Research Article

USING MULTI-CRITERIA DECISION-MAKING METHODOLOGIES FOR STRATEGIC SUPPLY CHAIN DESIGN CHOICES; SELECTION OF THE BEST TRANSPORTATION SETUP AND DISTRIBUTION NETWORK EXPANSION PLAN

Ibrahim H. Al-Dali (aldali.ih@gmail.com)
King Fahd University of Petroleum & Minerals Dhahran- 31261, Saudi Arabia, Sc Consultant and Executive Leader, Author, Msc. Systems Engineering, Saudi Arabia

*Corresponding Author: Dr. Umar Alturki

TO CITE THIS ARTICLE:
Al-Dali, I. H. . (2024). USING MULTI-CRITERIA DECISION MAKING METHODOLOGIES FOR STRATEGIC SUPPLY CHAIN DESIGN CHOICES; SELECTION OF THE BEST TRANSPORTATION SETUP AND DISTRIBUTION NETWORK EXPANSION PLAN. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 15(2), 217–240. https://doi.org/10.61841/turcomat.v15i2.14706

LIST OF ABBREVIATIONS

MCDM : Multi Criteria Decision Making
AHP : Analytic Hierarchy Process
TOPSIS : Technique for Order of Preference by Similarity to Ideal Solution
PROMETHEE : Preference Ranking Organization Method for Enrichment of Evaluations
ELECTRE : Elimination and Choice Expressing Reality
3PL : Third Party Logistics
AI : Artificial Intelligence

ABSTRACT

Full Name	:	Ibrahim Hassan Al-Dali
Paper Title	:	Using Multi-Criteria Decision-Making Methodologies for Strategic Supply Chain Design Choices; Selection of Best Transportation Setup and Distribution Network Expansion Plan
Major Field	:	Industrial & Systems Engineering
Date of Paper	:	July 2024

Supply chain is considered as one of the key areas of companies' success and it should be designed appropriately to be compatible with companies' objectives and strategies. In this thesis, a case study of supply chain network redesign in oil and gas industry will be thoroughly studied, analyzed and concluded. This research has been applied and deployed on an oil and gas local company called "X-LUBE". In brief, Multi-Criteria Decision Making (MCDM) approach is used to come up with the best transportation setup for X-LUBE distribution network among five available alternatives which are compared using predefined criteria. Several MCDM techniques were used such as AHP, TOPSIS, PROMETHEE and ELCTRE. Similarly; AHP technique were used to determine the expansion plan and strategies of X-LUBE distribution network along with associated cost and fleet type selection.

KEYWORDS: MCDM, AHP, TOPSIS, PROMETHEE, ELECTRE, 3PL, AI

CHAPTER 1
INTRODUCTION

X-LUBE company is an international oil and gas company that supplies wide range of industrial and automotive lubricants for various sectors across the kingdom. X-LUBE contributes to almost 10% of Saudi Arabia's annual business volume, which is fifty (50) million liters.

X-LUBE company sells its products in two main channels; Automotive and PGO (Power generation oil)/Marine. Automotive sector is split into B2C (Business-to-Customers) and B2B (Business-to-Business). There are four downstream sales segments; two under B2C which are PCO (passengers' car oil) and CTO (consumers' trucks oil) and two under B2B which are FWS (franchise workshops) and HD (heavy duty). **Figure 1** shows the X-Lube sales channels and segments. Also; **Figure 2** shows X-Lube business volume segmental split based on last three years performance.

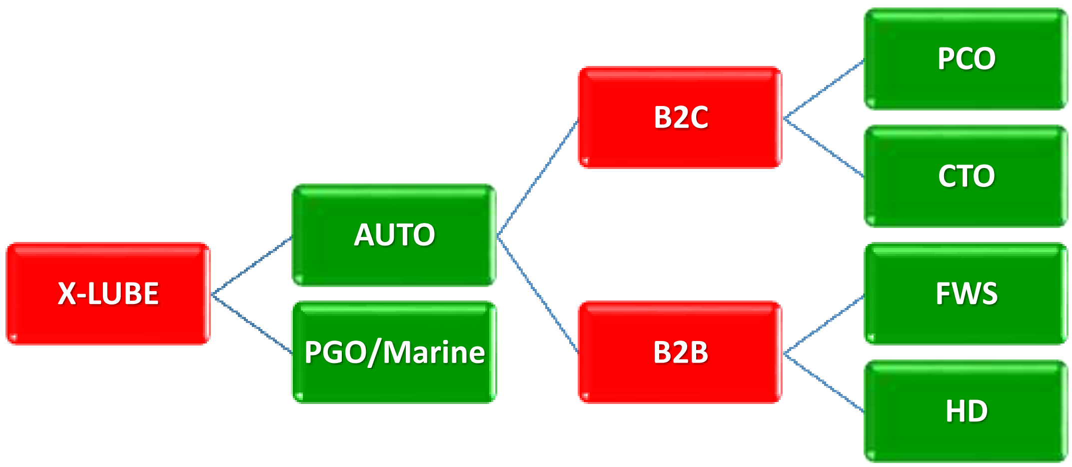


Figure 1: X-LUBE Sales Channels and Segments

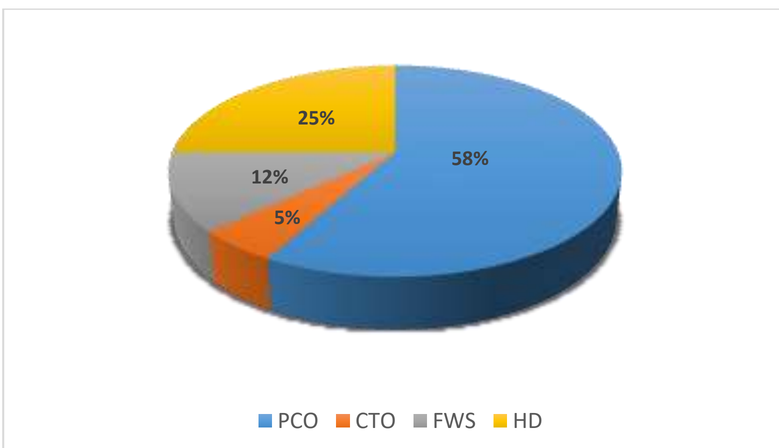


Figure 2: X-LUBE Segmental Volume Split

X-LUBE company supplies its lubricants via a distribution network composed of six sites that cover all Saudi Arabia regions; these sites are Jeddah, Riyadh, Dammam, Buraidah, Khamis Mushait and Tabuk. A newly introduced plant is located at Yanbu to supply demand to all these sites via established primary transportation network.

In the light of the above; this research aims to redesign X-LUBE distribution network via gathering, studying, analyzing related data for the sake of cost optimization and responsiveness rate enhancement. This includes deciding on ideal transportation mode to be used within X-LUBE network and finally proposing an appropriate setup for X-LUBE distribution network expansion. For that purpose; liner programing (LP) along with multi criteria decision making (MCDM) models are utilized and solved.

1.1 Lubrication Industry Overview

Lubricants contribute to almost 19% of the automotive aftermarket in Saudi Arabia. Between 2014 and 2018, lubricants sales had exceeded 2.37 billion liters taking into consideration that more than five hundred thousand (500,000) new cars and one hundred ten thousand (110,000) trucks are being injected into the Saudi market every year.

Saudi Arabia is considered as large automotive lubricants market in the globe due to the large number of vehicles users as well as the huge geographical transportation network. On average, forty million liters of lubricants volume is being sold in KSA market annually and automotive lubricants volume represents 70% of that demand. X-LUBE currently represents almost 10% of that demand.

Various types of lubricants are supplied in KSA market. Their main types are Synthetic Engine Oils, Gasoline Engine Oils, Diesel Engine Oils, Hydraulic Oils, Turbine Oils, Industrial Gear Oils, Greases, Industrial Greases, Transformers Oils, Break Fluids, ATF and Auto Gear Oils, 2-stroke Oils and Anti-Freeze Coolants

Currently, the main lubricant suppliers in Saudi Arabia are Castrol (10%), Shell (20%), Petromin (35%), Fuchs (13%), Mobil (12%) and several others with minor volumes such as Total, Chevron and Caltex. Only 20% of these suppliers own plants in Saudi Arabia and the rest are managed either via outsourcing from other local lubricants blenders or through importing from abroad.

Since X-LUBE company has its plant in KSA, this would provide more synchronization, flexibility and efficiency to the entire supply chain network and the need arises to redesign its supply chain model especially with the highly competitive environment.

1.2 Research Objective

This research aims to redesign X-LUBET supply chain network through three primary objectives.

The first objective is about deciding on the best transportation mode to be used by X-LUBE company for its products distribution; utilizing MCDM tools with predefined criteria. Several techniques can be used: analytic hierarchy process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) and Elimination and Choice Expressing Reality (ELECTRE). The five X-LUBE transportation alternatives are briefed below.

Dedicated Contracted Fleet (DCF)

Trip-Based Contracted Fleet (TBCF)

Mileage-Based Contracted Fleet (MBCF)

Full-Owned Company Fleet (FOF)

Lease-to-Own Company Fleet (LTOF)

The second objective is to come up with the best scenario/ setup for X-LUBE network expansion in the four specified cities; Makkah, Baha, Al-Ahsa and Qurayyat along with associated costs using one of MCDM tools which AHP.

There are 4 potential expansion cities in X-LUBE network, each with 2 salesmen, which are Al-Ahsa, Makkah, Al-Baha and Qurayyat. For Makkah and Al-Ahsa; the monthly volume is 3500 cases/city while 1500/city cases for Al-Baha and Qurayyat

1.3 Research Questions

The paper is trying to address the following research questions for the lubrication company

What transportation mode that X-LUBE company has to select to best satisfy the predefined criteria?

What are the best expansion alternatives for predefined potential cities and what is associated costs?

1.4 Problem Statement

Let X-LUBE company be the lubricant plant in Yanbu (supply node) and (I) be the set of retailers (Demand Nodes) in the distribution network. Also; X-LUBE company central distribution hub is to be located in Yanbu as per the transshipment model by **Alkhodairi (2019)**. The objective is to determine the following related decisions;

Select the best possible transportation mode to use for X-LUBE company distribution network using MCDM tools such as AHP, TOPSIS and PROMETHEE

Deciding on the best expansion modes for four predefined potential cities in X-LUBE distribution network.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a literature review will be provided in the areas of research, highlighting the common approaches and main methodologies that have been used in similar case studies in the literature.
MCDM techniques have been widely used in DND and facility location problems (FLP) in various fields and industries. For instance, Vaidya et al. (2006) listed more than 150 publications of using AHP in facilities planning and location. Later, new developments on AHP was introduced, i.e. Fuzzy AHP, Kuo et al. (1999). AHP is also integrated with other MCDM techniques such as TOPSIS, Prakash et al. (2015), PROMETHEE, Macharis et al. (2004) and Support Vector Machine TOPSIS (SVM-TOPSIS), Putra (2016).

Zhen-Song Chen et al. (2019) integrates both MCDM tools, TOPSIS and proportional hesitant fuzzy linguistic term set (PHFLTS) to determine the most appropriate transportation alternative for hazardous material, taking into consideration decisions criteria set by field experts.

Also, hybrid MCDM can be used to come up with the best alternative among various options. For example, **Chunguang Bai et al (2017)** applied hybrid MCDM integrating the three methods of interval grey numbers, rough set theory and the "VIekriterijumsko KOmpromisno Rangiranje" VIKOR method to select the best environmental-friendly and sustainable transportation means. This hybrid approach is used to come up with reliable, robust and comprehensive decisions as it is also equipped with sensitivity analysis and experiments

MCDM could be utilized on deciding the best fleet type to go for as a service provider with respect to predefined criteria such as safety, reliability, cost, maintenance easiness, useful life …etc. **Yavuz Ozdemir and Huseyin Basligil (2016)** combines both fuzzy ANP (Analytical Network Process), which is a generalization of AHP (Analytical Hierarchy Process), along with general choquet integral method to determine the best aircraft that Turkish airlines to go for its fleet.

Facility-location problem (FLP) can be also incorporated with multi-mode transportation selection to form multi-objective optimization problem. NSGA2 (Non-dominated sorting genetic algorithm) can be utilized to solve such model; **Laurent Lemarchand et al. (2017).**

MCDM is used for facility-location problem as well. **Changez Khan et al. (2015**) used both tools rough set theory approach (RSTA) and TOPSIS to determine the best location for food distribution centers.

MCDM can be used to determine the best machinery equipment for optimal continuous fluid in manufacturing process. For instance; **Suleyman Cakir (2016)** used both MCDM tools; fuzzy simple multi-attributes rating technique (SMART) and fuzzy weighted axiomatic design (FWAD) to decide the best machinery option for continuous flow of tea bed dryer in tea Plants.

Multi-objective optimization is widely used in transportation network design at different scale. **Taqwa Fahad and Abduladhem Ali (2018)** used mulit-objective optimization to establish optimized routing protocol VANETs.

Moreover, MCDM might be utilized to select sub-related systems of transportation network such as fleet maintenance. **Ikuobase Emoven et al. (2018)** applied hybrid MCDM of both tools Delphi-AHP along with PROMETHEE to select the optimum maintenance strategy for ship machinery systems.
Hybrid MCDM is also utilized to select celebrity endorser for transportation service providers. For example; **Sen-Kuel Liao et al (2018)** used fuzzy Delphi, DEMATEL (Decision Making Trial and Evaluation Laboratory), ANP and TOPSIS to determine the best celebrity endorser in Taiwan. Moreover, MCDM is used to determine vital decisions that widely affect large number of people, i.e. public transportation. **Serhat Aydin and Cengiz Kahraman (2014**) integrates fuzzy AHP and VIKOR methodology to deicide about the best public transportation means in Ankara, the capital of Turkey

CHAPTER 3

Best Transportation Setup Selection Using MCDM

This chapter deals with the transportation mode selection problem in which MCDM techniques will be utilized to come up with best transportation mode to be used in X-LUBE company distribution network among various available alternatives listed below,

1. Dedicated Contracted Fleet (DCF)
2. Trip-Based Contracted Fleet (TBCF)
3. Mileage-Based Contracted Fleet (MBCF)
4. Full-Owned Company Fleet (FOF)
5. Lease-to-Own Company Fleet (LTOF)

Section 1.1 will provide a thorough description of these alternatives with both the advantages and disadvantages of each.

3.1 Transportation Alternatives for Distribution Network

For X-LUBE distribution network; there are two types of transportation setups; secondary and primary transportation. The primary transportation setup is concerned with order's delivery from X-LUBE warehouses to its customers in the same region while the secondary setup focuses on plant-warehouse deliveries and shuttling between warehouses. The best transportation setup of secondary transportation is to be selected from the five alternatives available using MCDM techniques.

Basic information about each of these alternatives with their advantages and disadvantages will be discussed below.

Dedicated Contracted Fleet (DCF)

<u>Description</u>: This is a dedicated number of vehicles under legal contract between both parties; X-LUBE and transportation service provider in which the contracted vehicles and their drivers will be managed directly by X-LUBE logistics team with fixed monthly service charges

<u>Advantages</u>:

Company has the control over the fleet
High flexibility on deliveries
Better fleet utilization
Better quality and HSSE management

<u>Disadvantages</u>:

High loss in case of low sales volume
Long-term commitment due to high capital investment of securing the dedicated fleet which is high risk if business drops or partially lost.

Trip-Based Contracted Fleet (TBCF)

<u>Description</u>: In this option, a service legal contract is initiated between the two parties, X-LUBE and service provider with a clear agreed price list for all possible deliveries combinations between sources and destinations. A service request will be asked from the service provider/transporter and served based on availability with a monthly service charges of fulfilled requests only.

<u>Advantages</u>:

- No long-term commitment as no dedicated fleet required
- Better payment terms as service charges depend only on fulfilled request
- Possible saving opportunities when better coordination and planning is there

<u>Disadvantages</u>:

- No service provider/transporter is capable to service all regions with the same level of quality and responsiveness
- No commitment on service provider side especially if business volume is not justifiable
- No proper control on quality and HSSE aspects of provided service.

3- Mileage-Based Contracted Fleet (MBCF)
Description: This alternative depends on the served mileage as per of agreed contract; an agreement is to be made with fixed price per served mileage/kilometer and monthly service charges depends on total serviced mileages by the entire fleet as per client's requests
Advantages:
- Better fleet's utilization as only fulfilled services are to be paid
- No minimum commitment from client's side
- Best strategy for profit and loss (P&L) analysis and saving opportunity
- No capital investment is required and no commitment on client's side

Disadvantages:
- Service request's fulfillments are not guaranteed as no minimum commitment from transporter's side
- High service cost in case of low sales volume; it is justified at high volume level
- Low control in quality and HSSE compliance.

4- Full-Owned Company Fleet (FOF)
Description: In this approach; the client purchases its own vehicles to serve distribution network over a certain time horizon with full control of fleet and drivers. All related fleet services such as maintenance, fuel and drivers housing have to be provided directly by the client.
Advantages:
- Best control over the fleet and drivers; high flexibility is guaranteed
- Best option for quality and HSSE compliance
- Better fleet utilization as fleet can serve multi purposes as per the client's needs

Disadvantages:
- High level of coordination and planning is required to ensure high utilization
- Long-term commitment risk especially in case of volume drop
- High operating cost as the company has to manage all related services directly

5- Lease-to-Own Company Fleet (LTOF)
Description: This strategy allows the company to secure its fleet via lease-to-own agreement and directly manages all related fleet services. It differs from FOF strategy in two main aspects;
- Fleet dealer is responsible for maintenance services during the contracted period
- The service amount is paid on installments unlike FOF.

Advantages:
- Better cash management as service amount is paid as monthly installment
- More focus on service and deliveries as maintenance is provided by fleet dealer
- Possibility to quiet unneeded fleet; penalty clause is there

Disadvantages:
- Long-term commitment risk
- High level of planning and coordination is required
- High operating cost is required

2.2 MCDM Approach to Secondary Distribution Setup Selection

In this section; the selection criteria of X-LUBE secondary transportation setups and related approach will be thoroughly discussed. Below are the steps to be followed to come up with the best option of X-LUBE secondary transportation setup;

Criteria Definition and Data Gathering: all related data are gathered along with criteria definition
Criteria Weight Determination : stakeholders input on the criteria weights, reflecting the importance of the criteria, to be collected and processed

Development and Process of MCDM Model: MCDM tools are used to come up with the best mode based on the inputs from previous steps. Various MCDM tools are used in this study; AHP, TOPSIS, PROMETHEE and ELECTRE
Best Vehicle Sourcing Alternative Selection: data are processed and the best alternative is selected based on model results.

In order to come up with proper criteria that cover all important business aspects; several brainstorming sessions were conducted with key stakeholders who cover most of business functions, logistics operations, finance, sales and executives. Thus, the resulting criteria are; HSSE Compliance, Operating Cost, Delivery Flexibility, Control Level, Resources Utilization, and Long-Term Commitment Risk. Below are the basic definitions of these criteria.

HSSE Compliance: the degree by which HSSE related systems, guidelines and measures can be enforced, managed and monitored to a specific option. A higher score of an option means that the company has better control of fleet HSSE for that option.

Operating Cost: this criterion is related to the overall operating cost of the fleet based on a selected option; including both fixed and variable cost elements such as purchasing cost, fuel cost, manpower cost, maintenance cost …etc. A higher score is to be assigned for a lower-cost option.

Delivery Flexibility: the degree of flexibility the fleet has under a specific option in meeting customer requirements and delivery schedule. This includes but is not limited to flexible working hours, distribution routing change, possibility to change drivers …etc.

Resources Utilization: this criterion concerns about the level of utilization by which the fleet can be utilized under specific alternatives. Utilization can cover various resources of the fleet such as time, mileage, fuel …etc. High score of an option means that this option provides better fleet efficiency to the company.

Control over Fleet: in this criterion, the control level of the company on fleet parameters and specifications are measured; this means to which level the company might influence decisions related to fleet under a specific option. These decisions could vary with reference to intended objectives; i.e. working hours, routes selection, fleet branding ...etc.

Long-Term Commitment Risk: this criterion is related to the risk associated with long term commitment as business volume might be affected by several factors such as market response, company strategy, expansion plan …etc. In this criterion, the long-term associated risk on the company for specific option is to be measured and reflected.

It was agreed with X-LUBE leadership management to use 5-point evaluation scale as follows; 5 for very high level, 4 for high, 3 for medium, 2 for low and 1 for very low level. Also; a consensus has been made among all stakeholders to assign the following weights to respective criteria; 20% for “HSSE Compliance”, 30% for “Operating Cost”, 15% for “Delivery Flexibility”, 15% for “Resources Utilization”, 10% for “Control over Fleet” and 10% for “Long-Term Commitment Risk”.

One important consideration in criteria evaluation is that some criteria are better at higher values such as HSSE Compliance, Resource Utilization, Delivery Flexibility and Control over Fleet while other criteria are better at lower values like Operating Cost and Long-Term Commitment Risk. However, in this specific exercise, all criteria are ranked to be better at higher values for the sake of consistency, higher values are assigned to the best options even for cost and risk criteria.

3.3 Secondary Transportation Setup Selection using AHP

Analytic Hierarchy Process (AHP) is the most common approach in MCDM due to its simplicity and effectiveness at the same time. In AHP, the criteria are ranked using the 5-point scale explained in the previous section and then normalized via dividing individual scores by the highest score under each criterion. Then, resulted score of each criterion is multiplied by its related criterion’s weight and final outcomes is summed under each alternative. The highest score option will be selected as the best transportation mode under the AHP model.

In AHP, all selection criteria will be ranked with respect to all available secondary transportation alternatives, results are shown in Table 1

Table 1: Criteria Ranking with respect to Secondary Alternatives

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk
DCF	3	3	5	3	4	1
TBCF	2	4	1	5	2	5
MBCF	1	5	2	4	1	4
FOF	5	1	4	1	5	2
LTOF	4	2	3	2	3	3

Then, the normalized scores under each criterion are multiplied by its related criterion's weight and associated alternatives' scores are summed. The alternative with the highest score will be selected under AHP model. The resulted outcome is displayed in Table 2

Table 2: Secondary Transportation Alternative Final Outcomes under AHP

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk	Score
Criteria Score	20%	30%	15%	15%	10%	10%	100%
DCF	0.6	0.6	1	0.6	0.8	0.2	0.64
TBCF	0.4	0.8	0.2	1	0.4	1	0.64
MBCF	0.2	1	0.4	0.8	0.2	0.8	0.62
FOF	1	0.2	0.8	0.2	1	0.4	0.55
LTOF	0.8	0.4	0.6	0.4	0.6	0.6	0.55

In conclusion, either DCF or TBCF can be chosen under AHP model since both options have the same score (64%). Hence, the recommendation is to go further and compare with the outcomes for other MCDM techniques.

3.4 Secondary Transportation Setup Selection using TOPSIS

In this method, two artificial alternatives are hypothesized; the ideal alternative is the one which has the best level for all attribute values and the Negative ideal alternative is the one which has the worst attribute values. TOPSIS selects the alternative that is closest to the ideal solution and farthest from the negative ideal alternative.

In order to apply TOPSIS method, each criterion is assigned a number from 1 to 10 based on relative ranking among all alternatives. This is shown in the below Table 3.

Table 3: TOPSIS Criteria Ranking with respect to Secondary Alternatives

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk
DCF	5	7	10	6	7	10
TBCF	3	4	3	9	4	2
MBCF	1	2	5	8	3	4
FOF	10	10	9	4	10	9
LTOF	8	9	7	5	6	7
Type	Higher is Better	Lower is Better	Higher is Better	Higher is Better	Higher is Better	Lower is Better

Then; normalized scores shown in table 4 are generated from the above table using formula

$R_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}}$ (Equation 1)

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk
Weight	20%	30%	15%	15%	10%	10%
DCF	0.35	0.44	0.62	0.40	0.48	0.63
TBCF	0.21	0.25	0.18	0.60	0.28	0.13
MBCF	0.07	0.13	0.31	0.54	0.21	0.25
FOF	0.71	0.63	0.55	0.27	0.69	0.57
LTOF	0.57	0.57	0.43	0.34	0.41	0.44

Table 4: TOPSIS Secondary Transportation Criteria Ranking Normalization

Next; the ideal and negative ideal solutions will be determined. Table 5 below summarizes the outcome.

Table 5: TOPSIS Secondary Transportation Ideal and Negative Ideal Solution

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk
Weight	20%	30%	15%	15%	10%	10%
DCF	0.07	0.13	0.09	0.06	0.05	0.06
TBCF	0.04	0.08	0.03	0.09	0.03	0.01
MBCF	0.01	0.04	0.05	0.08	0.02	0.03
FOF	0.14	0.19	0.08	0.04	0.07	0.06
LTOF	0.11	0.17	0.06	0.05	0.04	0.04
Ideal Solution A*	0.14	0.04	0.09	0.09	0.07	0.01
Negative Ideal Solution A'	0.01	0.19	0.03	0.04	0.02	0.06

Moreover, the separation from both ideal and negative ideal solutions are calculated using below formulas.

Separation from Ideal Solution $S_i^* = \sqrt{\sum_j (V_j^* - V_{ij})^2}$ (Equation 2)

Separation from Negative Ideal Solution $S_i' = \sqrt{\sum_j (V_j' - V_{ij})^2}$ (Equation 3)

The separation from ideal and negative ideal solutions is presented in tables 6 and 7 respectively.

Table 6: Transportation Alternatives Scores Separation from Ideal Solution

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk	Sum	S*=Sqrt(Sum)
DCF	0.005	0.009	0.000	0.001	0.000	0.003	0.018	0.134
TBCF	0.010	0.001	0.004	0.000	0.002	0.000	0.017	0.131
MBCF	0.016	0.000	0.002	0.000	0.002	0.000	0.021	0.145
FOF	0.000	0.023	0.000	0.003	0.000	0.002	0.028	0.166
LTOF	0.001	0.018	0.001	0.002	0.001	0.001	0.023	0.150

Table 7: Transportation Alternatives Scores Separation from Negative Ideal Solution

Option	HSSE Compliance	Operating Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk	Sum	S'=Sqrt(Sum)
DCF	0.003	0.003	0.004	0.000	0.001	0.000	0.012	0.109
TBCF	0.001	0.013	0.000	0.003	0.000	0.002	0.018	0.135
MBCF	0.000	0.023	0.000	0.002	0.000	0.001	0.026	0.161
FOF	0.016	0.000	0.003	0.000	0.002	0.000	0.022	0.147
LTOF	0.010	0.000	0.001	0.000	0.000	0.000	0.012	0.111

Table 8 shows the relative closeness to the ideal solution C_i^* is calculated using the formula

$C_i^* = \frac{S_i'}{S_i^* + S_i'}$ (Equation 4)

Table 8: Secondary Transportation Alternatives Ideal Solution Closeness Scores

Option	S*	S'	C_i^*
DCF	0.134	0.109	0.448
TBCF	0.131	0.135	0.508
MBCF	0.145	0.161	0.527
FOF	0.166	0.147	0.470
LTOF	0.150	0.111	0.424

Consequently, MBCF is the best alternative under TOPSIS with a minor difference compared with TBCF score. Hence; TBCF is also a preferable alternative under TOPSIS.

3.5 Secondary Transportation Setup Selection using ELECTRE

ELECTRE is an outranking method invented in 1965 in France by Bernard Roy & colleagues; it encourages more interaction between decision making and the model. ELECTRE consists of the following.
Develop the Decision Matrix with alternatives, criteria, scores and weights
Define and determine the concordance and discordance scores
Build the concordance and discordance matrices
Define the concordance and discordance dominance thresholds
Determine the Aggregate dominance matrix
Generate a preference ordering of the alternatives

To apply ELECTRE, the same decision model matrix shown in table 9 will be used for further analysis.

Table 9: ELECTRE Decision Model Matrix

Alternatives	DCF	TBCF	MBCF	FOF	LTOF	%
HSSE Complaince	5	3	1	10	8	20%
Operations Cost	7	4	2	10	9	30%
Rsponposiveness	10	3	5	9	7	15%
Efficiency	6	9	8	4	5	15%
Control over Fleet	7	4	3	10	6	10%
Long Term Comittment Risk	10	2	4	9	7	10%

Then, concordance scores are calculated for every ordered pair of options (i,j) as:
Sum of the weights for all criteria where option i scores better than option j ones.

Discordance scores are calculated also. Discordance index, d(i,j) exists If i does not completely dominate j, then for each criterion k where j outperforms i, calculate ratio:

$$d_{ij,k} = \frac{S_{jk}-S_{ik}}{\max(S_k)-\min(S_k)} = \frac{\text{Difference in criterion } k \text{ score between options } j \,\&\, i}{\text{Max difference in criterion } k \text{ score between any 2 options}} \quad \text{(Equation 5)}$$

$$d(i,j) = max_k(d_{ij,k}) \quad \text{(Equation 6)}$$

Concordance and discordance matrices are shown in Table 10 and 11 respectively.

Table 10: ELECTRE Concordance Matrix

Criteria	DCF	TBCF	MBCF	FOF	LTOF
DCF	-	0.45	0.45	0.6	0.7
TBCF	0.55	-	0.55	0.55	0.55
MBCF	0.55	0.45	-	0.55	0.55
FOF	0.4	0.45	0.45	-	0.45
LTOF	0.3	0.45	0.45	0.55	-

T able 11: ELECTRE Discordance Matrix

Criteria	DCF	TBCF	MBCF	FOF	LTOF
DCF	-	1.000	0.750	0.556	0.375
TBCF	0.714	-	0.286	0.857	0.571
MBCF	0.714	0.250	-	1.000	0.778
FOF	0.400	1.000	1.000	-	0.250
LTOF	0.429	0.800	0.875	0.571	-

From the above tables, the overall averages will be calculated, Concordance Index **c*= 0.5** while Discordance Index **d*=0.659.**

Now, set initial concordance and discordance thresholds as follows;

Step1:

Concordance Index c* = 110% (average value) =1.1×0.5 = 0.55

Discordance Index d*=90% (average value) = 0.9×0.659= 0.59

Step2:

Concordance Index c* = 110% (0.55) = 0.61

Discordance Index d*=90% (0.59) = 0.53

Starting with the initial setup of c*=0.55 and d*=0.59 results in two dominating alternatives, DCF and TBCF while keep increasing the concordance index c* by 10% and decreasing the discordance index d* also by 10% ends up with only one dominating strategy which is DCF as shown in Table 12

Table 12: ELECTRE Dominance Partial Outranking Matrix

Step	c*	d*	Dominator	Dominated
1	0.55	0.59	DCF	FOF, LTOF
			TBCF	MBCF, LTOF
			MBCF	Nill
			FOF	Nill
			LTOF	FOF, LTOF
2	0.61	0.53	DCF	LTOF
			TBCF	Nill
			MBCF	Nill
			FOF	Nill
			LTOF	Nill

For full ranking; ordering of the options is obtained from the rows sum of concordance and discordance indices for each option. A rough ordering of options might be based on;

Difference between concordance and discordance summations ($\sum c - \sum d$)

Ratio of concordance and discordance summations ($\sum c \,/\sum d$)

Full ranking analysis is shown in Table 13 below.

Table 13: ELECTRE Dominance Full Outranking Outcome

Alternative	Concordance Sum	Discordance Sum	Ratio (∑c/∑δ)	Rank 1	∑c - ∑d	Rank 2
DCF	2.200	2.681	0.82	2	-0.481	2
TBCF	1.650	1.714	0.96	1	-0.064	1
MBCF	1.550	2.028	0.76	3	-0.478	3
FOF	1.350	2.250	0.60	5	-0.900	5
LTOF	1.450	2.246	0.65	4	-0.796	4

In conclusion; TBCF strategy is recommended for use in X-LUBE distribution network.

3.6 Secondary Transportation Setup Selection using PROMETHEE

PROMETHEE was developed in Belgium by Brans in 1982 and expanded by Brans and Mareschal in 1985. It helps decision makers to identify alternatives that most matching their goals and understanding. It is useful for decision-making groups and complex MCDM problems, where decision elements are difficult to quantify or compare. PROMETHEE has five main steps;
Determine pairwise preferences for each two options under each criterion
Calculate Multi-Criteria Pairwise Preference Matrix
Calculate Outranking Flows
Calculate Net Outranking Flows
Determine (partial) ranking of options
For the sake of simplicity, Criteria I (Usual) is going to be used for analysis as a preference function with the following formula;

$$P_j(d_j) = \begin{cases} 0 & \text{if } d_j \leq 0 \\ 1 & \text{if } d_j > 0 \end{cases}$$

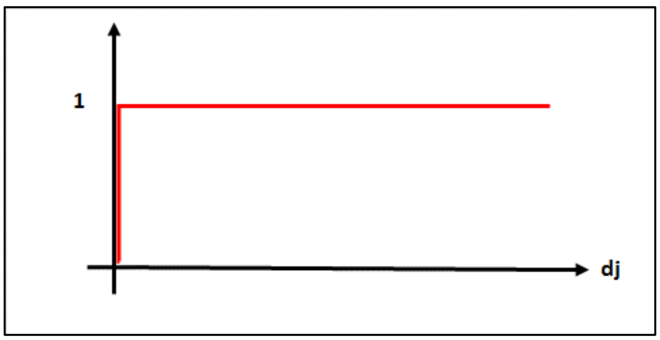


Figure 3: I. Usual

Preference Function

Table 14 below shows the scores of selection criteria under each available alternatives along with preference function used analysis

Table 14: PROMETHEE Decision Model Matrix

Option	HSSE Compliance	Operations Cost	Delivery Flexibility	Resources Utilization	Control over Fleet	Long Term Commitment Risk
DCF	5	7	10	6	7	10
TBCF	3	4	3	9	4	2
MBCF	1	2	5	8	3	4
FOF	10	10	9	4	10	9
LTOF	8	9	7	5	6	7
Weights	20%	30%	15%	15%	10%	10%
Criteria Type	Max	Min	Max	Max	Max	Min
PROMETHEE Criteria	Usual - I	Usual - I	Usual - I	Usual - I	Usual - I	Usual - I

Next; each criterion pairwise preference scores are determined and outranking flows will be calculated using below formulas;

$$\phi^{+}(a) = \frac{1}{n-1}\sum_{b \in A} \pi(a,b) \quad \text{(Equation 7)}$$

$$\phi^{-}(a) = \frac{1}{n-1}\sum_{b \in A} \pi(b,a) \quad \text{(Equation 8)}$$

The Net Outranking Flow

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \quad \text{(Equation 9)}$$

The resulting outranking flow scores can be summarized in ~~the~~ below Table 15.

Table 15: PROMETHEE Outranking Flows Scores

Criteria	DCF	TBCF	MBCF	FOF	LTOF	ϕ+
DCF	0	85%	85%	40%	50%	0.65
TBCF	15%	0	90%	15%	15%	0.3375
MBCF	15%	10%	0	15%	15%	0.1375
FOF	60%	85%	85%	0	85%	0.7875
LTOF	50%	85%	85%	15%	0	0.5875
ϕ-	0.35	0.6625	0.8625	0.2125	0.4125	
ϕ	0.3	-0.325	-0.725	0.575	0.175	

Partial ranking will be determined using the below criteria;

Option (a) outranks (is preferred to) option (b) if:

$\phi^{+}(a) \geq \phi^{+}(b)$ AND $\phi^{-}(a) \leq \phi^{-}(b)$ with at least 1 strict inequality

Table 16 shows the partial ranking between all available alternatives using PROMETHEE approach.

Table 16: PROMETHEE Partial Outranking between Alternatives

Criteria	DCF	TBCF	MBCF	FOF	LTOF
ϕ+	0.65	0.3375	0.1375	0.7875	0.5875
ϕ-	0.35	0.6625	0.8625	0.2125	0.4125
Outranks	TBCF MBCF LTOF	MBCF	None	DCF TBCF MBCF LTOF	TBCF MBCF
Rank	2	4	5	1	3

Full ranking is determined via the below methods;

Approach 1: Partial Ranking

Ranking all alternatives on decreasing order of ϕ^{+}

Ranking all alternatives on increasing order of ϕ^{-}

Partial Ranking: intersection of the two ranking

Unranked options are incomparable

Table 17: PROMETHEE Partial Ranking between Alternatives

Criteria	DCF	TBCF	MBCF	FOF	LTOF
ϕ+	0.65	0.3375	0.1375	0.7875	0.5875
Rank	2	4	5	1	3
ϕ-	0.35	0.6625	0.8625	0.2125	0.4125
Rank	2	4	5	1	3

Approach 2: Complete ranking

Rank options in decreasing order of $\phi(a) = \phi^{+}(a) - \phi^{-}(a)$

Criteria	DCF	TBCF	MBCF	FOF	LTOF
ϕ	0.3	-0.175	-0.575	0.425	0.025
Rank	2	4	5	1	3

Table 18: PROMETHEE Full Ranking between Alternatives

1.7 Conclusion: Secondary Transportation Mode Selection

This part of the study is about the determination of the best transportation mode using multi criteria decision making (MCDM) for X-LUBE company. On this regard, several MCDM techniques were used to come up with such decision; AHP, TOPSIS, PROMETHEE and ELECTRE. The resulting outcomes for this part are summarized below.

AHP recommends either TBCF or DCF

TOPSIS recommends MBCF

PROMETHEE recommends FOF

ELECTRE recommends TBCF

In fact; almost each technique comes with different recommendation due to different mechanisms used to come up with the best alternative taking into consideration the fact that each MCDM technique is best fit for certain applications than others. Thus; it seems that TBCF (Trip-Based Contracted Fleet) is the best mode that X-LUBE company. This is due to several factors;

It is the most frequent alternative resulting from MCDM analysis

It mitigates the commitment risk at both short and long terms

It provides more flexibility and control power to the service requester (X-LUBE company); i.e. can make the corrective decision to replace/change vehicles or drivers to maintain certain service, quality or HSSE levels.

It gives the requester to introduce more than one transporter and keep only the approved ones after assessing their service levels; i.e. X-LUBE can introduce unlimited numbers of transporters as there is no minimum volume commitment is asked

It provides more transparency on service fees as the requester gets a better chance to x-check and compare the prices received from quoted carriers.

In order to make TBCF option a more effective and efficient setup. The service fee figures need to be carefully examined and set with business volume consideration to ensure their payoff to the business. Also, contracted carriers' responsiveness rates have to be reported to check and verify their commitment towards the business and invest more in partnership rather than suppliers' type of relation.

CHAPTER 4

Determination of Best Distribution Network Expansion Using MCDM

As part of X-LUBE company strategic plan, volume has to grow by at least 50% in the next five years. On this regard, the company starts to look at various options to be in line with this direction and to establish a setup that supports such growth. One of these ideas is to strengthen the presence of the company in high-demand areas through one of the following alternatives.

Introducing new X-LUBE distribution sites, similar to the existing ones

Initiating new 3PL distribution contracts with accredited service providers

Creating a unique setup of "Satellite Warehouses" to cover needed sites

With a reference to the recent market research and analysis that have been done through an independent specialized agency, six regions in the kingdom associated with high potential and growth in business without strong competition existence were identified, namely; Madinah, Jizan, Al-Ahsa, Baha, Makkah and Qurayyat. The company has existing 3PL sites in Jizan and Madinah. Hence; a multi-criteria decision model (MCDM) will be used to determine the best alternative associated with each one of these cities based on certain criteria provided by X-LUBE company management. Analytical Hierarchy Process (AHP) is effectively utilized to come up with the best solution of this model. In addition, relative indices of the criteria are determined and their consistency levels are also examined.

4.1 Model Data and Parameters

The X-LUBE company's management team is asked to set main decision making criteria of the model along with their respective weights. This exercise is conducted via direct group discussion and outcome is discussed in the next section.

Each site is examined using several criteria that have been provided by the company management along with their relative weights. These criteria are; Initial Investment, Operating Cost, Health, Safety, Security and Environmental (HSSE), Responsiveness and Efficiency.

The below list shows DM criteria and their definitions as stated by the management team.

Initial Investment: Amount of money invested to set up infrastructure and other initial arrangement of an option (Buildings, IT, Security, Assets …etc.)

Operating Cost: Ongoing and running expenses of an option which includes manpower, material cost, utility …etc.

HSSE: Health, Safety, Security and Environment index associated with each setup which is an indicator of HSSE level.

Responsiveness: The degree by which a setup allows customer orders and requests satisfaction and fulfillment

Efficiency: The index by which setup utilizes available resources to maximize the overall returns of the organization

The relative weights of DM criteria with respect to each other are shown in ~~the~~ Table 19 below. Associated normalized matrix is calculated to determine the weighted score of each criterion to be used in the AHP model. This is shown in table

Table 19: Expansion Model Decision Making Criteria and Relative Scores

Criteria	Initial Investment	Operating Cost	HSSE	Responsiveness	Efficiency
Initial Investment	1	0.25	0.333	0.5	0.25
Operating Cost	4	1	0.333	4	3
HSSE	2	2.5	1	4	3
Responsiveness	3	0.75	0.25	1	0.45
Efficiency	4	0.5	0.25	5	1
Sum	14	5	2.166	14.5	7.7

X-LUBE company distribution network may be expanded in four cities; Makkah, Baha, Al-Ahsa and Qurayyat. The expected annual demand volume of these cities is shown in Table 20 below.

Table 20: Demand and Sales Team Size of Each City

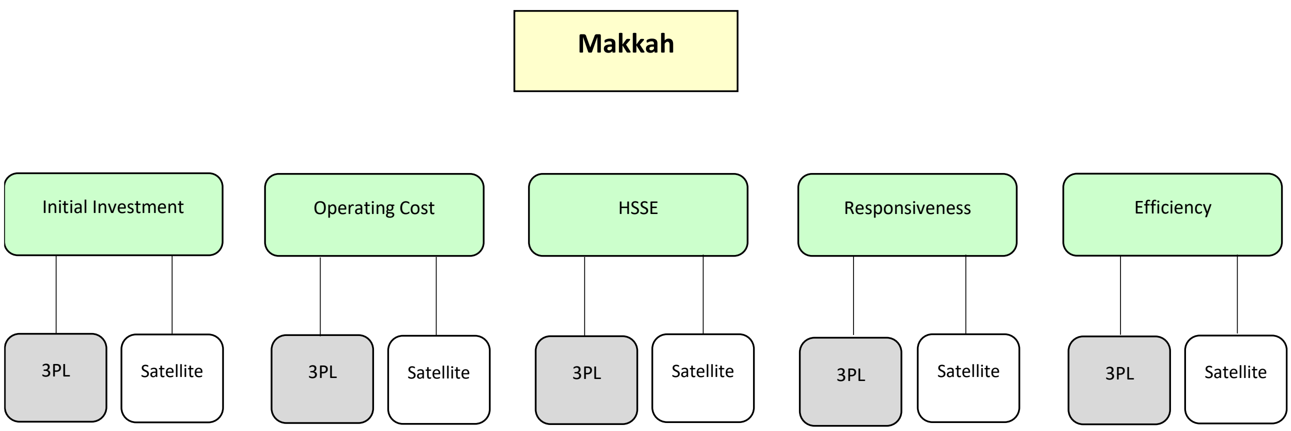
City	No. of Sales Team	Monthly Volume-Cases
Al-Ahsa	2	3500
Makkah	2	3500
Al-Baha *	2	1500
Qurayyat*	2	1500

* Two Salesmen for low number of cases because of the nature of mountain roads and high travel distances between customers

In addition; Note that not all alternatives are available for each city. Table 21 shows the possible alternatives available for each city to be used for AHP MCDM model.

Table 21: Possible Alternatives of Each City

Site	3PL	Satellite	Company-Managed
Makkah	✓	✓	☒
Baha	✓	☒	✓
Al-Ahsa	✓	✓	☒
Qurayyat	☒	✓	✓



As Illustration; Figure 4 shows Makkah city AHP model.

Figure 4: Makkah City AHP Model

2.2 Development and Process of the AHP Model

The relative weights of various alternatives (3PL, Satellite and CM) are determined within each criterion and city. The outcome is 15 metrics. In this section, data consistency will be checked before deploying the AHP model.

AHP Data Consistency Check

The analytical hierarchy process (AHP), developed by Saaty in 1977, is based on calculating utility functions value of certain alternatives according to their criteria weight's aggregation using hierarchy structure, pair-wise comparisons and judgment scales.

AHP, unlike other decision-making methodologies, is used for both quantitative and qualitative criteria or alternatives using same preference scale and hence needs ratio scales due to its pair-wise comparisons. In spite of several available comparison scales available, Saaty (1994) confirms that ratio scales are the only possible way to aggregate measurements from weighted sum. Such evaluation needs a certain level of matrix consistency which implies matrices elements to be linearly independent. This can be examined via consistency check via consistency index $CI = \frac{\lambda_{max} - n}{n-1}$ where λ_{max} is max eigenvalue of comparison matrix; $\lambda_{max} = \sum_{i=1}^{n} \frac{(M.\lambda)_i}{n\lambda_i}$, M represents pair-wise comparison matrix and λ is the matrix eigenvector. The matrix is perfectly consistent if CI is zero.

Also, consistency error increases proportionally with rising number of pair-wise comparisons. Hence, Saaty (1980) proposed another measure. The CR (consistency ratio) calculated as follows; $CR = \frac{CI}{RI}$ where *RI* is the average *CI* values gathered from a random simulation of Saaty pair-wise comparison matrices. In order to have consistent matrix; it is suggested to have a value of the CR no higher than 0.1 (Saaty, 1980).

A consistency check will be conducted for the ten generated matrices of criteria-setup combinations. Note that 2×2 criteria matrix does not need consistency check as the relative weights are complementary of each other and hence RI=0 and n-max is exactly equals to n.

Matrix 1: Initial Investment for 3PLSetup

Relative scores among the cities under this option and specific criterion are shown in below;

Table 22: Initial Investment for 3PL Setup Matrix

City	Makkah	Baha	Al-Ahsa
Makkah	1.00	4.00	3.00
Baha	0.25	1.00	0.85
Al-Ahsa	0.33	1.18	1.00
Sum	1.58	6.18	4.85

Below are the parameters of the consistency check;

$\lambda_{max} = 3$, CI= 0.001, RI= 0.58 and CR = 0.002

Conclusion: Consistent data as CR <0.1

Matrix 2: Operating Cost for 3PLSetup

Relative scores among the cities under this option and specific criterion are shown ~~in~~ below;

Table 23: Operating Cost for 3PL Setup Matrix

City	Makkah	Baha	Al-Ahsa
Makkah	1.00	2.50	2.00
Baha	0.40	1.00	1.15
Al-Ahsa	0.50	0.87	1.00
Sum	1.90	4.37	4.15

Below are the parameters of the consistency check;

$\lambda_{max} = 3.02$, CI= 0.009, RI= 0.58 and CR = 0.015

Conclusion: Consistent data as CR <0.1

Matrix 3: HSSE for 3PLSetup

Relative scores among the cities under this option and specific criterion are shown below;

Table 24: HSSE for 3PL Setup Matrix

City	Makkah	Baha	Al-Ahsa
Makkah	1.00	1.35	0.85
Baha	0.74	1.00	0.50
Al-Ahsa	1.18	2.00	1.00
Sum	2.92	4.35	2.35

Below are the parameters of the consistency check;

$\lambda_{max} = 3.01$, CI= 0.003, RI= 0.58 and CR = 0.005

Conclusion: Consistent data as CR <0.1

Matrix 4: Responsiveness for 3PLSetup

Relative scores among the cities under this option and specific criterion are shown ~~in~~ below;

Table 25: Responsiveness for 3PL Setup Matrix

City	Makkah	Baha	Al-Ahsa
Makkah	1.00	1.50	0.75
Baha	0.67	1.00	0.65
Al-Ahsa	1.33	1.54	1.00
Sum	3.00	4.04	2.40

Below are the parameters of the consistency check;

$\lambda_{max} = 3.01$, CI= 0.004, RI= 0.58 and CR = 0.006

Conclusion: Consistent data as CR <0.1

Matrix 5: Efficiency for 3PL Setup

Relative scores among the cities under this option and specific criterion are shown ~~in~~ below;

Table 26: Efficiency for 3PL Setup Matrix

City	Makkah	Baha	Al-Ahsa
Makkah	1.00	1.45	1.25
Baha	0.69	1.00	0.65
Al-Ahsa	0.80	1.54	1.00
Sum	2.49	3.99	2.90

Below are the parameters of the consistency check;

$\lambda_{max} = 3.01$, CI= 0.005, RI= 0.58 and CR = 0.008

Conclusion: Consistent data as CR <0.1

Matrix 6: Initial Investment for Satellite Setup

Relative scores among the cities under this option and specific criterion are shown below;

Table 27: Initial Investment for 3PL Setup Matrix

City	Makkah	Al-Ahsa	Qurayyat
Makkah	1.00	1.50	1.25
Al-Ahsa	0.67	1.00	0.85
Qurayyat	0.80	0.85	1.00
Sum	2.47	3.35	3.10

Below are the parameters of the consistency check;

$\lambda_{max} = 3.00$, CI= 0, RI= 0.58 and CR = 0

Conclusion: Consistent data as CR <0.1

Matrix 7: Operating Cost for Satellite Setup

Relative scores among the cities under this option and specific criterion are shown below;

Table 28: Operating Cost for Satellite Setup Matrix

City	Makkah	Al-Ahsa	Qurayyat
Makkah	1.00	2.25	2.00
Al-Ahsa	0.44	1.00	0.75
Qurayyat	0.50	0.75	1.00
Sum	1.94	4.00	3.75

Below are the parameters of the consistency check;
$\lambda_{max} = 3.00$, CI= 0.002, RI= 0.58 and CR = 0.003
Conclusion: Consistent data as CR <0.1
Matrix 8: HSSE for Satellite Setup
Relative scores among the cities under this option and specific criterion are shown below;

Table 29: HSSE for Satellite Setup Matrix

City	Makkah	Al-Ahsa	Qurayyat
Makkah	1.00	0.85	0.65
Al-Ahsa	1.18	1.00	1.50
Qurayyat	1.54	1.50	1.00
Sum	3.71	3.35	3.15

Below are the parameters of the consistency check;
$\lambda_{max} = 3.052$, CI= 0.026, RI= 0.58 and CR = 0.045
Conclusion: Consistent data as CR <0.1
Matrix 9: Responsiveness for Satellite Setup
Relative scores among the cities under this option and specific criterion are shown below;

Table 30 : Responsiveness for Satellite Setup Matrix

City	Makkah	Al-Ahsa	Qurayyat
Makkah	1.00	0.50	1.25
Al-Ahsa	2.00	1.00	1.75
Qurayyat	0.80	1.75	1.00
Sum	3.80	3.25	4.00

Below are the parameters of the consistency check;
$\lambda_{max} = 3.016$, CI= 0.008, RI= 0.58 and CR = 0.013
Conclusion: Consistent data as CR <0.1
Matrix 10: Efficiency for Satellite Setup
Relative scores among the cities under this option and specific criterion are shown below;

Table 31: Responsiveness for Satellite Setup Matrix

City	Makkah	Al-Ahsa	Qurayyat
Makkah	1.00	2.50	2.15
Al-Ahsa	0.40	1.00	1.50
Qurayyat	0.47	1.50	1.00
Sum	1.87	5.00	4.65

Below are the parameters of consistency check;

λ_{max} = 3.014, CI= 0.020, RI= 0.58 and CR = 0.035
Conclusion: Consistent data as CR <0.1

Now, using the 15 previously generated combination matrices, an AHP model will be developed for each city and the composite weights for the associated two options will be calculated using these formulas where applicable.

$$Weight(3PL) = \sum_{i=1}^{5} (P_i P_{3PL_i})$$

$$Weight(Satellite) = \sum_{i=1}^{5} (P_i P_{Satellite_i})$$

$$Weight(CM) = \sum_{i=1}^{5} (P_i P_{CM_i})$$

I. Makkah City AHP Model

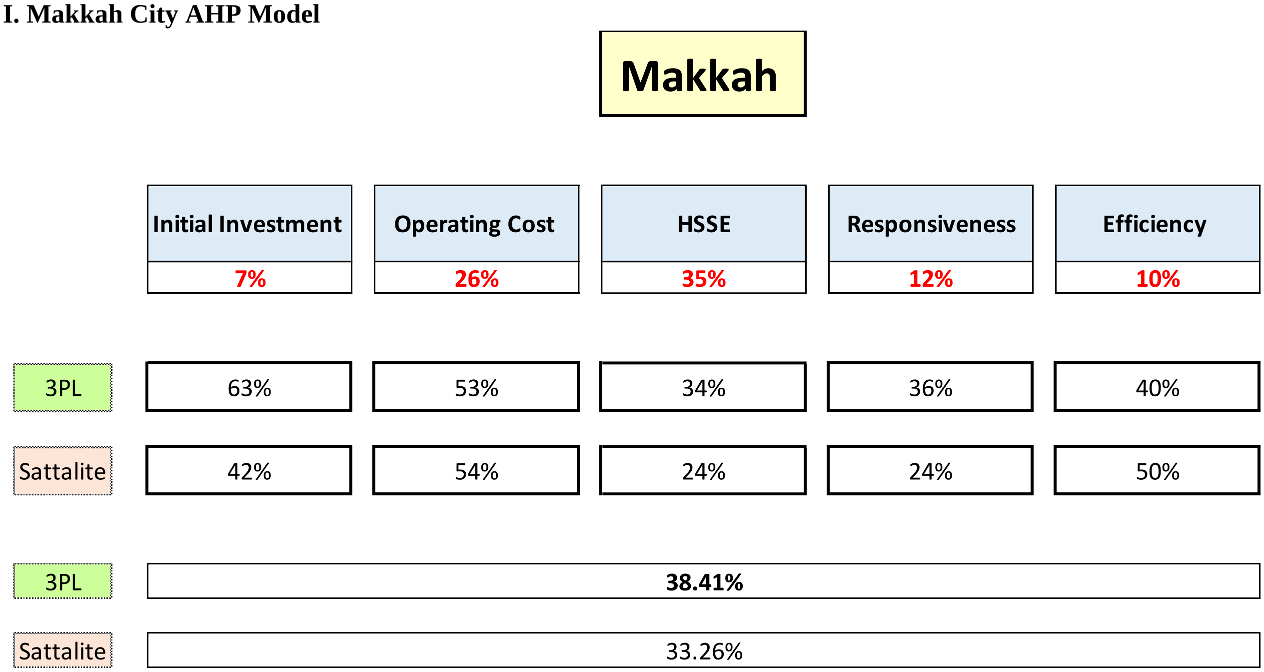


Figure 5: Makkah City AHP Model Outcome

Similarly; the AHP model is developed for the remaining three cities Baha, Al-Ahsa and Qurayyat and results and decisions are shown in table 32 below.

Table 32: AHP Model Setup Outcome with Scores

City	3PL	Satellite	CM	Decision
Makkah	38.41	33.26		3PL
Baha	23.36		48.19	CM
Al-Ahsa	34.23	30.58		3PL
Qurayyat		31.15	49.75	CM

4.3 Distribution Network Expansion Plan Costing and Budgeting

Now, the associated cost will be calculated to check whether the MCDM outcome is in line with management expectation. The cost of each one of the options has to be preciously calculated taking into consideration all incurred costs and the existing market practices and fares. Table 33 below shows the costing details of the three alternatives; company-managed, 3PL and satellite warehouses including all cost types; rental, manpower, fuel, supplies and contracted services fees.

Table 33: Cost Elements with Total Cost for Each Setup

Elements	Figure	Note
Number of Pallets	100	Average Cases Per Pallet is 35 cases
Pallet Area (m2)	1.56	Pallet Size is 120×130 cm
Pallets Storage Space	156	No. of Pallets × Pallet Area
Additional Space (Aisles, HSSE, Quality)	46.8	FIFO, Safety Cleranace, Aisles ...etc. (30%)
Warehouse and Office Space	120	Office Facility Area (m2)
Loading / Offloading Area	150	Trucks Parking and Forklift Operation
Total Area of Warehouse	472.8	Storage + Office + Loading/Offloading
Min Area Avilable for Rental	500	Market Pratice
Annual Rental Fees Per m2	120	Average Market Price - Real Estate Input
Total Annual Rental Fees	60000	Warehouse Rental Cost
Monthly Operating Expenses	10000	Fuel, Forklift Rental, Sationary, Food
Total Monthly Manpower Cost - 6 Personnel	33000	Warehouse Officer, Forklift Operator and Security Team
Total Monthly Cost	48000	WH Cost + Operation Cost + Manpower Cost
Unit Price (SR / Pallet)	19.2	Total Cost / No. of Pallets
Company-Managed Warehouse Monthly Cost	48000	Fixed Amount with a max of 100 pallets
3PL Monthly Cost (SR/Case)	10	SR 15000 for 1500 cases
	9.14	SR 32000 for 3500 cases
Sattalite WH Monthly Cost	24,000	Fixed Amount with a max of 100 pallets

Hence; the final outcome and its associated cost is shown in the table 34 below.

Table 34: Associated Cost for AHP Outcomes

City	Decision	Volume	Total Cost	Unit Cost (SR/Case/ Month)	Annual Total
Makkah	3PL	3500	32,000	9.14	SR 160,000
Baha	CM	1500	48,000	32	
Al-Ahsa	3PL	3500	32,000	9.14	
Qurayyat	CM	1500	48,000	32	

3.4 Vehicle Sourcing Plan for Expansion Sites

The management team has requested to come up with the best option of vehicle sourcing linked with the AHP best resulted option, given the below information.

Project Contracted Period = 24 Months
Two Sourcing Options: Lease or Purchase
Monthly Rental Fees per Vehicle = SR 12,000
Number of Vehicles per Site = 2
Monthly Revenue per Site Per Vehicle = SR 30,000
Project Success Chance = 60%
Project Failure Chance = 40%
Purchase Price per Vehicle = SR 140,000
Vehicle Monthly Operating Cost (in case of purchasing)= SR5000 / Vehicle
Return Fees per Vehicle (in case of failure)= SR 50,000

Salvage Value per Vehicle (in case of failure)= SR 60,000

Payoff (Lease-Success)

= (SR30, 000 /Site ×24 Months) – (SR 12,000×24 Months × 2 Vehicles) = SR 144,000

Payoff (Lease-Fail)

= (SR - 50, 000 /Vehicle ×2 Vehicles) = SR - 100,000

Payoff (Purchase-Success)

= (SR30, 000 /Site ×24 Months) – [(SR 140,000×2 Vehicles) + (5000×24 Months × 2 Vehicles)] = SR 200,000

Payoff (Purchase-Fail) = Purchasing Cost – Salvage Value

= (SR140, 000 /Vehicle ×2 Vehicles) - (SR50, 000 /Vehicle ×2 Vehicles) = SR -180,000

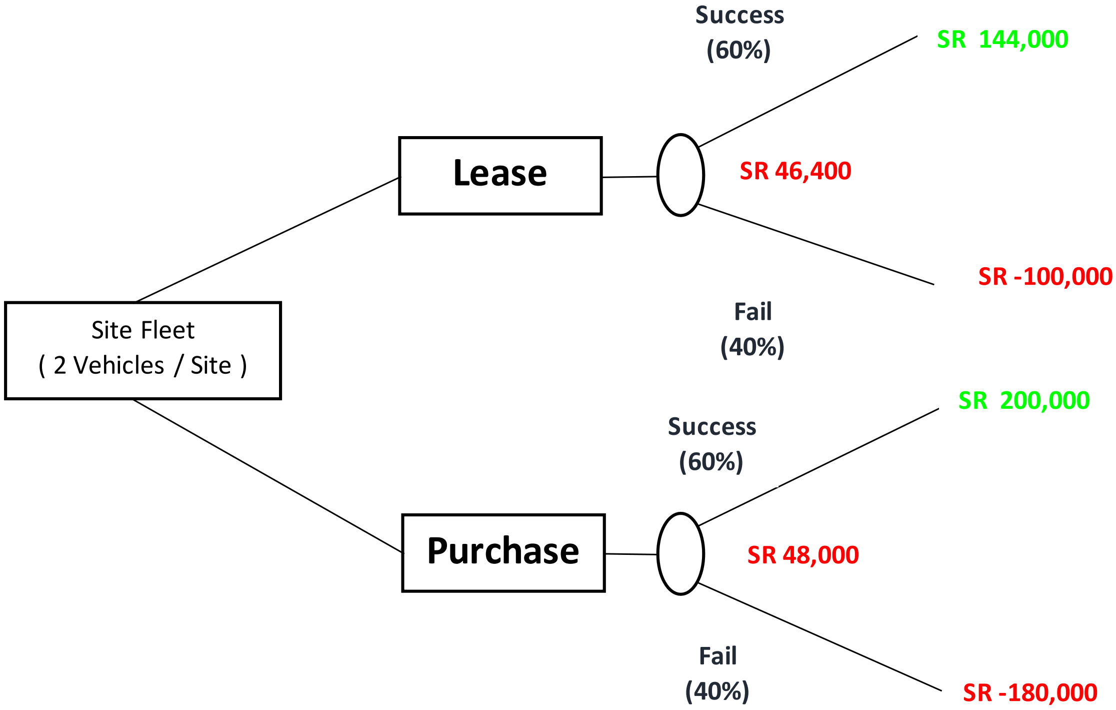


Figure 6: Vehicle Sourcing Decision Tree

Below Table summarizes the payoffs and the expected returns of each option

Expected Return (Lease) =0.6(144,000)-0.4(100,000) =SR 46,400

Expected Return (Purchase) =0.6(200,000)-0.4(180,000) =SR 48,000

It is obvious that “Purchase” option is to be selected as it has a higher expected return; SR 48,000 versus SR 46,400.

3.5 Conclusion: Distribution Network Expansion and Vehicle Sourcing

Part of the study aims to decide on the best X-LUBE distribution network expansion using Multi-Criteria Decision Making (MCDM). The outcome of this analysis is briefed in below points.

3PL alternative is recommended for Makkah and Al-Ahsa while CM is the best for Baha and Qurayyat.

The total annual cost of the optimal solution is SR 160,000.

The main observations and conclusion of the last part of this study can be briefly stated in the below points.

Data consistency does not necessarily imply its accuracy or precision. This resulting outcome is a clear example of this.

3PL option is verified to be the least cost alternative as it depends mainly on variable cost per case with the high level of flexibility to amend terms and conditions without major investment.

Vehicle “Purchase” option has a slightly higher expected return which can be selected to minimize operational cost. However, since the difference between the two expected values is minor (SR1600); It is recommended to go with the

"Lease" option for the sake of better control and focus on core business activities taking out the complications of fleet management related activities such as maintenance, routing planning …etc.

CHAPTER 4
CONCLUSION AND RECOMMENDATION

4.1 Results Summary

In this chapter, the overall conclusion of this study will be shared and discussed as each objective's conclusion is discussed at the end of that relevant chapter.

Overall, this study decides on important parameters of almost all X-LUBE supply chain network aspects, distribution and transportation. Below are the main recommendations and decisions related to this study.

TBCF is the best transportation setup for a secondary distribution network

For distribution network expansion, Makkah and Al-Ahsa would go for the 3PL alternative while CM would be the best alternative for Baha and Qurayyat with a total annual cost of SR 160,000.

Below are some relevant facts and highlights for consideration;

In spite of that fact that not all MCDM models result in TBCF as the best option, It is considered as the best since it is the most frequent resulted option along with other factors mentioned in section 5.7.

Distribution Network Expansion Setup, 3PL is proven to be the best alternative using AHP. Details are listed in section 6.4.

4.2 Paper Contribution

This thesis contributes to the knowledge field in the following points:

Shows how MCDM can be deployed and utilized in the field of supply chain network design.

Introduces a new thorough design case study in the oil and gas field

4.3 Future Work

The research work can be extended via;

Utilizing the design of experiments approach to come up with the same decisions and comparisons

Applying vehicle routing concept to sales vehicles operation to optimize the local and regional distribution.

Using other business analysis approaches empowered with AI tools for various available scenarios

REFERENCES

[1] Zhen-Song Chen, Min Li 1, Wen-Tao Kong and Kwai-Sang Chin. (2019). Evaluation and Selection of HazMat Transportation Alternatives: A PHFLTS- and TOPSIS-Integrated Multi-Perspective Approach. International Journal of Environmental Resources and Public Health 2019, 16, 4116.

[2] Ikuobase Emovon Rosemary A. Norman and Alan J. Murphy (2018). Hybrid MCDM based methodology for selecting the optimum maintenance strategy for ship machinery systems. Journal of International Manufacturing (2018) 29:519–531

[3] Changez Khana, Sajid Anwara, Shariq Bashirb, Abdul Raufc and Adnan Amina (2015). Site selection for food distribution using rough set approach and TOPSIS method. Journal of Intelligent & Fuzzy Systems 29 (2015) 2413–2419.

[4] Sen-Kuei Liao, Hsiao-Yin Hsu and Kuei-Lun Chang (2018). A Novel Hybrid MCDM Model to Select Celebrity Endorser for Airlines. J. of Mult.-Valued Logic & Soft Computing, Vol. 32, pp. 477–497

[5] Chunguang Bai, Behnam Fahimnia and Joseph Sarkis (2017). Sustainable transport fleet appraisal using a hybrid multi-objective decision making approach. Annals of Operations Research (2017) 250:309–340

[6] Yavuz Ozdemir and Huseyin Basligil (2016). Aircraft selection using fuzzy ANP and the generalized choquet integral method: The Turkish airlines case. Journal of Intelligent & Fuzzy Systems 31 (2016) 589–600

[7] Laurent Lemarchand ,Damien Massé ,Pascal Rebreyend and Johan Håkansson (2018). Multiobjective Optimization for Multimode Transportation Problems. Hindawi Advances in Operations Research Volume 2018, Article ID 8720643, 13 pages

[8] Süleyman Çakır (2018). An integrated approach to machine selection problem using fuzzy SMART-fuzzy weighted axiomatic design. Journal of International Manufacturing (2018) 29:1433–1445

[9] Taqwa O. Fahad and Abduladhem A. Ali (2018). Multiobjective Optimized Routing Protocol for VANETs. Hindawi. Advances in Fuzzy Systems Volume 2018, Article ID 7210253, 10 pages

[10] Serhat Aydına,b and Cengiz Kahramana (2014). Vehicle selection for public transportation using an integrated multi criteria decision making approach: A case of Ankara. Journal of Intelligent & Fuzzy Systems 26 (2014) 2467–2481.

[11] Khalid Alkhodairi. Supply Chain Network Redesign, Case Study in Lubrication Industry, Department of Systems Engineering, KFUPM, May 2019

[12] KSA Lubricants Market Data Analysis 2018, Lubref Report

[13] Grand View Research. (2018). Lubricants Market Size, Share & Trends Analysis Report