A Supply Chain Design Approach to Petroleum Distribution

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Abstract

Product distribution account for a significant portion of the logistical costs of a product. Distribution activities are repetitive in nature and they impact the delivery lead time to customers. A well designed supply chain network can substantially improve these costs and lead times. This paper presents a supply chain network design approach for distribution of petroleum products of a retailer by identifying the depot locations and gas station allocations. A heuristic procedure to solve large sized problems is also recommended. Finally, concluding remarks and recommendations for further research are presented.

Keywords: Supply Chain; Petroleum Distribution; Mathematical Programming.

1. INTRODUCTION

Supply chain managers frequently come across location and allocation problems at the design phase of a supply chain that involves determining the number of warehouses and assigning retail allocations. It appears imperative to treat the location and allocation decisions simultaneously. But due to the complexity of the problem, a breakdown into two stages i.e. location and allocation, helps to manage the complexity of large sized problems. The location decision involves substantial investment. Since it can't be changed frequently, therefore, it has long term implications. The warehouse location acts as a prelude to the overall process of supply chain design with far reaching effects on the performance of the logistics and distribution system. On the other hand, the allocation decision is more dynamic in nature as these assignments need to reviewed and changed from time to time as the supply chain grows. This is especially true for the natural gas and petroleum products distribution in developing countries where the retail outlets and gasoline fuel stations for such products are mushrooming at an increasing rate.

The present paper examines the supply chain network structure of a petroleum retail distributor in the Sultanate of Oman. The company called Al-Maha Distribution Company (AMC), is a national distributor of petroleum products. The company was founded in 1993 by extending the capabilities of Oman Refinery to engage in distribution and marketing of petroleum products. The company started operations in 1994 by opening a gas station in Al-Khuwair and now has more than 100 gas stations to cover most of the Sultanate. The company's head office is located in Authaibah with branch offices in Khasab, Salalah, Mina Al Fahal and Seeb. The company faces a stiff competition from two other major players: British Petroleum (BP) and Shell Select. Due to substantial investment in refinery and distribution operations, it is hard to exit the petroleum industry. Therefore, being a good competitor and adding value through its supply chain is the way to survive in this competition.

The company sells its products through direct sales at gas stations besides catering to the shipping and fishing industries through its marina fuel stations. In he past, AMC has strategically dominated in the capital region Muscat while serving other geographic areas as much as possible. The AMC product line consists of four main categories of products: petroleum, diesel, kerosene and jet fuels, in addition to fuel oils and lubricants. Petroleum products have further product proliferation into 90 Octane and 95 Octane, popularly known as regular and super brands of gasoline. Kerosene & Jet fuels benefit the aviation industry. They consist of higher specifications fuels and require separate trucks for delivery to different airports. The present paper will only focus on the retail segment of petroleum distribution, which is by far the most important operation of the company. It was estimated that 60% of the company sales are from petroleum sales through gas stations, 20% from Government and power companies and the remaining 20% from other buyers. AMC gas stations epitomize retail, operational and engineering efficiency. Different services offered at these gas stations include filling fuel, car-care, car wash and a stop-by shopping facility called “souk”. Apart from its retail business, AMC is also a prominent supplier of fuel and lubricants to a number of Ministries and institutional buyers. Its long client list includes the names of the Ministry of Electricity and Water, the Ministry of Defense, the Royal Air Force of Oman, the Royal Omani Police and Petroleum Development of Oman (PDO).

Given the fact that all the three major players in this industry carry good image for their products, possess state-of-the-art technology, meet the required standards, and the price structure that is centrally controlled by the Ministry of Oil; it is evident that the battlefield to gain higher market share would be in the supply chain and distribution area. Therefore, the company is convinced that a sound distribution strategy and an effective supply chain structure holds a great promise for the future and would be a key element of their plans to enjoy a superior market performance.

2. PETROLEUM SUPPLY CHAIN NETWORK

Supply chain managers frequently come across location and allocation problems at the design phase of a supply chain that involves determining the number of warehouses and assigning retail allocations. It appears imperative to treat the location and allocation decisions simultaneously. But due to the complexity of the problem, a breakdown into two stages i.e. location and allocation, helps to manage the complexity of large sized problems. The location decision involves substantial investment. Since it can’t be changed frequently, therefore, it has long term implications. The warehouse location acts as a prelude to the overall process of supply chain design with far reaching effects on the performance of the logistics and distribution system. On the other hand, the allocation decision is more dynamic in nature as these assignments need to reviewed and changed from time to time as the supply chain grows. This is especially true for the natural gas and petroleum products distribution in developing countries where the retail outlets and gasoline fuel stations for such products are mushrooming at an increasing rate.
Most of the oil wells are situated in Al Fahood and Murmul areas. The crude oil is extracted from the wells by Petroleum Development of Oman (PDO) and is shipped to Government owned refinery. The refinery processes this crude oil into a number of distinct petroleum products. As shown in Figure 1, the Oman Refinery ships these petroleum products to two depots, one located in Mina Al-Fahal near Muscat and the other located in Mina Al-Raysot near Salalah. The third depot in Khasab is not operational yet. AMC has ownership rights for the Raysot depot. The Mina Al Fahal depot has two terminals, one owned by Shell and the other jointly owned by AMC and British Petroleum. While the shipment to the Raysot depot is through sea transportation using a large ship, a pipeline mode of transportation is used for the shipment to Mina Al-Fahal depot.

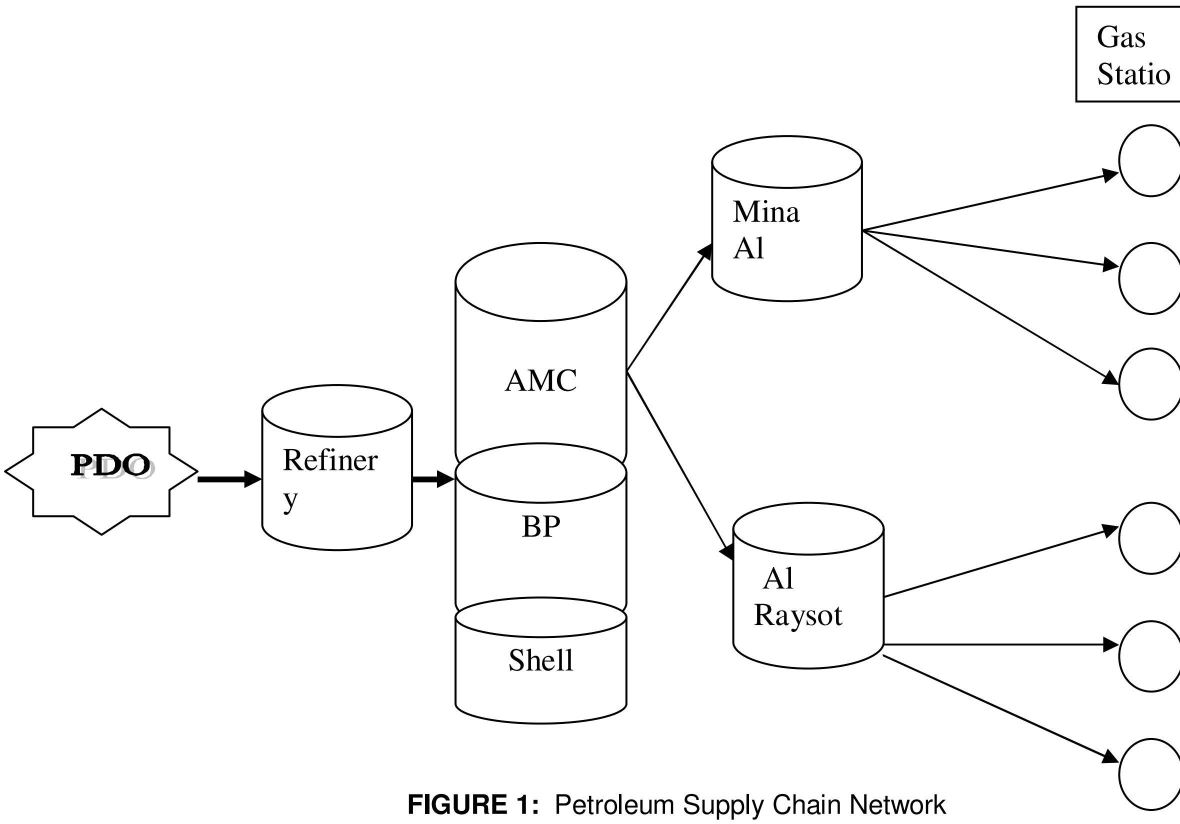

FIGURE 1: Petroleum Supply Chain Network

From the terminals, the secondary shipments to various gas stations are through the road transportation. Typically, two different types of trucks are used for this movement: standard four compartment 36,400 liters truck tractors with 9100 liters capacity for each compartment, and the rigid chassis 22,500 liters trucks with three compartments of 9000, 9000 and 4500 liters capacities. Although most of the dispatching decisions are taken by AMC, the actual transportation aspect is contracted out to trucking fleet companies and individual truck owners. This policy decision besides giving Omani businessmen opportunities in the competitive trucking industry, also provides excellent sources of income for individual truck owners and drivers.

3. LITERATURE REVIEW

In this section, the literature on location-allocation models has been reviewed. Shycon and Maffei [1] proposed the use of simulation tools for better product distribution. Perl and Daskin [2] considered the integration of transportation planning and location models. Lee and Luebbe [3] presented warehouse location models under multiple criteria. Hall [4] discusses a program to find new multi-facility locations. Brandeau and Chiu [5] provide an extensive review of location research problems. Crainic et. al [6] developed a model for multi-mode multi-commodity location-allocation problems with balancing requirements. Corrnuejols et al [7] discussed the un-capacitated facility location problem. Ho and Pearl [8] addressed the issue of facility location under service sensitive demand. Further work on multi-commodity location allocation problem is presented in Crainic [9] and Gendron and Crainic [10]. Application of tabu search methodology in emergency medical services locations can be found in Gendreau et. al [11]. Ingizio and Cavalier [12] discuss some heuristic approaches to solve set covering type location problems. Ballou [13] reviews and provides an introduction to some fundamental warehouse location models. Klose [14] uses a lagrangean relaxation approach for a two stage capacitated facility location model. Location decisions in light of demand probability have been considered in Berman and Krass [15]. Pal, Tardos and Wexler [16] considers hard capacities for facilities allowing demand splitting. Burkard and Dollani [17] present a restrictive optimal location problem on a tree network. Lin et al.

[18] analysis the location, routing and loading problem for bill delivery systems of a telecommunication company in Hong Kong. Han et al [19] discuss the integration issues at Wal-Mart supply chain in Korea. Zhou et al. [20] proposed a new balanced start spanning forest and genetic algorithm to solve location allocation problem. Syarif et al. [21] modeled and solved a facility location problem using a spanning tree based genetic algorithm. Ghosh [22] describes a tabu-search neighborhood heuristic for un-capacitated facility location model. Amiri [23] modeled the design of distribution network in a supply chain and solved it using a lagrangean relaxation method. Melo et al. [24] provided a mathematical modeling framework for dynamic facility location using decomposition techniques and meta-heuristics. The issue of supply chain design reliability has been addressed in Snyder [25]. Swamy and Kumar [26] propose primal-dual algorithm for multilevel hierarchical location problem. Ageev, Ye and Zhang [27] propose a combinatorial heuristic algorithm for k-level facility location. Gill and Bhatti [28] provided a set covering based model for identifying warehouse locations and a least distance allocation procedure.

4. LOCATION-ALLOCATION SUPPLY CHAIN MODEL

The model minimizes the number of depot locations selected (and hence investment) while ensuring that each gas station is assigned to exactly one selected depot location and such an allocation satisfies the maximum permissible distance from a gas station to depot. The model is presented as follows:

Find matrix **x** and vector **y** so as to

$$Minimize \sum_{j=1}^{n} y_j$$

subject to:

$$d_{ij} \, . \, x_{ij} \le d_{\max} \quad \forall \text{ i} = 1,2,3,\ldots, \text{m}; \quad \text{j} = 1,2,3,\ldots\text{n}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \quad \forall \text{ i} = 1,2,3,\ldots, \text{m}$$

$$(x_{ij} - y_j) \le 0 \quad \forall \text{ i} = 1,2,3,\ldots, \text{m}; \quad \text{j} = 1,2,3,\ldots\text{n}$$

$$x_{ij} \, , \, y_j \in \{0,1\} \quad \forall \text{ i, j}$$

where,
m = number of gas stations
n = number of candidate depot locations.
x_{ij} = 1 if gas station i is assigned to depot j, 0 otherwise
y_j = 1 if depot j is selected, 0 otherwise
d_{ij} = Distance of gas station i from depot location j expressed in kms.
d_{max} = Maximum threshold distance beyond which a gas station can not be assigned to a depot due to commuting distance, over-night costs etc.

For the reasonable sized problem with 50 gas stations and 10 candidate depot locations , it will give rise to 1050 constraints and 510 variables making it impractical to solve real problems using mathematical programming approach. Hence, the problem is broken down to into location and allocation stages to manage the complexity and size and a heuristic procedure is suggested below which could be applied for large sized practical problems.

5. HEURISTIC SOLUTION APPROACH

The approach is two folds. First, the depot locations are chosen from the available set of locations which can cover the gas stations based on a pre-assigned maximum threshold distance. Then the gas stations are allocated to these depot locations. The steps of the procedure are as follows:

5.1 Location of Depots

The location of depots involves two steps. First to construct a binary coefficient matrix so as to identify the potential locations, then selecting the actual locations using a mathematical programming model.

Step 1. Construction of a binary coefficient matrix

Based on the maximum permissible distance, d_{max} , a binary coefficient matrix [α_{ij}] is prepared, which is to be used as an input to the mathematically programming model of step 2. The following relation can be used to construct this binary matrix:

$$\alpha_{ij} = 1 \text{ if } d_{ij} \leq d_{max} \text{ or } 0 \text{ otherwise}; \; \forall \; i = 1,2,3,....,m; \; j = 1,2,3,...., n.$$

Step 2. Set covering mathematical model

Using the binary coefficient matrix in Step 1 as an input, the best depot locations to cover all the gas stations are selected based on the following set covering model (Gill & Bhatti [2007]):

Find vector **y** so as to

$$Minimize \sum_{j=1}^{n} y_j$$

subject to:

$$\sum_{j=1}^{n} \alpha_{ij} \, . \, y_j \geq 1 \quad \forall \; i = 1,2,3,....,m$$

$$y_j \in \{0,1\} \quad \forall \; j = 1,2,3,....,n$$

The objective function above expresses the minimization of the number of depot locations while the constraint set ensures that each gas station is covered by at least one depot..

5.2 Allocation of Gas Stations to Depots

Gas station allocation is done according to the following procedure.

Step 1. Identify a set θ={j} such that y_j =1.

Step 2. Consider a sub-matrix of distance matrix [d_{ij}] for those j ϵ θ.

Step 3. Set i = 1

Step 4. Find d_{ij}^* = min(vector $\mathbf{d}_{ij}$) for j ϵ θ, i.e., find the minimum entry in the i^{th} row. If the column index for this minimum entry is j*, assign i^{th} gas station to j* depot.

Step 5. While i<m, set i=i+1 and repeat step 4, i.e., we continue to repeat step 4 until all the gas stations have been assigned.

6. APPLICATION TO PETROLEUM SUPPLY CHAIN DESIGN

While analyzing the current distribution system, it became evident that catering to distant and newer gas station locations through a fewer depots results in longer lead time, uncertainties and lost sales. Looking at the tremendous growth in retail volumes over the past few years as well as the potential to grow in the coming years, it was felt that a larger number of inventory holding and forwarding points (depots) would be necessary to serve the interior regions of the Sultanate. Therefore, an important issue is to determine the number and locations of such depots. A major determinant of depot location is the distance to be covered. Apart from the depot locations, other issues that the company need to consider are consolidating demand of different gas stations on single trips, shipment sizes, dispatch rules and routes which are not a part of the current analysis.

The decision process consists of hierarchical decisions including:

- Deciding on the number and location of depots
- Allocation of the demand points to these depots

The problem is relatively complex because of the number of different but interrelated decisions that need to be made. The obvious choices are either to decompose the problem into different decision areas or alternately, to consider all the decision areas simultaneously in which case the decision-making process could be more accurate but less manageable. The scenario represents an application of the model presented in this paper.

6.1 Data Requirements

The first step in evaluating the data requirements for this case, is to identify the depot candidate locations. Based on a number of factors such as proximity to major towns, communication facilities, infrastructural considerations, driver availability; Sohar, Suwayk, Muscat, Dank, Nizwa, Sur, Mahawt, Marmul and Salalah were selected to be good candidates for depot locations. The next step required choosing a maximum distance between a depot and its allocated gas stations. After much deliberations and considering the driver's comfort, a maximum one way distance of 400 kilometers (800 Km round trip) seemed reasonable. As a driver has to deliver to gas station and make a return trip to the depot, a maximum total distance of 800 kilometers on a trip was considered reasonable. The distances between depot locations and gas stations as well as distances between gas stations posed a problem. Considering the geographical structure of the Sultanate and its road network that is still evolving after Guno cyclone, the difficult desert as well as mountainous terrain, it becomes evident that the concepts of geographic coordinate distances were not directly applicable in this case. The Sultanate of Oman has nine geographic regions: The Governorate of Muscat, Al-Batinah, Governorate of Musandam, Al-Dhahirah, Al-Dakhliyah, Ash-Sharqiyah, Al-Wusta, and the Governorate of Dhofar. Unfortunately, these geographic divisions didn't help because within the same geographic division, the terrains could be quite non-uniform making it impossible to apply the traditional approaches. Therefore, the entire region was divided into 18 different zones with the guiding principle that it was either possible to know the actual road distance between zonal centers from existing road maps or the intra-zonal distances were relatively easier to compute due to a uniform bed within a zone. Inter-zonal distances were calculated based on actual road distance. This effort resulted in the data regarding distances between potential depot locations and the gas stations and between the gas stations which is summarized in Tables 1 and Table 2. All the gas stations have been coded from 1 through 59.

	Z 1	Z 2	Z 3	Z 4	Z 5	Z 6	Z 7	Z 8	Z 9	Z 10	Z 11	Z 12	Z 13	Z 14	Z 15	Z 16	Z 17	Z 18
Z 1	0																	
Z 2	250	0																
Z 3	312	62	0															
Z 4	367	117	63	0														
Z 5	410	160	106	47	0													
Z 6	488	238	184	125	90	0												
Z 7	534	284	230	171	136	52	0											
Z 8	616	366	312	253	218	134	94	0										
Z 9	467	217	163	104	69	113	159	241	0									
Z 10	507	257	235	199	242	347	367	449	299	0								
Z 11	636	386	332	273	238	154	174	256	261	367	0							
Z 12	600	350	296	237	202	118	138	220	225	229	36	0						
Z 13	799	549	495	436	401	317	337	419	424	492	299	263	0					
Z 14	880	630	576	517	482	398	418	500	505	509	316	280	543	0				
Z 15	940	690	636	577	605	521	541	623	628	498	381	403	587	436	0			
Z 16	1390	1140	1086	1027	1055	971	991	1073	1078	948	831	853	1037	886	450	0		
Z 17	1345	1095	1147	982	1010	928	946	1028	1033	903	786	808	992	1428	405	855	0	
Z 18	1422	1172	1118	1059	1087	1003	1023	1105	1110	980	863	885	1069	1505	482	932	77	0

TABLE 1: Inter-zonal Distances (in KMs)

GS	Sohar	Suwayq	Muscat	Dank	Nizwa	Sur	Mahawt	Marmul	Salalah
1	313	411	535	508	637	800	881	1391	1423
2	292	390	514	487	616	779	860	1370	1402
3	231.5	329.5	453.5	427	555.5	719	799.5	1309.5	1341.5
4	55.5	153.5	277.5	251	379.5	543	623.5	1133.5	1165.5
5	17	106	230	235	315	478	559	1069	1101
6	5	106	230	235	327	490	571	1081	1113
7	10	106	230	235	322	485	566	1076	1108
8	13.5	106	230	235	345.5	509	589.5	1099.5	1131.5
9	28	12	136	164	238	401	482	992	1024
10	34.5	18.5	142.5	171	244.5	408	488.5	998.5	1030.5
11	43	27	151	179	253	416	497	1007	1039
12	73	57	181	209	283	446	527	1037	1069
13	94.5	11.5	124.5	231	226.5	390	470.5	1043.5	1075.5
14	114	8	144	250	246	409	490	1063	1095
15	129.5	23.5	159.5	266	261.5	425	505.5	1078.5	1110.5
16	169	75	37	332	139	302	383	956	988
17	204	110	72	367	174	337	418	991	1023
18	205	111	73	368	175	338	419	992	1024
19	192	98	60	355	162	325	406	979	1011
20	197.5	103.5	65.5	361	167.5	331	411.5	984.5	1016.5
21	212.5	118.5	80.5	376	182.5	346	426.5	999.5	1031.5
22	215.5	121.5	83.5	379	185.5	349	429.5	1002.5	1034.5
23	203.5	109.5	26.5	321	147.5	311	391.5	964.5	996.5
24	216.5	122.5	13.5	334	160.5	324	404.5	977.5	1009.5
25	237	143	7	354	181	344	425	998	1030
26	318.5	224.5	100.5	456	262.5	426	506.5	1079.5	1111.5
27	169.5	75.5	165.5	306	267.5	431	511.5	1084.5	1116.5
28	186.5	193.5	318.5	48.5	318.5	444	460.5	899.5	931.5

TABLE 2: Distance Matrix Between Depot Locations and Gas Stations (GS)

Table 2. continued….

GS	Sohar	Suwayq	Muscat	Dank	Nizwa	Sur	Mahawt	Marmul	Salalah
29	227	234	359	8	359	484	501	940	972
30	275	282	407	40	407	532	549	988	1020
31	282	289	414	47	414	539	556	995	1027
32	325	238	167	360	7	292	309	824	856
33	307	238	149	342	25	274	291	806	838
34	303	238	145	338	29	270	287	802	834
35	282	238	124	317	50	249	266	781	813
36	361	238	203	396	29	328	345	860	892
37	386	292	228	319	126	353	370	943	975
38	313	219	155	246	53	280	297	870	902
39	359	265	201	292	99	326	343	916	948
40	382	288	224	315	122	349	366	939	971
41	502	408	344	499	306	7	453	1044	1076
42	572	478	414	569	376	77	523	1114	1146
43	554	460	396	551	358	59	505	1096	1128
44	488	394	330	485	292	7	439	1030	1062
45	579	485	421	576	383	84	530	1121	1153
46	398	304	240	395	202	97	349	940	972
47	576	482	418	509	316	543	0	886	1505
48	668	574	510	601	408	635	92	978	1597
49	626	595	531	488	371	577	426	440	472
50	1091	1060	996	953	836	1042	891	5	937
51	1145	1114	1050	1007	890	1096	945	59	991
52	1238	1101	1037	994	877	1083	1519	946	168
53	1332	1195	1131	1088	971	1177	1613	1040	262
54	984	953	889	846	729	935	1371	798	134
55	1044	1013	949	906	789	995	1431	858	74
56	1140	1109	1045	1002	885	1091	1527	954	22
57	1135	1104	1040	997	880	1086	1522	949	17
58	1101	1070	1006	963	846	1052	1488	915	17
59	1091	1060	996	953	836	1042	1478	905	27

6.2 Model Application

In this section, we apply the approach presented in section 5.

Identifying Locations for Depots

Step 1. Binary Coefficient Matrix

Based on the maximum permissible distance of 400 KMS as discussed earlier, we prepared a binary coefficient matrix [α_{ij}], which is used as an input to the mathematical programming model.

Step 2. Solving the Mathematical Model

Using the binary coefficient matrix, the best depot locations to cover all the gas stations are selected based on the set covering model given in Gill and Bhatti (2007). Although such a model theoretically has m constraints and n variables but in the context of the present problem, a number of redundant constraints can be eliminated. Solving the above mathematical model resulted in the following depot locations: Sohar, Mascut, Nizwa, Mahawat, Marmul and Salalah. Note that the Salalah and Muscat depots are already operating.

Allocation of Gas Stations to Depots

Step 1. Identify a set of candidate locations θ. From solving the mathematical model, θ={Sohar, Mascut, Nizwa, Mahawat, Marmul, Salalah}.

Step 2. Consider a sub-matrix of distance matrix [d_{ij}] for those j є θ. Therefore, we consider matrix [d_{ij}] of Table 1 relevant to Sohar, Mascut, Nizwa, Mahawat, Marmul and Salalah.

Step 3. Set i = 1

Step 4. Find d_{ij}^* = min(vector $\mathbf{d}_{ij}$) for j є θ and assign i^{th} gas station to depot j*.

Step 5. While i<m, set i=i+1 and repeat step 4, i.e., we continue to repeat step 4 until all the gas stations have been assigned.

This procedure resulted in the following allocation of gas stations to the depots as given in Table 3.

Depot	Allocated Gas stations Number
Sohar	1 – 15 and 28 - 31
Muscat	16-27
Nizwa	32-46, and 49
Mahawt	47 and 48
Marmul	50 and 51
Salalah	52 - 59

TABLE 3: Depot Locations and Gas Stations Allocations

7. CONCLUDING REMARKS

The present paper analyses petroleum products distribution strategy of a company with a view to improve its distribution network for a better area coverage, to identify its major depot locations and allocation of gas stations.

It is envisioned that the scope of the analysis could further include issues such as depot capacities. The capacity issues is important if the company has a practice of frequently reviewing its supply chain decisions. The capacity decision was omitted from current analysis based on the assumption that depots with sufficient capacities can be constructed. Secondly, for the existing two depots, capacity had never been a problem.

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