Matching Gasoline Supply with Distribution Requirements Optimizes Depot Storage Capacity

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1. Abstract

The Nigerian National Petroleum Corporation, a refiner, owns and operates a petroleum products pipeline network connected to twenty one storage depots across Nigeria. Products are supplied to the depots from the local refineries and ex-jetties (for imports) mainly by pipeline. The main objective of establishing the pipeline network and the depot facilities by the refiner was to ensure efficient product distribution, reduce transportation cost and minimize products price differential across the country.

The concept, design and layout of the depot facilities were such as to maximize gasoline supply and distribution, which as a major transportation fuel, has the highest demand profile over kerosene and diesel. Since the early 1990s, as gasoline demand increased by over 30% the entire supply/distribution chain appeared inadequate. The refiner then began to find a solution to products supply and distribution.

This study was done for one of the refiners depot located in the central zone of the country but receives supplies from an upstream facility in the Western part of the same country. The depot receives products from a 6 inch pipeline designed to transport gasoline, kerosene and diesel at programmed periods and volumes depending on the depot ullage, loading capacities and the upstream facility products' availability. As gasoline is the priority product, the study aimed at maximizing its availability at all times.

For this depot, hourly gasoline supply capacity is 82 m3, whereas the loading/distribution is 100 m3 per arm. For a day's activity, twenty hours supply is 1,968 m3 while eight hours loading (distribution), will be 800 m3. Loading facility designed for two arms each for gasoline, kerosene and diesel (or 33.33% for each product) whereas gasoline storage capacity is 55%, kerosene 11%, diesel, 33% and slops, 1% of the total depot capacity. The design supply to distribution chain capacity ratio showed a mismatch, which in actual operation becomes 2:1. The above design created ullage problem at sustained supplies, gross under utilization of supply chain infrastructures and poor operational performance.

After a technical evaluation, a section of the depot storage to loading pipeline network was re-designed and modified to enable products supply capacity match loading, and minimize products accumulation over a period. Hence the gasoline loading became 66.67%, kerosene and diesel, each of 16.67%. Overall, the actual supply to distribution chain capacity ratio was increased in favour of the latter from 2:1 to 2:2 (and when required, can be maximized to 2:3) thereby correcting the apparent mismatch between the supply and distribution chain capacities. The modification has enabled the refiner to increase depot and upstream supply chain utilization. Since some of the depots may have similar problems and bottlenecks, the refiner can also apply the concept used here to those facilities and achieve optimum utilization.

Keywords: Supply, distribution, match, stock, capacity.

2. Introduction

The Nigerian National Petroleum Corporation, a refiner, owns and operates a petroleum products pipeline network connected to twenty one storage depots across Nigeria. Products are supplied to the depots from the local refineries and ex-jetties (for imports) mainly by pipeline. The main objective of establishing the pipeline network and the depot facilities by the refiner was to ensure efficient product distribution, reduce transportation cost and minimize products price differential across the country.

The concept, design and layout of the depot facilities were such as to maximize gasoline supply and distribution, which as a major transportation fuel, has the highest demand profile over kerosene and diesel. Since the early 1990s, as gasoline demand increased by over 30% the entire supply/distribution chain appeared inadequate. The refiner then began to find a solution to products supply and distribution. As gasoline is the priority product, the study aimed at maximizing its availability at all times.

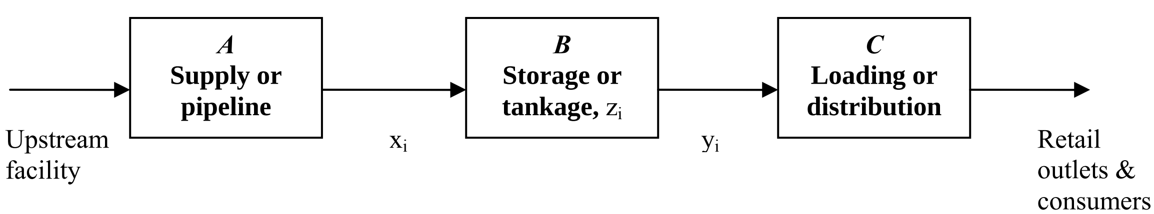
This study was carried out on one of the depots located in the North Central region of Nigeria, but receives products from upstream facilities (depot and pump station) in the Western region of the country.

Technical Evaluation

The Depot is supplied by a 6-inch multi-product (gasoline, diesel and kerosene) pipeline at 82 m3/hour and loading/distribution of 100 m3/hour per arm inside the depot.

The linkage between the depot facility and the upstream supply and downstream distribution chains is shown Figure 1 below.

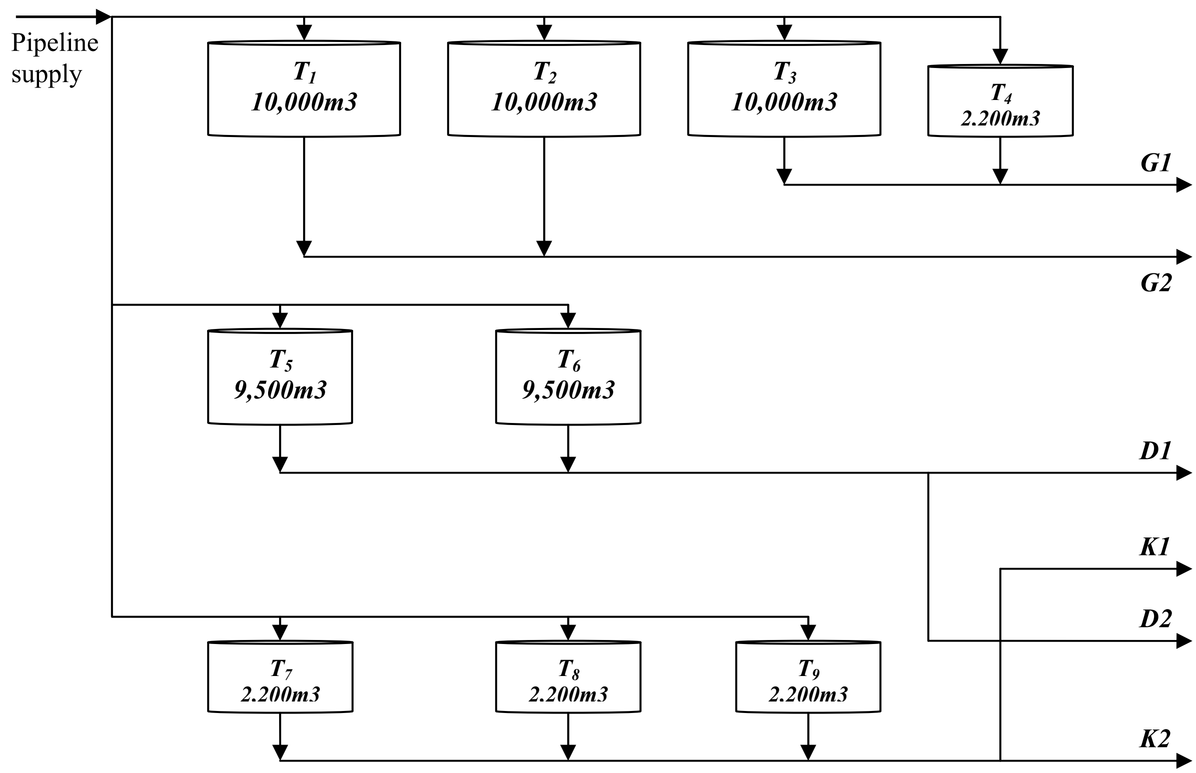
Figure 1: Supply Chain Linkage



Here ***A*** represents the pipeline and other supply sources, e.g., trucks; ***B*** and ***C*** represent the depot infrastructure linked as defined by the flowsheet defined below here.

Distribution/loading facility designed for two arms each for gasoline, kerosene and diesel (or 33.33% for each product) whereas gasoline storage capacity is 55%, diesel, 33%, kerosene 11%, and slops, 1% of the total depot capacity. The design supply to distribution chain capacity ratio showed a mismatch, which in actual operation becomes 2:1, creating bottlenecking in supply-distribution value chain. The ***Design*** flowsheet is shown below.

Figure 2: Representation of the ***Design*** Flowsheet



Total storage capacity profile shows:

	Formular	***Total Capacity (m3)***	***Capacity (%)***	***Capacity Ratio (Approx)***
Gasoline	$\sum T_{i\,(i=1,4)}$	32,200	55.0	6
Diesel	$\sum T_{i\,(i=5,6)}$	19,000	32.5	3
Kerosene	$\sum T_{i\,(i=7,9)}$	6,600	11.3	1
Slops		700	1.2	0
Total		58,500	100	10

This storage profile shows gasoline to diesel and kerosene at a ratio of 6:3:1. As per design, the maximum daily supply by the multi-product pipeline system is 1,980m3 for gasoline, 1,776m3 for diesel and 1,872m3 for kerosene. The loading arms and pumps are designed for 100 m3 per hour delivery each. The storage capacity profile, multi-product pipeline specification and scheduling limits this loading capacity. Products demand and supply have varied over the years, with the former becoming more than the latter, from late 1999. However, on a weekly 8-hour by 6-day operations, gasoline loading per day was 900m3 from two arms. Although the diesel and kerosene loading arms can do 900m3 each per day, the demand level, and the storage and multi-product pipeline services limits this capacity. Based on these, the weekly maximum gasoline supply was 13,860 and loading, 5,400m3 (when the pipeline is dedicated to gasoline supply only, during the period).

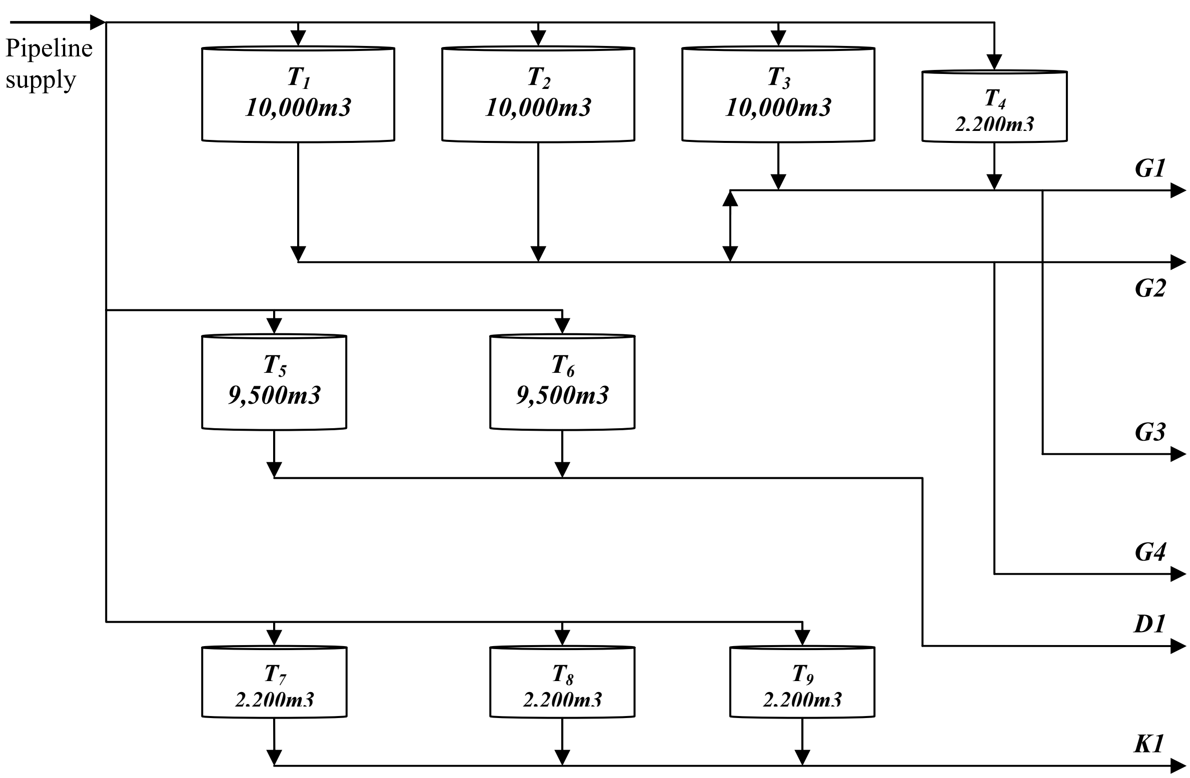
Flowsheet And Problem Analysis

The ***Design*** flowsheet provided for two loading arms each for gasoline, diesel and kerosene. Proper technical evaluation showed that this design appeared deficient as loading capacity did not match storage and distribution requirements. The ***Design*** flowsheet showed that for gasoline, two tanks T_1 and T_2, T_3 and T_4 are connected to two separate loading arms. This arrangement constrained operations and limited depot performance, especially with respect to gasoline.

The ***Design*** flowsheet shows the network to have 14 links between the tanks and the loading arms: gasoline and diesel 4 links each, and kerosene 6. In terms of flexibility in operations, kerosene has the greatest – 3 tanks can be loading from 2 arms, whereas gasoline, 2 tanks can be loaded from 1 arm.

A front-end evaluation of the depot facility revealed that integration of the tank farm and the loading arms pipeline network and re-distribution of the products tankage to loading arms linkage would improve distribution capacity, meet demand and reduce storage. This necessitated a detailed technical evaluation of the depot design concept, operations requirements, equipment capacity and flowsheet limitations, and products demand profile. Consequently, a section of the depot storage to loading pipeline network was re-designed and modified to enable products supply capacity match loading, and minimize products accumulation over a period. The depot pipeline network ***(Design)*** was modified ***(Modification)*** at negligible cost. The ***modification*** flowsheet is shown below.

Figure 3: Representation of the ***Modification*** flowsheet



Flowsheet Matrix Analysis

The depot's tank farm and loading sections flowsheets for design and modification can be defined as follows:

Design

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
G1	1	1	0	0	0	0	0	0	0
G2	0	0	1	1	0	0	0	0	0
D1	0	0	0	0	1	1	0	0	0
K1	0	0	0	0	0	0	1	1	1
D2	0	0	0	0	1	1	0	0	0
K2	0	0	0	0	0	0	1	1	1

Modification

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
G1	1	1	1	1	0	0	0	0	0
G2	1	1	1	1	0	0	0	0	0
G3	1	1	1	1	0	0	0	0	0
G4	1	1	1	1	0	0	0	0	0
D1	0	0	0	0	1	1	0	0	0
K1	0	0	0	0	0	0	1	1	1

Where for i=1,….,n, T_i, represents the tanks, and G_i, D_i, K_i, represent the loading arms (G for gasoline, D for diesel and K for kerosene): T_{1-4} (gasoline), T_{5-6} (diesel) and T_{7-9} (kerosene); and '1' represents a link between G_i, D_i, K_i, with T_i, and '0' implies no link.

The ***Design*** flowsheet of Figure 1 is defined by the ***Design*** FM, while the ***Modification*** flowsheet of Figure 3 is defined by the ***Modification*** FM. The ***Modification*** flowsheet shows the network now has 21 links, an increase of 7 (or 50 percent) over the ***Design.*** Two loading arms converted to gasoline resulting in four loading arms for gasoline. Gasoline tanks can supply any or all of the four loading arms. Diesel and kerosene where reduced by about half of the design distribution capacity thereby matching storage and demand requirements.

Since gasoline is the main focus of the modification, the flowsheet matrices can be re-defined on diesel- and kerosene-free basis as follows:

Design

	T_1	T_2	T_3	T_4
G1	1	1	0	0
G2	0	0	1	1

or

$$\hat{A}_d = \begin{vmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{vmatrix} \qquad 1$$

Modification

	T_1	T_2	T_3	T_4
G1	1	1	1	1
G2	1	1	1	1
G3	1	1	1	1
G4	1	1	1	1

or

$$\hat{A}_M = \begin{vmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix} \qquad 2$$

$\hat{A}_d$ is significantly and structurally upgraded as shown in $\hat{A}_M$ above, enabling a much more flexible and increased capacity. For a week of 8-hour by 6-day operations, the modified flowsheet allows gasoline loading up to 3,200m3 per day with the four arms; with diesel and kerosene loading capacity at 200m3 each per day to meet demand and supply. Based on these, the weekly maximum gasoline supply will be 13,860 and loading, 10,800m3. Although the gasoline loading capacity has been increased to 3,200m3 per day, loading must be within supply to avoid stock-out.

3. Supply and Distribution Balance

From Figure 1, for day i (i=1,…m), the relationship between supply (x_i), distribution (z_i) and stock (y_i) can be defined as

$$y_i = x_i - z_i \quad (3)$$

with accumulation as

$$\sum y_i = \sum x_i - \sum z_i. \quad (4)$$

And Stock Index (SI) defined as:

$$SI = ((x_i - z_i)/x_i). \quad (5)$$

The strategy here is to minimize SI. As defined above, since the pipeline is a multi-product system scheduling for optimum utilization is very critical[1,2].

Based on the above analysis, supply and distribution balance was determined to enable proper evaluation of the impact of the ***Modification*** over the ***Design*** flowsheet for a period of ten years – 1995-2005.

Observation

The analysis of the depot post modification performance compared pipeline scheduling, depot stock profile and overall products distribution. The result (from June 2004) showed significant improvement in pipeline transportation scheduling (Figure 4-5), depot stock (Figure 6) and overall products distribution (Figure 7).

The outcome of the pipeline scheduling on the depot stock profile showed that the modification has enhanced the management of stock levels, reducing the number of switching from one product to another, minimizing slops due to buffers, etc. Stock index in actual performance was maintained at minimum over the same period (June 2004 – December 2005).

Fig.4 Typical Yearly Supply Schedule – Design

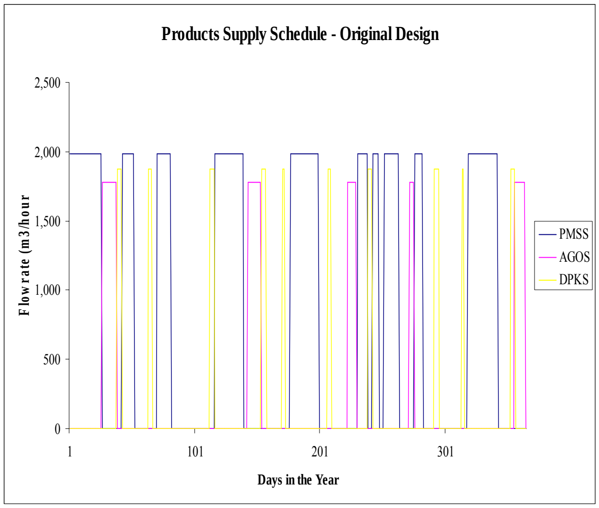


Fig.5 Typical Yearly Supply Schedule - Modification

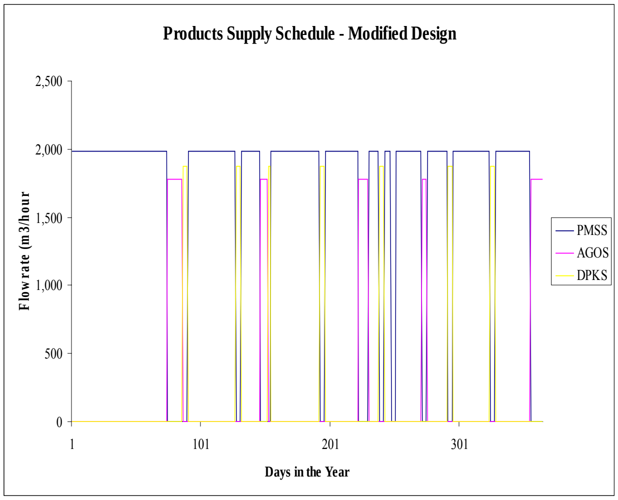


Fig.6 Stock Profile For Products Scheduling/Distribution

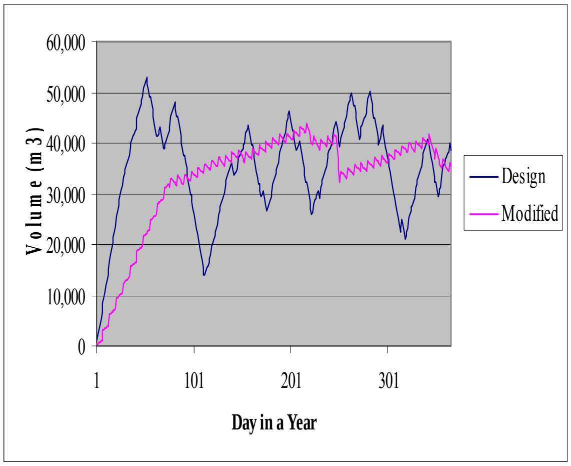
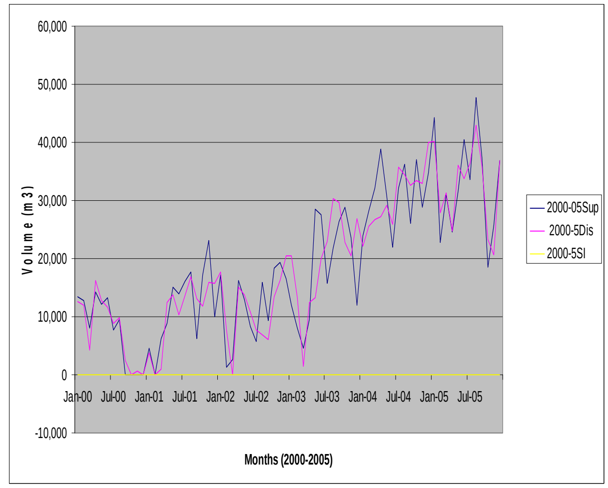


Fig. 7 Supply, Distribution & SI Profiles for gasoline (2000-05)



4. Conclusion

The above results showed that the modification has impacted positively on the depot facility – changing products distribution/loading ratio and improving installed capacity. The depot facility modified status has made gasoline loading to become 66.67% (up from 33.33%), kerosene and diesel, each of 16.67% (down from 33.33%). Overall, the actual supply to distribution chain capacity ratio was increased from 2:1 to 2:2 (and when required, can be maximized to 2:3) thereby correcting the apparent mismatch between the supply and distribution chain capacities.

The modification has enabled the refiner to increase depot and upstream supply chain utilization. Since some of the depots may have similar problems and bottlenecks, the refiner can also apply the concept used here to those facilities and achieve optimum utilization.

Nomenclature

T Product tank,
G/G_i Gasoline/Gasoline loading arm,
D/D_i Diesel/Diesel loading arm,
K/K_i Kerosene/Kerosene loading arm,
FM Flowsheet matrix,
$\hat{A}$ Flowsheet matrix representation,
SI Stock index,
x_i product supply, m3/hr,
y_i stock, m3,
z_i product distribution, m3/hr

Reference

1. Milidiu, RL, Liporace, F, and P. de Lacena CJ, Pipesworld: Planning pipeline transportation of petroleum derivatives. ICAPS Workshop on Competition, Italy, June, 2003
2. Smith, R Chemical Process design and integration. John Wiley & Sons, USA (2005).