

**SUPPLY CHAIN DISTRIBUTION NETWORK
DESIGN, CASE STUDY IN LUBRICANTS INDUSTRY**

BY

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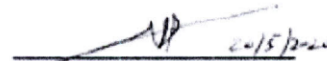
DEANSHIP OF GRADUATE STUDIES

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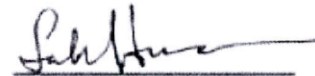
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Dedication

To my mother, who is behind all my success

To my lovely family members, friends, colleagues and everyone who provides support,
knowledge and advices

ACKNOWLEDGEMENT

First, I express my sincere thankfulness to my advisor Dr. Omar Al Turki for his remarkable help and support in my journey for knowledge. Also; deep thanks to the thesis committee members Prof. Saleh Duffua and Dr. Ahmet Kolus whose vast experience and knowledge contributed valuable addition to the thesis. I would like to express my deepest appreciation to my mother who is behind my patience, passion for success and all remarkable achievements in my life.

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LIST OF ABBREVIATIONS

IP	:	Integer Programming
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

ABSTRACT

Full Name : Ibrahim Hassan Al-Dali
Thesis Title : Supply Chain Distribution Network Design, Case Study in Lubricates Industry
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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 the first part of the study; a liner programming (LP) optimization model is built and solved to determine the most cost efficient operating strategy for X-LUBE company distribution hub. Moreover; 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 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

ملخص الرسالة

الاسم الكامل: إبراهيم حسن سالم الدالي

عنوان الرسالة: إعادة تصميم شبكة التوزيع في سلسلة الإمداد، دراسة حالة في صناعة الزيت والغاز

التخصص: الهندسة الصناعية

تاريخ الدرجة العلمية: مايو 2020

أنظمة الإمداد من أهم مجالات الإدارة التي تساهم بشكل مباشر في نجاح الشركات ، وعليه فإنه يجب تصميمها بشكل يتلائم مع أهداف واستراتيجيات الشركات التابعة لها. هذه الدراسة تتضمن إعادة تصميم منظومة سلسلة الإمداد في إحدى شركات قطاع صناعة النفط والغاز في المملكة العربية السعودية تدعى "X-LUBE"

يتكون الجزء الأول من البحث من إستخدام أدوات البرمجة الخطية لبناء وحل نموذج تحسين بهدف تحديد أفضل وأرخص الطرق التشغيلية لإدارة مركز التوزيع الخاص بالشركة ، أما الجزء الثاني فيتعلق باستخدام أدوات إتخاذ القرارات ذات المعايير المتعددة لتحديد أفضل خيار متاح للنقل في شبكة التوزيع الخاصة بالشركة من خلال مقارنة خمس خيارات متاحة من

خلال معايير محددة سابقاً من إدارة الشركة. الأدوات المستخدمة تشمل AHP, TOPSIS, PROMETHEE

ELCTRE

أما الجزء الأخير من البحث فيتعلق بتحديد أفضل الحلول المتاحة لتوسيع شبكة التوزيع الخاصة في الشركة باستخدام أداة واحدة من أدوات إتخاذ القرارات ذات المعايير المتعددة أيضاً وهي AHP وتحديد التكلفة ذات العلاقة ونوع شبكة التوزيع المرتبطة بها

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 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 1.1 shows the X-Lube sales channels and segments. Also; Figure 1.2 shows X-Lube business volume segmental split based on last three years performance.

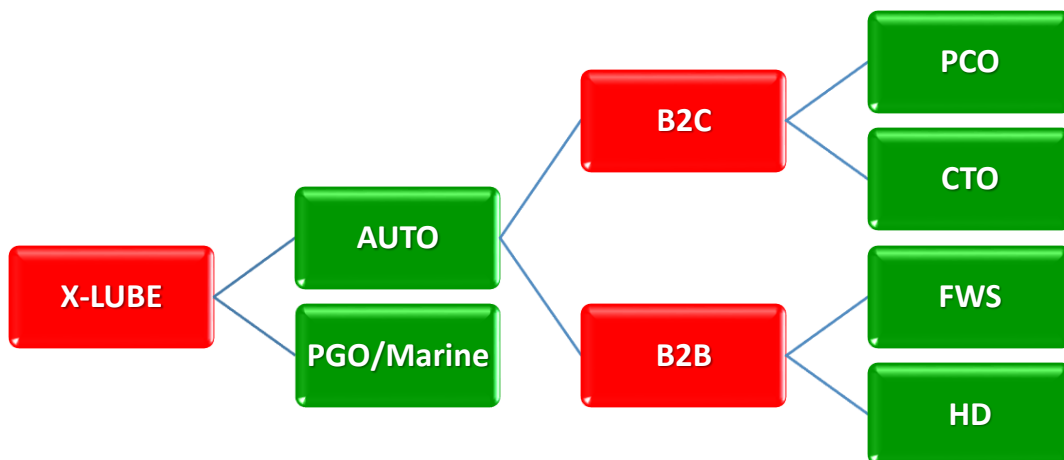


Figure 1.1: X-LUBE Sales Channels and Segments

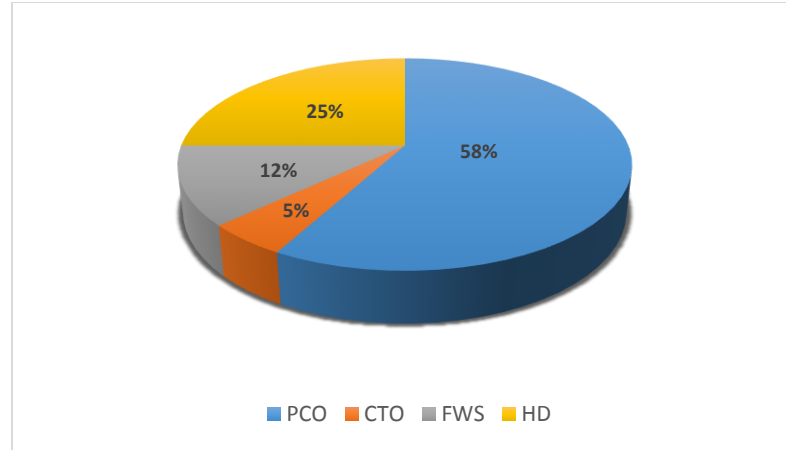


Figure 1.2: X-LUBE Segmental Volume Split

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 order to ensure supply chain synchronization ; the need arises to locate a distribution hub to serve as an intransient storage facility between plant and X-LUBE company sites to manage supply-demand fluctuation in supply chain flow. As per Alkhodairi (2019); the hub is recommended to be located in Yanbu somewhere next to the plant.

Alkhodairi (2019) developed a single-sourcing network redesign problem for multi-levels supply chain; suppliers, plants, distribution centers and markets to determine the optimal number and locations of plants and DC's for the same company in this study. The problem is formulated and solved as cost minimization mixed integer nonlinear programming models (MINLP). The study concludes to locate both plant and DC in Yanbu, Saudi Arabia.

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 determining best X-LUBE hub operating strategies, deciding on ideal transportation mode to be used within X-LUBE network and finally proposing appropriate setup for X-LUBE distribution network expansion. For that purpose; liner programming (LP) along with multi criteria decision making (MCDM) models are utilized and solved.

1.1 Lubrication Industry Overview

Lubricants contribute to almost 19% of 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 thousands (110,000) trucks are being injected to 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, fourty million liters of lubricants is being sold in KSA market annually and automotive lubricants represents 70% of that demand. X-LUBE currently represents almost 10% of that demand (Grand View Research., 2018).

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 volume such as Total, Chevron and Caltex. Only 20% of these suppliers own plants in Saudi Arabia and the rest are

managing either via outsourcing from other local lubricants blenders or through importing from abroad.

Since X-LUBE company has its own 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 high competitive environment.

1.2 Research Objective

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

The first objective is to determine the best operating strategy of X-LUBE company hub among below ones;

Strategy I: use of hub as exclusive in-transient storage: all plant stock to be sent to hub and shipped to X-LUBE company sites from that hub; no direct shipment from plant.

Strategy II: manage direct shipment to X-LUBE company sites from plant and use hub for stock build up

Strategy III: mixed strategy; agreed setup with defined criteria where direct shipment from plant and stock build up in hub to be used

The second 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;

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)

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

1. What is the best operating strategy of hub?
2. How X-LUBE company distribution network has to be designed in order to optimize overall supply chain flow and cost?
3. What is the best network model to be used in X-LUBE company network?

4. What transportation mode that X-LUBE company has to select to best satisfy the predefined criteria?
5. What are the best of 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;

- Determine the best operating strategy of X-LUBE company distribution hub in order to minimize overall operating expenses such as warehousing and transportation
- Determine X-LUBE company distribution network design based on selected operating strategy in order to satisfy customer demands and meet delivery time at optimal cost
- 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.

2.1 Distribution Network Design (DND)

Distribution network design (DND) is an integral part of overall supply chain (SC) process design as it covers essential aspects of products or services flow such as warehousing, orders management, transportation and distribution. The main motivator of DND is supply chain cycle effectiveness and efficiency that leads to best resources utilization and hence supply chain cost optimization. DND can be conducted taking into consideration several factors such as orders splitting, inventory decisions and operations cost. Stochastic demand can be assumed also.

Hongwei Ding et al. (2008) approached DND problem as multi-objective problem. They utilized multi-objective general algorithm (MOGA) along with simulation model to come up with optimal setup that best compromises operations cost and customer satisfaction.

Cross-docking concept can be utilized in DND along with multi-objectives (economical, environmental and social) optimization. Such problem can be formulated as multi-objectives mixed-integer linear programming (MILP). Cuckoo optimization approach is used to solve this model. **Saeid Rezaei and Amirsaman kheirkhah (2018)**

DND problems are concerned with serving certain number of customer sites (demand points) from existing distribution centers DC's (supply points) in the network and their related decisions such as capacitated network, single or multiple echelon centers under stochastic demand. The resulted design aims to be optimal for all objectives which are usually operations cost, delivery time (responsiveness) and fulfillment rate. **Gang Wang et al. (2016)** assume single echelon with capacitated DC for DND problem and utilized MILP to solve the optimization model and come up with the best setup.

Also, DND is highly sophisticated process as it has to deal with high level of uncertainty in customer demand and simultaneously ensure agility in customers' responsiveness. **Azam Moradi and Jafar Razmi (2019)** used principal component analysis (PCA) to develop multi-objectives DND model and utilized MILP to solve for optimal setup.

DND can focus also on suppliers-retailers network and its related decisions such suppliers sites locations and orders parameters, i.e. quantity and lead time. **Weu Zhang and Di Xu (2013)** designed logistics network using mixed-integer bi-level programming to solve a model with upper side which is LND (Logistics network Design) and lower side which is OQD (Order Quantity Determination). Stochastic customer demand is assumed.

DND also involves the decision of how many warehouses to open directly or outsource and the time span of operations along with transportation means to be used especially when there is a high uncertainty level in customer demands. **Mustapha Ouhimmou et al. (2019)** used robust optimization in pulp and paper case study with Benders decomposition to determine the best DND design.

In certain cases, DND problems are multi-dimensional in which the decisions are to be made for both locations and routings. **Si Zhang et al. (2019)** used particle swarm optimization (PSO) approach to design multi-products and multi-customers network, a case study for Omni-Channels.

Moreover, Reverse logistics (returns) can be part of DND problems with stochastic assumption. **Halit Uster and Sung Hwang (2016)** assumed uncertain product returns in DND and used both MILP and Benders decomposition in solving the model.

DND might be approached from game theory perspective in which payoffs and trade-offs exist between both retailers and suppliers. **Gaidi Li et al. (2015)** considered warehouse-retailer network design (WRND) as a game and proved the effectiveness of cost-sharing scheme of both involved parties. **Jia Shu (2010)** utilized greedy algorithm to solve large-scale WRND problem.

2.2 DND and Transportation Mode Selection via MCDM

MCDM techniques have been widely used in DND and facility location problems (FLP) in various fields and industries. For instance, Vaidya Omkarprasad and Kumar Sushil (2006) listed more than 150 publications of using AHP in facilities planning and location. Later, new development on AHP was introduced, i.e. Fuzzy AHP(L. Mikhailov, 2000). AHP is also integrated with other MCDM techniques such as TOPSIS, PROMETHEE, and Support Vector Machine TOPSIS (SVM-TOPSIS).

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 criterial 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 “Vlekkriterijumsko 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 multi-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 decide about the best public transportation means in Ankara, the capital of Turkey

CHAPTER 3

ASSUMPTIONS AND DATA ANALYSIS

3.1 Assumptions

In this chapter, models assumptions are listed and all relevant data are gathered, organized and analyzed to be used to build related models and draw appropriate conclusions accordingly. This includes total and regional demand historical data, transportation data and associated costing data.

The main assumptions of this study are listed in points below;

- 1- The demand plan is assumed to be deterministic with a finite uncertainty levels of $\pm 15\%$
- 2- The in-plant warehouse is mainly for in-bound logistics activities; i.e. raw and packing material storage where finished goods storage is very minimal.
- 3- Operating stand-alone distribution hub/ warehouse is not allowed in the plant and has to be located nearby the plant industrial area.
- 4- Holding cost is ignored since distribution hub operating cost is assumed to be the same in all operating strategies.
- 5- Single delivery point in each city is assumed, Gang Wang et al. (2016)
- 6- Transportation cost between any two demand points is the same regardless of direction
$$C_{ij} = C_{ji}.$$
- 7- MCDM criteria and their weights are based on X-LUBE management committee subjective input.
- 8- All data are based on actual and contracted figures that X-LUBE is currently using.

3.2 Input Data Analysis

All input data related to the distribution network and model parameters will be gathered, analysed and determined in a precise and structured way of calculation. The primary figures needed to build the model are;

- 1- Distribution Transportation Costs
- 2- Supply and Demand Volume Data

Distribution Transportation Costs: the objective of this part is to come up the transportation cost per distance unit traveled from one location to another. This is the “Total Cost per Distance Unit” in Saudi Riyal (SR). Total Cost per Distance Unit is calculated as per the below split;

- Cost of Consumables (Fuel and Oil)
- Cost of Vehicle Operations (Drivers, Insurance ...etc.)

As per appendix 1, the unit transportation comes to be SR 0.8 per kilometer. This will be the basis of distance-cost conversion between demand points within the distribution network.

Supply and Demand Volume Data: this part concerns about converting the volume data in both supply and demand nodes into number of delivery trips, which is the “Volume-Delivery Conversion Factor”. This figure can be calculated by finding the maximum volume load per each product type then to calculate the average volume per trip to convert each supply and demand associated volume in the model to its number of trips.

Table 3.1 below shows the “Volume-Delivery Conversion Factor” calculation approach.

Table 3.1: Volume-Delivery Conversion Factor Calculation

Type	Unit Volume-Liters	Flat Bed Trailer	
		Max Load-Units	Max Volume Liters
Cartons	24 × 1 L	810	19440
Drums	208 L	100	20800
Average Volume - Liters			20120
Average Volume - Tons			20

Total X-LUBE supply and demand volume data along with regional allocated demand data can be summarized in table 3.2. The expected number of trips is also determined using “Volume-Delivery Conversion Factor”, which is 20 tons / trip.

Table 3.2: Supply and Demand Volume and Delivery Trips Split

Demand	Cities	Volume%	Total Annual Volume -MLTR	Allocated Volume- MLTR	No. of Truck Loads
	Jeddah	30%	50	15	$D_3=750$
	Riyadh	20%		10	$D_4=500$
	Dammam	20%		10	$D_5=500$
	Buridah	10%		5	$D_6=250$
	Khamis	10%		5	$D_7=250$
	Tabuk	10%		5	$D_8=250$
Supply	Plant	Volume%	Total Annual Volume -MLTR	Allocated Volume- Liters	No. of Truck Loads
	Yanbu	100%	50	50	$X_M=2500$

CHAPTER 4

DISTRIBUTION HUB OPERATING STRATEGY AS IP MODEL

The X-LUBE distribution hub, which is going to be located in Yanbu as per Alkhodairi (2019), has three main operating strategies;

- I. **Strategy I:** The distribution hub is to serve as pure in-transient storage facility in which all produced stock is pushed to the hub and sent from there to demand points.
- II. **Strategy II:** The distribution hub is to be used exclusively for storage purpose while shipments are to be managed directly from the plant only.
- III. **Strategy III:** A hybrid strategy in which direct shipment are managed from the plant while in direct deliveries are managed from the distribution hub

Since IP is a common approach in DND problems (Saeid Rezaei and Amirsaman Kheirkhah, 2018), every strategy will be formulated as a cost minimization IP model with governing constraints and certain assumptions, taking into consideration the fact that the plant cannot accommodate such distribution hub as in-plant warehouse

4.1 Distribution Hub Operating Strategy IP Model Structure

Below are the elements and structure of operating strategy IP model;

Objective Function

The model objective's function is to minimize total transportation cost to satisfy customers' demand in the distribution network

Decision Variables

The IP model decision variables are listed below in the format of X_{ij} which represents trips from source (i) to destination (j) where;

1=plant, 2=Hub, 3=Jeddah, 4=Riyadh, 5=Dammam, 6=Khamis Mushait, 7= Buridah, 8=Tabuk,

Input Data

Input data to the IP model is composed of several types of figures listed below;

1- Transportation costs represented by notation C_{ij} , transportation cost per trip from source (i) to destination (j)

With reference to appendix 1 in which the transportation cost is calculated between possible source and destination combinations; Table 4.1 below shows the input figures to be used in the model formulation.

Table 4.1: Distribution Hub Operating Model Input (Transportation Costs)

Cij	1	2	3	4	5	6	7	8
1		500	480	1080	1400	1040	800	720
2	500		280	880	1200	840	600	520
3	480	280		760	1080	520	680	840
4	1080	880	760		360	880	280	1040
5	1400	1200	1080	360		1200	600	1400
6	1040	840	520	880	1200		1200	1320
7	800	600	680	280	600	1200		800
8	720	520	840	1040	1400	1320	800	

2- Supply and Demand Data which is mainly shown in table in chapter three

- Total Demand Volume Trips X_M

$$X_M = \text{Total Demand Trips} = \left(\frac{50,000,000 \text{ LTR}}{20,000 \text{ LTR/Trip}} \right) = 2500 \text{ trips}$$

- Regional Demand Volume Trips

$$D_3 = 750, D_4 = 500, D_5 = 500, D_6 = 250, D_7 = 250, D_8 = 250$$

4.2 Strategy I: In-Transient Storage Hub

This is a pure push strategy in which the produced stock is sent to the hub and prepared there for shipment to demand locations. This strategy allows the plant to focus mainly on in-bound logistics and utilizes the available resources on production-related activities. Also; the space of finished goods storage will be very minimal in which staging, rework or hold is needed. On the other hand; this strategy will not be suitable if volume is not enough to justify the high associated operating cost. Figure 4.1 below represents this strategy graphically.

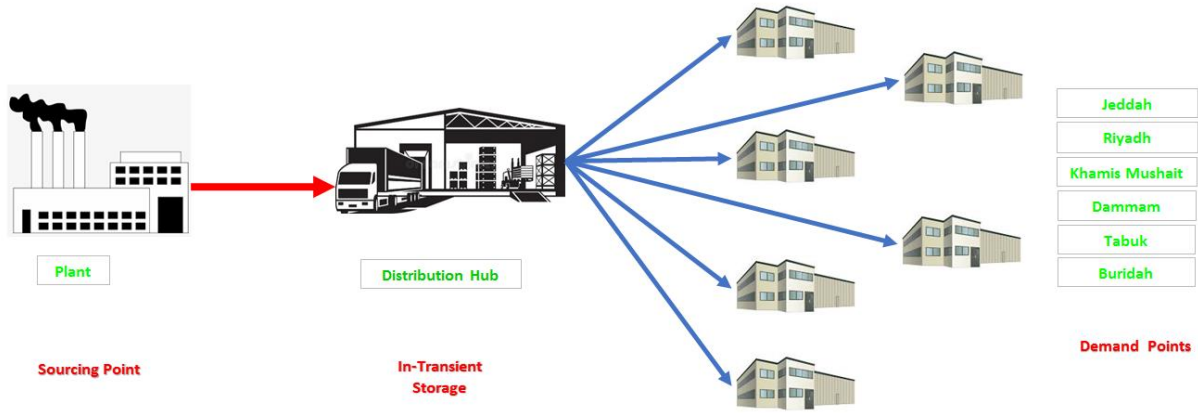


Figure 4.1: X-LUBE Distribution Hub Strategy I

Strategy I Assumption can be summarized in the below points;

- 1- The demand is high and steady in volume and assumed to cover the large operating transportation and storage cost
- 2- The cost of one way trip from plant to distribution hub is SR 500
- 3- Deliveries can occur between any two demand points within the network

Objective Function

Minimize Total Monthly Transportation Cost (TC)

$$TC = C_{12}X_{12} + \sum_{j=3}^8 C_{2j}X_{2j} + \sum_{k=3}^8 \sum_{j=3, j \neq k}^8 C_{kj}X_{kj}$$

Constraints

- The first constraint is to ensure minimum hub supply of 2500 trips

$$\sum_{i=3}^8 X_{2i} \geq 2500$$

- The second constraint is about managing supply-demand at each demand point. At each demand point, stock supplied will be at least equal to the demand of that point or more. If

supplies exceed demand, surplus stock will be transferred to other demand locations via exiting demand point.

$$X_{2i} \geq \sum_{j=1, j \neq k}^8 X_{kj} \quad k=3, 4, 5, 6, 7, 8$$

- The third constraint is to balance Supply-Demand at demand points. At each demand point, there is stock received (input) and stock transferred (out). The difference between stock received and stock transferred out has to be exactly equal to the requirements of that demand point.

$$X_{2k} - \sum_{i=3, i \neq k}^8 X_{ki} = D_k$$

- The last is the non-negativity constraint

$$X_{ij} \geq 0$$

Strategy I LP Model

$$\begin{aligned} \text{Minimize } TC = & 500 X_{12} + 280 X_{23} + 880 X_{24} + 1200 X_{25} + 840 X_{26} + 600 X_{27} + 520 X_{28} + \\ & 760 X_{34} + 1080 X_{35} + 520 X_{36} + 600 X_{37} + 840 X_{38} + 760 X_{43} + 360 X_{45} + 880 X_{46} + 280 X_{47} + \\ & 1040 X_{48} + 1080 X_{53} + 360 X_{54} + 1200 X_{56} + 600 X_{57} + 1400 X_{58} + 520 X_{63} + 880 X_{64} + \\ & 1200 X_{65} + 1200 X_{67} + 1320 X_{68} + 680 X_{73} + 280 X_{74} + 600 X_{75} + 1200 X_{76} + 800 X_{78} + \\ & 840 X_{83} + 1040 X_{84} + 1400 X_{85} + 1320 X_{86} + 800 X_{87} \end{aligned}$$

Subject to

$$X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + X_{28} \leq X_{12}$$

$$X_{34} + X_{35} + X_{36} + X_{37} + X_{38} \leq X_{23}$$

$$X_{43} + X_{45} + X_{46} + X_{47} + X_{48} \leq X_{24}$$

$$X_{53} + X_{54} + X_{56} + X_{57} + X_{58} \leq X_{25}$$

$$X_{63} + X_{64} + X_{65} + X_{67} + X_{68} \leq X_{26}$$

$$X_{73} + X_{74} + X_{75} + X_{76} + X_{78} \leq X_{27}$$

$$X_{83} + X_{84} + X_{85} + X_{86} + X_{87} \leq X_{28}$$

$$X_{23} - X_{43} - X_{53} - X_{63} - X_{73} - X_{83} = 750$$

$$X_{25} - X_{35} - X_{45} - X_{65} - X_{75} - X_{85} = 500$$

$$X_{24} - X_{34} - X_{54} - X_{64} - X_{74} - X_{84} = 500$$

$$X_{26} - X_{36} - X_{46} - X_{56} - X_{76} - X_{86} = 250$$

$$X_{28} - X_{38} - X_{48} - X_{68} - X_{78} - X_{58} = 250$$

$$X_{27} - X_{37} - X_{47} - X_{67} - X_{87} - X_{57} = 250$$

$$X_{ij} \geq 0$$

Using LINGO 18 to solve the above Model (1) results in following solution;

$$X_{12} = 2500, \quad X_{23} = 750, \quad X_{24} = 500, \quad X_{25} = 500, \quad X_{26} = 250, \quad X_{27} = 250, \quad X_{28} = 250$$

Value of Objective Function = **SR 2,990,000**

Figure 4.2 below presents strategy I solution graphically

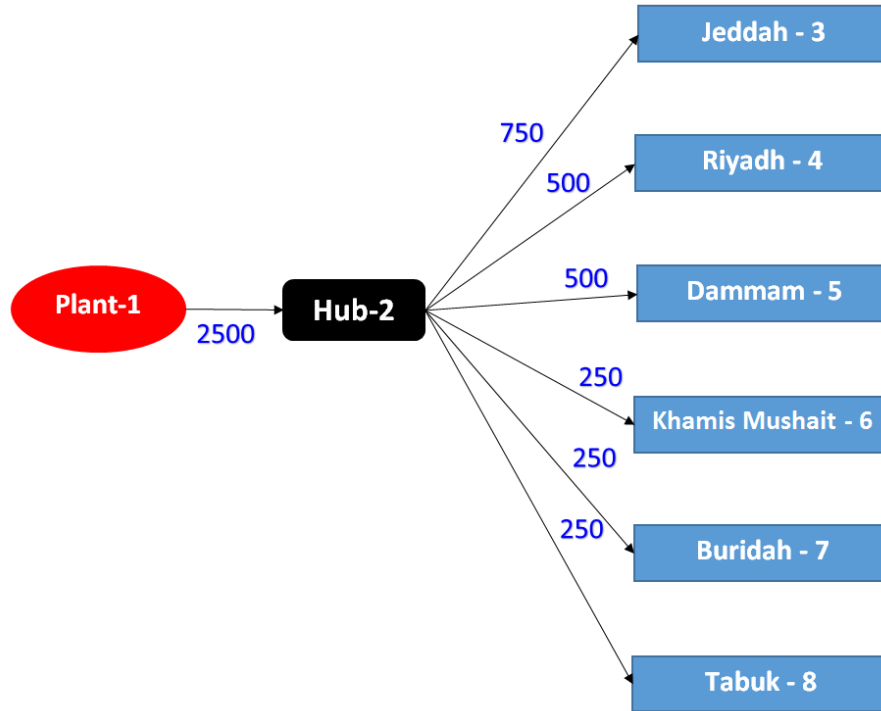


Figure 4.2: Graphical Presentation of Strategy I Solution

4.3 Strategy II: Exclusive Storage Hub

This strategy allows deliveries to be dispatched from plant only while utilizing the distribution hub as a storage facility. This strategy works perfectly when in-plant finished goods storage capacity is low (no enough space to store production output at plant) and back-load transportation is allowed (material supply trucks to be used to carry finished goods in their way back to demand points). This will increase the trucks utilization in the entire supply chain network; inbound and outbound. On the other hand; the main drawback of this strategy is the double handling of loads via shuttling operation between plant and distribution hub which results in extra transportation cost and high number of product touches which increase the damages rates in finished goods. Figure 4.3 provides a graphical representation of this strategy.

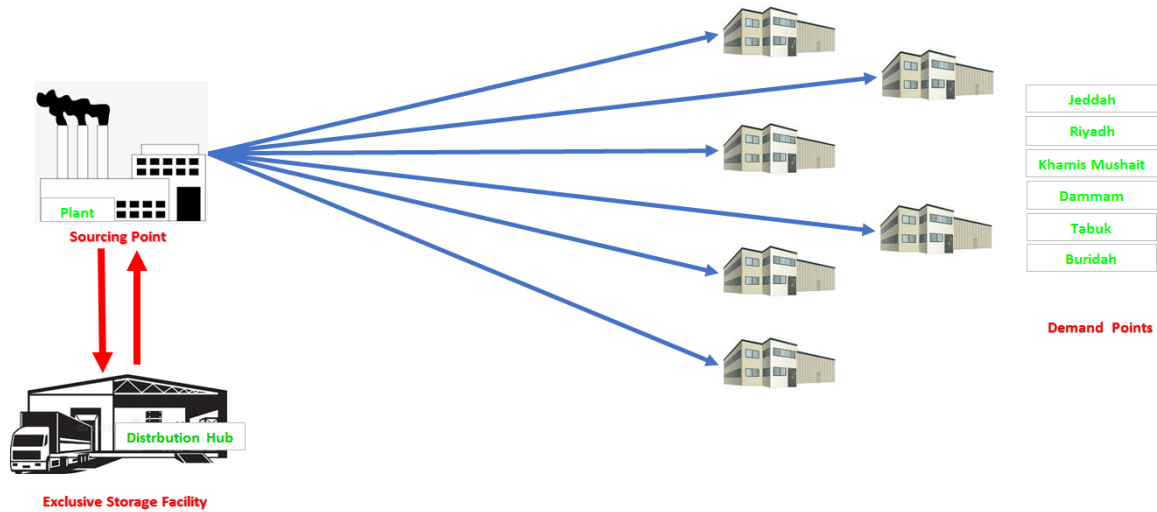


Figure 4.3: X-LUBE Distribution Hub Strategy II

Strategy II Assumptions are briefed in the below points;

- 1- Deliveries to be sent only from the plant to demand points; no deliveries to occur from the distribution hub
- 2- Only main sites which are Jeddah, Riyadh and Dammam can send deliveries to other demand sites i.e. Khamis Mushait, Buridah and Tabuk.
- 3- Shuttling process is to be initiated between the plant and the distribution hub.
- 4- Capacity-to-Demand Ratio (C: D) is assumed to be 130% which means that the plant is capable of producing 30% over the average demand. This is due the capability buffer built in the plant at the design stage.
- 5- Average volume per pallet = 1000 Liters
- 6- Average Volume Per Trip = 20,000 Liters = 20 Tons
- 7- Produce-to-Demand (PtD) volume represents 40% of total X-LUBE demand of 50 million liters. Hence, 60% of plant production will be stored in the distribution hub till demand arises, then it will be shipped back to the plant for delivery to the requested demand points.

- 8- For the sake of control and capital investment optimization, deliveries are assumed to be sent via plant as cross-docking setup is available and proper control can be maintained.

$$1\text{-PtD} = (1-40\%) \times \text{Supply} = 60\% \times \text{Supply}$$

$$\text{Hub Stock} = 60\%(50,000,000) = 30,000,000 \text{ LTR} \approx 1,500 \text{ trips} = 31,500 \text{ pallets}$$

- 9- All delivered volume from plant to hub is shipped back to plant when demand arises to send directly to demand points.

Table 4.2 below shows the average number of pallets to be carried in each trip; assuming flat-bed transportation trailer.

Table 4.2: Average Number of Pallets per Flat-Bed Trailer Trip

Type	Volume %	Flat Bed	
		Max Load-Units	No. of Pallets
Cartons	70%	810 *	13
Drums	30%	100**	8
Average No. of Pallets Per Trip			21

* 45 cartons / pallet

** 4 drums / pallet

Objective Function

Minimize Total Monthly Transportation Cost (TC)

$$TC = 2(C_{12}X_{12}) + \sum_{j=3,4,5,6,7,8} C_{1j}X_{1j} + \sum_{k=3}^5 \sum_{j=3, j \neq k}^8 C_{kj}X_{kj}$$

Constraints

- The first constraint is to ensure that plant supply covers all demand points requirements

$$\sum_{i=3}^8 X_{1i} \geq \sum_{k=3}^5 \sum_{j=3, j \neq k}^8 X_{kj}$$

- The second constraint is to balance supply and demand at each demand points

$$X_{1k} - \sum_{i=3, i \neq k}^8 X_{ki} = D_k$$

- The third constraint confirms no demand requirements to be fulfilled directly from hub

$$X_{2k} = 0 \quad k=3, 4, 5, 6, 7, 8$$

- The fourth constraint ensures no demand requirements to be fulfilled from non-primary sites, i.e. Khamis Mushait, Buridah or Tabuk

$$X_{ij} = 0 \quad \text{for } i=6, 7, 8, i \neq j$$

- The last is non-negativity constraint

$$X_{ij} \geq 0$$

Strategy II IP Model

$$\begin{aligned} \text{Minimize } TC = & 1000 X_{12} + 480 X_{13} + 1080 X_{14} + 1400 X_{15} + 1040 X_{16} + 800 X_{17} + 720 X_{18} + \\ & 760 X_{34} + 1080 X_{35} + 520 X_{36} + 600 X_{37} + 840 X_{38} + 760 X_{43} + 360 X_{45} + 880 X_{46} + 280 X_{47} + \\ & 1040 X_{48} + 1080 X_{53} + 360 X_{54} + 1200 X_{56} + 600 X_{57} + 1400 X_{58} \end{aligned}$$

Subject to

$$X_{12} = X_{21} \leq 1500;$$

$$X_{13} - X_{34} - X_{35} - X_{36} - X_{37} - X_{38} \geq 750$$

$$X_{15} - X_{53} - X_{54} - X_{56} - X_{57} - X_{58} \geq 500$$

$$X_{14} - X_{43} - X_{45} - X_{46} - X_{47} - X_{48} \geq 500$$

$$X_{16} - X_{63} - X_{64} - X_{65} - X_{67} - X_{68} \geq 250$$

$$X_{18} - X_{83} - X_{84} - X_{85} - X_{86} - X_{87} \geq 250$$

$$X_{17} - X_{73} - X_{74} - X_{75} - X_{76} - X_{78} \geq 250$$

$$X_{23} = X_{24} = X_{25} = X_{26} = X_{27} = X_{28} = 0$$

$$X_{63} = X_{64} = X_{65} = X_{67} = X_{68} = 0$$

$$X_{73} = X_{74} = X_{75} = X_{76} = X_{78} = 0$$

$$X_{83} = X_{84} = X_{85} = X_{86} = X_{87} = 0$$

$$X_{ij} \geq 0$$

Using LINGO 18 to solve the above Model (1) results in following solution;

$$X_{12} = 1500 \quad X_{13} = 750, \quad X_{14} = 500, \quad X_{15} = 500, \quad X_{16} = 250, X_{17} = 250, \quad X_{18} = 250$$

Value of Objective Function = **SR 3,740,000**

Figure 4.4 below presents strategy II solution graphically

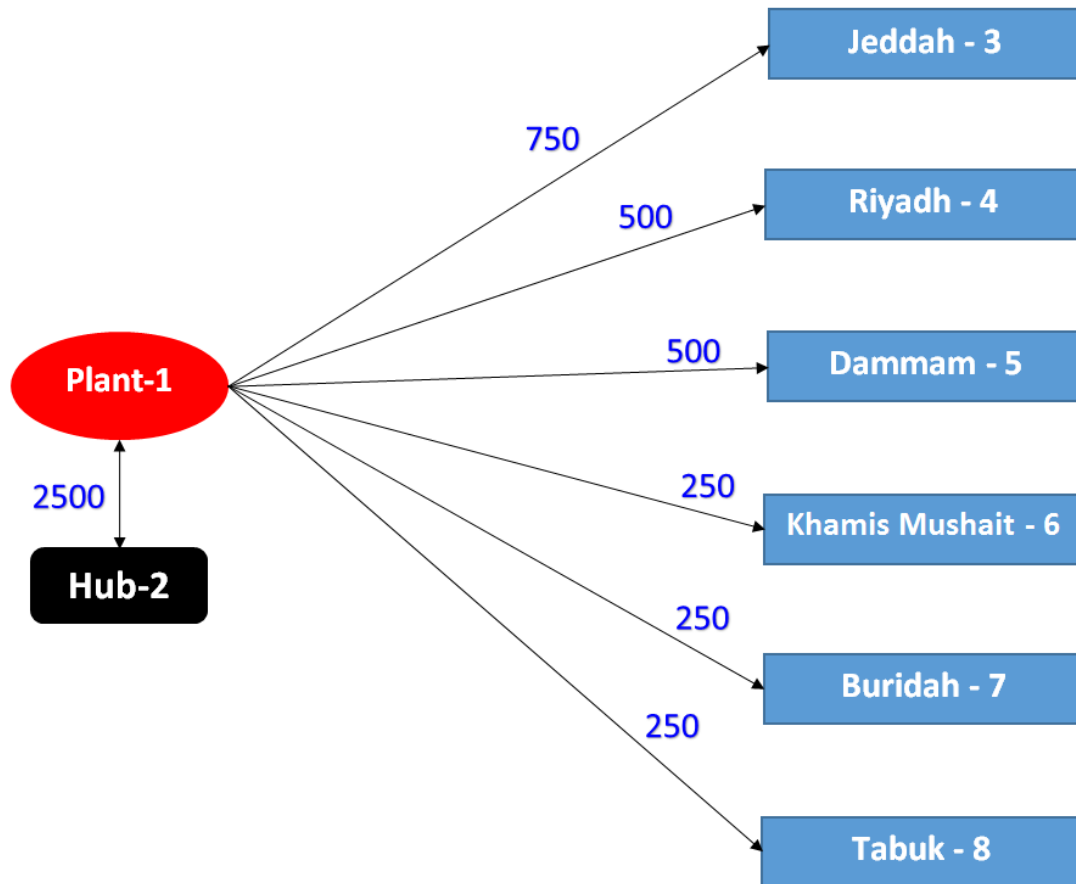


Figure 4.4: Graphical Presentation of Strategy II Solution

4.4 Strategy III: Hybrid Distribution Strategy

This is a mix strategy where Full-Truck-Loads (FTL) stock is to be sent directly from plant to various demand points and customers while partial-orders demand is to be sent to the distribution hub for preparation and delivery. This strategy allows better resources utilization and flexibility in both in-plant warehouse as well as the distribution hub in spite of high required level of planning and coordination. Figure 4.5 graphically shows this strategy.

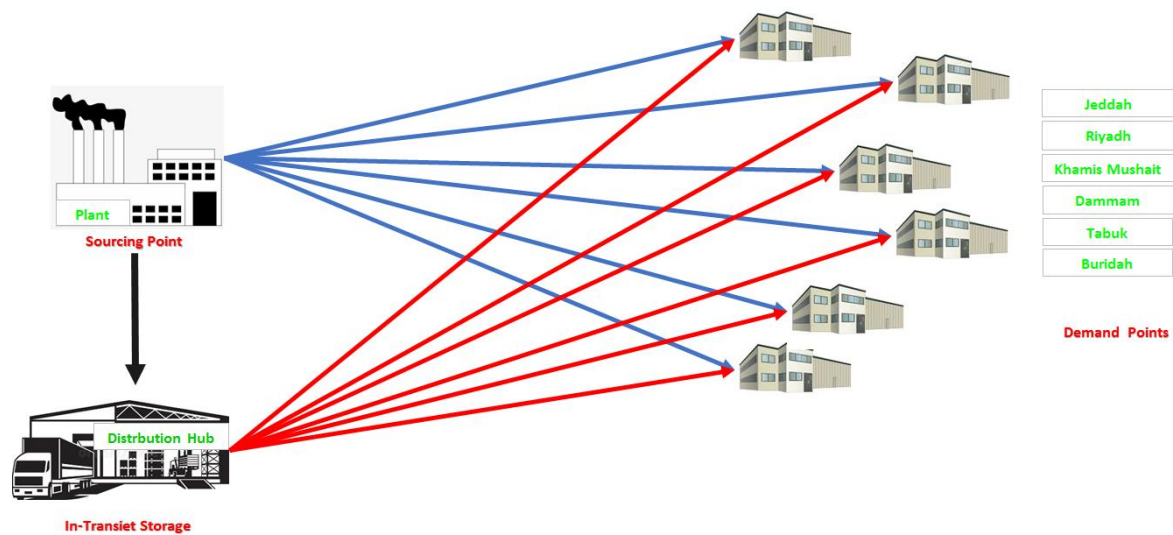


Figure 4.5: X-LUBE Distribution Hub Strategy III

Strategy III Assumptions are listed below;

- 1- Sales Volume (Demand) is classified into two categories; Direct Demand and Indirect Demand. Direct demand is sent directly from plant to customers with no need to be stored to distribution hub while indirect demand is sent to distribution hub to preparation, handling and dispatching
- 2- Direct Demand represents 35% of total demand while indirect deliveries contributes to 65% of total demand as shown in appendix 2 related analysis.
- 3- FTL's deliveries can be sent directly to certain demand points or customers within the same region; no cost differences are assumed.
- 4- FLT deliveries are either orders to same customer or loads with one SKU.
- 5- No shuttling back to from the distribution hub to plant
- 6- Direct deliveries represents 35% of total volume trips (X_M) of 2500
- 7- Indirect deliveries represents 65% of total volume trips (X_M) of 2500

$$X_D = \sum_{j=3}^8 X_{1j} = 35\% X_M = 875$$

$$X_I = \sum_{j=3}^8 X_{2j} = 65\% X_M = 1625$$

Objective Function

Minimize Total Monthly Transportation Cost (TC)

$$TC = C_{12}X_{12} + \sum_{j=3,4,5,6,7,8} C_{1j}X_{1j} + \sum_{j=3,4,5,6,7,8} C_{2j}X_{2j} + \sum_{k=3}^8 \sum_{j=3, j \neq k}^8 C_{kj}X_{kj}$$

Constraints

- The first constraint balances plant supply with direct volume fulfillment to demand points

$$\sum_{j=3}^8 X_{1j} = X_D$$

- Similarly, the second constraint balances hub supply with indirect volume fulfillment to demand points

$$\sum_{j=3}^8 X_{2j} = X_I$$

- The third constraint ensures that direct and indirect volume equals to total supply of 2500 trips

$$X_D + X_I = 2500$$

- The fourth constraint is for supply-demand balancing. At each demand point, there is stock received (input from both plant and hub) and stock transferred (out). The difference between stock received and stock transferred out has to be at least equal to the requirements of that demand point

$$X_{1k} + X_{2k} - \sum_{i=3, i \neq k}^8 X_{ki} \geq D_k$$

- The last is non-negativity constraint

$$X_{ij} \geq 0$$

Strategy III IP Model

$$\begin{aligned} \text{Minimize } TC = & 500 X_{12} + 480 X_{13} + 1080 X_{14} + 1040 X_{16} + 1400 X_{15} + 800 X_{17} + 720 X_{18} + \\ & 280 X_{23} + 880 X_{24} + 1200 X_{25} + 840 X_{26} + 600 X_{27} + 520 X_{28} + 760 X_{34} + 1080 X_{35} + 520 X_{36} + \\ & 600 X_{37} + 840 X_{38} + 760 X_{43} + 360 X_{45} + 880 X_{46} + 280 X_{47} + 1040 X_{48} + 1080 X_{53} + 360 X_{54} + \\ & 1200 X_{56} + 600 X_{57} + 1400 X_{58} + 520 X_{63} + 880 X_{64} + 1200 X_{65} + 1200 X_{67} + 1320 X_{68} + \\ & 680 X_{73} + 280 X_{74} + 600 X_{75} + 1200 X_{76} + 800 X_{78} + 840 X_{83} + 1040 X_{84} + 1400 X_{85} + \\ & 1320 X_{86} + 800 X_{87} \end{aligned}$$

Subject to

$$X_{13} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18} \leq 875$$

$$X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + X_{28} \leq 1625$$

$$X_{12} \geq 1625$$

$$X_{13} + X_{23} - X_{34} - X_{35} - X_{36} - X_{37} - X_{38} \geq 750$$

$$X_{14} + X_{24} - X_{43} - X_{45} - X_{46} - X_{47} - X_{48} \geq 500$$

$$X_{15} + X_{25} - X_{53} - X_{54} - X_{56} - X_{57} - X_{58} \geq 500$$

$$X_{16} + X_{26} - X_{63} - X_{64} - X_{65} - X_{67} - X_{68} \geq 250$$

$$X_{17} + X_{27} - X_{73} - X_{74} - X_{75} - X_{76} - X_{78} \geq 250$$

$$X_{18} + X_{28} - X_{83} - X_{84} - X_{85} - X_{86} - X_{87} \geq 250$$

$$X_{ij} \geq 0$$

Using LINGO 18 to solve the above Model (3) results in following solution;

$$X_{12} = 1625 \quad X_{13} = 375, \quad X_{15} = 500, \quad X_{23} = 375, \quad X_{26} = 250, X_{27} = 250, \quad X_{24} = 500, \quad X_{28} = 250$$

Value of Objective Function = **SR 2,727,500**

Figure 4.6 below presents strategy III solution graphically

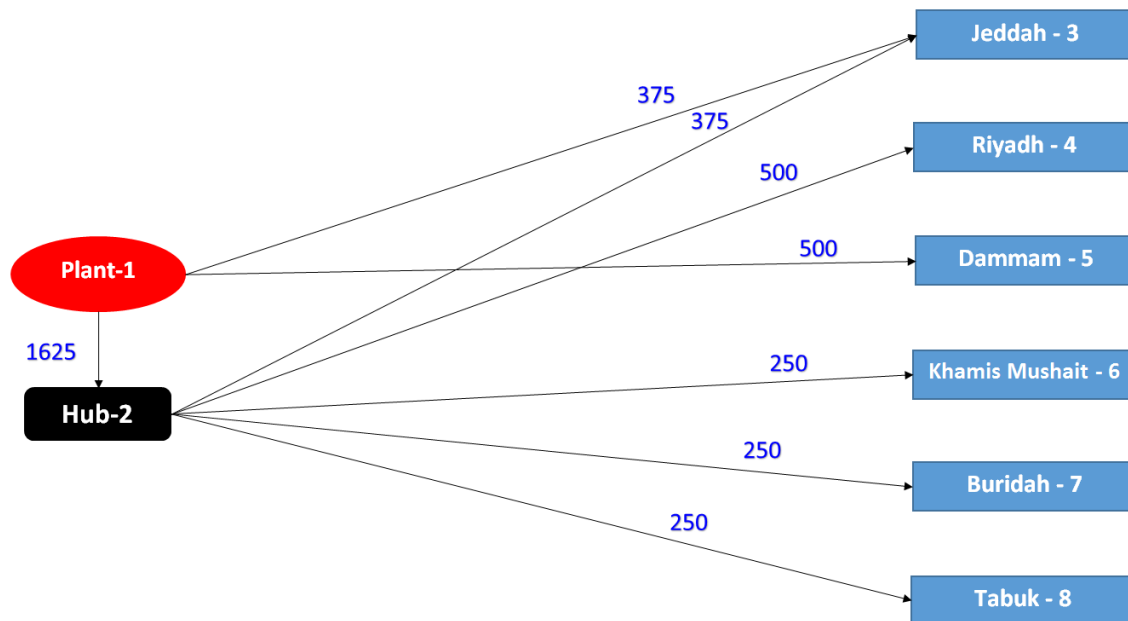


Figure 4.6: Graphical Presentation of Strategy III Solution

In brief; here is the summary of the three available operating strategy of X-LUBE company distribution hub;

- I. Strategy I: In-Transient Storage Hub; Total Annual Cost= **SR 2,990,000**
- II. Strategy 2: Exclusive Storage Hub; Total Annual Cost= **SR 3,740,000**
- III. Strategy 3: Hybrid Distribution Strategy; Total Annual Cost= **SR 2,727,500**

4.5 Sensitivity Analysis for Best Strategy

Since strategy III is proven to be the best strategy as per IP model solution outcome, a sensitivity analysis is conducted to check the effect of certain factors on the model objective function value. The factors to be examined are; direct and indirect deliveries, transportation cost and business volume. In section A, direct and indirect deliveries split impact on objective function value will be discussed whereas section B discusses transportation cost and business volume impact

A. Direct vs. Indirect Deliveries Impact on Optimal Solution

In this part, strategy III IP model is solved for different direct-indirect deliveries split combinations and results are shown in table 4.3;

Table 4.3: Strategy III Direct/Indirect Deliveries Sensitivity Analysis

Combination	Direct	Indirect	Total	Total Transportation Cost-SR
1	0	100%	100%	2,990,000
	0	2500	2500	
2	5%	95%	100%	2,952,500
	125	2375	2500	
3	10%	90%	100%	2,915,000
	250	2250	2500	
4	15%	85%	100%	2,877,500
	375	2125	2500	
5	20%	80%	100%	2,840,000
	500	2000	2500	
6	25%	75%	100%	2,802,500
	625	1875	2500	
7	30%	70%	100%	2,765,000
	750	1750	2500	
8	35%	65%	100%	2,727,500
	875	1625	2500	
9	40%	60%	100%	2,690,000
	1000	1500	2500	
10	45%	55%	100%	2,652,500
	1125	1375	2500	
11	50%	50%	100%	2,615,000
	1250	1250	2500	
12	55%	45%	100%	2,577,500
	1375	1125	2500	
13	60%	40%	100%	2,540,000
	1500	1000	2500	
14	65%	35%	100%	2,502,500
	1625	875	2500	
15	70%	30%	100%	2,465,000
	1750	750	2500	
16	75%	25%	100%	2,427,500
	1875	625	2500	
17	80%	20%	100%	2,390,000
	2000	500	2500	
18	85%	15%	100%	2,352,500
	2125	375	2500	
19	90%	10%	100%	2,315,000
	2250	250	2500	
20	100%	0%	100%	2,240,000
	2500	0	2500	

The following observations are noticed from resulted outcomes;

- 1- Objective function value (Total Transportation Cost) decreases with the increase of direct deliveries percentage. This goes in line with the fact that ex-hub shipments incur additional shuttling cost of SR 500 / trip for volume transferred from plant and shipped from there. This is clearly demonstrated in figure 4.7
- 2- Combination number 1 represents exactly strategy 1 where all shipments are managed from hub with total transportation cost of SR 2,990,000
- 3- If back transportation cost of 1500 round trips at SR 500/trip (**SR 1,500,000**) is added to combination number 20, it will result in strategy II where the total cost is SR 3,740,000

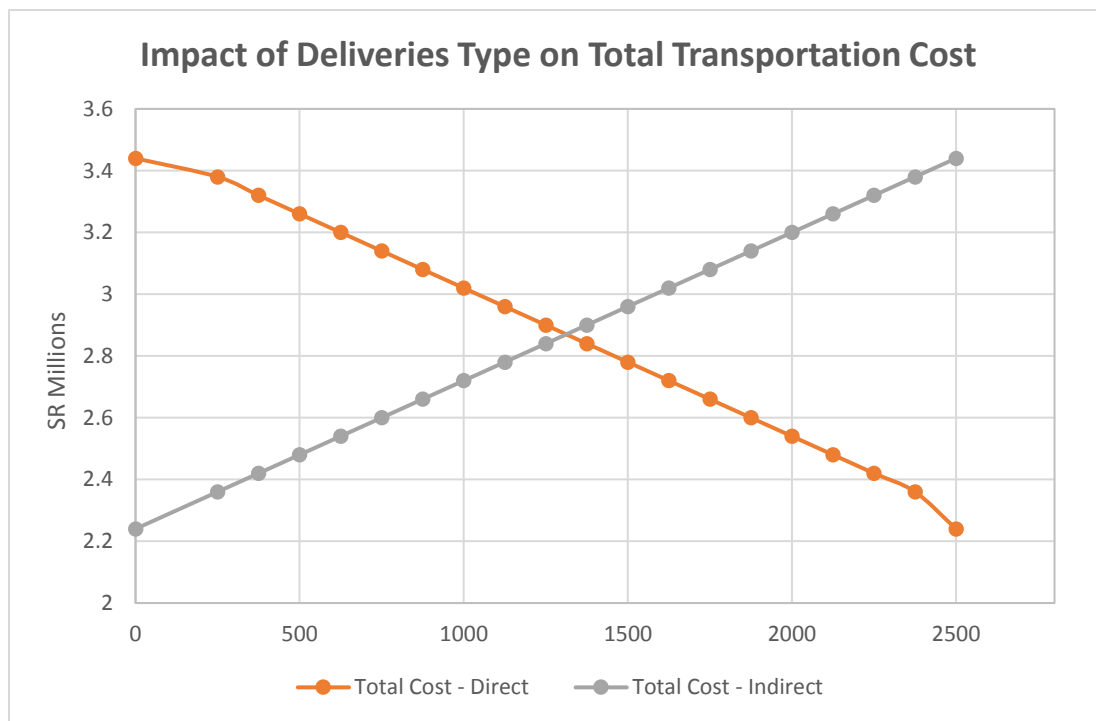


Figure 4.7: Direct/Indirect Impact on Total Transportation Cost

B. Impact of Demand and Transportation Cost Variation on relevant Decision Variable and Total Transportation Cost

There are two main factors that could vary and hence have impact on the optimal solution. These factors are;

I. The Total Demand Volume

II. The Transportation Cost (SR/KM)

The total demand is set with certain uncertainty range $\pm 15\%$ with a step change of 5% at a time; table 4.4 below shows the possible volume plans

Table 4.4: X-LUBE Annual Demand Tolerance

-15%	-10%	-5%	MLTR	+5%	+10%	+15%
42.5	45	47.5	50	52.5	55	57.5
Plan 1	Plan 2	Plan 3	Base	Plan 4	Plan 5	Plan 6

Also; the transportation unit cost is subjected to increase no higher than 20% with a step change of 10% at a time at maximum. The two possible values are SR 0.88/KM and SR 0.96/KM which represent 10% and 20% increase respectively.

In order to analyze the effect of changes in the two factors on optimal solution, different scenarios are considered with various combinations of demand variation and transportation unit cost, table 4.5 shows these scenarios.

Table 4.5: Possible Scenarios of Volume and Transportation Cost Changes

Volume-MLTR	42.5	45	47.5	50	52.5	55	57.5
SR 0.8/KM	1	4	7	10	13	16	19
SR 0.88/KM	2	5	8	11	14	17	20
SR 0.96/KM	3	6	9	12	15	18	21

For annual demand data; allocated number of trips will be calculated according the volume % of each demand point using the volume-trip conversion factor of 20 tons / trip for all various six plans similar to base plan in table 2.

Now, strategy III IP model is solved for all scenarios in table 15 and results are shown in table 4.6 below.

Table 4.6: Summary of Objective Function Values for Different Business Plan Scenarios

Volume - MLTR		-15%	-10%	-5%	Base	5%	10%	12%
		42.5	45	47.5	50	52.5	55	57.5
Rate - SR/KM	0.8	2,318,750	2,454,750	2,591,125	2,727,500	2,863,875	3,000,250	3,136,625
	0.88	2,466,275	2,611,350	2,756,425	2,901,500	3,046,575	3,191,650	3,336,725
	0.96	2,614,175	2,767,950	2,921,725	3,075,500	3,229,525	3,383,050	3,536,825

Below are the conclusions resulted from relevant data analysis,

- Increasing transportation unit cost by 10% results in raising the total transportation cost by 6% while 20% increase in transportation unit cost results in 13% rise in total transportation cost.
- Increasing the annual demand volume by 5% while keeping same transportation unit cost results in raising total transportation cost by 5%

- Similarly; decreasing the annual demand volume by 5% while keeping same transportation unit cost results in declining total transportation cost by an average of 5%
- Increasing both demand volume and transportation unit cost simultaneously will result in increasing total transportation cost by more than 10% overall
- Strategy III optimal solution demand shares will remain optimal under examined ranges; $\pm$ 15% of business volume and +20% of transportation cost. Table 4.7 below shows optimal solution demand shares

Table 4.7: Optimal Solution of Strategy III IP Model

Cost	Variable	Shipment Route	Optimal Solution
C_{12}	X_{12}	Plant to Hub	65% of Total Demand
C_{13}	X_{13}	Plant to Jeddah	50% of Jeddah Demand
C_{15}	X_{15}	Plant to Dammam	100% of Dammam Demand
C_{23}	X_{23}	Hub to Jeddah	50% of Jeddah Demand
C_{24}	X_{24}	Hub to Riyadh	100% of Riyadh Demand
C_{26}	X_{26}	Hub to Khamis Mushait	100% of Khamis Demand
C_{27}	X_{27}	Hub to Buridah	100% of Buridah Demand
C_{28}	X_{28}	Hub to Tabuk	100% of Tabuk Demand

- Overall; total transportation cost increases proportionally with volume increase for the same transportation cost (SR/KM). Figure 4.8 below shows the impact of increasing the volume for all three transportation cost values SR/KM 0.8, 0.88 and 0.96.

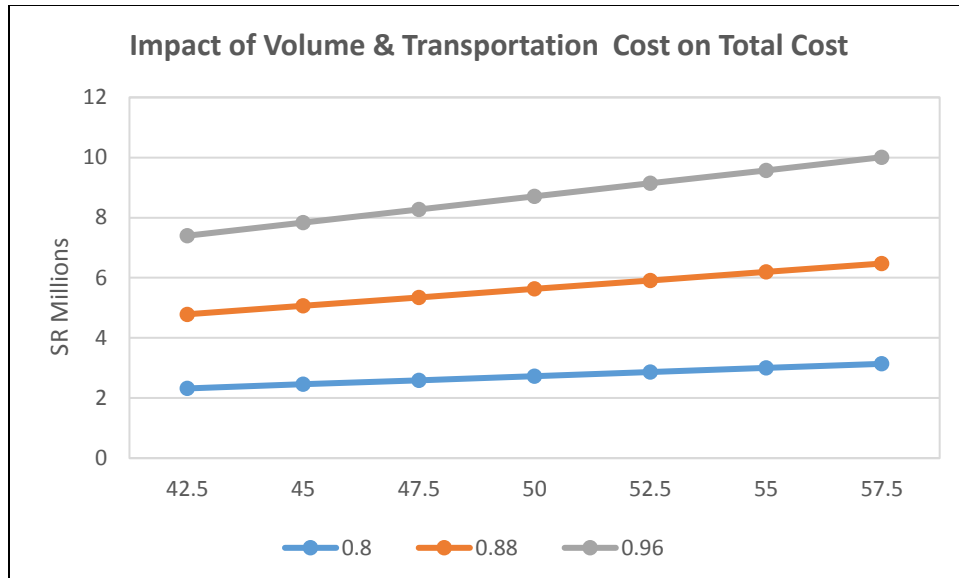


Figure 4.8: Impact of Volume & Transportation Cost on Total Cost

4.6 Logistics Services Outsourcing and Its Impact on Relevant Logistics Costs

Previous analysis assumes exactly same setup and operating cost of distribution hub in all examined strategies. In fact and in order to be more realistic in the approach, a 3rd party logistics (3PL) service contract can be initiated with agreed variable cost per pallet per month with monthly payment for exactly handled number of pallets. Below are some figures to be considered in determining the monthly cost of 3PL service contract;

- I. Monthly Inventory Turnover Rate = 2 → Average Holding Time = 0.5 month
- II. Average 3PL Handling Cost = SR 18 / Pallet / Month as per contract
- III. Inventory Holding Cost= (SR18/Month)× 0.5 Month × Total Annual Handled Pallets

Hence, Table 4.8 shows the total cost including both transportation and handling costs for each strategy. For strategies I and II, the handling cost is the same as same number of handled pallet is assumed which unlike the case of strategy III where direct and indirect deliveries are split.

Table 4.8: Total Supply Cost of the Three Distribution Hub Operating Strategies

Strategy	Transportation Cost	Annual Pallets	Total Handling Cost	Total Cost
I	SR 2,990,000	50,000 Pallets	SR 450,000	SR 3,440,000
II	SR 3,740,000	50,000 Pallets	SR 450,000	SR 4,190,000
III	SR 2,727,500	32,500 Pallets	SR 292,500	SR 3,020,000

In conclusion; strategy III is still shown as the best alternative to select and go for. Also; 3PL service contract with agreed variable cost is highly recommended versus setting up X-LUBE company own distribution hub due to the following facts.

- Elimination of distribution hub setup cost, given that the minimum space needed is 2000 square meters with an average setup cost of SR 1.2 million.
- 3PL service contract with variable cost provides high level of flexibility in case of sales volume drop/increase due to market conditions changes.

In summary; this study recommends that X-LUBE company to go for strategy 3 where direct deliveries to be managed via plant while indirect ones to be processed through variable-cost 3PL service contract. Additionally; it is proposed that X-LUBE company works to increase the portion of direct versus indirect deliveries as this results in reducing total cost given that handling cost will not exceed 18% of total transportation cost and 15% of total cost. Table 19 below shows both transportation and handling cost for strategy III for various direct-indirect split combinations.

Moreover, the impact of direct and indirect deliveries percentages on relevant logistics costs is shown in figures 6 and 7 respectively. Figure 4.9 below also summarize the impact of different types of deliveries on logistics costs.

Table 4.9: Total Cost of the Best Distribution Hub Operating Strategy III

Combination	Direct	Indirect	Total	Total Transportation Cost-SR	Total Handling Cost - SR	Total Cost - SR
1	0	100%	100%	2,990,000	450,000	3,440,000
	0	2500	2500			
2	5%	95%	100%	2,952,500	427,500	3,380,000
	125	2375	2500			
3	10%	90%	100%	2,915,000	405,000	3,320,000
	250	2250	2500			
4	15%	85%	100%	2,877,500	382,500	3,260,000
	375	2125	2500			
5	20%	80%	100%	2,840,000	360,000	3,200,000
	500	2000	2500			
6	25%	75%	100%	2,802,500	337,500	3,140,000
	625	1875	2500			
7	30%	70%	100%	2,765,000	315,000	3,080,000
	750	1750	2500			
8	35%	65%	100%	2,727,500	292,500	3,020,000
	875	1625	2500			
9	40%	60%	100%	2,690,000	270,000	2,960,000
	1000	1500	2500			
10	45%	55%	100%	2,652,500	247,500	2,900,000
	1125	1375	2500			
11	50%	50%	100%	2,615,000	225,000	2,840,000
	1250	1250	2500			
12	55%	45%	100%	2,577,500	202,500	2,780,000
	1375	1125	2500			
13	60%	40%	100%	2,540,000	180,000	2,720,000
	1500	1000	2500			
14	65%	35%	100%	2,502,500	157,500	2,660,000
	1625	875	2500			
15	70%	30%	100%	2,465,000	135,000	2,600,000
	1750	750	2500			
16	75%	25%	100%	2,427,500	112,500	2,540,000
	1875	625	2500			
17	80%	20%	100%	2,390,000	90,000	2,480,000
	2000	500	2500			
18	85%	15%	100%	2,352,500	67,500	2,420,000
	2125	375	2500			
19	90%	10%	100%	2,315,000	45,000	2,360,000
	2250	250	2500			
20	100%	0%	100%	2,240,000	0	2,240,000
	2500	0	2500			

Figure 4.9 shows the impact on increasing direct deliveries number on relevant costs; transportation, handling and total cost. Increasing number of direct deliveries decreases all relevant costs. In contrast, figure 4.10 demonstrates that indirect deliveries increase results in raising all relevant costs. The impact interdependency of direct and indirect deliveries on all types of costs is shown in figure 4.11

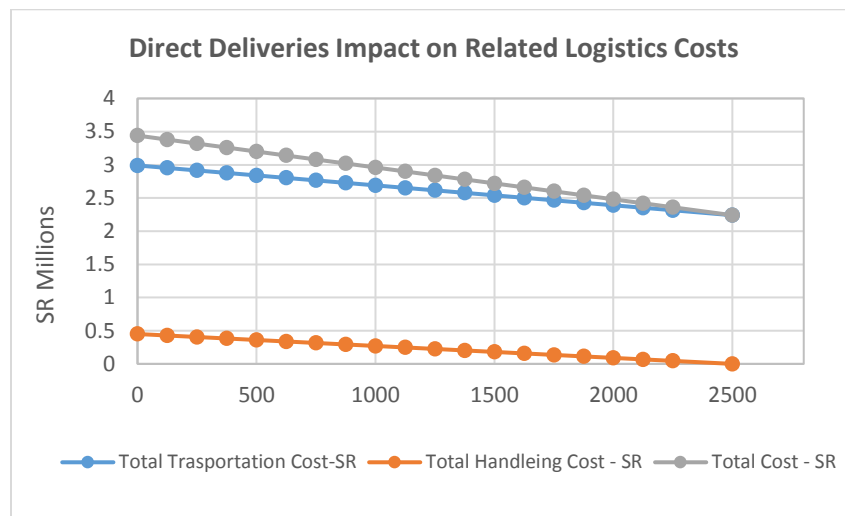


Figure 4.9: Direct Deliveries Impact on Logistics Costs

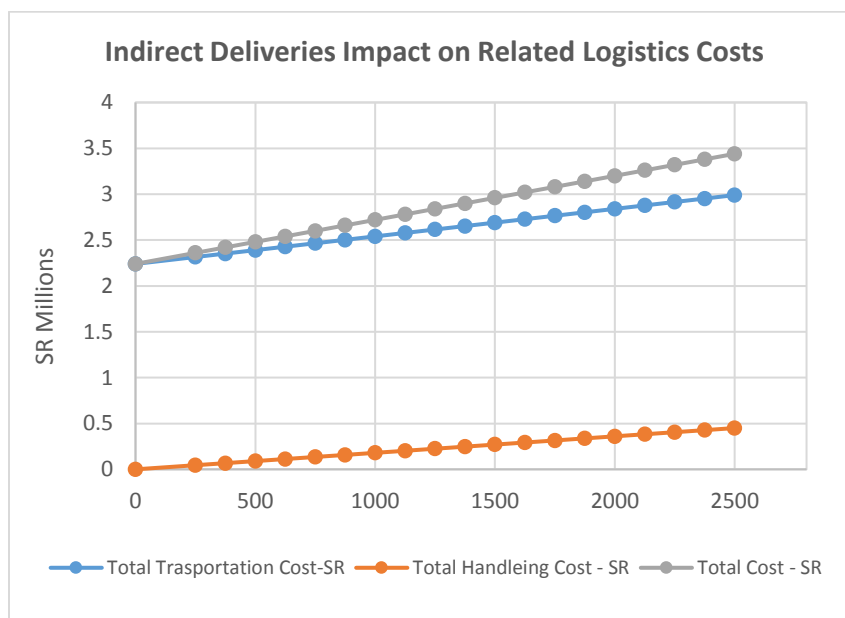


Figure 4.10: Indirect Deliveries Impact on Logistics Costs

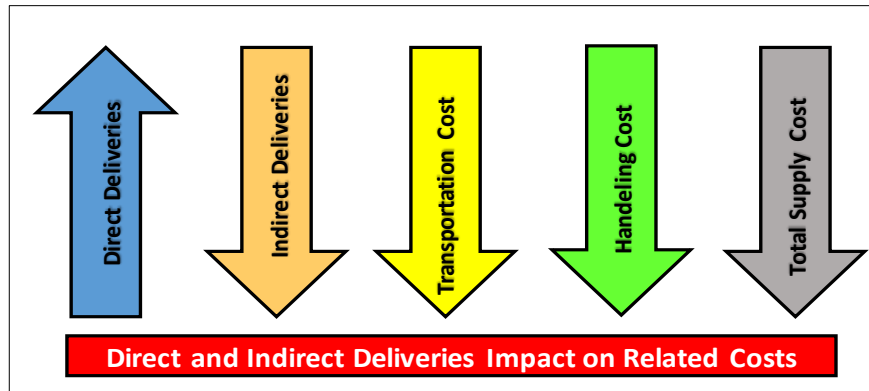


Figure 4.11: Deliveries/Costs Impact Interdependency

4.7 Conclusion: Distribution Hub Operating Strategy

For X-LUBE Distribution Hub Operating Strategy, it is obvious that hybrid distribution strategy is the most cost efficient option to for as operating strategy; Table 4.10 shows the summary of distribution hub operating strategy along with associated annual cost. This strategy enhances the best utilization of both plant and transportation resources as direct and full orders will be shipped directly from plant while partial orders will be prepared in the distribution hub then shipped to the demand points in X-LUBE network. Also; this strategy avoid unnecessarily products handling and transfers which helps in reducing extra touches to the products and hence better management of products' quality and conditions.

Table 4.10: Distribution Hub Operating Strategy Outcome

Strategy	Strategy Description	Annual Cost-SR
1	In-Transient Storage Hub	SR 2,990,000
2	Exclusive Storage Hub	SR 3,740,000
3	Hybrid Distribution Strategy	SR 2,727,500

From strategy III sensitivity analysis; it can be concluded that objective function value (total transportation cost) proportionally increases with direct deliveries raise and indirect deliveries decline. Also; objective function value will increase or decrease with almost the same percentage by which volume is increases or decreased with respect to the base plan of fifty million liters. Also; increasing the transportation cost by 10% results in raising the objective function value by 6% while it incurs 13% increase if transportation costs increases to 20%. Moreover; the percentage regional split of optimal solution remains the same within $\pm 15\%$ of volume along with 10% and 20% of transportation cost.

On top of above; it can be concluded that strategy III along with variable-cost 3PL contract is the best operating setup for X-LUBE company, aiming to reduce the portion of plant direct deliveries at the cost of distribution hub indirect deliveries as this will results in overall supply cost reduction as shown in section **4.5**

CHAPTER 5

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 5.1 will provide a thorough description of these alternatives with both advantages and disadvantages of each.

5.1 Transportation Alternatives for Distribution Network

For X-LUBE distribution network; there are two types of transportation setups; secondary and primary transportation. 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-warehouses 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.

1- Dedicated Contracted Fleet (DCF)

Description: 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

Advantages:

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

Disadvantages:

- 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.

2- Trip-Based Contracted Fleet (TBCF)

Description: 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 service

provider/transporter and served based on availability with a monthly service charges of fulfilled requests only.

Advantages:

- 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

Disadvantages:

- 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 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 certain time horizon with full control on 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 over 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

5.2 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;

- 1- **Criteria Definition and Data Gathering:** all related data are gathered along with criteria definition
- 2- **Criteria Weight Determination :** stakeholders input on the criteria weights, reflecting the importance of the criteria, to be collected and processed
- 3- **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
- 4- **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 covers 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.

- 1- **HSSE Compliance:** the degree by which HSSE related systems, guidelines and measures can be enforced, managed and monitored to specific option. Higher score of an option means that the company has better control on fleet HSSE for that option.
- 2- **Operating Cost:** this criterion is related to overall operating cost of the fleet based on selected option; including both fixed and variable cost elements such as purchasing cost,

fuel cost, manpower cost, maintenance cost ...etc. Higher score is to be assigned for lower cost option.

- 3- **Delivery Flexibility:** the degree of flexibility that the fleet has under specific option in meeting customer requirements and delivery schedule. This includes but not limited to flexible working hours, distribution routing change, possibility to change drivers ...etc.
- 4- **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
- 5- **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 specific option. These decisions could vary with reference to intended objectives; i.e. working hours, routes selection, fleet branding ...etc.
- 6- **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 agree with X-LUBE leadership management to use 5-points 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 on 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 best options even for cost and risk criteria.

5.3 Secondary Transportation Setup Selection using AHP

Analytic Hierarchy Process (AHP) is the most common approach in MCDM (Vaidya Omkarprasad and Kumar Sushil, 2006).due to its simplicity and effectiveness at the same time. In AHP, the criteria are ranked using the 5-points scale explained in 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. Highest score option will be selected as the best transportation mode under AHP model.

In AHP, all selection criteria will be ranked with respect to all available secondary transportation alternatives, results are shown in table 5.1

Table 5.1: 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 5.2

Table 5.2: 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.

5.4 Secondary Transportation Setup Selection using TOPSIS

TOPSIS is a common MCDM tool in logistics relevant decisions, i.e. (Kou-Huang Chen, 2014) used TOPSIS to come up with the best locations of logistics centers in airlines industry. In TPOSIS method, two artificial alternatives are hypothesized; ideal alternative is the one which has the best level for all attribute values and 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 negative ideal alternative.

In order to apply TOPSIS method, each criteria is assigned a number from 1 to 10 based on relative ranking among all alternatives. This is shown in the table 5.3.

Table 5.3: 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 5.4 are generated from the above table using formula

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

Table 5.4: TOPSIS Secondary Transportation Criteria Ranking Normalization

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

Next; the ideal and negative ideal solutions will be determined. Table 5.5 summarizes the outcome.

Table 5.5: 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 solution are calculated using below formulas.

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

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

The separation from ideal and negative ideal solutions is presented in tables 5.6 and 5.7 respectively.

Table 5.6: 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 5.7: 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 5.8 shows the relative closeness to the ideal solution C_i^* is calculated using the formula

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

Table 5.8: 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. However, since the difference between MBCF and TBCF is minor then it can concluded that TBCF is also a preferable alternative under TOPSIS.

5.5 Secondary Transportation Setup Selection using ELECTRE

ELECTRE is an outranking methods invented in 1965 in France by Bernard Roy & colleagues; it encourages more interaction between decision making and the model. ELECTRE consists of the following;

1. Develop the Decision Matrix with alternatives, criteria, scores and weights
2. Define and determine the concordance and discordance scores
3. Build the concordance and discordance matrices
4. Define the concordance and discordance dominance thresholds
5. Determine the Aggregate dominance matrix
6. Generate a preference ordering of the alternatives

ELECTRE is widely used in environmental and transportation problems as it, unlike other methods, allows alternative ordering even when options are not directly comparable (Rogers Martin and Bruen Michael, 2000)

To apply ELECTRE, same decision model matrix shown in table 5.9 will be used for further analysis.

Table 5.9: ELECTRE Decision Model Matrix

Alternatives	DCF	TBCF	MBCF	FOF	LTOF	%
HSSE Compliance	5	3	1	10	8	20%
Operations Cost	7	4	2	10	9	30%
Responsiveness	10	3	5	9	7	15%
Efficiency	6	9	8	4	5	15%
Control over Fleet	7	4	3	10	6	10%
Long Term Commitment 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:

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

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

Concordance and discordance matrices are shown in Table 5.10 and 5.11 respectively.

Table 5.10: ELECTRE Concordance Matrix

Criteria	DCF	TBCF	MBCF	FOF	LTOF	Sum
DCF	-	0.45	0.45	0.6	0.7	2.200
TBCF	0.55	-	0.55	0.55	0.55	1.650
MBCF	0.55	0.45	-	0.55	0.55	1.550
FOF	0.4	0.45	0.45	-	0.45	1.350
LTOF	0.3	0.45	0.45	0.55	-	1.450

Table 5.11: ELECTRE Discordance Matrix

Criteria	DCF	TBCF	MBCF	FOF	LTOF	Sum
DCF	-	1.000	0.750	0.556	0.375	2.681
TBCF	0.714	-	0.286	0.857	0.571	1.714
MBCF	0.714	0.250	-	1.000	0.778	2.028
FOF	0.400	1.000	1.000	-	0.250	2.250
LTOF	0.429	0.800	0.875	0.571	-	2.246

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) $= 1.1 \times 0.5 = 0.55$

Discordance Index $d^* = 90\%$ (average value) $= 0.9 \times 0.659 = 0.59$

Step2:

Concordance Index $c^* = 110\% (0.55) = 0.61$

Discordance Index $d^* = 90\% (0.59) = 0.53$

Starting with initial setup of $c^*=0.55$ and $d^*=0.59$ results in two dominating alternatives, DCF and TBCF while keep increasing 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 5.12

Table 5.12: ELECTRE Dominance Partial Outranking Matrix

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

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;

- 1) Difference between concordance and discordance summations ($\sum c - \sum d$)
- 2) Ratio of concordance and discordance summations ($\sum c / \sum d$)

Full ranking analysis is shown in Table 5.13.

Table 5.13: ELECTRE Dominance Full Outranking Outcome

Alternative	Concordance Sum	Discordance Sum	Ratio ($\sum c/\sum d$)	Rank 1	$\sum c - \sum d$	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.

5.6 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 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. PROMOTHEE has wide applications in different fields of industry such as supply chain, finance, environment and social studies due to its ability to solve sophisticated decision making problems (Majid Behzadian et al., 2010).

PROMETHEE has five main steps;

- I. Determine pairwise preferences for each two options under each criterion
- II. Calculate Multi-Criteria Pairwise Preference Matrix
- III. Calculate Outranking Flows
- IV. Calculate Net Outranking Flows
- V. Determine (partial) ranking of options

For the sake of simplicity, Criteria I (Usual) shown in figure 5.1 is going to be used for analysis as preference function with following formula;

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

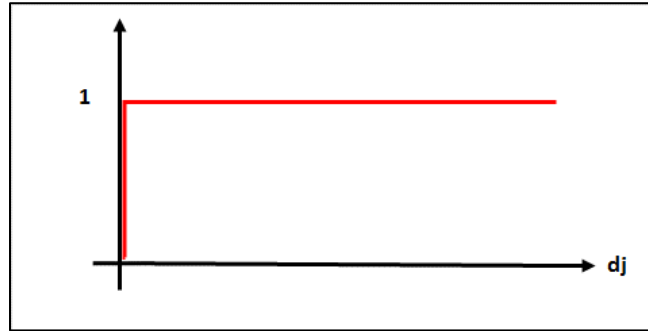


Figure 5.1 : I. Usual Preference Function

Table 5.14 below shows the scores of selection criteria under each available alternatives along with preference function used analysis

Table 5.14: 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 resulted outranking flows scores can be summarized in the below Table 5.15.

Table 5.15: 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:

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

Table 5.16 shows the partial ranking between all available alternatives using PROMETHEE approach.

Table 5.16: 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	None	DCF	TBCF
	MBCF			TBCF	
	LTOF			MBCF	MBCF
				LTOF	
Rank	2	4	5	1	3

Full ranking is determined via below methods;

Approach 1: Partial Ranking

- 1- Ranking all alternatives on decreasing order of ϕ^+
- 2- Ranking all alternatives on increasing order of ϕ^-
- 3- Partial Ranking: intersection of the two ranking
- 4- Unranked options are incomparable

Table 5.17: 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 $\phi(a) = \phi^+(a) - \phi^-(a)$

Table 5.18: PROMETHEE Full Ranking between Alternatives

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

5.7 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 resulted outcomes for this part are summarized below.

- AHP recommends either TBCF or DCF
- TOPSIS recommends either MBCF or TBCF
- 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 resulted 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.it can take 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 number of transporters as there is no minimum volume commitment is asked

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

In order to make TBCF option more effective and efficient setup. The service fees 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 6

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;

- 1- Introducing new X-LUBE distribution sites, similar to the existing ones
- 2- Initiating new 3PL distribution contracts with accredited service providers
- 3- 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 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.

6.1 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's are; Initial Investment, Operating Cost, Health, Safety, Security and Environmental (HSSE), Responsiveness and Efficiency.

Below list shows DM criteria and their definitions as stated by management team.

- 1- **Initial Investment:** Amount of money invested to set up infrastructure and other initial arrangement of an option (Buildings, IT, Security, Assets ...etc.)
- 2- **Operating Cost:** Ongoing and running expenses of an option which includes manpower, material cost, utility ...etc.
- 3- **HSSE:** Health, Safety, Security and Environment index associated with each setup which is an indicator of HSSE level.
- 4- **Responsiveness:** The degree by which a setup allows customer orders and requests satisfaction and fulfillment
- 5- **Efficiency:** The index by which setup utilizes available resources to maximize the overall returns of organization

The relative weights of DM criteria with respect to each other is show in the table 6.1 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 6.1

Table 6.1: 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 6.2 below.

Table 6.2: 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 6.3 shows the possible alternatives available for each city to be used for AHP MCDM model.

Table 6.3: Possible Alternatives of Each City

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

As Illustration; Figure 6.1 shows Makkah city AHP model.

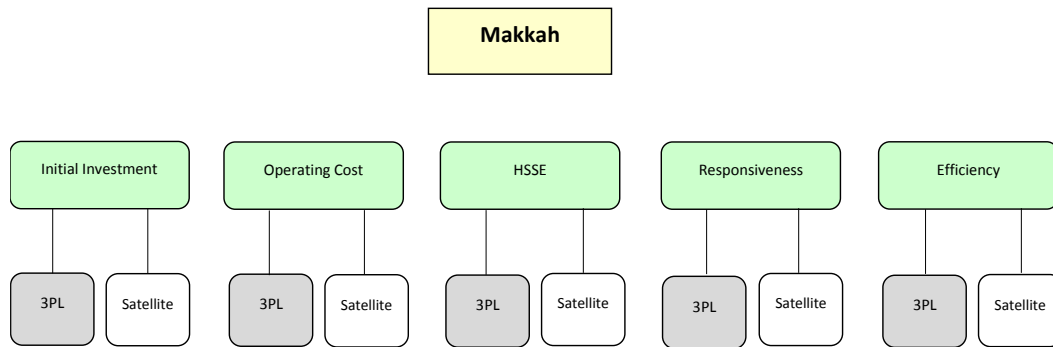


Figure 6.1: Makkah City AHP Model

6.2 Development and Process of the AHP Model

The relative weights of various alternatives (3PL, Satellite and CM) are determined within each criteria 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 weights 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 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 value of the CR no higher than 0.1.

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 3PL Setup

Relative scores among the cities under this option and specific criterion are shown in table 6.4 below.

Table 6.4: 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 consistency check;

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

Conclusion: Consistent data as $CR < 0.1$

Matrix 2: Operating Cost for 3PL Setup

Relative scores among the cities under this option and specific criterion are shown in table 6.5 below.

Table 6.5: 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 consistency check;

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

Conclusion: Consistent data as $CR < 0.1$

Matrix 3: HSSE for 3PL Setup

Relative scores among the cities under this option and specific criterion are shown in table 6.6 below.

Table 6.6: 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 consistency check;

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

Conclusion: Consistent data as $CR < 0.1$

Matrix 4: Responsiveness for 3PL Setup

Relative scores among the cities under this option and specific criterion are shown in table 6.7 below.

Table 6.7: 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 consistency check;

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

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 table 6.8 below.

Table 6.8: 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 consistency check;

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

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 in table 6.9 below.

Table 6.9: Initial Investment for Satellite 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 consistency check;

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

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 in table 6.10 below.

Table 6.10: 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 consistency check;

$$\lambda_{max} = 3.00, CI = 0.002, RI = 0.58 \text{ and } CR = 0.003$$

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 in table 6.11 below.

Table 6.11: 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 consistency check;

$$\lambda_{max} = 3.052, CI = 0.026, RI = 0.58 \text{ and } CR = 0.045$$

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 in table 6.12 below.

Table 6.12: 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 consistency check;

$$\lambda_{max} = 3.016, CI = 0.008, RI = 0.58 \text{ and } CR = 0.013$$

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 in table 6.13 below.

Table 6.13: 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;

$$\lambda_{max} = 3.014, CI = 0.020, RI = 0.58 \text{ and } CR = 0.035$$

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

Makkah					
	Initial Investment	Operating Cost	HSSE	Responsiveness	Efficiency
	7%	26%	35%	12%	10%
3PL	63%	53%	34%	36%	40%
Sattalite	42%	54%	24%	24%	50%
3PL	38.41%				
Sattalite	33.26%				

Figure 6.2: 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 6.14 below.

Table 6.14: 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

6.3 Distribution Network Expansion Plan Costing and Budgeting

Now, 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 6.15 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 6.15: 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 Clearance, 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 Available for Rental	500	Market Practice
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, Stationary, 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 6.16 below.

Table 6.16: 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	

6.4 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 60,00

The case is demonstrated in figure 6.3

Payoff (Lease-Success)

$$= (\text{SR}30,000 / \text{Site} \times 24 \text{ Months}) - (\text{SR}12,000 \times 24 \text{ Months} \times 2 \text{ Vehicles}) = \text{SR}144,000$$

Payoff (Lease-Fail)

$$= (\text{SR} - 50,000 / \text{Vehicle} \times 2 \text{ Vehicles}) = \text{SR} - 100,000$$

Payoff (Purchase-Success)

$$\begin{aligned} &= (\text{SR}30,000 / \text{Site} \times 24 \text{ Months}) - [(\text{SR}140,000 \times 2 \text{ Vehicles}) + (5000 \times 24 \text{ Months} \times 2 \text{ Vehicles})] \\ &= \text{SR}200,000 \end{aligned}$$

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

$$= (\text{SR}140,000 / \text{Vehicle} \times 2 \text{ Vehicles}) - (\text{SR}50,000 / \text{Vehicle} \times 2 \text{ Vehicles}) = \text{SR} -180,000$$

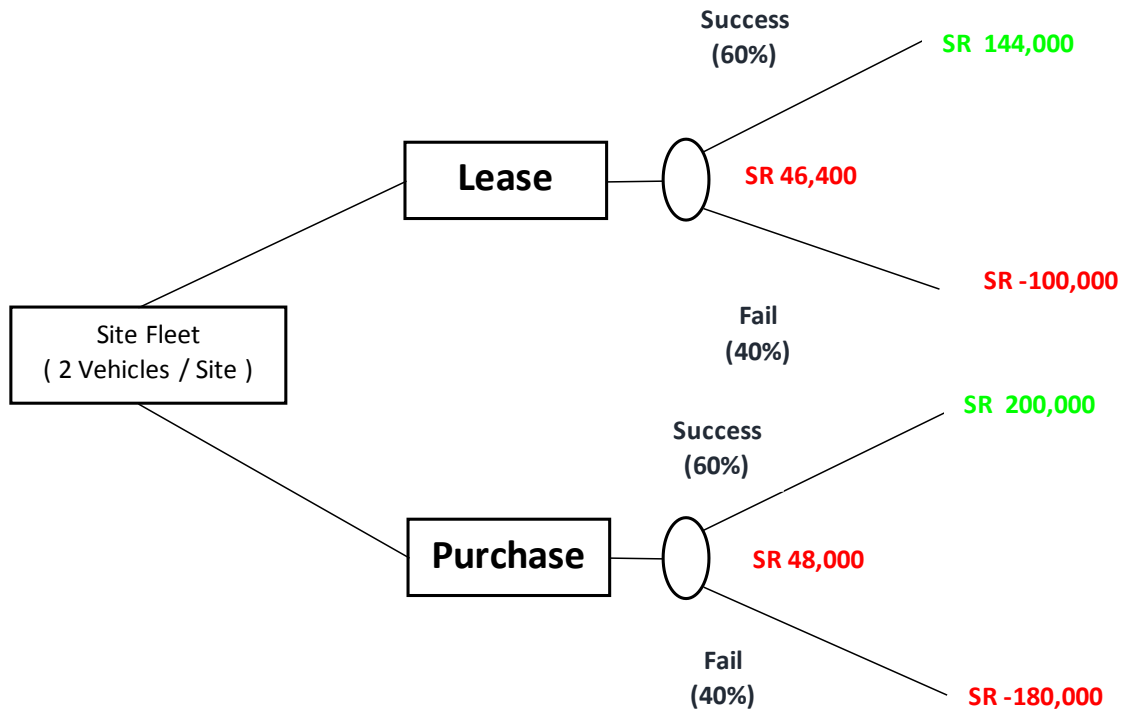


Figure 6.3: Vehicle Sourcing Decision Tree

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

Expected Return (Lease) $= 0.6(144,000) - 0.4(100,000) = \text{SR } 46,400$

Expected Return (Purchase) $= 0.6(200,000) - 0.4(180,000) = \text{SR } 48,000$

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

6.5 Conclusion: Distribution Network Expansion and Vehicle Sourcing

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

- 1- 3PL alternative is recommended for Makkah and Al-Ahsa while CM is the best for Baha and Qurayyat.
- 2- 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 sated in the below points;

- 1- Data consistency does not necessarily imply its accuracy or precision. This resulted outcome is a clear example of this.
- 2- 3PL option is verified to be the least cost alternative as it depends mainly on variable cost per case with high level of flexibility to amend terms and conditions without major investment
- 3- Vehicle “Purchase” option has slight 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 “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 7

CONCLUSION AND RECOMMENDATION

7.1 Results Summary

In this chapter; 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; warehousing, distribution and transportation. Below are the main recommendations and decisions related to this study,

- 1- For distribution hub operating strategy, it is recommended to go for hybrid strategy with total annual cost of SR 2,665,000
- 2- TBCF is the best transportation setup for secondary distribution network
- 3- For distribution network expansion, Makkah and Al-Ahsa would go for 3PL alternative while CM would be the best alternative for Baha and Qurayyat with total annual cost of SR 160,000.

Below are some relevant facts and highlights for consideration;

- For distribution hub operation; hybrid strategy along 3PL variable-cost contracting would be the best option with X-LUBE objectives; see section 4.7.
- 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 6.5.

7.2 Thesis Contribution

This thesis contributes to knowledge field in the following points:

- Demonstrates the effective use of IP models in logistics and supply chain related decisions.
- Shows how MCDM can be deployed and utilized in the field of supply chain network design.
- Introduces a new thorough case study in the oil and gas field

7.3 Future Work

The research work can be extended via;

- Extending the distribution hub operating IP model to include the storage and warehouse management approach.
- Utilizing the design of experiments approach to come up with same decisions and comparisons
- Applying vehicle routing concept to sales vehicles operation to optimize the local and regional distribution.
- Considering the use of double deck trailers in transportation process optimization using IP model.

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Appendices

Appendix 1: Distribution Transportation Costs

Appendix 2: Demand and Supply Data

Appendix 1

Distribution Transportation Costs

Various costs are incurred in transportation operation which includes manpower, registration fuel, maintenance, insurance and others. The details of these costs and their contribution to transportation unit mileage will be shown and explained below. Table A.1 shows the details of insurance cost of transportation fleet. Similarly; Table A.2 shows registration and license costs details based on eight years of service.

Table A.1: Insurance Cost Details Calculation

Brand	Model (5 Years Old)	Market Value		Total	Insurance %	Insurance Amount-SR
		Head	Flat Bed			
Mercedes Benz	2012-2016	270,000	85,000	355,000	3%	10,650
Man	2012-2017	230,000	85,000	315,000	3%	9,450
Volvo	2012-2018	250,000	85,000	335,000	3%	10,050
Vehicle Insurance Cost				Total Annual Cost		10,050
				Monthly Average Cost		838
				Cost / KM		SR 0.056

Table A.2: Registration and License Cost Details Calculation

Year of Service	1	2	3	4	5	6	7	8
Vehicle Registration Fees	4,500	0	0	600	0	0	600	0
Annual Inspection Program	158	158	158	158	158	158	158	158
Operating Card	100	100	100	100	100	100	100	100
GBS	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700
Driver's License Fees	200	0	200	0	200	0	200	0
Total	6,658	1,958	2,158	2,258	2,158	1,958	2,758	1,958
Registration and License Fees					Annual Average			22,200
					Monthly Average			2,775
					Cost / KM			0.185

Table A.3: Total Transportation Cost Details Calculation

Transportation Cost Details Calculator		
Fleet & Operations Details		
Vehicle Utilization	km/year	180,000
Sump Capacity (Liters per Oil Change Service)	liters	32
Vehicle Mileage (No. of KM driven in 1 liter fuel)	km	2.50
Vehicle Downtime (per oil change service)	hours	3.00
Filter Set Price (one piece to be replaced per Oil Change Service)	SAR	82.00
Diesel Price (per liter)	SAR	0.47
Vehicle Downtime Cost per Oil Service (lost production time)	SAR	60.0
Key Elements Definitions		
Oil Price / Liter	SAR	7.00
Top up Quantity (during one oil service)	liters	2.00
Oil Change Interval	km	10,000
No. Of Oil Changes/year	number	18.00
Oil Annual Consumption	liters	612.0
Other Oil Change Related Cost (Down Time Cost + Filter Cost)	SAR	262.0
Consumables Cost Figures (Fuel and Oil)	SAR	Figures
Annual Oil Cost (=Annual Consumption × Oil Price/Liter)	SAR	9,000
Average Oil Cost Per Km (=Annual Oil Cost/Truck Annual Mileage)	SAR	0.05
Average Fuel Cost Per Km (=Diesel Cost/Liter/Vehicle Mileage/Fuel Liter)	SAR	0.188
Total Operating Cost Per Km (Fuel and Oil)	SAR	0.238
Operational Cost Figures	SAR	Figures
Driver Salary	SAR	5,000
Regular Maintenance	SAR	2,500
Insurance	SAR	838
Registration & License Fees	SAR	231
Total Monthly Cost	SAR	8,569
Total Annual Cost	SAR	102,825
Total Annual Mileage	SAR	180,000
Number of Monthly KM	SAR	15,000
Operational Cost Per Unit KM	SAR	0.57
Total Cost per Unit Distance - KM	SAR	0.8

In addition to the above, the transportation costs between all possible combinations / combinations has to be calculated with reference to Total Cost per Distance Unitfigure. The distances between all supply and demand cities are shown in the below table A.4;

Table A.4: Distances between Supply and Demand Cities in KSA Network in KM

Cities	Dammam	Riyadh	Jeddah	Yanbu	Tabuk	Buridah	Khamis
Dammam	X	450	1350	1500	1750	750	1500
Riyadh	450	X	950	1100	1300	350	1100
Jeddah	1350	950	X	350	1050	750	650
Yanbu	1500	1100	350	X	650	1000	1050
Tabuk	1750	1300	1050	650	X	1000	1650
Buridah	750	350	850	750	1000	X	1500
Khamis	1500	1100	650	1050	1650	1500	X

Using the “Total Cost per Distance Unit” to convert the above distances to their equivalent transportation costs will result in the below table A.5

Table A.5: Transportation Costs between Supply and Demand Cities in KSA Network in SR

Cities	Dammam	Riyadh	Jeddah	Yanbu	Tabuk	Buridah	Khamis
Dammam	X	360	1080	1200	1400	600	1200
Riyadh	360	X	760	880	1040	280	880
Jeddah	1080	760	X	280	840	680	520
Yanbu	1200	880	280	X	520	800	840
Tabuk	1400	1040	840	520	X	800	1320
Buridah	600	280	680	600	800	X	1200
Khamis	1200	880	520	840	1320	1200	X

Appendix 2

Demand and Supply Data

One of the model parameters is the percentage of direct customers' deliveries out of total demand volume to be used to formulate the related LP model of DC operations. Below table A.6 clearly shows the parentage of plant direct deliveries with respect to total volume.

Table A.6: X-LUBE Network Direct Split vs. Total Volume

Months	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20
Direct Volume	1,276,725	1,276,725	1,278,764	1,453,418	1,453,418	1,455,456	1,512,305
Total Volume	3,143,853	3,840,589	4,269,261	4,104,023	4,032,467	4,111,182	4,334,060
Direct Deliveries %	41%	33%	30%	35%	36%	35%	35%

Months	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Total	Average
Direct Volume	1,512,305	1,515,199	1,571,178	1,571,178	1,573,232	17,449,902	1,454,159
Total Volume	4,211,283	4,500,371	4,464,214	4,417,026	4,591,979	50,020,308	4,168,359
Direct Deliveries %	36%	34%	35%	36%	34%	35%	35%

Transportation costs between plant/demand points are also updated in accordance. On top of original transportation unit cost data, the two tables A.7 and A.8 below show the data of unit costs of SR/KM 0.88 and 0.96.

Table A.7: Transportation Data of SR/KM 0.88 Rate

Cij	1	2	3	4	5	6	7	8
1		500	508	1168	1520	1124	860	772
2	500		308	968	1320	924	660	572
3	508	308		836	1188	572	748	924
4	1168	968	836		396	968	308	1144
5	1520	1320	1188	396		1320	660	1540
6	1124	924	572	968	1320		1320	1452
7	860	660	748	308	660	1320		880
8	772	572	924	1144	1540	1452	880	

Table A.8: Transportation Data of SR/KM 0.96 Rate

Cij	1	2	3	4	5	6	7	8
1		500	536	1256	1640	1208	920	824
2	500		336	1056	1440	1008	720	624
3	536	336		912	1296	624	816	1008
4	1256	1056	912		432	1056	336	1248
5	1640	1440	1296	432		1440	720	1680
6	1208	1008	624	1056	1440		1440	1584
7	920	720	816	336	720	1440		960
8	824	624	1008	1248	1680	1584	960	

For annual demand data; table A.9 below show the volume plans in addition to associated number of trips as input to the IP model.

Table A.9: Various Supply-Demand Plans Scenario with $\pm 15\%$ Tolerance

Base	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	50	15	750
		Riyadh	20%		10	500
		Dammam	20%		10	500
		Buridah	10%		5	250
		Khamis	10%		5	250
		Tabuk	10%		5	250
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	50	50	2500

Plan 1	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	42.5	12.75	637.5
		Riyadh	20%		8.5	425.0
		Dammam	20%		8.5	425.0
		Buridah	10%		4.25	212.5
		Khamis	10%		4.25	212.5
		Tabuk	10%		4.25	212.5
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	42.5	42.5	2125

Plan 2	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	45	13.5	675.0
		Riyadh	20%		9	450.0
		Dammam	20%		9	450.0
		Buridah	10%		4.5	225.0
		Khamis	10%		4.5	225.0
		Tabuk	10%		4.5	225.0
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	45	45	2250

Plan 3	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	47.5	14.25	712.5
		Riyadh	20%		9.5	475.0
		Dammam	20%		9.5	475.0
		Buridah	10%		4.75	237.5
		Khamis	10%		4.75	237.5
		Tabuk	10%		4.75	237.5
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	47.5	47.5	2375.0

Plan 4	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	52.5	15.75	787.5
		Riyadh	20%		10.5	525.0
		Dammam	20%		10.5	525.0
		Buridah	10%		5.25	262.5
		Khamis	10%		5.25	262.5
		Tabuk	10%		5.25	262.5
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	52.5	52.5	2625.0

Plan 5	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	55	16.5	825.0
		Riyadh	20%		11	550.0
		Dammam	20%		11	550.0
		Buridah	10%		5.5	275.0
		Khamis	10%		5.5	275.0
		Tabuk	10%		5.5	275.0
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	55	55	2750.0

Plan 6	Demand	Cities	Volume%	Total Volume - MLTR	Allocated Volume- MLTR	No. of Truck Loads
		Jeddah	30%	57.5	17.25	862.5
		Riyadh	20%		11.5	575.0
		Dammam	20%		11.5	575.0
		Buridah	10%		5.75	287.5
		Khamis	10%		5.75	287.5
		Tabuk	10%		5.75	287.5
	Supply	Plant	Volume%	Total Volume- Liters	Allocated Volume- Liters	No. of Truck Loads
		Yanbu	100%	57.5	57.5	2875.0

Now; strategy III IP model is solved for all possible scenarios shown in table; results are in the table A.10 below;

Table A.10: Decision Variables Objective Function Values for Different Business Plan Scenarios

Cost	Value	Variable	S1	S4	S7	S10	S13	S16	S19
C_{12}	500	X_{12}	1625	1706.25	1787.5	1868.75	1543.75	1462	1381.25
C_{13}	480	X_{13}	375	393.75	412.5	431.25	356.25	337.5	318.5
C_{14}	1080	X_{14}	-	-	-	-	-	-	-
C_{15}	1400	X_{15}	500	525	550	575	475	450	425
C_{16}	1040	X_{16}	-	-	-	-	-	-	-
C_{17}	800	X_{17}	-	-	-	-	-	-	-
C_{18}	720	X_{18}	-	-	-	-	-	-	-
C_{23}	280	X_{23}	375	393.75	412.5	431.25	356.25	337.5	319
C_{24}	880	X_{24}	500	525	550	575	475	450	425
C_{25}	1200	X_{25}	-	-	-	-	-	-	-
C_{26}	840	X_{26}	250	262.5	275	287.5	237.5	225	212.5
C_{27}	600	X_{27}	250	262.5	275	287.5	237.5	225	212.5
C_{28}	520	X_{28}	250	262.5	275	287.5	237.5	225	212.5
Objective Function – SR			2,727,500	2,863,875	3,000,250	3,136,625	2,591,125	2,454,750	2,318,750

Cost	Value	Variable	S2	S5	S8	S11	S14	S17	S20
C_{12}	500	X_{12}	1625	1706.25	1787.5	1868.75	1543.75	1462	1381.25
C_{13}	508	X_{13}	375	393.75	412.5	431.25	356.25	337.5	318.5
C_{14}	1168	X_{14}	-	-	-	-	-	-	-
C_{15}	1520	X_{15}	500	525	550	575	475	450	425
C_{16}	1124	X_{16}	-	-	-	-	-	-	-
C_{17}	860	X_{17}	-	-	-	-	-	-	-
C_{18}	772	X_{18}	-	-	-	-	-	-	-
C_{23}	308	X_{23}	375	393.75	412.5	431.25	356.25	337.5	319
C_{24}	968	X_{24}	500	525	550	575	475	450	425
C_{25}	1320	X_{25}	-	-	-	-	-	-	-
C_{26}	924	X_{26}	250	262.5	275	287.5	237.5	225	212.5
C_{27}	660	X_{27}	250	262.5	275	287.5	237.5	225	212.5
C_{28}	572	X_{28}	250	262.5	275	287.5	237.5	225	212.5
Objective Function – SR			2,901,500	3,046,575	3,191,650	3,336,725	2,756,425	2,611,350	2,466,275

Cost	Value	Variable	S3	S6	S9	S12	S15	S18	S21
C_{12}	500	X_{12}	1625	1706.25	1787.5	1868.75	1543.75	1462	1381.25
C_{13}	536	X_{13}	375	393.75	412.5	431.25	356.25	337.5	318.5
C_{14}	1256	X_{14}	-	-	-	-	-	-	-
C_{15}	1640	X_{15}	500	525	550	575	475	450	425
C_{16}	1208	X_{16}	-	-	-	-	-	-	-
C_{17}	920	X_{17}	-	-	-	-	-	-	-
C_{18}	824	X_{18}	-	-	-	-	-	-	-
C_{23}	336	X_{23}	375	393.75	412.5	431.25	356.25	337.5	319
C_{24}	1056	X_{24}	500	525	550	575	475	450	425
C_{25}	1440	X_{25}	-	-	-	-	-	-	-
C_{26}	1008	X_{26}	250	262.5	275	287.5	237.5	225	212.5
C_{27}	720	X_{27}	250	262.5	275	287.5	237.5	225	212.5
C_{28}	624	X_{28}	250	262.5	275	287.5	237.5	225	212.5
Objective Function – SR			3,075,500	3,229,525	3,383,050	3,536,825	2,921,725	2,767,950	2,614,175

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 - Logistics continuous improvement projects in both FMCG and lubricants industry with total savings of more than \$ 9,000,000 annually
 - Supply chain network redesign for better resources synchronization, inventory reduction and productivity improvement