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Optimization Modelling for Multi-Objective Supply Chains, A Case Study of the Oil and Gas Sector

Okwu, Modestus O.
Department of Mechanical Engineering,
Federal University of Technology Owerri, Imo State
E-mail: mechanicalmodestus@yahoo.com
Phone: +2347037925341

Opara, Ignatius O.
Department of Mechanical Engineering,
Federal University of Technology Owerri, Imo State
E-mail: mechanicalmodestus@yahoo.com
Phone: +2348138594232

Abstract

One of the key problems managers of companies face is the high cost of distributing multiple products to downstream locations. They often rely on their intuition and rule of thumb while making allocation decisions. In this *study a mathematical model was developed for minimizing the distribution cost in a multi-product supply chain system. The oil and gas sector was studied to understand the underlying supply chain system. Attempt was made to identify system parameters, variables, limitations, criteria so as to be able to define the distribution problem. This study was done using information from one of the major source in the oil and gas sector in Nigeria. The interactions and flow of products in the system were properly studied. It was then observed that the source distribute products to downstream at a higher cost without fulfilling demand at some destination. The data gotten from the plant shows that a total distribution cost of ₦2,353,050 was incurred at the source for the fortnight. The model was solved for a 12 product 8 destination case. The problem developed was an LP linear program formulation with three major constraints defined; demand, availability and company policies. And at the end of the analyses, it was observed that a LP minimization process would distribute a set of products to all the downstream without any suffering a zero product at an optimal cost of ₦2,025,200 . About 14% of the optimal cost was reduced. It is concluded that the model is effective to reduce or minimize distribution expenses for any multi-product multiple destination system and fulfilling demand at various destinations.*

Key words: Optimization, Modelling, Supply chain, Oil and gas,

Introduction

The deregulation of the downstream oil and gas sector (petroleum refining and marketing) in Nigeria has been in focus for quite some years now. Scarcity of petroleum products and the gradual deregulation of petroleum product prices have generated much heated controversies. There is no doubt that the government of Nigeria is vigorously pursuing the deregulation of the downstream sector. Government is determined to nurture private sector participation hence the licensing of private refineries and the partial deregulation of petroleum product prices, in order to improve local capacity. In the next three to five years, consolidation is expected in the oil refining and marketing sectors.

Some of the challenges facing the oil and gas industries and the manufacturing sector in today's business in Nigeria include: The high cost incurred in shipping or transporting raw materials to upstream, high cost of distributing finished products to downstream, how to consistently meet with customers' requirements and demands at the lowest possible cost so as to remain competitive in the market. These are common cases in the downstream oil and gas sector. Such challenges could be met through optimization in the production process, through effective supply chain management.

Lambert (2008) defined supply chain as the integration of key business processes across agents for the purpose of adding value to customers and stakeholders. Also Cohen and Lee (2006) identified that supply chain decision can be classified into two broad categories: Strategic decision and Operational decision. In some cases such as the soft drink industry, distribution costs represent approximately 70% of the value added costs of goods (Golden and Wasil, 1997). This may also be applicable in the oil and gas sector. In addition, greater demands are being placed on the system to provide products and services quicker with greater added value, at correct quality, in the correct quantity, to the right place, at the right time, in the correct condition and packaging, at the right cost, to the right location and to the correct customer, so as to remain competitive in business. (Sunil and Meindl, 2001; Hokoma et al., 2006).

Chan and Chung (2005) developed an optimization algorithm to solve the problem of distribution in a given supply network, taking into account variables like demand allocation and production scheduling. Ambrosino and Scutellà (2004) studied the complex distribution network design problem that involves not only locating production plants and distribution warehouses, but also searching the best distribution strategy from plant to warehouses and from warehouses to customers using an MIP model for the minimization of global costs given by the sum of six factors, each containing a binary variable.

Amiri (2004) defined an important strategic element as the best sites for intermediate stocking points, or warehouses introducing an MIP model that minimizes total costs on three different levels: costs to satisfy customers' demands from the warehouse, shipment costs from the plants to the warehouse, and costs associated with opening and operating both warehouses and the plant.

This study address a case of distribution problem faced by the downstream oil and gas sector (petroleum retailing and marketing) with multiple products to be supplied to multiple destinations such that products delivered satisfy retailers' expectation. Optimal allocation of products to downstream locations is a major requirement for minimizing the distribution cost associated with supply chain systems. Unfortunately some managers rely on their intuition and feelings to make these allocation decisions rather than using scientific optimization models.

TABLE 1: Examples of Multiple Products to be distributed to Multiple Destinations

No	Source	Products	Destination
***	**Single**	**Multiple**	**Multiple**
1.	**Pipeline & Product Marketing Company(PPMC) a subsidiary of NNPC**	✓ Gasoline ✓ Kerosene ✓ Gas oil /Diesel ✓ Fuel oil ✓ Lubricating Oils ✓ Waxes ✓ Asphalt(Bitumen) ✓ Gases e.t.c	All Retail outlets

Objective

The objective of this study is to develop a methodology that involves mathematical modelling to support complex supply chain task by optimizing distribution cost. The effective distribution of products requires a model with perfect, user-friendly programmes and software which managers in reputable organizations can apply.

The sub-aims are:

- To develop an optimization model to take care of oil and gas companies of multi-products to multi-destination distribution problems
- To identify/develop a solution procedure for the model.
- To develop a programme that would help solve the mathematical model for oil and gas sector in particular and manufacturing organizations in general, irrespective of parameters, variables, limitations and criteria.

- To apply the methodology to a real life supply chain problem in oil and gas manufacturing/distribution system.

The final goal of this thesis is to have a generic methodology as well as a specific software implementation that is validated in the manufacturing/oil and gas domain.

Methodology

The oil and gas downstream sector was studied to understand the underlying supply chain structure (See Fig 1.0). Attempt was made to identify system parameters, variables, limitations, criteria so as to be able to define the distribution problem. The interaction and flow of products in the system was identified and modelled after which the solution procedure for solving the model was established, then a software/programme was developed to solve the problem.

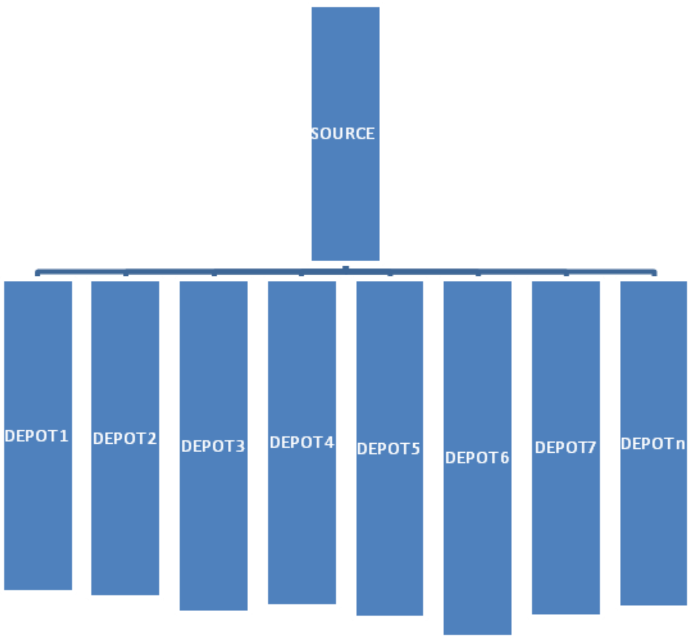
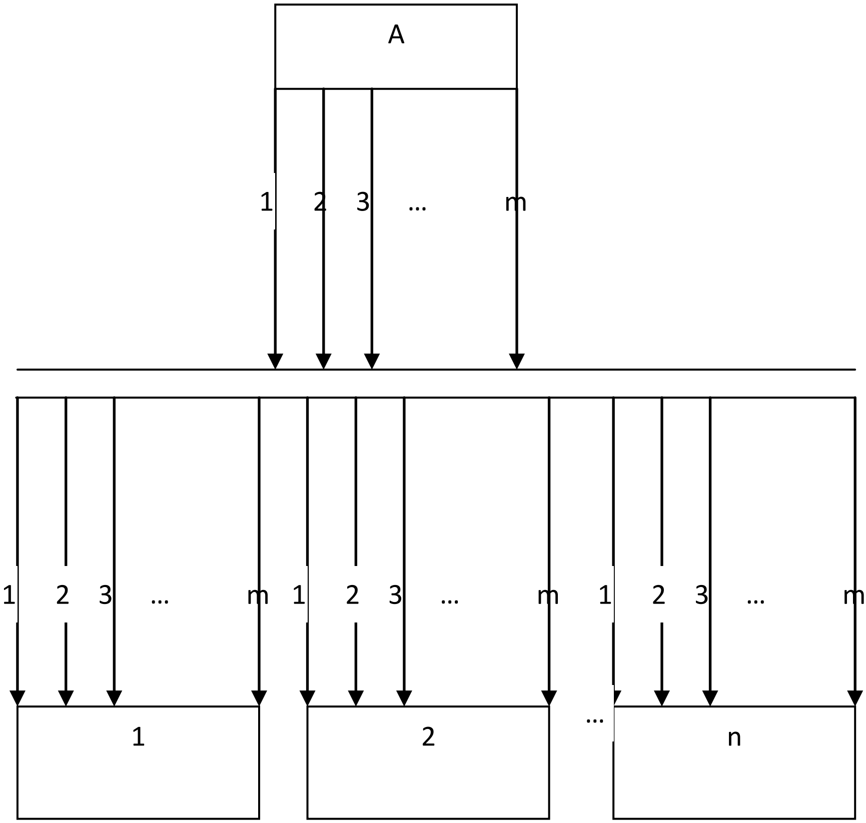


Fig 1: The Underlying Supply Chain Structure



Notations and Terms Definition

i	Index identifying products with i = 1,2…m
j:	Index identifying destinations/depots with j = 1, 2, 3, …n
X_{ij}:	The quantity of product i shipped to destination j (The decision variable)
Ai	Quantity of product i available at the source for distribution

m	Total number of products to be distributed.
n	Number of destinations/depots to be served
c_{ij}:	unit cost of shipping product i to destination j
C:	Total distribution cost
D_{ij}:	Demand of product i at destination j
bj:	Fraction of demand that must be met at any destination j

Problem Constraints

The problem constraints and equations describing them were identified as follows:

Availability Limitation

In this model, one of the systems of constraints is related to product availability. This puts a limit on the quantity of any product i that can be sent to destinations. For each product i, the available quantity is A_i. This is shown as system of equation 1 below:

$$\sum_{j=1}^{n} X_{ij} \le A_i \qquad i = 1, 2, 3 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

Demand Constraint:

This constraint requires that only what can be paid for by the depots is sent. This implies that not more than the respective depots demand D_{ij} should be sent. This is represented as system of equation 2 shown below:

$$X_{ij} \le D_{ij} \qquad \text{for all } i= 1,2,3\ldots m \text{ and } j= 1,2,3\ldots n. \qquad \ldots\ldots\ldots\ \ldots\ldots 2$$

Company policies: There are a number of company policies that guide the distribution of products. One of the critical policies is that no depot must be sent zero quantity or there is a minimum quantity that must be sent to any given depot because of the need to keep customer loyalty at every region. This is represented as the system of equation 3 shown in notation form below:

$$X_{ij} \ge b_{ij}D_{ij} \quad \text{for all } i = 1, 2, 3\ldots m \text{ and } j = 1, 2, 3\ldots n \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Non-negativity constraint:

There explains the fact that there is no negative distribution. This is represented as the system of equation 4 as shown below:

$$X_{ij} \geq 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Objective function:

The objective function of this model is to minimize the total distribution cost. This is represented as system of equation five as shown below:

$$\text{Minimize } C = \sum_{j=1}^{n}\sum_{i=1}^{m} C_{ij}X_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

THE MODEL

Aggregating al[illegible]ations result in the generic optimization model below:

$$\text{Minimize } C = \sum_{j=1}^{n}\sum_{i=1}^{m} C_{ij}X_{ij}$$

Subject to:

$$\sum_{j=1}^{n} X_{ij} \leq A_i \qquad \text{for all} \qquad i = 1,2,3\ldots..m$$

$$X_{ij} \leq D_{ij} \qquad \text{for all} \quad i = 1, 2 \ldots m; \; j = 1, 2 \ldots n$$

$$X_{ij} \leq b_j D_{ij} \qquad \text{for all} \quad i = 1, 2 \ldots m; \; j = 1, 2 \ldots n$$

$$X_{ij} \geq 0 \qquad \text{for all} \quad i = 1, 2 \ldots m; \; j = 1, 2 \ldots n$$

A close observation shows that the model is the well known LP.

Application

An oil and gas depot in Port Harcourt, Nigeria has 12 different products which are to be distributed to 8 destinations within that region. The table below gives information of the product available at the source and the demands at each depot. Thus, the depot manager wants to determine the most economical allocation which minimizes distribution cost.

Table 2: Demand matrix (d_{ij}) of products from various depots

	Destinations								Availability
Product i	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	A_i
1	3700	2010	444	48	228	11174	744	1104	16470
2	15272	10526	19520	4112	9254	10512	12040	9838	43088
3	15024	970	350	2988	2258	11416	8168	4674	37234
4	16580	326	1406	22	192	696	1668	838	13216
5	1920	180	722	692	400	772	1996	820	12480
6	1560	550	1510	556	204	822	156	696	11130
7	2304	456	1978	274	574	862	1316	622	3192
8	10260	4592	3682	2874	4308	7610	5750	5130	17086
9	4310	4120	5150	1030	1694	3214	1926	3384	15008
10	8508	56	82	746	1250	7416	4030	616	16424
11	1068	480	528	92	156	960	240	152	3072
12	70	16	32	6	20	96	18	18	2016
Unit cost	9	18	18	15	28	14	12	18	0
Policy	0.2	0.2	0.4	0.4	0.6	0.8	1.4	1.8	0

TABLE 3: THE QUANTITY OF PRODUCTS DISTRIBUTED TO THE DESTINATIONS

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
1	1690	2010	44	4	228	10554	744	994
2	4746	10526	1952	822	2776	4204	8428	8582
3	14054	970	36	598	2258	6846	8168	4206
4	11210	326	140	4	58	278	1168	0
5	750	180	96	692	120	308	0	820
6	232	550	152	200	62	240	0	110
7	1000	456	498	54	172	344	0	622
8	2730	4592	368	574	1292	3044	4026	0
9	190	4120	516	206	1694	2898	1926	3046
10	8452	56	8	150	376	2966	3856	554
11	0	480	290	18	46	384	168	0
12	8	16	4	2	6	38	12	0
Total Distribution Cost					**N2,353,050**			

Solution procedure

The procedure for solving the problem for the case at hand (Table 3.1) is shown clearly below by following the model gotten.

The Oil and Gas Plant Allocation Model

$$Minimize C = \sum_{j=1}^{8} \sum_{i=1}^{12} C_{ij} X_{ij}$$

Subject to

$\sum_{j=1}^{8} X_{ij} \le A_i$ for all i=1….12 (availability constraint)

$X_{ij} \le D_{ij}$ $\begin{cases} i = 1, 2 \ldots 12 \\ j = 1, 2 \ldots 8 \end{cases}$ (demand constraint)

$X_{ij} \ge b_j D_{ij}$ $\begin{cases} i = 1, 2 \ldots 12 \\ j = 1, 2 \ldots 8 \end{cases}$ (policy constraint)

$X_{ij} \ge 0$ $\begin{cases} i = 1, 2 \ldots 12 \\ j = 1, 2 \ldots 8 \end{cases}$ (non-negativity constraint

Results and discussion

The solution for minimizing the distribution cost is ₦2,025,200. This is the optimal cost which shows that for any set of distribution considering the same decision process, the least cost that could be incurred no matter the redistribution of the products is ₦2,025,200. Table 4.1 shows the distribution of products to all destinations

TABLE 4.1 TOTAL PRODUCTS TO BE DISTRIBUTED USING THE MODEL

Product i	D_1	D_2	D_3	D_4	D	D6	D7	D8	Ai
1	3700	202	44	4	288	10554	744	994	16470
2	15000	1052	1952	822	2776	4204	8428	8854	43088
3	15024	98	36	598	2258	6846	8168	4206	37234
4	10782	32	140	4	58	278	1168	754	13216
5	1920	180	722	692	400	772	1996	820	12480
6	1560	550	1510	556	204	822	156	696	11130
7	896	46	198	54	172	344	922	560	3192
8	2704	460	368	574	1292	3044	4026	4618	17086
9	4310	412	516	206	1694	2898	1926	3046	15008
10	8508	6	8	150	376	2966	3856	554	16424
11	1068	480	528	92	156	960	240	152	3072
12	70	16	32	6	20	96	18	18	2016

X_{11} =1850 ; X_{12} =7,500 ; X_{13} =7,512 ; X_{14} = 5,391… X_{21} = 101; X_{22} = 526 etc

Conclusion

This paper models the problem of minimizing the cost of distributing multiple products. Linear programming model is suggested. This problem is easy to solve using software like TORA, or QM. A real life problem was solved to demonstrate the usefulness of the model using TORA. The study was done using the data gathered from an oil and gas plant in Nigeria. The distribution system of the plant for a particular period was observed as shown in Table 3.1, with the company incurring a total distribution cost of ₦2,353,050 without meeting with demand at some downstream locations. Then the mathematical model developed was applied. The solution procedure show that all depots received the exact or a fraction of their demands (no zero product) at an optimal cost of ₦2,025,200. This is roughly 14% reduction of the true distribution cost. Meaning that the total sum of ₦327,850 would have been saved by the company for a forthnight using the model developed, with all destination receiving all products demanded.

In conclusion, the model is effective to reduce or minimize distribution expenses for any multi-product multi-destination system while fulfilling demand at all destinations.

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