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DETERMINATION OF DISTRIBUTION HUB OPERATING STRATEGY AS IP MODEL
A CASE STUDY IN OIL AND GAS INDUSTRY

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ABSTRACT
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 paper, 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 this study; an integer linear programing (ILP) optimization model is built and solved to determine the most cost efficient operating strategy for X-LUBE company distribution hub. Also, relevant sensitivity analysis is conducted on resulted optimal strategy.

KEYWORDS: *Integer Programing (IP), Distribution Network Design (DND), Operations Research (OR), Distribution Strategy, Sensitivity Analysis , 3rd Party Logistics (3PL) Outsourcing*

1. INTRODUCTION & BACKGROUND

Saudi Arabia is one of the most active and promising lubricants markets worldwide [1] and hence there are many lubricants providers available, one of these is X-LUBE. It is an international oil and gas company that supplies wide range of industrial and automotive lubricants for various sectors across kingdom of Saudi Arabia. X-LUBE contributes to almost 10% of Saudi Arabia annual business volume, which is equivalent to fifty (50) million liters.

X-LUBE sells its products in two main sectors; B2C (Business-to-Customers) and B2B (Business-to-Business). In Saudi Arabia, there are six sales and storage sites where X-LUBE is using to distribute its products across all Saudi Arabia geographical regions. These six sites are 3, 4,5,6,7 and 8. All are being supplied from a plant located in the industrial city Yanbu (next to local base oil factory) [2]. X-LUBE has decided to operate a distribution HUB in Yanbu also next to the plant.

This distribution hub has three main operating strategies;
Strategy I: use of hub as exclusive in-transient storage: all plant stock to be sent to hub and shipped to X-LUBE sites from that hub; no direct shipment from plant.
Strategy II: manage direct shipment to X-LUBE 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 paper is trying to address the following research questions for X-LUBE,
1. What is the best operating strategy of the distribution HUB?
2. How X-LUBE company distribution network must 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 network?

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 ±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, [5]
6. Transportation cost between any two demand points is the same regardless of direction

$$C_{ij} = C_{ji}.$$

2. RELEVANT 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 relevant figures and calculations, 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 umber 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 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

Table 1 shows the “Volume-Delivery Conversion Factor” calculation approach.

Total X-LUBE supply and demand volume data (in Million Liters-MLTR) along with regional allocated demand data can be summarized in table 2. The expected number of trips is also determined using "Volume-Delivery Conversion Factor", which is 20 tons / trip.

Table 2: Supply and Demand Volume and Delivery Trips Split

	Cities	Volume %	Total Annual Volume –MLTR	Allocated Volume-MLTR	No. of Truck Loads
Demand	3	30%	50	15	D_3=750
	4	20%		10	D_4=500
	5	20%		10	D_5=500
	6	10%		5	D_6=250
	7	10%		5	D_7=250
	8	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

3. METHODOLOGY APPROACH

In spite of several existing optimization methods for such problem like simulation **[3]**, Principal Components Analysis (PCA) **[6]** and Improved Particle Swarm Optimization Algorithm **[9]**, Integer Programing (IP) is a the most common approach in DND problems **[4]**, each 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.

3.1 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 (Supply Node), 2=Hub (Supply Node),
3=Demand Node No. 3, 4=Demand Node No. 4, 5=Demand Node No. 5,
6=Demand Node No. 6, 7= Demand Node No. 7, 8=Demand Node No. 8

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 3 below shows the input figures to be used in the model formulation.

Table 3: 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 2

- 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

$D_3 = 750$, $D_4 = 500$, $D_5 = 500$, $D_6 = 250$, $D_7 = 250$, $D_8 = 250$
where D_i is the demand at demand node *i* (measured by load trips)

3.2 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 by suitable if volume is not enough to justify the high associated operating cost. Figure 1 below shows this strategy graphically.

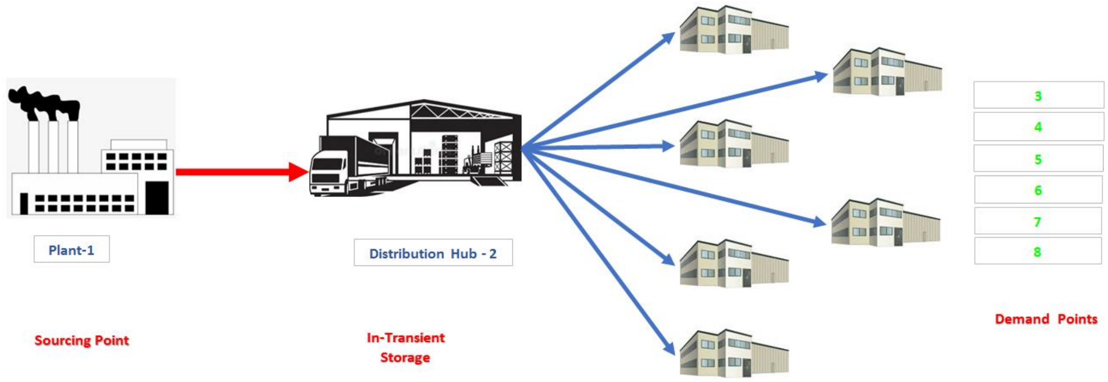

Figure 1: X-LUBE Distribution Hub Strategy I

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.

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

- 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

Minimize $TC = 500\, X_{12} + 280\, X_{23} + 880\, X_{24} + 1200\, X_{25} + 840\, X_{26} + 600\, X_{27} + 520\, X_{28} + 760\, X_{34} + 1080\, X_{35} + 520\, X_{36} + 600\, X_{37} + 840\, X_{38} + 760\, X_{43} + 360\, X_{45} + 880\, X_{46} + 280\, X_{47} + 1040\, X_{48} + 1080\, X_{53} +$

$360\ X_{54} + 1200\ X_{56} + \ 600\ X_{57} + 1400\ X_{58} + 520\ X_{63} + 880\ X_{64} + 1200\ X_{65} + \ 1200\ X_{67} + 1320\ X_{68} +$
$680\ X_{73} + 280\ X_{74} + 600\ X_{75} + 1200\ X_{76} + 800\ X_{78} + 840\ X_{83} + 1040\ X_{84} + 1400\ X_{85} + 1320\ X_{86} + 800\ X_{87}$

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 2 below shows strategy I solution graphically

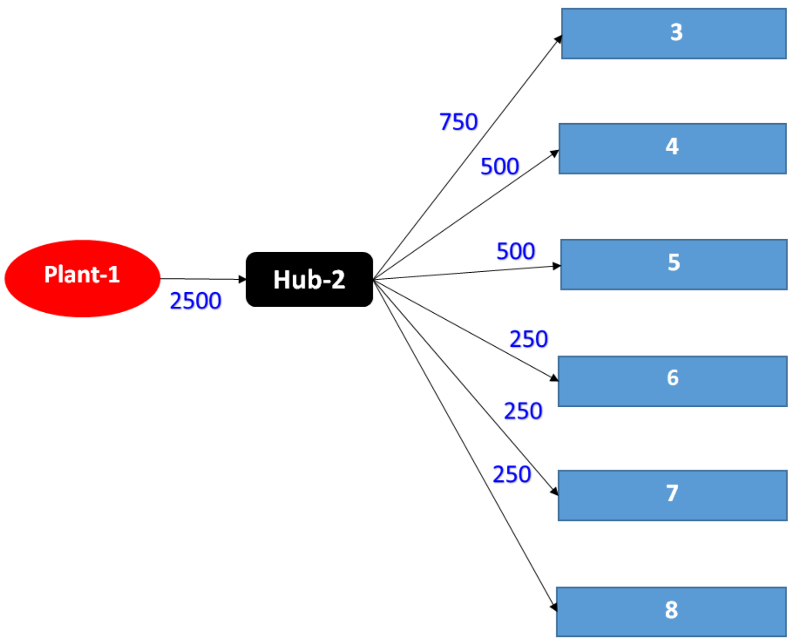

Figure 2: Graphical Presentation of Strategy I Solution

3.3 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 3 provides a graphical representation of this strategy.

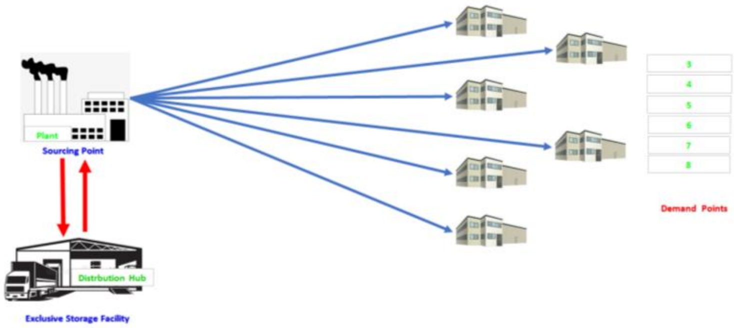

Figure 3: X-LUBE Distribution Hub Strategy II

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-PtD = (1-40%) × Supply = 60% × Supply

Hub Stock $= 60\%(50{,}000{,}000) = 30{,}000{,}000$ LTR $\approx=$ 1,500 trips =31,500 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 below shows the average number of pallets to be carried in each trip; assuming flat-bed transportation trailer.

Table 4: 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

$X_{2k} = 0$ 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

$X_{ij} = 0$ for i=6,7,8, i≠j

- The last is non-negativity constraint

$$X_{ij} \geq 0$$

Strategy II IP Model

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

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 below shows strategy II solution graphically

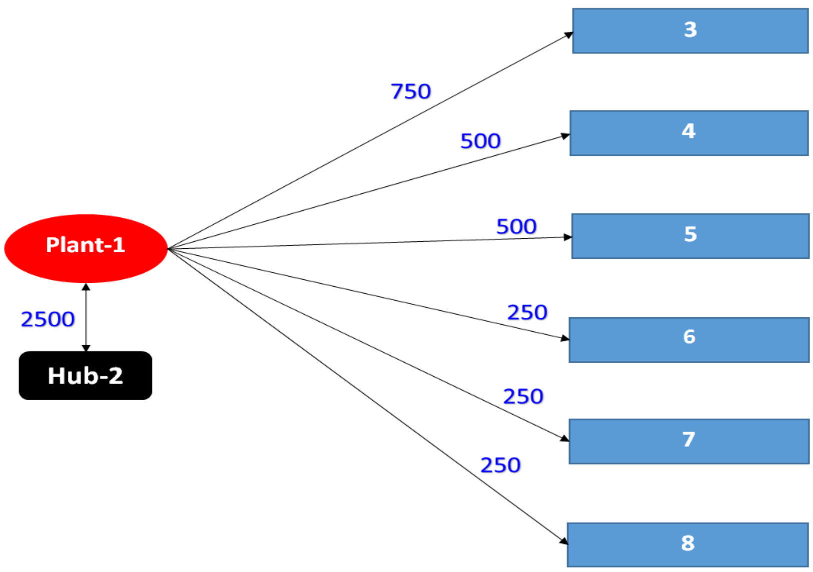

Figure 4: Graphical Presentation of Strategy II Solution

3.4 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 5 graphically shows this strategy.

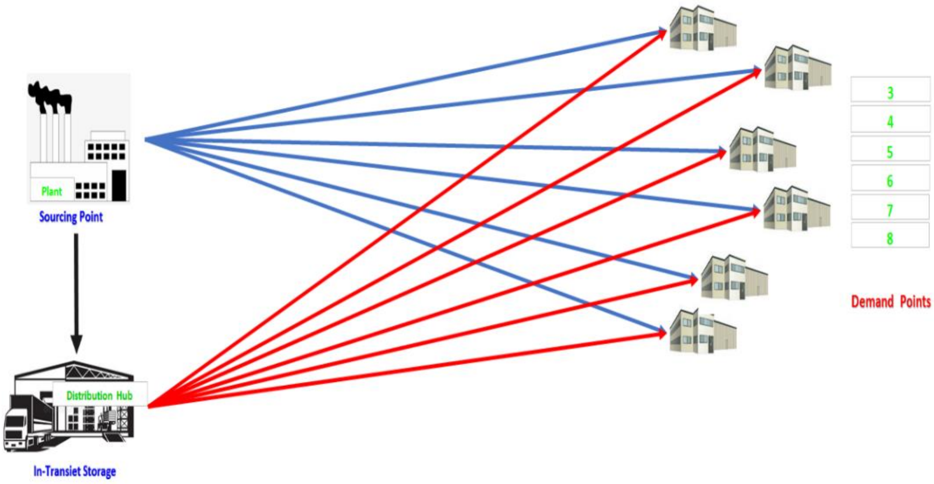

Figure 5: X-LUBE Distribution Hub Strategy III

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
   $X_D = \sum_{j=3}^{8} X_{1j} = 35\%\, X_M = 875$
7- Indirect deliveries represents 65% of total volume trips (X_M)of 2500
   $X_I = \sum_{j=3}^{8} X_{2j} = 65\%\, X_M = 1625$

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

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

Subject to

$$
\begin{aligned}
&X_{13} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18} \le 875\\
&X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + X_{28} \le 1625\\
&X_{12} \ge 1625\\
&X_{13} + X_{23} - X_{34} - X_{35} - X_{36} - X_{37} - X_{38} \ge 750\\
&X_{14} + X_{24} - X_{43} - X_{45} - X_{46} - X_{47} - X_{48} \ge 500\\
&X_{15} + X_{25} - X_{53} - X_{54} - X_{56} - X_{57} - X_{58} \ge 500\\
&X_{16} + X_{26} - X_{63} - X_{64} - X_{65} - X_{67} - X_{68} \ge 250\\
&X_{17} + X_{27} - X_{73} - X_{74} - X_{75} - X_{76} - X_{78} \ge 250\\
&X_{18} + X_{28} - X_{83} - X_{84} - X_{85} - X_{86} - X_{87} \ge 250\\
&X_{ij} \ge 0
\end{aligned}
$$

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

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

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

Figure 6 below shows strategy III solution graphically

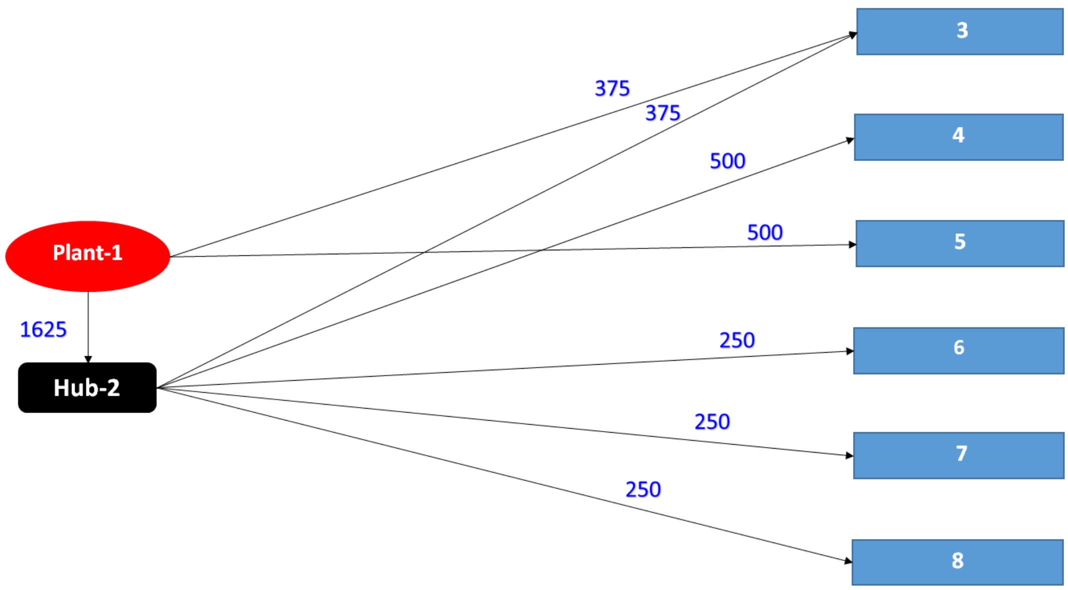

Figure 6: Graphical Presentation of Strategy III Solution

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. 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 5;

Table 5: 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 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

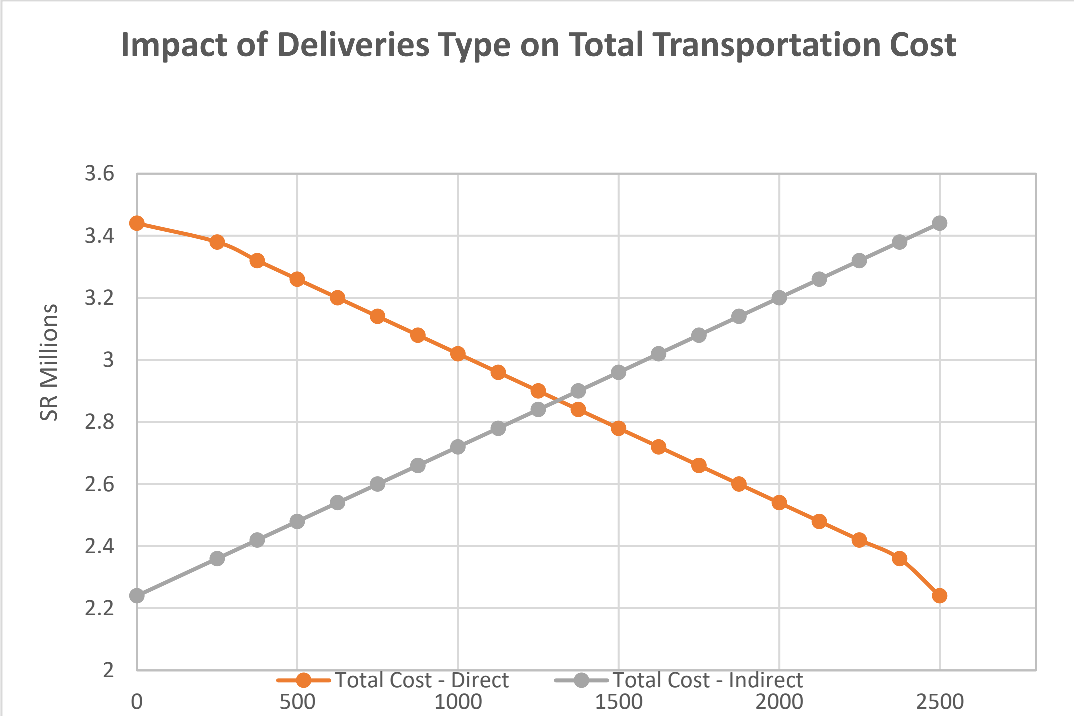

Figure 7: Direct/Indirect Impact on Total Transportation Cost

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 ±15% with a step change of 5% at a time; table 6 below shows the possible volume plans

Table 6: 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 7 shows these scenarios.

Table 7: 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 8 below.

Table 8: 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; ± 15% of business volume and +20% of transportation cost. Table 9 below shows optimal solution demand shares

Table 9: 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 8 below shows the impact of increasing the volume for all three transportation cost values SR/KM 0.8, 0.88 and 0.96.

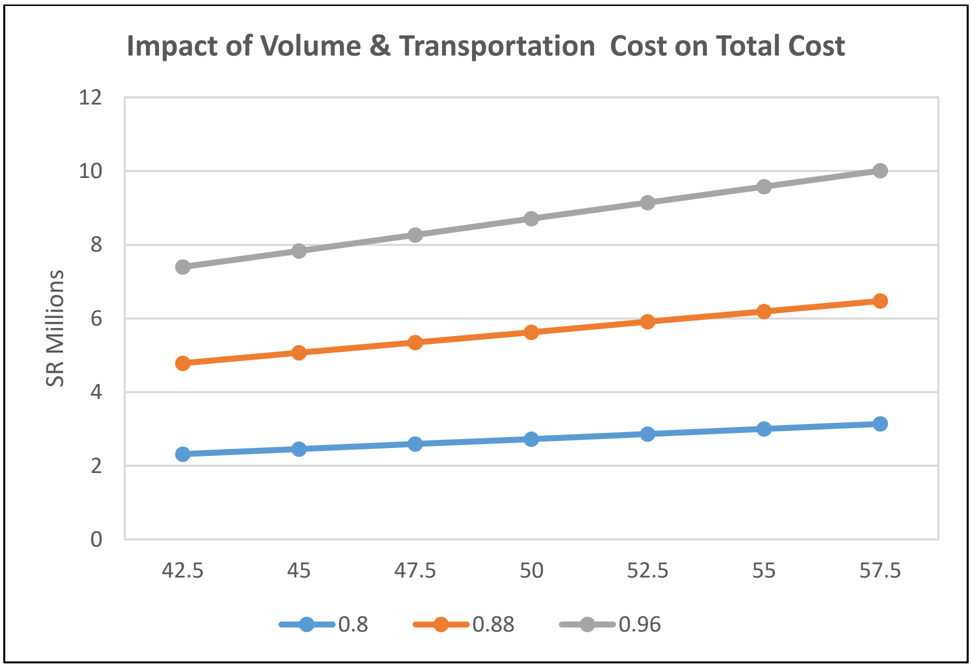

Figure 8: Impact of Volume & Transportation Cost on Total Cost

C. 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 10: Total Supply Cost of the Three Distribution Hub Operating Strategies

Combination	Direct	Indirect	Total	Total Transportation Cost-SR	Total Handling Cost - SR	Total Cost - SR	**Transportation Cost**	**Annual Pallets**	**Total Handling Cost**	**Total Cost**
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							
Strategy										
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 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. Table 11 below also summarize the impact of different types of deliveries on logistics costs.

Table 11: 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

Figure 9 shows the impact on increasing direct deliveries number on relevant costs; transportation, handling and total cost. The increasing number of direct deliveries decreases all relevant costs. In contrast, figure 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 11

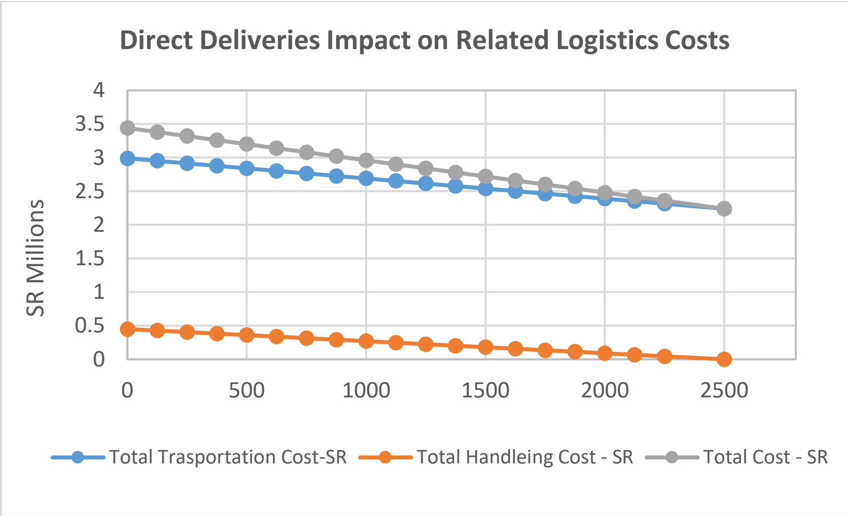

Figure 9: Direct Deliveries Impact on Logistics Costs

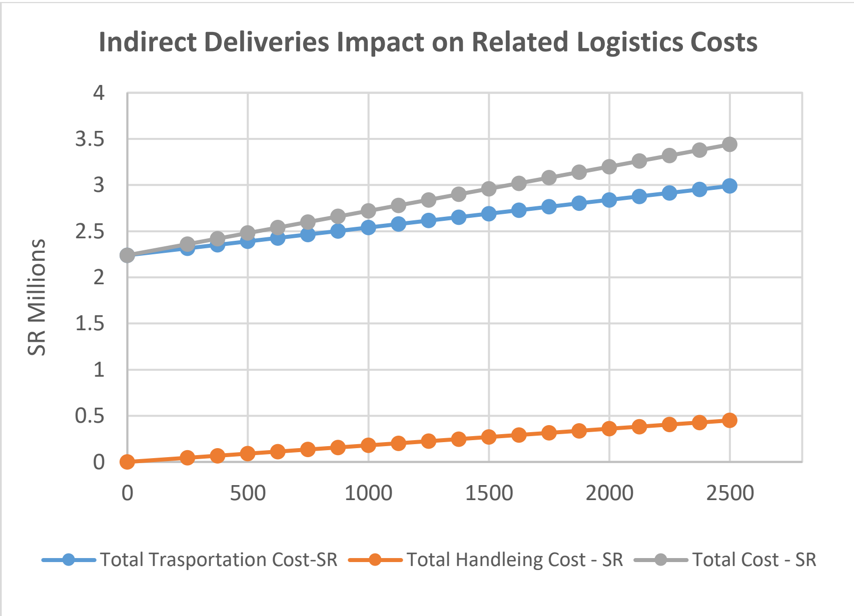

Figure 10: Indirect Deliveries Impact on Logistics Costs

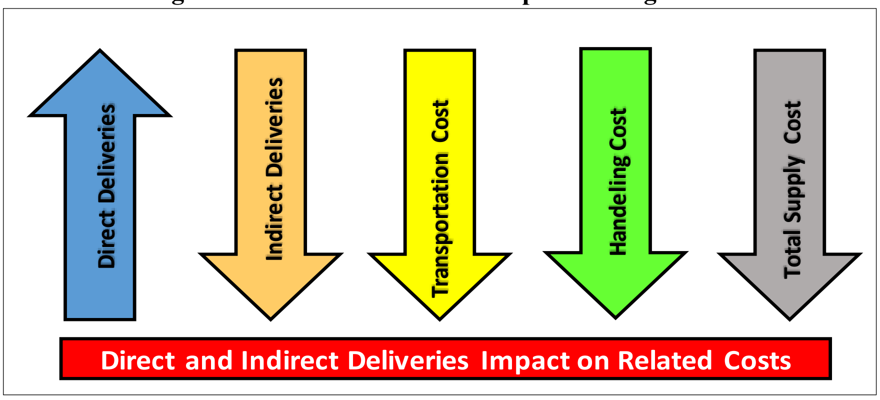

Figure 11: Deliveries/Costs Impact Interdependency

5. 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 12 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 12: 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 ±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, 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 above relevant analysis.

Further extension to this study can be made to include other dimensions, i.e. reverse logistics and orders returns **[8, 10]**, retailers' distribution network and sites **[11]** and orders requirements determination **[7].** Also, vendor-managed-inventory can be assumed once retailers' distribution networks are considered in the optimization model **[12]**

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 Unit figure. 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	3	4	5	Plant	6	7	8
3	X	360	1080	1200	1400	600	1200
4	360	X	760	880	1040	280	880
5	1080	760	X	280	840	680	520
Plant	1200	880	280	X	520	800	840
6	1400	1040	840	520	X	800	1320
7	600	280	680	600	800	X	1200
8	1200	880	520	840	1320	1200	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	**3**	**4**	**5**	**Plant**	**6**	**7**	**8**
3	X	450	1350	1500	1750	750	1500
4	450	X	950	1100	1300	350	1100
5	1350	950	X	350	1050	750	650
Plant	1500	1100	350	X	650	1000	1050
6	1750	1300	1050	650	X	1000	1650
7	750	350	850	750	1000	X	1500
8	1500	1100	650	1050	1650	1500	X

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