a decision accordingly, the AHP approach concurs with the behavior of a decision maker.

Yang and Lee (1997) utilized AHP as a stand-alone technique to make location decisions. They presented an AHP decision model for facility location selection that contemplated locations of a new facility or a relocation of existing facilities from the view of organizations. They based their system on Levine (1991), who found that the location factors that have been widely used in industrial location could generally be grouped into market, transportation, labor, site considerations, raw materials and services, utilities, government regulations, and community environment. Besides, location factors have also been addressed according to the uniqueness of industry type, facility type, and product life-cycle stage (Harvard Business School, 1989).

Obviously, these non-programming MCDM techniques can be used to determine the final location selection. But, it has a major drawback because they are not used to minimize the distance deviations from preemptive priority criteria. This implies that mathematical programming models are more appropriate in solving selection problem. The best alternative is the one that minimizes the distance deviations from preemptive priority criteria.

3.1.6 Other Single Selection Models of Optimization Type

Generally, optimization models are also mathematical programming models which can be used in solving selection problems. These include linear programming (LP), mixed integer linear programming (MILP), integer linear programming (ILP), 0-1 integer programming (0-1 IP), and goal programming (GP). They have been popularly utilized in previous works, as described in the following sections:

3.1.6.1 Linear Programming

Linear programming **(**LP) is a mathematical programming method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear equation. In a formal way, an LP is a method of optimizing a linear objective function, given constraints, such as linear equation and linear inequality. With respect to a real-valued function on polyhedron, LP locates an existing point on polyhedron by searching through its vertices to indicate the smallest or largest value of the function.

LP can be expressed as shown in Equation 3.1:

Maximize

$$Z = \sum_{i=1}^{m} CX_i \tag{3.1}$$

Subject to

$$AX_i \leq B_i \tag{3.2}$$

Where X_i represents the vector of variables (to be determined), C and B are vectors of (known) coefficients and A is a (known) matrix of coefficients. The expression to be maximized or minimized is called the objective functionCX_i, while the equation $AX_i \leq B$ is the constraint that specifies a convex polytope, over which the objective function is to be optimized. The number of inequalities and variables depends on the complexity of the problem whose solution is found by solving the system of inequalities like a system of equations.

In different areas of study, LP is also applicable. It has an important role in guiding quantitative decisions in the field of business as well as in areas of economics, but can, in addition, be employed in some problems relating to engineering. The greater employment of LP can be seen in the period of World War II in resources allocation as well as in tackling transportation and scheduling problems. The cost constraints, stimulated the uses of LP in the postwar period (Ignizio and Cavalier, 1994; Taha, 2003). Besides, studies using LP can also be found in solving logistical (Ghodsypour and Obrien, 1998; Lee and Hsu, 2004), and business problems (Saaty et al., 2003).

The main advantage of LP lies in its ability to help make the best possible use of available productive resources (such as time, labor, and machines). In addition, in a production process, bottle necks may occur. As an illustration, some machines in factories may be in great demand while others may lie idle for some time. This bottleneck problem is addressable by LP. On the other hand, LP technique is applicable only on problems where the constraints and objective functions are linear. In real life situations, when constraints or objective functions are not linear, this technique cannot be used. In addition, other uncertain factors, such as weather conditions, are not taken into consideration.

3.1.6.2 Integer and Mixed Integer Linear Programming

Integer linear programming (ILP) is a class of LP. The LP is called an ILP problem if the unknown variables are all required to be integers. In contrast to regular LP, which can be solved efficiently in the worst case, ILP problems are found in many practical situations (those with bounded variables) (Taha, 2003).Studies have used ILP to solve environmental problems (Malczewski et al., 1997), manufacturing problems (Braglia et al., 2001; Akgunduz et al., 2002), logistical problems (Cebi and Bayraktar, 2003), business problems (Kearns, 2004), and education problems (Ozdemir and Gasimov, 2004).

Meanwhile, Mixed Integer Linear Programming (MILP) problems are a class of mathematical programming problems that are capable of modeling a wide variety of situations. This is due to the great versatility exhibited by this type of model which is able to represent variables that range from discrete sets to logical decision-making procedures. MILP problems are characterized by models containing both continuous (real) and discrete (integer) variables, and for only being composed, like LP problems, by linear expressions on these variables as their constraints and objective function. If only some of the unknown variables are required to be integers, then the problem is called MILP problem (Taha, 2003). It has been applied in solving logistical problems (Tyagi and Das, 1997; Korpela and Lehmusvaara, 1999; Korpela et al., 2001a, b; Korpela et al., 2002), military problems (Crary et al., 2002) and government problems (Malladi and Min, 2005; Stannard and Zahir, 2006). In addition, there is also a special case of ILP which is 0-1 integer programming (0-1 IP) or binary integer programming (BIP), in which variables are required to be 0 or 1 (rather than arbitrary integers) (Tamiz et al., 2002).

Generally, any type of ILP has several advantages. They are very expressive in formulating optimization problems. Besides, they can capture, in a natural and direct way, a large number of combinatorial optimization problems. The problem under study is a facility location problem where only one location is required to be selected. Accordingly, based on the characteristics outlined in the previous paragraphs, the 0-1 IP is the most appropriate technique to tackle the current problem.

3.1.6.3 Goal Programming

Goal programming **(**GP) is a method of analysis involving multiple objective decisions, which are applicable in decision making in public and industrial sectors. It was first hypothesized and recognized by Charnes and Cooper in 1962. Multiple objectives that always conflict with each other are considered by LP, and are known as GP. Usually, the multiple goals cannot be achieved precisely in entirety. The objective in a GP model is to realize multiple goals rather than optimizing one criterion. The fundamental method is to reduce the deviational variables to the minimum by employing preferred factors and distinctive weights. The GP model's objective function is represented in a form of the deviations from the objectives targeted. It has received a great deal of attention among optimization techniques, as it attempts to optimize a number of objectives simultaneously. These objectives include maximizing utilization of full-time staff, minimizing understaffing and overstaffing costs, minimizing payroll costs, as well as minimizing deviations from desired staffing requirements.

As a start, the goal program considers the goals with the highest priority with possible minimization done to d^+ and d^-. This implies that minimization is done to the deviation between what the organization prefers to realize and what is possible to be realized by the organization. This is also applicable to the second goal, subject to constraints of minimizing the first goal, in which case, deviational variables have been included in the model. In most cases, the first two to three goals are realized completely. Ultimately, goals with lower rank conflict with the past goals which are unable to be realized completely.

Theoretically, the objective function contains constants, deviational variables, and "preemptive" priority factors. These priority factors, usually denoted as p_i, indicate the relative importance that is attached in the minimization of each deviational variable. A commonly-accepted statement of GP is outlined by Charnes and Cooper (1977), as follows: suppose there are n options evaluated under m criteria to be evaluated. Let w_i be the weight of a criterion which is ranked at ith position.

Objective function: Minimize:

$$Z = \sum_{i=1}^{m} w_i (d_i^+ - d_i^-) \tag{3.3}$$

Subject to:

$$\left(\sum_{j=1}^{n} a_{ij} X_j\right) + d_i^- - d_i^+ = b_i \tag{3.4}$$

$$d_i^+, d_i^-, X_j \geq 0 \;\; for\; i = 1, \ldots, m; j = 1, \ldots, n \tag{3.5}$$

where

w_i = numerical weight assigned of the ith constraint

d_i^+= positive deviational variable from the ith goal (overachievement)

d_i^- = negative deviational variable from the ith goal (underachievement)

a_{ij} = the coefficient associated with variable j in the ith goal

x_j = the jth decision variable

b_i = the associated right hand side value

In general, the characteristics of all LGP models are:

i. There is a distinct constraint showing the appearance of each goal and the goal's targeted value showing on the right hand side.

ii. For each goal, deviation variables represented by d_i^- and d_i^+ are included to indicate likely over-realization or under-realization of the goal.

iii. As in any model of LP, other constraints or restrictions showing the capabilities of resource are included.

iv. As a requirement of the objective function, the weighted value of the deviation variables is minimized. The deviation variables' weights or coefficients in the objective function indicate the relative "cost" or "penalty" with respect to each unit deviation from the respective targeted goal value. There is no penalty for the respective deviations from the target values where the coefficients are zero.

The advantage of GP can be seen in its computation efficiency. It allows staying within an efficient LP computational environment. The weights are aspiration levels, and preemptive priorities can be changed during the analysis as the decision makers' knowledge of the decision problem changes. On the other hand, there are several disadvantages, such as GP requires that the decision makers specify fairly detailed a priori information about his or her aspiration levels, preemptive priorities, and the importance of goals in the form of weights. In many complex problems, it is difficult or even impossible for the decision makers to provide the precise information required by this method. The resulting solutions to GP may be dominated (a better solution may exist in terms of some or all of the objectives than the solution obtained through GP). Also, there is a tendency to generate inefficient solutions; the GP approach does not attempt to use additional information to find an efficient solution.

Schniederjans et al. (1982) applied the GP model to deal with a problem related to a trucking terminal site location. This was realized by considering the quantified priority of personal individuals who offer and utilize the services of terminal trucks. Similarly, Badri (1999) employed a combination of GP techniques to deal with the problem of facility location in order to develop the system of quality control in a service-based organization to select the best alternatives combination on the basis of resource limitation. In fact, it was also utilized in logistics (Badri, 1999; Zhou et al., 2000; Wang et al., 2004, 2005), business (Schniederjans and Garvin, 1997), higher education (Kwak and Lee, 1998), marketing (Radasch and Kwak, 1998; Kwak et al., 2005), agriculture (Guo and He, 1999), military (Kim et al., 1999), healthcare (Kwak and Lee, 2002), services (Badri, 2001), industry (Radcliffe and Schniederjans, 2003), and manufacturing (Yurdakul, 2004; Bertolini and Bevilacqua, 2006). Other examples can be seen in facility location problem (Bogdan, 2004; ReVelle and Eiselt, 2005; Drezner et al., 2006; Berman & Huang, 2007; Ogryczak, 2008; Chan et al., 2008).

In addition, there are other possible approaches to be applied in solving the MCDM problems in terms of selecting the best solution. These are integrated techniques, where two or more techniques are combined together to be used in solving the selection problem. In relation to that, the following section discusses the previous researches:

3.2 Integrated Selection Models

Due to AHP's wide applicability and ease of use, the AHP has been studied extensively for the last several years. Recently, it has been observed that the focus has been confined to the applications of the integrated AHP, rather than the stand-alone AHP. There are several tools commonly combined with AHP, including mathematical programming techniques to be applied to select the best solution. These techniques include MILP, ILP, LP, and GP.

In most cases, the AHP is used to find the weight of the criteria, and then these weights are used to build the objective function and constraints. The details of these steps are discussed in detail in Chapter Four, Section 4.3.4.5. Studies have been carried out to select the best solution using AHP-MILP model (Korpela et al., 2001a, b; Korpela et al., 2002; Crary et al., 2002; Malladi and Min, 2005; Stannard and Zahir, 2006), AHP-ILP model (Braglia et al., 2001; Akgunduz et al., 2002; Cebi and Bayraktar, 2003; Kearns, 2004; Ozdemir and Gasimov, 2004), AHP-LP model (Saaty et al., 2003; Lee and Hsu, 2004), and AHP-GP model (Zhou et al., 2000; Kwak and Lee, 2002; Cebi and Bayraktar, 2003; Radcliffe and Schniederjans, 2003; Yurdakul, 2004;Wang et al., 2004, 2005; Kwak et al., 2005; Bertolini and Bevilacqua, 2006).

In terms of facility location problem, Partovi (2006) studied the evaluation and selection of facility locations for a company producing digital mass measurement weighted products for industrial use. The approach was akin to Partovi (1999), Partovi and Epperly (1999), and Partovi and Corredoira (2002), in which the AHP was used to determine the strength of the relationship between the variables involved in the four QFD matrices: (i) linking market segments and competitive priorities; (ii) linking competitive priorities and critical processes; (iii) linking critical processes and location attributes; and (iv) linking location attributes and location alternatives. Also, it is seen in a work byBadri (1999), who used the combined AHP-GP to deal with the location-allocation problem. In his study, the AHP was adopted to evaluate the alternative locations with respect to several criteria, such as political situation, global competition and survival, government regulations, and economic factors. After assigning weightings to alternative locations, a GP model was formulated to select the best combination of alternatives based on the resource limitations and to determine the allocation of products from locations to distribution centers.

3.3 Summary

This chapter explains the single and integrated selection models. After taking into consideration the advantages and disadvantages of the identified techniques from previous studies, the three approaches: ROC, AHP and 0-1 IP; are combined to identify the best location. ROC and AHP are used to weight the criteria, and 0-1 IP is used together in choosing the best location according to the identified criteria. More specifically, three models are used to solve a facility location problem in this study. The first model is ROC, which is combined with 0-1 IP model, whereas the second model, the AHP, is combined with 0-1 IP model. Finally, the mean of weights of ROC and AHP are combined with 0-1 IP model. These models are suitable to weight and rank the criteria according to their importance and to select the best location. It is argued that this integrated model has not been used in solving the facility location problem under study.

Further, the specified three techniques are discussed in detail in terms of their procedures and implementation in the following chapter. All steps and formulas involved in these techniques, the ROC, AHP, and the 0-1 IP model, are also presented in this chapter.

CHAPTER FOUR

RESEARCH METHODOLOGY

Previous chapters have mentioned that the purpose of this study is to identify the criteria for selecting the best location for the date palm packaging factory, by ranking the criteria, so as to determine the best location for the date palm packaging factory, based on the criteria.

Chapter Four explains how this study was carried out. It starts with an explanation of the research design, followed by the actual study.

4.1 Research Design

This study combined qualitative and quantitative approaches in collecting data. It began with phase I, in which a preliminary study was carried out to determine the criteria from previous studies, as well as through interviews. Then, in the second phase, the main study was carried out, which is divided into two parts:(1) the ranking techniques to be used to rank the criteria which includes the ROC, the AHP, and the combination of the ROC and the AHP; and (2) the process of selecting the best factory location from several selections through the proposed integrated techniques. Specifically, the integrated techniques were: (1) the 0-1 IP model which was combined with the weights of the criteria obtained through the ROC, called the ROC-0-1 IP model; (2) combination of the AHP criteria weight together with the 0-1 IP called the AHP-0-1 IP model; and (3) combined weight from the AHP and the ROC with the 0-1 IP called the ROC+AHP-0-1 IP model.

4.2 Preliminary Study: Criteria Determination

Besides reviewing the literature, the selection criteria of possible locations were also determined through interview session. For that purpose, the source of data and data collection, as well as data analysis techniques are discussed in the following sub-sections.

4.2.1 Data and Source of Data

There are two types of data involved in this study, i.e., primary and secondary data.

4.2.1.1 The Primary Data

The sources of primary data were the decision makers and farmers in prospective locations. Their views were gathered through interviews or meetings. The respondents in this study consisted of two groups. The first group consisted of 21 decision makers from the local councils. This study collected usable responses from them. Meanwhile, the second group consisted of the farmers, who supported and gave their opinions to decision makers. The data collected in this study were the criteria suitable for this study, the rank of the criteria and the importance level of each criterion. In addition, the estimated value required for each criterion in each location, and the estimated total budget for each criterion, were also obtained.

4.2.1.2 The Secondary Data

Another source of the selection criteria were obtained from the literature. Related works in journals, books, conference proceedings, newspapers, electronic sources, and reports were reviewed to identify the selection criteria. The data collected from the secondary data were the criteria which were constrained in the model in this study.

4.2.2 Data Collection Procedures

This section explains the procedures for data collection divided into three stages:

a. The first stage commenced when the researcher was in Yemen for a brief period in 2008 and 2011. During this stage, the data were collected from different official records, reports, and papers presented in national and international conferences, about date palm cultivation and production in the Republic of Yemen. These records, reports, and conference papers were found to be in different places in Yemen. Therefore, procedures were implemented through the collection of data from the following places:

    i. Ministry of Agriculture and Irrigation (Yemen).
    ii. Central Statistics Organization in the Ministry of Development and Planning.
    iii. Documentation Agriculture Centre.
    iv. Agriculture Research Centre in Hadhramout.
    v. Date Palm Cultivation and Honey Production Centre in Hadhramout University.
    vi. Ranches of Hadhramout (Sah,Seyoun, Tareem, Shabam, Al-Qaten, Doean, and Wadi Alaeen and Horah) in the Ministry of Agriculture.
    vii. Fieldwork conducted in some farms in Hadhramout Governorate.

b. In the second stage, the data were collected by contacting the Ministry of Agriculture and Irrigation of Yemen. The purpose of this stage was to collect data on factors that affect the date palm production, including workers, capital, and other factors. In response, some documents were sent along with a letter in which the Ministry declared that there was a lack of data on labor force and capital with regards to date palm cultivation.

c. Seven districts which offered locations for the date palm packaging factory were chosen by the government in Yemen because these districts produce the most dates. The decision makers from those districts who were earlier involved in the interview sessions regarding the locations for the factory were the target respondents. Therefore, the identified criteria were discussed with them to obtain their perceptions on the selection of prospective locations. Hence, they were met personally and inquired about the potential of the identified criteria. They compared between the selection criteria obtained from the primary and secondary sources and suggested suitable and appropriate criteria to select the best prospective locations for building the factory.

This study assumed that the identified prospective location selection criteria are valid and efficient to select the best prospective locations. Further, this study assumed that all the people who attended the meetings have similar understanding on the selection criteria and interpret them consistently.

4.2.3 Criteria Identification

Based on the collected data, the decision makers in the prospective locations identified the selection criteria. Hence, an agreement on the finalised criteria was achieved. Eventually, the identified criteria were listed.

4.3 Main Study: Ranking the Criteria and Location Factory Selection

The purpose of this study is to propose a model to select the best location among the available alternatives. Firstly, a group of respondents were asked to determine the level of importance of each criterion and rank the criteria to determine the location of the date palm packaging factory. Next, the criterion-importance mean value for each criterion was calculated using the arithmetic mean. These mean values represented the group average values for the level of importance of each criterion towards the final location selection.

The sources of data and data collection techniques, instruments as well as data analysis techniques for this location selection problem are discussed in the next section:

4.3.1 Source of Data and Data Collection

A set of structured and specific ROC (Appendix A), AHP (Appendix B) and 0-1 IP (Appendix C) questionnaires were distributed to the respondents to get their perceptions on the importance of each selection criterion. In addition, primary data in the form of order of the criterion based on respondents' perception and experience were also obtained through these questionnaires to be used for comparison purposes.

It took approximately six months to collect the data. The researcher met the respondents in groups in each location to avoid inconsistencies in their responses. At the same time, meeting them in groups in each location enabled the respondents to have clear understanding of the questionnaire.

4.3.2 The Respondents

The respondents were selected from among the decision makers and farmers in each location. The data regarding the selected locations in Hadhramout and the whereabouts of the respondents were gathered from the Ministry of Agriculture. The whole approval process was obtained in a descending line by several governmental bodies of Hadhramout Governance, Hadhramout Government's Agent for Valley and Desert Affairs, Watering and Agriculture Valley and Desert Office, and the General Managers of the selected districts of Hadhramout. Then, the General Managers sent official letters together with data and permission for conducting interviews with the local farmers, the Local Council Managers, the Deputy Manager for Work and Social Affairs, the Assistant of Service Affairs, and the Manager of Watering and Agriculture Valley and Desert Office.

4.3.3 Data Collection Instruments

In order to allocate weights to the selection criteria, order of criteria and performance scores, the questionnaire approach was used. Three types of questionnaire were used to obtain the respondents' perception. The first set of questionnaire was for the purpose of the ROC technique as shown in Appendix A. In this questionnaire, the respondents were required to rank the criteria in an order based on their perception and experience.

The second set of questionnaire was for the AHP technique as shown in Appendix B. In the questionnaire, a numerical scale from 1 to 9 was utilized. However, instead of doing pairwise comparisons, respondents or evaluators were asked to firstly rate the importance of each criterion using the scale, whereby 1 represented "least important", to 9 representing "extremely important". Next, the evaluation values were transformed into a pairwise comparison matrix $[y_{im}]_{mxm}$, using the approach described in Section 4.3.4.2.

Finally, the third set of questionnaire was for the purpose of the 0-1 IP techniques as shown in Appendix C. In this questionnaire, the respondents were required to estimate the values of each criterion in each location.

4.3.4 Data Analysis Techniques

Literatures suggest the ROC, the AHP, and the 0-1 IP techniques for solving the location selection problem. In this study, for weight allocation purpose, the ROC, AHP, and ROC combined with AHP techniques were used. The 0-1 IP model technique was used for selecting the best location based on the allocated weight of each criterion. The procedures of each technique adopted in this research are discussed in the following sections:

4.3.4.1 Rank Order Centroid Technique

The Rank Order Centroid (ROC) technique is a way to allocate weights to the defined criteria. As mentioned previously, a set of questionnaire was distributed to the respondents and interviews with decision makers and farmers in the prospective locations in Hadhramout Province were carried out. The questionnaires of ROC consisting of criteria to be ranked by respondents based on their perception were distributed. For instance, out of *m* criteria listed, the respondents were required to rank those according to their preferences.

Based on the respondents' perception, each criterion was allocated weights using the ROC technique. Initially, a ranking table was constructed; next the respondents' responses were transferred into the ranking table. The criteria weights by using ROC were calculated using the following formula (Barron and Barrett, 1996):

$$w_j(ROC) = \frac{1}{m}\sum_{k=j}^{m}\frac{1}{k} \tag{4.1}$$

Where

k = rank of criteria where $k = 1, 2, \ldots, m$

m = total number of criteria

w_j = weight for jth criteria where $j = 1, 2, \ldots, m$

Two possibilities of ranking may occur.

4.3.4.1(a) Possibility 1: Unique Ranking of the Criteria

If the respondent gave the rank for each criterion without having two or more criteria at the same rank, the sum of the weights would be equal to 1. For example, the evaluation and the calculation of weights from one respondent are as shown in Table 4.1.

Table 4.1 Calculation of the weight for one respondent

Criteria Number	first respondent's evaluation	Criteria Weight calculation	Criteria weight
C_1	5	$\frac{1}{5}\left(\frac{1}{5}\right)$	0.0400
C_2	1	$\frac{1}{5}\left(\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.4567
C_3	2	$\frac{1}{5}\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.2567
C_4	3	$\frac{1}{5}\left(\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.1567
C_5	4	$\frac{1}{5}\left(\frac{1}{4}+\frac{1}{5}\right)$	0.0900
Total			1

4.3.4.1(b) Possibility 2: Equal Ranking of the Criteria

Suppose r_1=r_2. Then, w_1=w_2. Where r_1 and r_2 are the rank of the criteria 1 and 2 respectively, while w_1 and w_2 are the weights of the criteria 1 and 2. Thus, in this case, the total of raw weight would not equal 1, i.e. $\sum_{j=1}^{m} w_j \neq 1$.In this situation, the weights should be normalized by dividing each weight by the sum of the weights as below. Final weight can be computed by equation 4.2:

$$w_j = \frac{w_j}{\sum_{j=1}^{m} w_j} \tag{4.2}$$

Then the total raw weight would equal 1. For example, the evaluation and the calculation of weights from one respondent are as shown in Table 4.2.

Table 4.2 Calculation of the weight and final weight for one respondent

Criteria Number	first respondent's evaluation	Criteria Weight calculation	Criteria weight	Final weight
C_1	4	$\frac{1}{5}\left(\frac{1}{4}+\frac{1}{5}\right)$	0.0900	0.0722
C_2	1	$\frac{1}{5}\left(\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.4567	0.3753
C_3	2	$\frac{1}{5}\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.2567	0.2109
C_4	2	$\frac{1}{5}\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.2567	0.2109
C_5	3	$\frac{1}{5}\left(\frac{1}{3}+\frac{1}{4}+\frac{1}{5}\right)$	0.1567	0.1288
Total			1.2168	1

This research involved more than one respondent; so the final weights were obtained using the arithmetic mean. As an example, when there are p respondents, the final weight for criterion j is computed as follows:

$$w_j = \frac{\sum_{l=1}^{p} w_{jl}}{p} \tag{4.3}$$

Where l=1,2, …,p and p is the number of respondents.

4.3.4.2 Analytic Hierarchy Process Technique

The Analytic Hierarchy Process (AHP) (Saaty, 1977) is a technique for ranking decision alternatives and selecting the best one when the decision makers have multiple criteria on which to base their decision (Taylor, 2004). Although the AHP has been applied in various fields (discussed in Chapter One), this study applied it in the scope of facility locations.

In our case, the decision makers (local council members) had difficulties in accurately determining the various criteria, weights, and evaluation. Hence, the AHP technique was employed to examine how facility location selection criteria were considered and how at the end, the location was selected. The AHP is a powerful and flexible decision making process to help people set priorities and make the best decisions, when both qualitative and quantitative aspects of a decision need to be considered (Saaty, 1994). The analysis in AHP is described in four parts as follows:

i. To set up the decision hierarchy after specifying the criteria.
ii. To collect input data before weighting the criteria using pairwise comparison
iii. To rank or give weight to the criteria through pairwise comparisons

iv. To compute the consistency for each pairwise comparison matrix.

Step (i): set up the decision hierarchy after specifying the criteria

Chapter Two presents the facility location selection criteria. In carrying out this study, a survey was conducted through interviews with the farmers and local council members. The purpose of the interviews was to find out which location selection criteria were relevant to each location and were commonly preferred.

The study found m criteria denoted $C_1, \ldots, C_m$. The relation between the criteria and the location $L_1, \ldots, L_n$ is presented in Figure 4.1.

As shown in Figure 4.1, the first step in the AHP is developing a graphical representation of the problem in terms of the overall goal, the criteria to be used, and the decision alternatives. The figure depicts the hierarchy for the problem from left to right. The first level of the hierarchy shows that the overall goal is to select the best alternative for location. The second level contains the location selection criteria (C_1 to C_m), in which each criterion contributes to the achievement of the overall goal. Finally, the third level contains the decision alternatives (L_1 to L_n) where L represents the location.

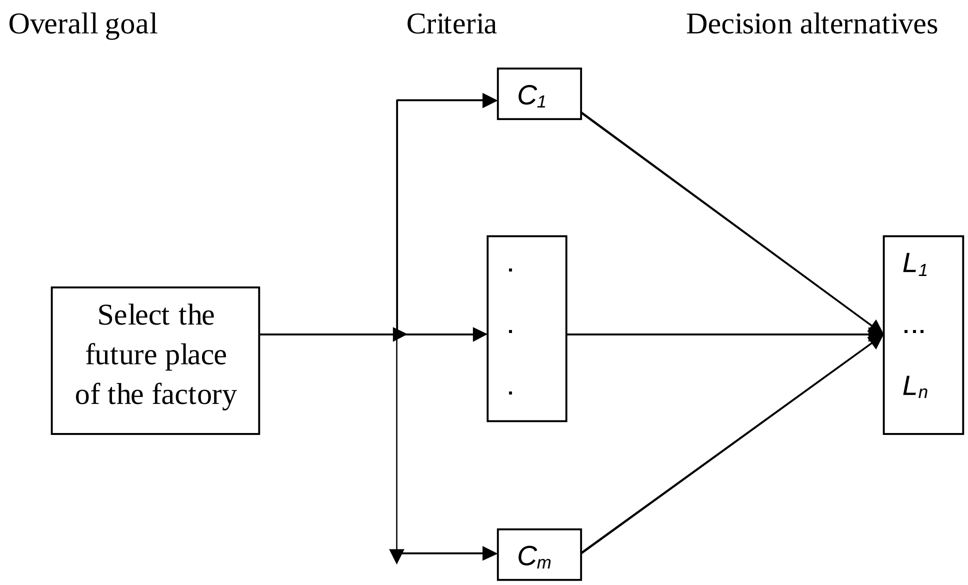

Figure 4.1 Hierarchy for place of factory selection problem

Step (ii): collect input data before weighting the criteria using pairwise comparison judgments.

In this section, the input data (criteria and locations) were obtained from a set of questionnaires. The target populations for this study were the local council members and farmers in Hadhramout province. The AHP questionnaire (Appendix B) was designed after several discussions and consultations with the local council members and farmers. Firstly, the researcher listed all the criteria used in several previous studies in several sectors and presented and explained the list to the local council members and farmers. They were then asked to choose the suitable criteria for their locations from the list. Then, after the decision makers selected the suitable criteria, the researcher designed the next set of questionnaire. The members of the local councils were asked to answer the questionnaire with help of this researcher. Specifically, the members of the local councils were briefed on: (1) how to fill the

AHP comparison table; (2) the purpose of collecting the data; and (3) the assurance of confidentiality. In addition, all the local council members were assumed to already have some exposures or have a fair knowledge on the criteria and decision alternatives decided by them.

The AHP questionnaire was designed specifically for this study to ease pairwise comparison (refer to Appendix B). Furthermore, it was designed to overcome the inconsistency problem. From the evaluation done by the respondents, a pairwise comparison matrix (matrix *D*) was formed to obtain the weights for the various criteria. The entry in row *i*. i= 1, 2,…, m and column m of the matrix was labeled with $y_{im,}$ indicating how much more (or less) important is criterion i compared to criterion m. In addition, pairwise comparison matrices were built from the questionnaires, by utilizing the values between 1 and 9, with interpretations as listed in Table 4.3.

Table 4.3 Interpretation of the values used in pairwise comparison matrix

***Preference Level**	**Numeric Value**
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

*Preference level can also be replaced by importance level, significance level, or any other appropriate levels.

Step (iii): Rank or give weights to the criteria through pairwise comparisons.

Firstly, each decision maker was requested to rate each criterion according to the perception of how important the criterion was towards the determination of the location of the date palm factory. Suppose that criterion i was rated as a_i and criterion m was given a rating a_m. Then

$$\text{if } i \leq m \tag{4.4}$$

$$\text{let } b = a_i - a_m \tag{4.5}$$

$$\text{if } b < 0, \text{ then } y_{im} = \frac{1}{1-b} \tag{4.6}$$

$$\text{if } b = 0, \text{ then } y_{im} = 1 \tag{4.7}$$

if $b > 0$, then $y_{im} = b + 1$ (4.8)

Where, y_{im}, the value in the matrix.

Saaty uses 9 to represent the most extreme case. In our case, the most extreme will be when one criterion is rated 1 and the other criterion is rated 9. If we use 9-1, the result is 8. This is not quite consistent with Saaty's scale. On the other hand, if one criterion gets a rating 7 and the other criterion also get a rating7; Saaty's scale should be 1. But here, 7-7 = 0. Therefore we need to add 1.

All the data collected from the respondents were transferred into a matrix form, *D*. The comparison matrix was manipulated mathematically to determine the weights of the criteria w_j, $j = 1, 2, \dots, m$. In particular, the pairwise comparison matrix *D* should be of the following form or as shown in Table 4.4.

$$D = \begin{bmatrix} 1 & y_{12} & \cdots & y_{1m} \\ y_{21} & 1 & \cdots & y_{2m} \\ \vdots & \vdots & & \vdots \\ y_{i1} & y_{i2} & \cdots & y_{im} \\ \vdots & \vdots & & \vdots \\ y_{m1} & y_{m2} & \cdots & 1 \end{bmatrix} \quad (4.9)$$

Table 4.4 The pairwise comparison matrix

	C_1	C_2	C_3	C_4	…	C_m
C_1	1	y_{12}	y_{13}	y_{14}	…	y_{1m}
C_2	$1/y_{12}$	1	y_{23}	y_{24}	…	y_{2m}
C_3	$1/y_{13}$	$1/y_{23}$	1	y_{34}	…	y_{3m}
C_4	$1/y_{14}$	$1/y_{24}$	$1/y_{34}$	1	…	y_{4m}
…	…	…	…	…	1	…
C_m	$1/y_{1m}$	$1/y_{2m}$	$1/y_{3m}$	$1/y_{4m}$	…	1

Step iv: Compute the consistency for each matrix

The following step is a very important procedure, which is to compare the consistency of the pairwise judgment provided by the decision makers. Perfect consistency is difficult to achieve with numerous pairwise comparisons; therefore, some degrees of inconsistency can be expected to be exhibited in almost any set of pairwise comparisons. The AHP provides a method for measuring the degree of consistency among the pairwise comparison provided by the respondents. If the degree of consistency is unacceptable, the decision maker should review and revise the pairwise comparison before proceeding with the AHP analysis. AHP provides a measure of consistency for the pairwise comparison by computing the *CR*.

An acceptable level of consistency is determined by the *CR*. In general, the degree of consistency is satisfactory if $CR < 0.10$. In contrast, if $CR \geq 0.10$, then there are probably serious inconsistencies and the AHP results may not be meaningful (Saaty, 1980; Taylor, 2004).

Using the pairwise matrix obtained, with the help of the Expert Choice software, the *CR* value for each matrix was calculated. By skipping the normal pairwise comparison exercises suggested by Saaty, and using the approach that we suggested instead, all the pairwise matrices produced consistent pairwise comparisons, i.e. $CR < 0.1$.

4.3.4.2(a) Prove of Pairwise Consistency Using the New Approach

Once the pairwise matrix was obtained, the weight for each criterion was calculated using AHP technique, in which the process included the consistency tests. However, it is believed that the suggested approach would give a consistency ratio value of less than 0.1. To rationalize the belief, Saaty's logic in proving the consistency was compared. According to Saaty, suppose c_{im}= 2 and c_{mk}= 3,then for a perfect consistency, c_{ik}= 6.

Now, let us compare Saaty's logic with the proposed approach. Suppose the values for criteria *i*, *m*, and *k* are 6, 4, and 1 respectively, then c_{im} = 3, c_{mk} = 4, and c_{ik} = 6. To get a perfect consistency, c_{ik} should be 12. However, even by Saaty's approach, a comparison value 12 is not allowed since the largest value is set at 9. Therefore, Saaty's approach allows for some inconsistencies. Hence, this study strongly believes that the inconsistencies in the proposed approach are within the acceptable range, in which *CR* value is less than 0.1.To further justify the belief, 100 judgments were simulated for each for criteria involving problems with 3, 4, 5, 6, 7, 8, and 9 criteria respectively.

An example for each experiment is illustrated subsequently. For all experiments, the first instruction is similar: "Please state the level of importance (from the scale of 1 to 9) of each criterion in determining your final goal;1= least important, 9 = extremely important.

Example 1: Three criteria.

Table 4.5(i) Rating table for m = 3

Criteria	**Rating**								
	1	2	3	4	5	6	7	8	9
A					X				
B				X					
C							X		

Table 4.5(ii) Converted pairwise comparison table for m = 3

		Criteria		
		A	**B**	**C**
Criteria	A	1	2	1/3
	B	½	1	1/4
	C	3	4	1

CR = 0.02

Example 2: Four criteria.

Table 4.6(i) Rating table for m = 4

Criteria	**Rating**								
	1	2	3	4	5	6	7	8	9
A		X							
B							X		
C				X					
D									X

Table 4.6(ii) Converted pairwise comparison table for m = 4

		Criteria			
		A	**B**	**C**	**D**
Criteria	A	1	1/6	1/3	1/8
	B	6	1	4	1/3
	C	3	¼	1	1/6
	D	8	3	6	1

CR = 0.05

Example 3: Five criteria.

Table 4.7(i) Rating table for m = 5

Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
A						X			
B					X				
C		X							
D				X					
E				X					

Table 4.7(ii) Converted pairwise comparison table for m = 5

		Criteria				
		A	**B**	**C**	**D**	**E**
Criteria	A	1	2	5	3	3
	B	½	1	4	2	2
	C	1/5	¼	1	1/3	1/3
	D	1/3	½	3	1	1
	E	1/3	½	3	1	1

CR = 0.01.

Example 4: Six criteria.

Table 4.8(i) Rating table for m = 6

Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
A							X		
B									X
C							X		
D					X				
E		X							
F						X			

Table 4.8(ii) Converted pairwise comparison table for m = 6

		Criteria					
		A	**B**	**C**	**D**	**E**	**F**
Criteria	A	1	1/3	1	3	6	2
	B	3	1	3	5	8	4
	C	3	1	1	3	6	2
	D	1/3	1/5	1/3	1	4	1/2
	E	1/6	1/8	1/6	1/4	1	1/5
	F	½	¼	½	2	5	1

CR = 0.03.

Example 5: Seven criteria.

Table 4.9(i) Rating table for m = 7

Criteria	1	2	3	4	5	6	7	8	9
A		X							
B							X		
C					X				
D						X			
E				X					
F								X	
G			X						

Table 4.9(ii) Converted pairwise comparison table for m = 7

		Criteria						
		A	**B**	**C**	**D**	**E**	**F**	**G**
Criteria	A	1	1/6	1/4	1/5	1/3	1/7	½
	B	6	1	3	2	4	1/2	5
	C	4	1/3	1	½	2	1/4	3
	D	5	½	2	1	3	1/3	5
	E	3	¼	½	3	1	1/6	2
	F	7	2	4	3	6	1	6
	G	2	1/5	1/3	1/5	1/2	1/6	1

CR = 0.02

Example 6: Eight criteria.

Table 4.10(i) Rating table for *m = 8*

Criteria	1	2	3	4	5	6	7	8	9
A							X		
B						X			
C					X				
D				X					
E			X						
F		X							
G	X								
H								X	

Table 4.10(ii) Converted pairwise comparison table for m = 8

		Criteria							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Criteria	A	1	2	3	4	5	6	7	½
	B	½	1	2	3	4	5	6	1/3
	C	1/3	½	1	2	3	4	5	¼
	D	¼	1/3	½	1	2	3	4	1/5
	E	1/5	¼	1/3	½	1	2	3	1/6
	F	1/6	1/5	¼	1/3	½	1	2	1/7
	G	1/7	1/6	1/5	¼	1/3	½	1	1/8
	H	2	3	4	5	6	7	8	1

CR = 0.03

Example 7: Nine criteria.

Table 4.11(i) Rating table for m = 9

Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
A		X							
B							X		
C					X				
D						X			
E				X					
F								X	
G			X						
H					X				
I									X

Table 4.11(ii) Converted pairwise comparison table for m = 9

		Criteria								
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Criteria	A	1	1/6	¼	1/5	1/3	1/7	½	¼	1/8
	B	6	1	3	2	4	1/2	5	3	1/3
	C	4	1/3	1	½	2	1/4	3	1	1/5
	D	5	½	2	1	3	1/3	4	2	1/4
	E	3	¼	½	1/3	1	1/5	2	½	1/6
	F	7	2	4	3	5	1	6	4	½
	G	2	1/5	1/3	¼	½	1/6	1	1/3	1/7
	H	4	1/3	1	½	2	¼	3	1	1/5
	I	8	3	5	4	6	2	7	5	1

CR = 0.03

Based on the experiments illustrated in Tables 4.5(ii) to 4.11(ii), all simulated judgments yield *CR* values less than the allowed value, which is 0.1. Thus, all the simulated pairwise comparisons are considered consistent and acceptable. The summary for the results are given in Table 4.12.

Table 4.12Summary of pairwise comparison experiments

Number of criteria *m*	***N***	**Min *CR***	**Max *CR***	**Mean *CR***	**Std. Deviation**
3	100	.000	.09	.0270	.02855
4	100	.000	.07	.0272	.01807
5	100	.000	.05	.0237	.01259
6	100	.004	.09	.0257	.01211
7	100	.005	.04	.0261	.00960
8	100	.006	.05	.0235	.00885
9	100	.001	.07	.0244	.00939

4.3.4.3 Combination of AHP and ROC

The AHP technique was used to allocate the weights for the selection criteria. The ROC technique was also employed for similar purpose. The weights and the rankings of the criteria obtained from both techniques were then compared to see whether or not the rankings were similar.

The evaluation methods may influence the final results. As previously mentioned, the ROC use sranking for the whole criteria, while, the AHP uses the pairwise comparison. Thus, it was expected that the weights of the criteria obtained from each method would not be exactly similar. Therefore, to further strengthen the decision making process, the mean of weights from the ROC and the AHP were obtained. The mean of the weights between the ROC and the AHP was calculated using the formula in Equation 4.10

$$w_j(ROC + AHP) = \frac{w_j(ROC)+w_j(AHP)}{2} \tag{4.10}$$

The next step was to select the best location among the available alternatives. Based on the summary of the techniques used to determine the final location selection, it was noted that the approach is either through optimization techniques such as LP, ILP, or MIP, or through heuristic approaches. Our problem did not involve many constraints and many variables. Thus, it could be solved using any optimization approach, i.e. heuristic approaches were not required. Furthermore, as only one final location is required to be selected, 0-1 IP was sufficient to tackle the problem. Therefore, the ROC-0-1 IP model, theAHP-0-1 IP model, and the mean of

ROC+AHP combined with 0-1 IP were used in this study. As such, the three models are described in subsequent sub-sections:

4.3.4.4 Utilizing the Weights for Criteria Obtained in ROC with 0-1 IP

$$\text{Decision Variables: } X_i = \begin{cases} 1 & \text{if location i is selected} \\ 0 & \text{otherwise} \end{cases} \quad (4.11)$$

Where $i = 1, 2\ldots, n$

Objective function: Minimize total deviation,

$$\sum_{i=1}^{m} WROC_i d_i^+ - WROC_i d_i^- \quad (4.12)$$

Where *WROC* is the weights of ROC, *m* is the number of criteria, *d* is the deviation of the criteria.

Subject to constraints:

$$\left(\sum_{i=1}^{n} C_i X_i\right) + d_i^- - d_i^+ = C_e \forall_i \quad (4.13)$$

Where *n* is the number of the location, *d* is the deviation of the location, C_e is the estimated value allocated total budget of the criteria in each location, C_i is the criteria value that needs to be facilitated at the factory in location *n*.

$$\sum_{i=1}^{n} X_i = 1 \quad (4.14)$$

$$d_i^+, d_i^- \geq 0 \quad (4.15)$$

4.3.4.5 Utilizing the Weights for Criteria Obtained in AHP with 0-1 IP

$$\text{Decision Variables: } X_i = \begin{cases} 1 & \text{if location i is selected} \\ 0 & \text{otherwise} \end{cases} \quad (4.16)$$

Where $i = 1, 2, \ldots, n$

Objective function: Minimize total deviation,

$$\sum_{i=1}^{m} WAHP_i d_i^+ - WAHP_i d_i^- \quad (4.17)$$

Where *WAHP* is the weights of AHP, *m* is the number of criteria, *d* is the deviation of the criteria.

Subject to constraints:

$$\left(\sum_{i=1}^{n} C_i X_i\right) + d_i^- - d_i^+ = C_e \forall_i \quad (4.18)$$

Where *n* is the number of the location, *d* is the deviation of the location, C_e is the estimated value allocated total budget of the criteria in each location, C_i is the criteria value that needs to be facilitated at the factory in location *n*.

$$\sum_{i=1}^{n} X_i = 1 \quad (4.19)$$

$$d_i^+, d_i^- \geq 0 \quad (4.20)$$

4.3.4.6Utilizing the Weights for Criteria Obtained in ROC + AHP with 0-1 IP

Decision Variables: $$X_i = \begin{cases} 1 & \text{if location i is selected} \\ 0 & \text{otherwise} \end{cases} \quad (4.21)$$

Where $i = 1, 2, \ldots, n$

Objective function: Minimize total deviation,

$$\sum_{i=1}^{m} W(ROC + AHP)_i d_i^+ - W(ROC + AHP)_i d_i^- \quad (4.22)$$

Where *W(ROC+AHP)* is the weights of the mean of ROC+AHP, *m* is the number of criteria, *d* is the deviation of the criteria

Subject to constraints:

$$\left(\sum_{i=1}^{n} C_i X_i\right) + d_i^- - d_i^+ = C_e \forall_i \quad (4.23)$$

Where n is the number of the location, d is the deviation of the location, C_e is the estimated value allocated total budget of the criteria in each location, C_i is the criteria value that needs to be facilitated at the factory in location n.

$$\sum_{i=1}^{n} X_i = 1 \quad (4.24)$$

$$d_i^{+}, d_i^{-} \geq 0 \quad (4.25)$$

This chapter discusses the methodologies and the procedure of data collection. The following chapter provides the analysis of the data as well as the implementation of the methods and the results.

CHAPTER FIVE

RESULTS AND DISCUSSION

This chapter describes the data used in this study, followed by the selection of criteria used in evaluating the factory location. The third section of this chapter describes in detail the weights of the criteria obtained through the ROC, the AHP, and the mean of the weights of ROC+AHP. Then, the chapter discusses the work done to choose the factory location by using the three integrated models; the ROC - 0-1 IP, the AHP-0-1 IP, and the ROC +AHP - 0-1 IP.

5.1 The Profile of the Respondents

The Ministry of Agriculture and Ministry of Local Administration were involved in the study. Due to politics and security of the districts covered, the collection of data took approximately six months. The respondents in this study consisted of two groups. The first group consisted of twenty one decision makers from the local councils. This study collected usable responses from them. Meanwhile, the second group consisted of the farmers, who supported and gave their opinions to decision makers. Detailed numbers of respondents in each district in Hadhramout are provided in Table 5.1.

Table 5.1Number of the farmers and decision makers in each district

Location	**Number of farmers**	**Attended farmers**	**Percentage of attended farmers**	**Decision makers**
Sah	40	32	80	3
Seyoun	25	18	72	3
Tareem	42	34	81	3
Shabam	38	31	82	3
Alqaten	20	14	70	3
WadiAlaeen and Horah	21	15	71	3
Doean	20	14	70	3
Total	206	158	77	21

The respondents listed in Table 5.1 were asked to evaluate the importance of each criterion in determining the date palm factory location using the ROC and AHP questionnaires. For example, Table 5.1 explains Sah is one of the locations which produce the date palm trees. There are 40 farmers in Sah, in which only 32 farmers or 80% attended the meeting. The rest were absent because they were staying so far from the meeting place. The meeting was also attended by three members of local councils (decision makers). Their educational background is detailed in Table 5.2.

Table 5.2 Descriptive analysis of educational level of the decision makers and farmers

Education level	**Decision maker**	**Farmers**
Primary school	0	97
Secondary school	6	59
Bachelor	12	2
Master	3	0
PhD	0	0
Total	21	158

Table 5.2 describes that most of the local council members have bachelor's degrees. In contrast, most of the farmers only finished their primary school.

5.2 Analysis of the Identification of the Criteria

As the result of the preliminary study, the selection criteria for prospective locations were used to be evaluated by the decision makers and farmers in the interview sessions. The identified criteria which may affect the facility location selection were grouped into a number of main criteria, as listed in Table 5.3.

Table 5.3 Main criteria and sub-criteria

Main criteria	Sub-criteria
Process input	Raw material, personnel, transportation of raw material, workforce availability, availability of water and power, and road-rails.
Process output	Market nearness.
Process characteristics	Environmental factors such as pollution, noise, weather, level of humidity and seasons, rainfall.
Personal Preference	Preference of executives or entrepreneur
Govt. Policy	Tax exemption, legal requirement, incentives, availability of loan/land.
Local conditions	Community culture and attribute, past history of industry located in the area, incidence of labor unrest in the area, political interference.
Cost factors	Cost of land, cost of transportation, and wages of unskilled and skilled labor.
Competition	Location of other industries in the area, market forces for competition.
Intangible factors	International consideration, room for expansion and growth, school, medical facilities, recreational facilities.

The criteria in Table 5.3 were provided to the decision makers to select the final set of suitable criteria. Then, the decision makers in each location selected the criteria, which differed among locations. Then, the decision makers in all the seven locations were asked to meet together in Seyoun: the capital city of Wadi Hadhramout, to discuss and agree on the final criteria to be used. This meeting in Seyoun between the decision makers in all seven locations was organised by the Ministry of Agriculture and Irrigation to discuss and to agree on the same criteria for all seven locations. Then, the decision makers finally selected the criteria as outlined in Figure 5.1.

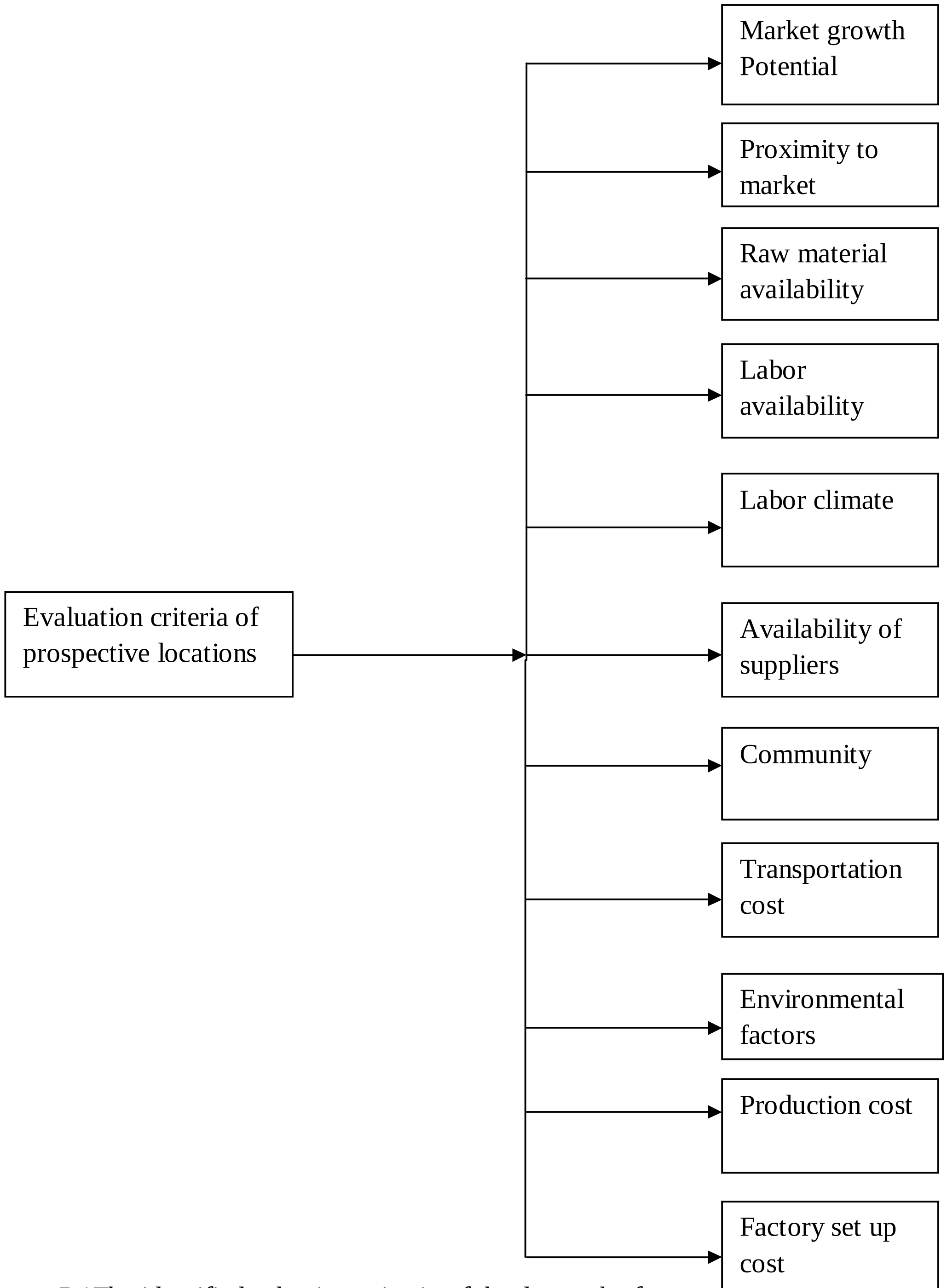

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Figure 5.1The identified selection criteria of the date palm factory

5.2.1 Justification of the Criteria

The identified criteria used were sourced from the literatures and experts' opinions. These criteria were used to develop a multi-criteria selection model in the main study.

5.3 Analysis of Main Study (Criteria Weights)

Once the prospective selection criteria locations had been identified in the preliminary study, these criteria were allocated with weights (degree of importance) using the ROC and the AHP techniques. Later, a selection model was developed using the ROC and the AHP combined with the 0-1 Integer Programming (0-1 IP) model.

5.3.1 Ranking of Criteria Using the Rank Order Centriod Technique

The Rank Order Centriod technique (ROC) method was applied to allocate the weights for the selection criteria. The respondents were asked to rank the selection criteria. The data collected from the respondents were used to identify the weights for the criteria. Later, to aggregate the individual judgments, an arithmetic mean approach was used. The ROC analysis was performed separately for all criteria.

The weights of the criteria were determined based on the rank made by the respondents. The weights (w_j) were calculated using the formula in Equation 5.1 as explained in the previous chapter.

$$w_j(ROC) = \frac{1}{m}\sum_{k=j}^{m}\frac{1}{k} \qquad (5.1)$$

Where

k = rank of criteria

m = number of criteria

w_j= weight for jth criteria

Two possibilities of ranking may occur:

5.3.1.1 Possibility One: Unique Ranking of the Criteria

Altogether, there were 11 criteria and 21 respondents. Each respondent ranked the criteria. The first respondent ranked the criteria as exhibited in Table 5.4.

Table 5.4 The weight by the first respondent for all the criteria

Criteria Number	Criterion name	First respondent's evaluation	Weight calculation	Criteria weight
C_1	Market growth	9	$\frac{1}{11}\left(\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.0275
C_2	Proximity to the markets	10	$\frac{1}{11}\left(\frac{1}{10}+\frac{1}{11}\right)$	0.0174
C_3	Proximity to the raw materials	2	$\frac{1}{11}\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.1836
C_4	Labor	3	$\frac{1}{11}\left(\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.1382
C_5	Labor climate	6	$\frac{1}{11}\left(\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.0670
C_6	Suppliers	1	$\frac{1}{11}\left(\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.2745
C_7	Community	11	$\frac{1}{11}\left(\frac{1}{11}\right)$	0.0083
C_8	Transportation cost	4	$\frac{1}{11}\left(\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.1079
C_9	Environmental factors	7	$\frac{1}{11}\left(\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.0518
C_{10}	Production cost	5	$\frac{1}{11}\left(\frac{1}{5}+\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.0851
C_{11}	Factory set up cost	8	$\frac{1}{11}\left(\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)$	0.0388

Based on Table 5.4, the most important criterion selected by the first respondent was suppliers (weight = 0.2745), while the second most important criterion was proximity to the raw materials (weight = 0.1836), followed by labor (weight = 0.1382). In contrast, the least important criterion was community (weight = 0.0083).

5.3.1.2 Possibility Two: Equal Ranking of the Criteria

It can happen sometimes when one or more respondents gave equal rank to more than one criterion as mentioned in section 4.3.4.1(b).

Based on Appendix D, which contains the summary of the different individual ranks and weights of all the criteria obtained from the evaluation done by all the decision makers, the final single rank and weight for each criterion was calculated using the arithmetic mean approach. In this approach, the weights (w_j) given by each respondent for the corresponding criteria were summed up and divided by the number of respondents (i), which is 21.

$$\overline{w}_j = \frac{w_{1j} + w_{2j} + \cdots + w_{ij}}{21} \quad (5.2)$$

For

$i = 1,2,\ldots,21$

$j = 1, 2, \ldots, 11$

Where

$\overline{w}_j$ = mean weight for criterion j

w_{ij} = relative weight given by respondents i for criterion j of the main criteria

Further, Table 5.5 exhibits the aggregated weights and ranks of criteria (details in Appendix D).

Table 5.5Final weights and ranks for the criteria using ROC model for the whole group

Criteria no.	**Criteria name**	**Weight**	**Rank**
C_1	Market growth	0.0219	9
C_2	Proximity to the markets	0.0236	10
C_3	Proximity to the raw materials	0.1135	6
C_4	Labor	0.1584	2
C_5	Labor climate	0.0498	8
C_6	Suppliers	0.2012	1
C_7	Community	0.0119	11
C_8	Transportation cost	0.1225	4
C_9	Environmental factors	0.0575	7
C_{10}	Production cost	0.1135	5
C_{11}	Factory set up cost	0.1262	3
Total		1	

Based on the ROC analysis for the criteria in Table 5.5, Suppliers (c_6) were perceived as most important (weight = 0.2012),followed by Labor (c_4) (weight = 0.1584) as the second most important criterion, and factory set up cost (c_{11}) as the third most important criterion (weight = 0.1262). In contrast, community (c_7) (weight = 0.0119) was the least important criterion.

5.3.2 Ranking of the Criteria Using the AHP Technique

Similar to the ROC technique, the AHP technique was mainly employed to allocate the weights to the identified selection criteria shown in Figure 5.1. Data collected from respondents were transformed into a matrix format and were later normalized to determine the weights as explained in Chapter Four. The AHP analysis was conducted individually for the criteria. The ranks by each respondent for the criteria are exhibited in Appendix E. Further, the AHP analysis is divided into four parts, as explained in the subsequent paragraphs.

i. To set up the decision hierarchy after specifying the criteria.

ii. To collect input data before weighting the criteria using pairwise comparison.

iii. To rank or weight the criteria through pairwise comparisons.

iv. To compute the consistency for each matrix.

While, Step (i) and (ii) have been discussed in Section 5.2, step (iii) and (iv) are explained in subsequent paragraphs. The questionnaire in Appendix B was designed after several discussions and consultations with the local council members and farmers. The members of the local councils were asked to answer in their respective classes with assistance of the researcher. They were briefed on the purpose of collecting data and the correct way to fill the AHP evaluation form.

Step (iii): Rank or weight the criteria through pairwise comparisons

Table 5.6 shows the decision maker‘s verbal description of the level of importance for each criterion in determining the date palm location using a numerical rating of 1 (least important) to 9 (extremely important). The first respondent evaluated the criteria as shown in Table 5.6

Table 5.6 The importance of selection criteria for factory location by first respondent

Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
C_1							7		
C_2								8	
C_3								8	
C_4									9
C_5							7		
C_6									9
C_7						6			
C_8						6			
C_9						6			
C_{10}									9
C_{11}							7		

Based on Table 5.6, the preference scale comparison for the first respondent of the pairwise comparison matrix is shown in pairwise comparison matrix (see Table 5.7) need to determine the priorities. An example for the first respondent of the pairwise comparison matrix is shown in Table 5.7.

Table 5.7Thepairwise comparison matrix and the summation of each column for the first respondent

	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
C_1	1	½	½	1/3	1	1/3	2	2	2	1/3	1
C_2	2	1	1	½	2	½	3	3	3	½	2
C_3	2	1	1	½	2	½	3	3	3	½	2
C_4	3	2	2	1	3	1	4	4	4	1	3
C_5	1	½	½	1/3	1	1/3	2	2	2	1/3	1
C_6	3	2	2	1	3	1	4	4	4	1	3
C_7	½	1/3	1/3	¼	½	¼	1	1	1	¼	½
C_8	½	1/3	1/3	¼	½	¼	1	1	1	¼	½
C_9	½	1/3	1/3	¼	½	¼	1	1	1	¼	½
C_{10}	3	2	2	1	3	1	4	4	4	1	3
C_{11}	1	½	½	1/3	1	1/3	2	2	2	1/3	1

By using EXPERT CHOICE software for the matrix comparison for the first respondent, the weights and rank for the criteria are given in Table 5.8. All the calculations to find the final weight for all the criteria evaluated by the first respondent are in Appendix E.

Table 5.8 Final weights and rank for the criteria using AHP model for the first respondent

Criteria no.	Criteria name	Weight	Rank
C_1	Market growth	0.0603	8
C_2	Proximity to the markets	0.1025	5
C_3	Proximity to the raw materials	0.1026	4
C_4	Labor	0.1691	2
C_5	Labor climate	0.0604	7
C_6	Suppliers	0.1692	1
C_7	Community	0.0354	11
C_8	Transportation cost	0.0355	10
C_9	Environmental factors	0.0356	9
C_{10}	Production cost	0.1690	3
C_{11}	Factory set up cost	0.0605	6
Total		1	

CR = 0.0057

All comparison matrices produced *CR* value of less than 0.10;so the evaluation given by the first respondent is consistent. The process was repeated for all respondents.The results and the consistency ratio for each data set for all the 21 respondents'are summarized in Appendix F.

The data collected from the respondents were used to identify the weights of the criteria. Based on Appendix F, the maximum, minimum, average, and the standard deviation of the weights of each criterion evaluated by all the respondents are shown in Table 5.9. Later, to aggregate the individual judgments, a geometric mean approach was used. Although, Saaty suggested the geometric mean to be used, we decided to use the arithmetic mean because we want to show that each respondent did their pairwise comparison consistently. Also by using the arithmetic mean, we were able to compare the decision /weight given by each respondent. Meanwhile, Table 5.9 explains that the values of *CR* for all 21 evaluators are below 0.1 as the maximum value is 0.09 and the minimum value is 0.001.

Table 5.9Descriptive analysis of the criteria weights and the values of consistency ratio, CR for all 21 evaluations

Criteria No	**Criteria Name**	**Maximum**	**Minimum**	**Average**	**Std. Deviation**
C_1	Market growth	.1710	.0470	.0771	.0377
C_2	Proximity to the markets	.1460	.0120	.0651	.0366
C_3	Proximity to the raw materials	.1760	.0330	.0829	.0465
C_4	Labor	.1730	.0220	.1052	.0458
C_5	Labor climate	.1990	.0270	.0869	.0453
C_6	Suppliers	.1800	.0200	.1102	.0520
C_7	Community	.1710	.0120	.0663	.0422
C_8	Transportation cost	.1910	.0050	.1048	.0525
C_9	Environmental factors	.1990	.0140	.0875	.0511
C_{10}	Production cost	.1800	.0140	.1039	.0511
C_{11}	Factory set up cost	.1790	.0390	.1100	.0396
	Consistency value, *CR*	.0900	.0010	.0079	.0249
Total				1.0000	

Accordingly, the final weights and ranks of the criteria evaluated by the group of respondents were obtained and are shown in Table 5.10.

Table 5.10Final weights and rank for the criteria using the AHP model

Criteria no.	Criteria name	Weight	Rank
C_1	Market growth	.0771	9
C_2	Proximity to the markets	.0651	11
C_3	Proximity to the raw materials	.0829	8
C_4	Labor	.1052	3
C_5	Labor climate	.0869	7
C_6	Suppliers	.1102	1
C_7	Community	.0663	10
C_8	Transportation cost	.1048	4
C_9	Environmental factors	.0875	6
C_{10}	Production cost	.1039	5
C_{11}	Factory set up cost	.1100	2
	Total	1.0000	

Based on the AHP analysis for the criteria, Suppliers (c_6) was perceived as the most important criterion (weight = 0.1102); Factory set up cost (c_{11}) (weight = 0.1100) was next, while the Labor (c_4) (weight = 0.1052) stood as the third most important criterion. In contrast, Proximity to the markets (c_2) (weight = 0.0651) was the least important criterion. Based on Tables 5.5 and 5.10 shows the ranking from the ROC and the AHP; and the summary of the ROC and the AHP ranking are given in Table 5.11

Table 5.11Comparison of the rank of the criteria in the ROC and the AHP models

Criteria no.	Criteria name	ROC	AHP
C_1	Market growth	9	9
C_2	Proximity to the markets	10	11
C_3	Proximity to the raw materials	6	8
C_4	Labor	2	3
C_5	Labor climate	8	7
C_6	Suppliers	1	1
C_7	Community	11	10
C_8	Transportation cost	4	4
C_9	Environmental factors	7	6
C_{10}	Production cost	5	5
C_{11}	Factory set up cost	3	2

It can be noticed from Table 5.11 that the rankings produced by the ROC and the AHP models are not exactly similar. For example, the proximity to markets (c_2) in the ROC was ranked 10th while in the AHP, it was ranked 11th. Similarly, labor climate (c_5) in the ROC was ranked 8th while in the AHP it was ranked 7th. On the other hand, as expected, there were some similarities in the rankings. For example, Transportation cost (c_8) was ranked 4thin both the ROC and the AHP. Production cost (c_{10}) was ranked 5th, Suppliers (c_6) was ranked 1st, and Market growth (c_1) was ranked 9th. The slight difference in the criteria ranking between the ROC and the AHP was due to the magnitude of the weights given by each individual decision maker in the AHP ranking, which affected the mean average when combined.

5.3.3 Analysis of Weighting Mean of ROC and AHP

The ROC and the AHP techniques were used together to yield the weights of the third set of criteria. For this, a combined analysis was carried out for the criteria. The weights assigned for the criteria were based on the mean of the weights obtained from the ROC and the AHP techniques and are shown in Table 5.12.

Table 5.12Final weights and rank for the criteria using the mean of ROC and AHP model

Criteria no.	Criteria name	ROC+AHP	Mean	Rank
C_1	Market growth	0.0990	0.0495	9
C_2	Proximity to the markets	0.0887	0.0444	10
C_3	Proximity to the raw materials	0.1964	0.0982	6
C_4	Labor	0.2636	0.1318	2
C_5	Labor climate	0.1367	0.0684	8
C_6	Suppliers	0.3114	0.1557	1
C_7	Community	0.0782	0.0391	11
C_8	Transportation cost	0.2273	0.1137	4
C_9	Environmental factors	0.1450	0.0725	7
C_{10}	Production cost	0.2174	0.1087	5
C_{11}	Factory set up cost	0.2362	0.1181	3
Total			1	

The third column of Table 5.12 contains the summation of the two (ROC and AHP) weights for each criterion, and then the fourth column (the mean) contains the values obtained by dividing the values in the third column by two. For example, the first value in the third column (0.0990) was computed by adding the weight of Market growth (0.0219) in ROC weights in Table 5.5 and the weight of the same criterion (0.0771) in AHP weights in Table 5.10. Then, it was divided by two which gave the value in column 4 (the mean). The same process was applied for all criteria. Based on the mean of ROC and AHP analysis for the criteria in Table 5.12, Suppliers (c_6) was perceived as the most important criterion(weight = 0.1557), while the second most important criterion was Labor (c_4) (weight = 0.1318) and the third most important criterion was Factory set up cost(c_{11}) (weight = 0.1181). Meanwhile, the least important criterion was Community (c_7) (weight = 0.0391). Based on Tables 5.5, 5.10, and 5.12, the results are summarized in Table 5.13.

Table 5.13Comparison of the rank of the criteria in the three models

Criteria no.	**Criteria name**	**ROC**	**AHP**	**ROC+AHP**
C_1	Market growth	9	9	9
C_2	Proximity to the markets	10	11	10
C_3	Proximity to the raw materials	6	8	6
C_4	Labor	2	3	2
C_5	Labor climate	8	7	8
C_6	Suppliers	1	1	1
C_7	Community	11	10	11
C_8	Transportation cost	4	4	4
C_9	Environmental factors	7	6	7
C_{10}	Production cost	5	5	5
C_{11}	Factory set up cost	3	2	3

Table 5.13 exhibits that the first criterion (Market growth) was ranked at the ninth position in the ROC, the AHP, and the mean of ROC+AHP. Meanwhile, the second criterion (Proximity to the markets) was ranked 10^{th} in the ROC and the ROC+AHP, while, it was ranked 11^{th} in the AHP.

5.4 Factory Location Selection

Once the selection criteria for prospective locations had been identified and given proper weights in the preliminary study, the palm date factory locationwas identified using three different mathematical models: the ROC combined with the 0-1 IP, the AHP combined with the 0-1 IP model, and the mean of the ROC and the AHP combined with the 0-1 IP model. The general model for all the three models is the same. The only difference is with regards to the weights given in the objective function as obtained in the next set of equations.

Decision Variables: $X_i = \begin{cases} 1 \text{ if location i is selected} \\ 0 \quad\quad\quad\quad \text{otherwise} \end{cases}$ (5.3)

Where $i = 1, 2, \ldots, 7$.

Refer to Equation 4.12, 4.17, and 4.22 then,

The Objective function: Minimize total deviation,

$$-W_1C_1d_1^- + W_2C_2d_2^+ - W_3C_3d_3^- + W_4C_4d_4^+ + W_5C_5d_5^+ + W_6C_6d_6^+ - W_7C_7d_7^- + W_8C_8d_8^+ + W_9C_9d_9^+ + W_{10}C_{10}d_{10}^+ - W_{11}C_{11}d_{11}^- \quad (5.4)$$

Constraints:

The constraints were initially measured by different units. For example, *MG*, *TC*, *PC*, *TS*, and *FSC* were measured by USD, while the kilometer square was used to measure *PM* and *PRM*. On the other hand, *LC*, *CO*, and *EF* were measured by the scales (1 = low, 2 = above low, 3 = moderate, 4 = less than high, and 5 = high) and *LO* was measured by the number of the people. Thus, to satisfy the condition for the model to work (i.e. the unit measurements for all variables and parameters in the objective function must be the same) the researcher converted all units of measurements to USD by assuming that, each kilometer square equaled USD5. As for the scale, the conversion was done using the following: 1 = USD100, 2 =

USD200, 3 = USD300, 4 = USD400, and 5 = USD500. Finally, each person was considered equaling USD10.

Thus, the constraints are as follows.

Market growth (*MG*)

The market growth should meet the estimated target value, *EMG*.

$$MGX_1+MGX_2+MGX_3+MGX_4+MGX_5+MGX_6+MGX_7+d_1^- -d_1^+=EMG \quad (5.5)$$

Proximity to the market (*PM*)

The proximity to the market should not exceed the expected proximity to the market, *EPM*.

$$PMX_1+PMX_2+PMX_3+PMX_4+PMX_5+PMX_6+PMX_7+d_2^- -d_2^+= EPM \quad (5.6)$$

Proximity to the raw materials (*PR*)

The proximity to the raw materials should not exceed the estimated proximity to the raw materials, *EPR*.

$$PRX_1+PRX_2+PRX_3+PRX_4+PRX_5+PRX_6+PRX_7+d_3^- - d_3^+ = EPR \quad (5.7)$$

Labor (*LO*)

The labor should meet the estimated target value, *ELP*.

$$LOX_1+LOX_2+LOX_3+LOX_4+LOX_5+LOX_6+LOX_7+d_4^- -d_4^+=ELO \quad (5.8)$$

Labor climate (*LC*)

The labor climate must meet the estimated labor climate value, *ELC*.

$$LCX_1+LCX_2+ LCX_3 + LCX_4 + LCX_5 + LCX_6 + LCX_7+ d_5^- - d_5^+ =ELC \quad (5.9)$$

Total suppliers (*TS*)

The total suppliersshould be more than the estimated target of total suppliers, *ETS*.

$$TSX_1+TSX_2+TSX_3+TSX_4+TSX_5+TSX_6+TSX_7+d_6^- - d_6^+ = ETS \quad (5.10)$$

Community (*CO*)

The community should meet the estimated target value, *ECO*.

$$COX_1+COX_2 + COX_3 + COX_4 + COX_5 + COX_6 + COX_7+ d_7^- - d_7^+ = ECO \quad (5.11)$$

Transportation cost (*TC*)

The transportation cost should not exceed the estimated target transportation cost, *ETC*.

$$TCX_1+TCX_2+TCX_3+TCX_4+TCX_5+TCX_6+TCX_7+d_8^- - d_8^+ = ETC \quad (5.12)$$

Environmental factors (*EF*)

The environmental factors should not exceed the estimated target value, *EEF*.

$$EFX_1+ EFX_2 + EFX_3 + EFX_4 + EFX_5 + EFX_6 + EFX_7+ d_9^- - d_9^+ = EEF \quad (5.13)$$

Cost of production (*CP*)

The cost of production should not exceed the estimated target value of the cost of production, *ECP*.

$$CPX_1+CPX_2+CPX_3+CPX_4+CPX_5+CPX_6+CPX_7+d_{10}^- - d_{10}^+ = ECP \quad (5.14)$$

Factory set-up cost (*FSC*)

The factory set-up cost should not exceed the estimated factory set-up cost,*EFC*.

$$FSCX_1+FSCX_2+FSCX_3+FSCX_4+FSCX_5+FSCX_6+FSCX_7+d_{11}^- - d_{11}^+ = EFC \quad (5.15)$$

Only one location will be selected.

$X_1+X_2 + X_3 + X_4 + X_5 + X_6 + X_7 = 1$ (5.16)

Non-negativity constraints

$d_i^+, d_i^- \geq 0$ (5.17)

The values in the right hand side of the constraints were estimated by the decision makers and farmers as shown in Appendix G.

5.4.1 Combined ROC- 0-1 IP Model

Since the data in this study involves less than 29 variables and not more than 12 constraints, it can be solved using any optimization approach. Therefore, as only one final location is required to be selected, 0-1 IP is sufficient to tackle the problem. Utilizing the weights for the criteria listed in Table 5.5 and in Appendix F, the 0-1 IP model is shown in Equation 5.18.

Decision Variables: $X_i = \begin{cases} 1 & \text{if location i is selected} \\ 0 & \text{otherwise} \end{cases}$ (5.18)

Where i = 1,2,3,4,5,6,7.

Refer to Equations 4.12 and 5.4 - then,

Objective function: Minimize total deviation,

$-0.0219d_1^- + 0.0236d_2^+ - 0.1135d_3^- + 0.1584d_4^+ + 0.0498d_5^+ + 0.2012d_6^+ - 0.0119d_7^- + 0.1225d_8^+ + 0.0575d_9^+ + 0.1135d_{10}^+ - 0.01262d_{11}^-$ (5.19)

Subject to constraints:

Market growth

The market growth should not be less than the target value estimated by the respondents which equaled to USD25000.

$12000X_1+20000X_2+21000X_3+17000X_4+16500X_5+13000X_6+11000X_7+d_1^- - d_1^+ = 25000$ (5.20)

Proximity to the market

The proximity to the market should not exceed the target value estimated by the respondents which equaled to USD1000.

$$9000X_1+7500X_2+7000X_3+6500X_4+6250X_5+9500X_6+10500X_7+d_2^- - d_2^+ = 10000 \quad (5.12)$$

Proximity to the raw materials

The proximity to the raw materials should be not exceeding the target value estimated by the respondents which equaled to USD700.

$$500X_1+1000X_2+500X_3+750X_4+600X_5+650X_6+750X_7+ d_3^- - d_3^+ = 700 \quad (5.22)$$

Labor

The labor should be not exceeding the target value estimated by the respondents which equaled to USD1500.

$$1000X_1+800X_2+1200X_3+1000X_4+1100X_5+1000X_6+900X_7+ d_4^- - d_4^+ = 1500 \quad (5.23)$$

Labor climate

The labor climate should be not exceeding the target value estimated by the respondents which equaled to USD500.

$$400X_1+500X_2+ 500X_3 + 400X_4 + 400X_5 + 300X_6 + 400X_7+ d_5^- - d_5^+ = 500 \quad (5.24)$$

Total suppliers

The total suppliers, should if possible, exceed the target value estimated by the respondents which equaled to USD18000.

$$15000X_1+12000X_2+14000X_3+13000X_4+13000X_5+12000X_6+15000X_7+d_6^- - d_6^+ = 18000 \quad (5.25)$$

Community

The community should not be less than the target value estimated by the respondents which equaled to USD500.

$$500X_1+300X_2 + 400X_3 + 400X_4 + 500X_5+ 500X_6 + 500X_7+ d_7^- - d_7^+ = 500 \qquad (5.26)$$

Transportation cost

The transportation cost should be not exceeding the target value estimated by the respondents which equaled to USD15000.

$$18000X_1+13000X_2+11000X_3+13000X_4+14000X_5+15000X_6+18000X_7+d_8^- -d_8^+=15000 \qquad (5.27)$$

Environmental factors

The environmental factors should be not exceeding the target value estimated by the respondents which equaled to USD500.

$$500X_1+ 300X_2 + 500X_3 + 400X_4+ 300X_5 + 400X_6 + 500X_7+ d_9^- - d_9^+ = 500 \qquad (5.28)$$

Cost of production

The cost of production should be not exceeding the target value estimated by the respondents which equaled to USD35000.

$$30000X_1+32000X_2+31000X_3+30000X_4+30000X_5+31000X_6+32000X_7+d_{10}^- -d_{10}^+=35000 \qquad (5.29)$$

Factory set-up cost

The factory set up cost should be not exceeding the target value estimated by the respondents which equaled to USD28000.

$$20000X_1+35000X_2+25000X_3+27000X_4+23000X_5+20000X_6+20000X_7+d_{11}^- -d_{11}^+=28000 \qquad (5.30)$$

$$X_1+X_2 + X_3 + X_4 + X_5 + X_6 + X_7 = 1 \quad (5.31)$$

$$d_i^+, d_i^- \geq 0 \quad (5.32)$$

By using LINDO software, the 0-1 IP model and ROC weights gave the following results:

a) The factory should be built in location 6, which is Doean.

b) The market growth exceeded the minimum expected requirement by USD12000.

c) The budget for proximity to market was less than the total estimated allocated budget by USD10000.

d) The proximity to raw materials exceeded the minimum expected requirement by USD50.

e) The labor was less than the total estimated allocated budget by USD500.

f) The labor climate exceeded the minimum expected requirement by USD200.

g) The total suppliers exceeded the minimum expected requirement by USD600.

h) The community exceeded the minimum expected requirement by USD0.

i) The transportation cost was less than the total estimated allocated budget by USD0.

j) The environmental factors were less than the total estimated allocated budget by USD100.

k) The cost of production was less than the total estimated allocated budget by USD4000.

l) Finally, the factory set up cost was less than the total estimated allocated budget by USD8000.

5.4.2 Combined AHP- 0-1 IP Model

Similar to the case of ROC-0-1 IP model, only one final location is required to be selected. Hence, the 0-1 IP is sufficient to tackle the problem. Therefore, utilizing the weights for the criteria exhibited in Table 5.10, the 0-1 IP model is shown in Equation 5.33.

Decision Variables: $$X_i = \begin{cases} 1 & \text{if location i is selected} \\ 0 & \text{otherwise} \end{cases} \quad (5.33)$$

Where i = 1,2,3,4,5,6,7.

Refer to Equations 4.17 and 5.4 then,

The objective function: Minimize total deviation,

$$-0.0770d_1^- + 0.0651d_2^+ - 0.0829d_3^- + 0.1052d_4^+ + 0.0869d_5^+ + 0.1102d_6^+ - 0.0663d_7^- + 0.1048d_8^+ + 0.0875d_9^+ + 0.1039\, d_{10}^+ - 0.1100d_{11}^- \quad (5.34)$$

Subject to constraints:

Market growth

$$12000X_1+20000X_2+21000X_3+17000X_4+16500X_5+13000X_6+11000X_7+d_1^- - d_1^+ = 25000 \quad (5.35)$$

Proximity to the market

$$9000X_1+7500X_2+7000X_3+6500X_4+6250X_5+9500X_6+10500X_7+ d_2^- - d_2^+ = 10000 \quad (5.36)$$

Proximity to the raw materials

$$500X_1+ 1000X_2 + 500X_3 + 750X_4 + 600X_5+ 650X_6 + 750X_7+ d_3^- - d_3^+ = 700 \quad (5.37)$$

Labor

$$1000X_1+ 800X_2 + 1200X_3 + 1000X_4 + 1100X_5 + 1000X_6 + 900X_7 + d_4^- - d_4^+ = 1500 \quad (5.38)$$

Labour climate

$400X_1 + 500X_2 + 500X_3 + 400X_4 + 400X_5 + 300X_6 + 400X_7 + d_5^- - d_5^+ = 500$ (5.39)

Total suppliers

$15000X_1+12000X_2+14000X_3+13000X_4+13000X_5+12000X_6+15000X_7+d_6^- - d_6^+ = 18000$ (5.40)

Community

$500X_1 + 300X_2 + 400X_3 + 400X_4 + 500X_5 + 500X_6 + 500X_7 + d_7^- - d_7^+ = 500$ (5.41)

Transportation cost

$18000X_1+13000X_2+11000X_3+13000X_4+14000X_5+15000X_6+18000X_7+d_8^- - d_8^+ = 15000$ (5.42)

Environmental factors

$500X_1 + 300X_2 + 500X_3 + 400X_4 + 300X_5 + 400X_6 + 500X_7 + d_9^- - d_9^+ = 500$ (5.43)

Cost of production

$30000X_1+32000X_2+31000X_3+30000X_4+30000X_5+31000X_6+32000X_7+d_{10}^- - d_{10}^+ = 35000$ (5.44)

Factory set-up cost

$20000X_1+35000X_2+25000X_3+27000X_4+23000X_5+20000X_6+20000X_7+d_{11}^- - d_{11}^+ = 28000$

(5.45)

$X1 + X2 + X3 + X4 + X5 + X6 + X7 = 1$ (5.46)

$d_i^+, d_i^- \geq 0$ (5.47)

Further, using the data, and using LINDO software, the 0-1 IP model and AHP weights gave the following results:

a) The factory should be built in location 6, which is Doean.

b) The market growth exceeded the minimum expected requirement by USD12000.

c) The budget for proximity to market was less than the total estimated allocated budget by USD10000.

d) The proximity to raw materials exceeded the minimum expected requirement by USD50.

e) The labor was less than the total estimated allocated budget by USD500.

f) The labor climate exceeded the minimum expected requirement by USD200.

g) The total suppliers exceeded the minimum expected requirement by USD600.

h) The community exceeded the minimum expected requirement by USD0.

i) The transportation cost was less than the total estimated allocated budget by USD0.

j) The environmental factors were less than the total estimated allocated budget by USD100.

k) The cost of production was less than the total estimated allocated budget by USD4000.

l) Finally, the factory set up cost was less than the total estimated allocated budget by USD8000.

5.4.3 Combined the Mean of ROC and AHP with 0-1 IP

Based on the summary of the techniques used to determine the final location selection, it can be deduced that the approach is either through optimization techniques such as LP, ILP, or MIP, or through heuristic approaches. The conditions are similar with both ROC-0-1 IP and AHP-0-1 IP, in which only one final location is required to be selected. Therefore, 0-1 IP is sufficient to solve the problem.

Consequently, utilizing the weights for the criteria obtained in Table 5.11, the 0-1 IP model is as follows:

Decision Variables: $X_i = \begin{cases} 1 & \text{if location i is selected} \\ 0 & \text{otherwise} \end{cases}$ (5.48)

Where i = 1,2,3,4,5,6,7.

Refer to Equations 4.22 and 5.4 then,

The objective function: Minimize total deviation,

$$-0.0495d_1^- + 0.0444d_2^+ - 0.0982d_3^- + 0.1318d_4^+ + 0.0684d_5^+ + 0.1557d_6^+ - 0.0391d_7^- + 0.1137d_8^+ + 0.0725d_9^+ + 0.1087d_{10}^+ - 0.1181d_{11}^- \quad (5.49)$$

Subject to constraints:

Market growth

$$12000X_1+20000X_2+21000X_3+17000X_4+16500X_5+13000X_6+11000X_7+d_1^- - d_1^+ = 25000 \quad (5.50)$$

Proximity to the market

$$9000X_1+7500X_2+7000X_3+6500X_4+6250X_5+9500X_6+10500X_7+ d_2^- - d_2^+ = 10000 \quad (5.51)$$

Proximity to the raw materials

$$500X_1 + 1000X_2 + 500X_3 + 750X_4 + 600X_5 + 650X_6 + 750X_7 + d_3^- - d_3^+ = 700 \quad (5.52)$$

Labor

$$1000X_1 + 800X_2 + 1200X_3 + 1000X_4 + 1100X_5 + 1000X_6 + 900X_7 + d_4^- - d_4^+ = 1500 \quad (5.53)$$

Labour climate

$$400X_1 + 500X_2 + 500X_3 + 400X_4 + 400X_5 + 300X_6 + 400X_7 + d_5^- - d_5^+ = 500 \quad (5.54)$$

Total suppliers

$$15000X_1+12000X_2+14000X_3+13000X_4+13000X_5+12000X_6+15000X_7+d_6^- - d_6^+ = 18000 \quad (5.55)$$

Community

$$500X_1 + 300X_2 + 400X_3 + 400X_4 + 500X_5 + 500X_6 + 500X_7 + d_7^- - d_7^+ = 500 \quad (5.56)$$

Transportation cost

$$18000X_1+13000X_2+11000X_3+13000X_4+14000X_5+15000X_6+18000X_7+d_8^- - d_8^+=15000 \quad (5.57)$$

Environmental factors

$$500X_1 + 300X_2 + 500X_3 + 400X_4 + 300X_5 + 400X_6 + 500X_7 + d_9^- - d_9^+ = 500 \quad (5.58)$$

Cost of production

$$30000X_1+32000X_2+31000X_3+30000X_4+30000X_5+31000X_6+32000X_7+d_{10}^- - d_{10}^+=35000 \quad (5.59)$$

Factory set-up cost

$$20000X_1+35000X_2+25000X_3+27000X_4+23000X_5+20000X_6+20000X_7+d_{11}^- - d_{11}^+=28000 \quad (5.60)$$

$$X1 + X2 + X3 + X4 + X5 + X6 + X7 = 1 \quad (5.61)$$

$$d_i^+, d_i^- \geq 0 \quad (5.62)$$

Eventually, using the data, and using LINDO software, the 0-1 IP model and the mean of ROC+AHP weights gavethe following results:

a. The factory should be built in location 6, which is Doean.
b. The market growth exceeded the minimum expected requirement by USD12000.
c. The budget for proximity to market was less than the total estimated allocated budget by USD10000.
d. The proximity to raw materials exceeded the minimum expected requirement by USD50.
e. The labor was less than the total estimated allocated budget by USD500.

f. The labor climate exceeded the minimum expected requirement by USD200.

g. The total suppliers exceeded the minimum expected requirement by USD600.

h. The community exceeded the minimum expected requirement by USD0.

i. The transportation cost was less than the total estimated allocated budget by USD0.

j. The environmental factors were less than the total estimated allocated budget by USD100.

k. The cost of production was less than the total estimated allocated budget by USD4000.

l. Finally, the factory set up cost was less than the total estimated allocated budget by USD8000.

The results of the three models are summarized in Table 5.14 as follows.

Table 5.14Summary of the results of three models in USD

Constraints	**ROC + 0-1 IP**	**AHP + 0-1 IP**	**ROC+AHP + 0-1 IP**
market growth	12000	12000	12000
proximity to market	10000	10000	10000
proximity to raw materials	50	50	50
Labor	500	500	500
labor climate	200	200	200
total of suppliers	600	600	600
Community	0	0	0
transportation cost	0	0	0
environmental factors	100	100	100
cost of production	4000	4000	4000
factory set up cost	8000	8000	8000
Location	6 (Doean)	6 (Doean)	6 (Doean)

It can be concluded that, the suitable location for date palm factory is number six which is Doean. According to this result, the market growth (12000 USD) in Doean will be less than the estimated value (25000 USD) yearly. The proximity to market from Doean will cost 10000 USD which is less than the highest market value estimated, i,e., 20000 USD. The proximity to raw materials will cost 50 USD; this is less than the raw materials cost (140USD) at greater distance. The labor will cost 500 USD in Doean, while in other locations, it may cost 1500 USD. The labor climate will cost 200 USD which is less than the highest cost of labor climate at 500 USD. The total suppliers cost will be 600 USD which is less than the estimated total suppliers cost of 18000 USD. The community and transportation cost will not be considered because it will not cost anything. The environmental effect in Doean will cost 100 USD which is less than the budget of environmental factors cost, i.e., 500 USD. The production of date palm in Doean will cost 4000 USD which is less than the highest cost of the production, i.e., 35000 USD. Lastly, the factory building cost will be around 8000 USD which is less than the budget of the building cost in other locations (28000 USD).

5.5 Conclusion

The analyses incurred in the preliminary study and the main study are discussed in this chapter. The preliminary study had identified the suitable and practicable location selection criteria for the prospective locations. Further, the main study allocated the weights for selection criteria for the prospective locations and was subsequently used to develop an efficient multi-criteria location candidates' selection model.

The AHP, the AHP and the combination of the AHP and the ROC techniques were used for weight allocation purposes. Comparisons were made between these techniques in terms of the range of the weights and the ranking of criteria. The ROC-0-1 IP, the AHP-0-1 IP, and the ROC+AHP-0-1 IP models were then employed to determine and select the best location from the several suggested locations.

The models suggested that the factory should be built in location 6, which is Doean. Since all the three models, the ROC and the 0-1 IP, the AHP and the 0-1 IP, and the ROC+AHP and the 0-1 IP gave the same results as mentioned in Table 5.14, the decision to select Doean as the location for the date palm factory is properly justified.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

This chapter summarizes the study in general and discusses some of the limitations. Additionally, it also addresses some recommendations for potential work in the future.

6.1 Summary of the Study

This study attempts to solve facility location problems especially in selecting the best location in Hadhramout, Yemen. Specifically, this study proposes a model that identified and evaluated the criteria, ranked the criteria, and selected the best location of date palm packaging factory in Hadhramout, Yemen. The solution is addressed in responses to the identified problem relating to facility location as discussed in Section 1.1.1.

The objectives of this study were to identify the criteria for selecting the best location for the date palm packaging factory, propose the techniques for ranking the criteria, formulate an approach in reducing the inconsistent pairwise comparisons in the AHP technique, propose the models for selecting the best location, and determine the best location of the date palm packaging factory, based on the criteria.

With reference to the proposed model, first, the criteria were identified by the decision makers. Among the currently in-place criteria include market growth, proximity to the markets, proximity to the raw materials, labor, labor climate, suppliers, community, transportation cost, environmental factors, production cost, and factory set up cost. Those criteria were identified by 21 members of local councils, who were selected based on their qualifications, work experience and field exposure with farmers. This led towards achieving the first objective in Section 5.2.

Second, three techniques were proposed to analyze the selected criteria in terms of relative importance and rank the weights of the criteria. In particular, the ROC, the AHP, mean of the ROC and the AHP were the selected techniques. This ensured the second objective of the study is achieved in Section 5.3. Third, this study deduced that a problem may occur with the ROC when the decision makers gave the same order or rank to more than one different criteria. Then, the sum of the weights would not equal to 1. In overcoming this, the normalization technique was used to weigh the criteria in the ROC technique. In addition, it was also observed that the AHP technique may have consistency problems that have not been fixed by previous researchers. In terms of the results, the modified approach in the AHP technique was suggested to transfer the regular Likert Scale techniques from the decision makers to the pairwise comparison matrix. By doing this, the inconsistency problem was solved, thus ensuring that the third objective of the study is achieved in Sections 5.3.1 and 5.3.2.

Fourth, all criteria were weighted and ranked by the three models (i.e. ROC, AHP, the mean of ROC+AHP) as mentioned in Tables 5.5, 5.10, and 5.12. In the operation, the ROC used ranking for the whole criteria, while AHP used the pairwise comparison. This resulted in different weight of the criteria. As an illustration, the most significant criterion in the ROC, the AHP, and in the mean of the ROC and the AHP was suppliers. The second most significant criterion in ROC and the mean of

ROC and AHP was labor, but, it was factory set up cost in the AHP. Subsequently, the third most significant criterion in ROC and AHP was factory set up cost, while in AHP, it was labor. Further discussions are available in Chapter Five, provided in Table 5.13. This explains that the fourth objective of the study is achieved in Sections 5.3.1, 5.3.2, and 5.3.3.

Fifth, three models were proposed to select the best location of date palm packaging factory, i.e.,the combination of the ROC with the 0-1 IP model, the AHP with the 0-1 IP model, and the mean of the ROC and the AHP with 0-1 IP model. This led to the achievement of the fifth objective of the study in Section 5.4. Finally, the best location of the date palm packaging factory was selected. The factory should be built in location 6, namely Doean. Interestingly, all the three models: the ROC with the 0-1 IP model, the AHP with the 0-1 IP model, and the mean of the ROC and the AHP with the 0-1 IP model, proposed the same location. Hence, this proves the achievement of the sixth objective of the study in Sections 5.4.1, 5.4.2, and 5.4.3.

6.2 Limitation of the Study

The limitations of this study lie on the sizes of respondents, criteria, and locations. Particularly, the size of respondents is the major problem. Only three out of five members of the local councils in each location were considered in this study.

In terms of the limitations of the criteria, this study assumes that the selected criteria were independent. This means that there is no correlation among the suggested criteria. Although the criteria proposed for the suggested locations are appropriate for the current situation, they are possibly valid for short-term run. This is because the selection criteria were highly influenced by external determinants, such as the rules enforced and the needs and desires of the society. Thus, the selection criteria may change continuously in line with globalization.

Additionally, the locations; referring to the valley or Wadiin Hadhramout; are also limited. These locations include Sah,Seyoun, Tareem, Shabam, Al-Qaten, Doean, Horah, and Wadi Alaeen. Although there are several other locations in the coast of Hadhramout as well as in Yemen, such as Hodeidah, Marib, and Almahrah, they are not within the scope of this study because these provinces are located very far away. Besides, the Ministry of Agriculture and Irrigation has suggested Hadhramout Province.

6.3 Assumptions of the Study

This study assumes that the identified prospective location selection criteria are valid and efficient to select the best prospective locations. Therefore, these criteria can possibly be used for further analysis.In terms of the limitations of the criteria; this study assumes that the selected criteria are independent. Further, this study assumes that all the people who attended the meetings have similar understandings on the selection criteria and interpret them consistently as discussed in Section 4.2.2.

6.4 Contribution of the Study

Based on the results gathered from the tests as described in Chapter Five, the researcher would like to highlight important contribution and also to put forward a few recommendations for future enhancement of this study and other similar studies. They are divided into two parts; theoretical and practical.

6.4.1 Theoretical Part

This study suggests that studies in facility location field can make use of ROC, AHP, and the mean of the weights of AHP and ROC in ranking and weighting criteria. Besides, studies in facility location problem can combine the ROC, AHP, and the mean of AHP and ROC with 0-1 IP or any mathematical programming model to select the best solution. In addition, studies can also use normalization to rank criteria if two criteria or more give the same rank in the ROC technique. Nevertheless, studies can use the modified approach in AHP technique to transfer the rates from the decision makers to the matrix and guarantee the consistency all the time.

6.4.2 Practical part

Several suggestions can be made to the readers, Yemeni government, and farmers. Firstly, the results of this study suggest that the date palm packaging factory is going to be built in Doean, Hadhramout.

In addition, it is recommended for the authorities to compile accurate data on dates production and date palm numbers in the whole of Yemen, so as to facilitate researchers to carry out scientific studies on the tree and the fruit. Further, the dates' production can be increased for export in order to gain foreign currency that will contribute to the national economic well-being.

6.5 Future Research

This study investigates the effects of the identified criteria on selecting the best location in Hadhramout, Yemen. The weights of the criteria were calculated using

ROC, AHP, and the mean of the weights of ROC and AHP models and the best location was selected by using 0-1 IP model.

In this study, only 11 criteria are considered and it was noticed that the weights of the 11 criteria were computed. This shows that the location was affected by the aforementioned criteria. It is clear that the model does not analyze the data related to certain criteria as the data was not available. It is hoped that future research will increase the number of criteria. This will help in analyzing these criteria using this model.

It is suggested that the data can be analyzed by Fuzzy AHP (FAHP) technique especially in the event the information and evaluations are not certain. If the criteria can be presented in more than one hierarchy sets, this means it is in the main criteria and sub-criteria. The use of two different methods allows this study to make comparison and suggests different ways to have better results. In addition, it is suggested that the correlation and the interdependencies between the criteria can be included in future studies.

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Appendix A

Questionnaire for Rank Order Centroid Technique

Instructions:

The respondent is requested to kindly rank the criteria's priority based on their perceptions. For each criterion below, please rank the level of its importance in determining the location for a date-palm factory in Yemen, by numbering the appropriate criteria from 1 to 11.

Criteria	Rank
Market Growth	
Proximity to the markets	
Proximity to the raw materials	
Labour	
Labour climate	
Suppliers	
Community	
Transportation Cost	
Environmental Factors	
Production Cost	
Factory set up cost	

Your corporation is kindly appreciated. Thank you

Appendix B

Questionnaire for Analytical Hierarchy Process Technique

A) Background of the respondent

1) Please tick your gender?

☐ Male ☐ female

2) Please tick your level of education?

☐ Primary ☐ Secondary ☐ Bachelor ☐ Master ☐ PhD

3) Please write your possession

B) Questionnaire for Analytical Hierarchy Process Technique (AHP)

Instructions:

The respondent is requested to kindly give rating from 1-9 based on the importance of the criteria being considered. The judgements for the rating are as given below:-

*Preference Level	Numeric Value
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

*Preference level can also be replaced by importance level, significance level, or any other appropriate levels.

C) Pair wise comparison for factory location selection criteria

For each criterion below, please rate the level of its importance in determining the location for a date-palm factory in Yemen, by circling or ticking the appropriate number. (Hint: 1 = Not important at all, 9 = extremely important)

Criteria	1	2	3	4	5	6	7	8	9
Market Growth									
Proximity to the markets									
Proximity to the raw materials									
Labour									
Labour climate									
Suppliers									
Community									
Transportation Cost									
Environmental Factors									
Production Cost									
Factory set up cost									

Your corporation is kindly appreciated. Thank you

Prepared by: Mohammed Ahmed Salem Balhuwaisl, PhD of Decision Science (Operational Research)

Appendix C

Questionnaire for 0-1 Integer Programming

Instructions: The respondent is requested to kindly estimate the criteria's values (for example 1000 USD the cost of labor in location 1) based on their perceptions. For each criterion in each location below; please estimate the value of the criteria for determining the location for a date-palm factory in Yemen.

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	total
Market Growth								
Proximity to the markets								
Proximity to the raw materials								
Labour								
Labour climate								
Suppliers								
Community								
Transportation Cost								
Environmental Factors								
Production Cost								
Factory set up cost								

Appendix D

Final weights of all the respondents for the criteria by using ROC technique as explained in Table 5.4

	Criteria	R1	W1	R2	W2	R3	W3	R4	W4	R5	W5	R6	W6
C1	market growth	9	0.0275	9	0.027	9	0.0275	9	0.0275	9	0.0275	9	0.0275
C2	proximity to the markets	10	0.0174	10	0.017	10	0.0174	10	0.0174	10	0.0174	10	0.0174
C3	proximity to the raw materials	2	0.1836	3	0.138	2	0.1836	3	0.1382	2	0.1836	1	0.2745
C4	labor	3	0.1382	2	0.184	1	0.2745	2	0.1836	1	0.2745	4	0.1079
C5	labor climate	6	0.067	8	0.039	7	0.0518	8	0.0388	8	0.0388	8	0.0388
C6	Suppliers	1	0.2745	1	0.275	3	0.1382	1	0.2745	3	0.1382	2	0.1836
C7	Community	11	0.0083	11	0.008	11	0.0083	11	0.0083	11	0.0083	11	0.0082
C8	transportation cost	4	0.1079	5	0.085	4	0.1079	4	0.1079	5	0.0851	5	0.0851
C9	environmental factors	7	0.0518	7	0.052	6	0.067	7	0.0518	7	0.0518	7	0.0518
C10	production cost	5	0.0851	6	0.067	5	0.0851	5	0.0851	6	0.067	6	0.0669
C11	location of building	8	0.0388	4	0.108	8	0.0388	6	0.067	4	0.1079	3	0.1382

R7	W7	R8	W8	R9	W9	R10	W10	R11	W11	R12	W12	R13	W13	R14	W14	R15	W15
11	0.0083	9	0.0275	9	0.0275	9	0.0275	10	0.0174	11	0.0083	11	0.0083	9	0.0275	11	0.0083
8	0.0388	11	0.0083	10	0.0174	10	0.0174	9	0.0275	9	0.0275	9	0.0275	8	0.0388	9	0.0275
7	0.0518	3	0.1382	8	0.0388	2	0.1836	6	0.067	5	0.0851	5	0.0851	10	0.0174	6	0.067
2	0.1836	6	0.067	1	0.2745	8	0.0388	1	0.2745	6	0.067	7	0.0518	2	0.1836	4	0.1079
9	0.0275	7	0.0518	6	0.067	6	0.067	7	0.0518	8	0.0388	8	0.0388	6	0.067	7	0.0518
1	0.2745	2	0.1836	7	0.0518	1	0.2745	5	0.0851	4	0.1079	1	0.2745	1	0.2745	3	0.1382
10	0.0174	10	0.0174	11	0.0083	11	0.0083	11	0.0083	10	0.0174	10	0.0174	11	0.0083	10	0.0174
4	0.1079	5	0.0851	3	0.1382	4	0.1079	3	0.1382	2	0.1836	3	0.1382	4	0.1079	1	0.2745
5	0.0851	8	0.0388	5	0.0851	7	0.0518	8	0.0388	7	0.0518	4	0.1079	7	0.0518	8	0.0388
6	0.067	1	0.2745	4	0.1079	5	0.0851	4	0.1079	3	0.1382	6	0.067	5	0.0851	2	0.1836
3	0.1382	4	0.1079	2	0.1836	3	0.1382	2	0.1836	1	0.2745	2	0.1836	3	0.1382	5	0.0851

R16	W16	R17	W17	R18	W18	R19	W19	R20	W20	R21	W21	TOTAL	WEIGHT	rank
9	0.0275	10	0.0174	9	0.0275	10	0.0174	10	0.0174	9	0.0275	0.4594	0.0219	9
10	0.0174	7	0.0518	11	0.0083	8	0.0388	9	0.0275	10	0.0174	0.4956	0.0236	10
6	0.067	6	0.067	5	0.0851	3	0.1382	3	0.1382	7	0.0518	2.3829	0.1135	6
1	0.2745	2	0.1836	2	0.1836	7	0.0518	8	0.0388	2	0.1836	3.3271	0.1584	2
7	0.0518	9	0.0275	6	0.067	9	0.0275	7	0.0518	5	0.0851	1.0461	0.0498	8
5	0.0851	1	0.2745	1	0.2745	2	0.1836	2	0.1836	1	0.2745	4.2243	0.2012	1
11	0.0083	11	0.0083	8	0.0388	11	0.0083	11	0.0083	11	0.0083	0.2496	0.0119	11
2	0.1836	4	0.1079	4	0.1079	6	0.067	4	0.1079	3	0.1382	2.5728	0.1225	4
8	0.0388	8	0.0388	10	0.0174	5	0.0851	5	0.0851	6	0.067	1.2083	0.0575	7
3	0.1382	5	0.0851	3	0.1382	1	0.2745	6	0.067	4	0.1079	2.3834	0.1135	5
4	0.1079	3	0.1382	7	0.0518	4	0.1079	1	0.2745	8	0.0388	2.6505	0.1262	3

Appendix E

First respondent calculations by using AHP technique

The pairwise comparison matrix and the summed of each column for first respondent. Sum the value in each column

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C_1	1	½	½	1/3	1	1/3	2	2	2	1/3	1
C_2	2	1	1	½	2	½	3	3	3	½	2
C_3	2	1	1	½	2	½	3	3	3	½	2
C_4	3	2	2	1	3	1	4	4	4	1	3
C_5	1	½	½	1/3	1	1/3	2	2	2	1/3	1
C_6	3	2	2	1	3	1	4	4	4	1	3
C_7	½	1/3	1/3	¼	½	¼	1	1	1	¼	½
C_8	½	1/3	1/3	¼	½	¼	1	1	1	¼	½
C_9	½	1/3	1/3	¼	½	¼	1	1	1	¼	½
C_{10}	3	2	2	1	3	1	4	4	4	1	3
C_{11}	1	½	½	1/3	1	1/3	2	2	2	1/3	1
$\sum$	17.5	10.5	10.5	5.75	17.5	5.75	27	27	27	5.75	17.5

Divide each element in the pairwise comparison by column total.

	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
C_1	0.0571	0.0476	0.0476	0.058	0.0571	0.058	0.0741	0.0741	0.0741	0.058	0.0571
C_2	0.1143	0.0952	0.0952	0.087	0.1143	0.087	0.1111	0.1111	0.1111	0.087	0.1143
C_3	0.1143	0.0952	0.0952	0.087	0.1143	0.087	0.1111	0.1111	0.1111	0.087	0.1143
C_4	0.1714	0.1905	0.1905	0.1739	0.1714	0.1739	0.1481	0.1481	0.1481	0.1739	0.1714
C_5	0.0571	0.0476	0.0476	0.058	0.0571	0.058	0.0741	0.0741	0.0741	0.058	0.0571
C_6	0.1714	0.1905	0.1905	0.1739	0.1714	0.1739	0.1481	0.1481	0.1481	0.1739	0.1714
C_7	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03
C_8	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03
C_9	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03
C_{10}	0.17	0.19	0.19	0.17	0.17	0.17	0.15	0.15	0.15	0.17	0.17
C_{11}	0.06	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06

Average of the element in each row, to determine the priority for each criterion

	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	**Total**	**Priorities**
C_1	0.0571	0.0476	0.0476	0.058	0.0571	0.058	0.0741	0.0741	0.0741	0.058	0.0571	0.6628	0.0603
C_2	0.1143	0.0952	0.0952	0.087	0.1143	0.087	0.1111	0.1111	0.1111	0.087	0.1143	1.1275	0.1025
C_3	0.1143	0.0952	0.0952	0.087	0.1143	0.087	0.1111	0.1111	0.1111	0.087	0.1143	1.1275	0.1026
C_4	0.1714	0.1905	0.1905	0.1739	0.1714	0.1739	0.1481	0.1481	0.1481	0.1739	0.1714	1.8614	0.1691
C_5	0.0571	0.0476	0.0476	0.058	0.0571	0.058	0.0741	0.0741	0.0741	0.058	0.0571	0.6628	0.0604
C_6	0.1714	0.1905	0.1905	0.1739	0.1714	0.1739	0.1481	0.1481	0.1481	0.1739	0.1714	1.8614	0.1692
C_7	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.3908	0.0354
C_8	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.3908	0.0355
C_9	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.3908	0.0356
C_{10}	0.17	0.19	0.19	0.17	0.17	0.17	0.15	0.15	0.15	0.17	0.17	1.8614	0.1690
C_{11}	0.06	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.6628	0.0605

$$(.0603)\begin{bmatrix}1\\2\\2\\3\\1\\3\\1/2\\1/2\\1/2\\3\\1\end{bmatrix}+(.1025)\begin{bmatrix}1/2\\1\\1\\2\\1/2\\2\\1/3\\1/3\\1/3\\2\\1/2\end{bmatrix}+(.1025)\begin{bmatrix}1/2\\1\\1\\2\\1/2\\2\\1/3\\1/3\\1/3\\2\\1/2\end{bmatrix}+(.1692)\begin{bmatrix}1/3\\1/2\\1/2\\1\\1/3\\1\\1/4\\1/4\\1/4\\1\\1/3\end{bmatrix}+(.0603)\begin{bmatrix}1\\2\\2\\3\\1\\3\\1/2\\1/2\\1/2\\3\\1\end{bmatrix}+(.1693)\begin{bmatrix}1/3\\1/2\\1/2\\1\\1/3\\1\\1/4\\1/4\\1/4\\1\\1/3\end{bmatrix}+(.0355)\begin{bmatrix}2\\3\\3\\4\\2\\4\\1\\1\\1\\4\\2\end{bmatrix}+(.0355)\begin{bmatrix}2\\3\\3\\4\\2\\4\\1\\1\\1\\4\\2\end{bmatrix}$$

$$+(.0355)\begin{bmatrix}2\\3\\3\\4\\2\\4\\1\\1\\1\\4\\2\end{bmatrix}+(.1692)\begin{bmatrix}1/3\\1/2\\1/2\\1\\1/3\\1\\1/4\\1/4\\1/4\\1\\1/3\end{bmatrix}+(.0603)\begin{bmatrix}1\\2\\2\\3\\1\\3\\1/2\\1/2\\1/2\\3\\1\end{bmatrix}=\begin{bmatrix}0.67\\1.14\\1.14\\1.89\\0.67\\1.89\\0.39\\0.39\\0.39\\1.89\\0.67\end{bmatrix}$$

$C1 = \frac{0.67}{0.0603} = 11.0469$, $C2 = \frac{1.14}{0.1025} = 11.1223$, $C3 = \frac{1.14}{0.1025} = 11.1223$, $C4 = \frac{1.89}{0.1692} = 11.1467$, $C5 = \frac{0.67}{0.0603} = 11.0469$, $C6 = \frac{1.89}{0.1692} = 11.1467$, $C7 = \frac{0.39}{0.0355} = 11.0408$, $C8 = \frac{0.39}{0.0355} = 11.0408$, $C9 = \frac{0.39}{0.0355} = 11.0408$, $C10 = \frac{1.89}{0.1692} = 11.1467$, and $C11 = \frac{0.67}{0.0603} = 11.1467$

$$\lambda_{max} = \frac{11.0469+11.1223+11.1223+11.1467+11.0469+11.1467+11.0408+11.0408+11.0408+11.1467+11.0469}{11} = 11.0861$$

$$CI = \frac{11.0861-11}{11-1} = \frac{0.0861}{10} = .00861$$

The value of RI

M	3	4	5	6	7	8	9	10	11	12	13
RI	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484	1.513	1.535	1.555

Sources: Saaty (1980)

$$CR = \frac{.00861}{1.513} = 0.0057$$

Appendix F

Final weights of all the respondents for the criteria and the consistency. Where dm is the decision maker

	dm1	dm2	dm3	dm4	dm5	dm6	dm7	dm8	dm9	dm10	dm11	dm12
C_1	0.0603	0.03	0.106	0.034	0.086	0.014	0.131	0.023	0.082	0.09	0.171	0.066
C_2	0.1025	0.146	0.04	0.057	0.073	0.109	0.023	0.012	0.018	0.035	0.069	0.123
C_3	0.1026	0.146	0.038	0.176	0.073	0.175	0.047	0.033	0.14	0.088	0.036	0.066
C_4	0.1691	0.082	0.02	0.176	0.129	0.175	0.089	0.033	0.14	0.158	0.049	0.123
C_5	0.0604	0.047	0.106	0.102	0.04	0.063	0.071	0.048	0.053	0.09	0.069	0.027
C_6	0.1692	0.082	0.173	0.102	0.104	0.063	0.116	0.151	0.14	0.022	0.121	0.04
C_7	0.0354	0.047	0.04	0.034	0.086	0.063	0.054	0.151	0.012	0.024	0.171	0.066
C_8	0.0355	0.146	0.173	0.057	0.086	0.063	0.131	0.151	0.082	0.09	0.043	0.123
C_9	0.0356	0.146	0.065	0.057	0.048	0.063	0.119	0.096	0.053	0.156	0.171	0.123
C_{10}	0.1690	0.047	0.173	0.102	0.138	0.175	0.109	0.151	0.14	0.158	0.014	0.123
C_{11}	0.0605	0.082	0.065	0.102	0.138	0.039	0.109	0.151	0.14	0.158	0.086	0.123
Consistency	0.005	0.04	0.01	0.005	0.03	0.01	0.09	0.02	0.02	0.007	0.08	0.003

dm13	dm14	dm15	dm16	dm17	dm18	dm19	dm20	dm21	average	average
0.109	0.199	0.037	0.039	0.106	0.049	0.087	0.104	0.156	0.0675	0.0771
0.109	0.064	0.037	0.07	0.057	0.049	0.087	0.104	0.047	0.057	0.0651
0.109	0.037	0.064	0.136	0.034	0.049	0.087	0.055	0.086	0.0726	0.0829
0.034	0.118	0.118	0.07	0.18	0.16	0.087	0.104	0.047	0.0921	0.1052
0.109	0.118	0.199	0.136	0.057	0.049	0.047	0.179	0.086	0.076	0.0868
0.057	0.118	0.118	0.136	0.057	0.16	0.156	0.055	0.156	0.0964	0.1102
0.057	0.064	0.064	0.07	0.057	0.091	0.047	0.055	0.156	0.0581	0.0663
0.191	0.037	0.118	0.136	0.106	0.16	0.156	0.055	0.047	0.0917	0.1048
0.057	0.064	0.064	0.07	0.057	0.091	0.047	0.055	0.086	0.0766	0.0875
0.109	0.064	0.064	0.07	0.18	0.091	0.049	0.055	0.047	0.091	0.1039
0.057	0.118	0.118	0.07	0.106	0.049	0.152	0.179	0.086	0.0963	0.1100
									0.8754	
0.003	0.004	0.004	0.001	0.004	0.002	0.004	0.002	0.002	0.008	1

Appendix G

Estimated values for the criteria in each location to apply 0-1 Integer Programming

Instructions: The respondent is requested to kindly estimate the criteria's values based on their perceptions. For each criterion in each location below; please estimate the value of criteria for determining the location for a date-palm factory in Yemen. Where the MG, TC, PC, TS, and FSC were measured by USD, and PM and PR were measured by kilometer, and the other constraints they are LC, CO, EF were measured by the scales (1=low, 2= above low, 3= moderate, 4= less than high, and 5= high). While, LO measured by the number of the people.

	Location 1	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**	**Location 7**	**Total**
Market Growth (GW)	12000	20000	21000	17000	16500	13000	11000	25000
Proximity to the markets (PM)	1800	1500	1400	1300	1250	1900	2100	20000
Proximity to the raw materials (PR	100	200	100	150	120	130	150	140
Labour (LO)	100	80	120	100	110	100	90	150
Labour climate (LC)	4	5	5	4	4	3	4	5
Suppliers (TS)	15000	12000	14000	13000	13000	12000	15000	18000
Community (CO)	5	3	4	4	5	5	5	5
Transportation Cost (TC)	18000	13000	11000	13000	14000	15000	18000	15000
Environmental Factors (EF)	5	3	5	4	3	4	5	5
Production Cost (PC)	30000	32000	31000	30000	30000	31000	32000	35000
Location of Building (FSC)	20000	35000	25000	27000	23000	20000	20000	28000