Decision Support System for Design and Evaluation of Pipeline Projects

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Background

Petronet India Limited (PIL) was created to give impetus to investments in pipeline projects for transportation of petroleum products in the country. Since these projects have a long life and require large investments, correct assessment of location, capacity and financial viability are of critical importance. This paper is based on the study undertaken for PIL to evaluate a few of their pipeline projects. The study resulted in creation of a comprehensive software package that is capable of operational and financial evaluation of pipeline projects based on countrywide view on production and distribution of petroleum products. The core of the package is an LP based optimization model. The package is capable of performing sensitivity analysis to investigate the impact of uncertainty on the proposed project due to from changes in the values of key factors including distribution network and capacities, refining capacities and pattern of demand.

Objectives of the Study

The specific objectives of the study were as follows:

- To develop a model for identification of viable pipeline projects, taking into account the demand and capacity additions to production and distribution network for petroleum products in the future,
- To develop a model for financial evaluation of such projects based on appropriate assumptions to forecast the investments required as well as the net cash flows from the project,
- To implement the solution procedure for the models developed in the form of a software package that would allow the decision maker to experiment with assumption and generate solutions with ease and with little manual intervention,
- To embellish the software package developed above so that it also provides additional information to the decision maker in the form of reports that contain details of movement of products and the mode combinations used for the movements.

Methodology

The supply of petroleum products to users in a vast country like India is a challenging exercise. Since the government still makes most decisions regarding production and distribution of several petroleum products, the existing or the past pattern of production and distribution can not be a guide to the pattern that would prevail in the future once the petroleum sector is completely deregulated. The methodology is based on the assumption that sooner than later the oil sector will be completely decontrolled on the same lines as some of the other sectors such as cement and steel have been. The market forces would then determine the pattern of production and distribution of petroleum products. In such a scenario, in all probability, competition would ensure that the flow of petroleum products would be such as to minimize the total production and distribution costs for the country. The search for financially viable pipeline projects and the evaluation of proposed pipeline projects are therefore be based on the assumption that such optimal production and distribution pattern would prevail in the sector. The optimal flows are therefore determined by using a comprehensive optimization model for the entire country. Though the optimal solution is the core of the methodology, several other procedures are required to achieve the objectives stated in the preceding section. The different segments of the entire procedure are described separately.

Optimization Model

Two possible approaches to building an optimization model for production, sourcing through imports and multi-modal distribution of petroleum products were available: a) a network-flow model, b) a transshipment model. We decided to use the transshipment model. The major advantage of the transshipment model is that unlike the network flow model, it provides complete information on the route and the mode combinations used by every source-destination pair that is connected in the optimal solution. The attributes of the model developed are as follows:

- it minimizes the production and distribution costs for petroleum products for the entire country for a specified year
- it takes into account the demand and supply constraints for petroleum products
- it takes into account the port capacities for import of products
- it provides for multi-modal (combination of one or several modes of transportation) distribution, the modes considered being road, rail, pipeline and sea (for coastal movement)
- it assumes that the last segment of transportation to the final consumer (demand point) is always by road
- it uses the districts as the demand points or final destinations (these are 467 in number)
- it uses the existing refineries and the proposed refineries as the sources (these are 20 in number)
- it uses the existing ports as being available for imports (these are 18 in number)
- it takes into account the port capacities

- it assumes that imports would be resorted to only if there is a shortage of products in the country in aggregate
- it uses existing and planned storage as transshipment points (these are 141 in number)
- it assumes that adequate road and rail transportation capacity would be available if the capacity requirements are planned
- it takes into account the pipeline capacities

The model has the flexibility to accommodate changes in the number of sources, ports, destinations and trans-shipment points. The model also uses the idea of a "super source" or the source of last resort that is to be used in case it is infeasible to meet the demand from legitimate sources. The super source supplies at a prohibitively high cost and is connected to all destinations. It comes into use only when supply to a destination from legitimate sources is inadequate either due to the sources operating at full capacity or due to absence of connectivity to the destination. The inclusion of a super source ensures that the model does not encounter infeasibility due to inadequate availability of petroleum products. The mathematical formulation of the model is as follows:

Minimize Total Production and Distribution Cost, $Z = \sum_{i-k,m} c^m_{i-k} x^m_{i-k}$

Subject to:

(1) Demand constraints.

$$\sum_{i-,m} x^m_{i-k} \geq D_k \quad \text{for every source destination}$$

(2) Availability constraints.

$$\sum_{-k,m} x^m_{i-k} \leq S_i \quad \text{for every source}$$

(3) Pipeline capacity constraints

$$\sum_{i-k,m \, e \, \text{pipeline pl}} x^m_{i-k} \leq PL_{pl} \quad \text{for every pipeline}$$

(4) Port capacity constraints

$$\sum_{i-k,m \, e \, \text{port p}} x^m_{i-k} \leq Port_p \quad \text{for every port}$$

(5) Import constraints

$$\sum_{i-k,m \, e \, \text{ports}} x^m_{i-k} \geq \max(0, \sum_k D_k - \sum_i S_i)$$

imports are resorted to only if there is shortage in the country

Where the subscripts i, j, k, p, pl and m denote source, depot, district, port, pipeline segment and mode combination.

c_{i-k}^{m} denotes the unit cost of transporting from source i to district k through one, two or three depots by mode m

x_{i-k}^{m} denotes the quantity to be sent from source i to district k through one, two or three depots by mode m

The symbol m that stands for the mode of transportation, can take values from 1 to 8, depending upon the mode combination used (these are described later).

The notation i-k represents ij_1k or ij_1j_2k or $ij_1j_2j_3k$. If the supply from a source to a district takes place through one depot then the subscript for the variable is ij_1k. If the supply to a district takes place through two or three depots then the subscripts for the variable are ij_1j_2k or $ij_1j_2j_3k$ respectively.

Choice of Software

The description of the model clearly shows that we are talking about an optimization problem of a very large size, involving tens of thousands of variables and thousands of constraints. Several software packages are available for solving large optimization problems. However, all of them may not have been fully tested on reliability of performance, particularly when the size is very large. At the time of the study, Petronet was using LINDO software. This software has several versions. The professional version of the software is adequately equipped to deal with the proposed model. The software however had a major limitation with regard to naming of variables. The version of LINDO at the time accommodated a maximum name length of 8 characters. As would become apparent later, we required larger number of characters to meaningfully name the variables. We therefore decided to opt for another software, CPLEX. This package is regarded as a leading software package for solving optimization problems. In addition to providing larger width for naming of variables, the package deals very effectively with cycling, that is an occurrence where the optimal seeking procedure is unable to proceed to the optimal solution. Since there is always a fair chance of encountering cycling in large problems, ability to deal with cycling is an important feature of any software. The package is also one of the fastest is generating an optimal solution. These were the considerations that prompted us to choose CPLEX.

Implementation Issues

Even when software such as CPLEX is available, considerable effort is required to customize the use of the software for the specific problem at hand. The algebraic formulation of the problem needs automation to eliminate the errors arising from tedious manual procedures and to make it possible to change the formulations quickly to generate

solutions under alternate scenarios. Such pre-processor software is of essential for such large sized optimization problems.

The pre-processor software can be written in any of the high level languages such as C, C++, Visual C++, Visual Basic, or Visual Basic for Applications (VBA). The choice of the language in which the software is written is crucial since that determines the flexibility - ease of modification, ease of interfacing with data, and ease of reading and writing the input and output files. Since the basic data were provided to us as Excel workbooks, we decided to write the pre-processor software in VBA, a language that works seamlessly with Excel. The language has all the desirable attributes mentioned earlier. In addition, it is easy to learn and comes as a component of the Microsoft Office suit. The pre-processor software developed by us contains about 3000 lines of coding. It reads the data, carries out broad checks on the data for correctness, identifies routes for problem formulation, computes the costs for the routes and generates the algebraic formulation for the problem that is directly accessible by CPLEX for generating the optimal solution.

The output of CPLEX, that is the optimal solution, is in the form of a text file. Since the output is very large, meaningful interpretation of the output becomes a difficult task without assistance. To help the decision-maker to interpret the solution therefore, we wrote a post-processor software. The post-processor software was also written in VBA. This software first reads the output text file into a workbook. The results are then analyzed using Excel's processing capability to generate a set of ten summary reports. The last four characters of the names of standard reports represent the year. Needless to add, any non-standard report can be easily generated since the optimal output is available on a worksheet.

Data

The data required for the problem can broadly be grouped into four categories. The first category is the cost data – the mode-wise cost of transportation from sources to depots/districts, from depots to depots and from depots to districts and the differential cost of production for the refineries. The second category of data is the consumption data – the product-wise, year-wise consumption of petroleum products over six years (1994-1999) for each district. The third category of data is the supply data – the product-wise, year-wise output expected from various refineries over eleven years (2001-2011). The fourth category of data is the capacity data – the capacities of the existing and planned pipelines and the port capacities. Since the quality of data would decide the usefulness of the outputs, we developed software that carries out broad checks on the correctness of the data. These checks are performed whenever the data set is modified.

Forecasting of Demand and Availability

Assessment of Demand

District-wise consumption data was made available for the five products, namely, motor spirit, high-speed diesel, naphtha, aviation turbine fuel, and kerosene for each of the six years - 1994 to 1999. The forecast for demand for these products is based on this data.

The two possible ways of modeling the demand for petroleum products would be : a) assume a linear growth in demand over time (Model 1), b) assume a constant growth rate in the demand (Model 2). The two would give rise to the following specifications of the models for demand for petroleum products:

Model 1:

$$D_t = a + bt + e_t$$

Model 2:

$$D_t = a + b(1+g)^t + e_t$$

The second model implies an exponential increase in the demand for petroleum products. A preliminary analysis of the data indicated that such an explosion of demand is unlikely to happen. Hence, the more realistic Model 1, implying a steady increase in demand over time was chosen for forecasting the demand in the future.

The Aggregate Demand

The coefficients for the linear model were estimated, using the aggregate consumption data for the six years from 1993-94 to 1998-99. The demand (consumption) functions for each product are presented in Table 0.

Table 0 : The Aggregate Demand (Consumption) Function

Product	The Estimated Demand Function	The R-square
MS	3538.41 + 336.61 T	0.984
SKO	8272.50 + 356.50 T	0.970
HSD	24269.47 + 2322.27 T	0.941
Naphtha	2252.59 + 557.77 T	0.852
ATF	1768.04 + 70.09 T	0.683

The R-squares for all the products are statistically highly significant. This establishes the validity of the model for forecasting the aggregate demand (consumption) for each of the products.

District-wise Demand for Products

The coefficients of the model were estimated for each of the five products, for each of the districts that had consumption data. The distribution of the multiple coefficient of determination (R-square) and the distribution of R-squares according to level of significance, for each product are presented in Table 1 and Table 2 respectively. It is clear that the model fits the consumption data quite well for MS, SKO and HSD. The fit is not good for Naphtha and ATF. On closer examination of the data the reasons for the poor fit were quite evident. For many districts, the consumption of Naphtha and ATF is flat, that is, unchanging over time. In such cases, obviously, the linear model returns a poor fit. In addition, in case of Naphtha and ATF, for several districts, the consumption was sporadic, with the consumption being nil for some of the six years. In such situations too the linear model shows a poor fit.

The forecasting of demand (consumption) of the products was done using the models as estimated for every year from 1999-2000 to 2009-2010. Since these are point forecasts, even when the fit is poor, the forecast appears quite reasonable. For example, when the fit is poor because of a flat consumption pattern, the forecast will essentially be the average for the past six years - which ought to be a good assessment of the demand in the future. Overall, there were very few situations where the forecasts appeared to be unreasonable. However, with the objective of keeping manual interventions to the minimum, no attempt was made to subjectively change the output arrived at on the basis of the regression estimates. This ensures that the methodology can be easily automated and does not require intervention by the user. The software for forecasting is also written in VBA and consists of about 500 lines of coding.

Table 1 : Distribution of R-square

| R-square | Frequency | | | | |
	MS	SKO	HSD	Naphtha	ATF
0.05	19	18	24	11	32
0.10	8	12	10	3	8
0.15	7	8	6	1	4
0.20	3	7	2	14	22
0.25	8	12	2	2	5
0.30	9	9	6	1	9
0.35	6	6	3	2	5
0.40	10	10	11	2	6
0.45	7	7	10	17	22
0.50	9	16	10	4	7
0.55	14	12	11	2	5
0.60	9	13	11	1	10
0.65	9	13	15	1	5
0.70	11	25	16	8	15
0.75	13	25	19	4	7
0.80	27	26	35	2	6
0.85	18	47	41	0	3

0.90	45	70	64	1	6
0.95	75	66	76	2	3
> 0.95	153	57	91	0	4
Total	**460**	**459**	**463**	**78**	**184**

Table 2: Significance of R-squares

Significance	MS	SKO	HSD	Naphtha	ATF
< 10%	18.70%	22.88%	18.14%	73.08%	65.22%
at 10%	6.96%	8.28%	7.99%	5.13%	10.87%
at 5%	11.09%	16.56%	15.12%	17.95%	15.22%
at 1%	63.26%	52.29%	58.75%	3.85%	8.70%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

Assessment of Availability

The availability of products at various refineries was assessed based on the three sets of production plans for the refineries, one each for years 2002-3, 2006-7 and 2010-11, provided by Petronet. Interpolation was used to assess the availability of products for the others years. The availability of a product at a port was restricted to the overall port capacity. The model formulation ensures that imports are used only when the domestic production is inadequate to meet the requirement. The software for the module is written in VBA and consists of about 150 lines of coding.

Coding, Path and Variable Names

It is necessary to name the variables such that the path and the mode combination used from the source to the district can be identified. The codes used for names also need to be within the length permitted by the optimization software. While LINDO permits use of a maximum of 8 characters, CPLEX permits use of up to 15 character codes. As pointed out earlier, this is another significant advantage of CPLEX.

As is evident from the algebraic formulation of the mathematical model in an earlier section, the products may be transported through one, two or three depots to the districts from a source. This path may use different mode combinations. The code for the variables therefore should capture the identities of the source, depots, district, the mode combinations used and the product group.

There are 10 coastal refineries, 10 inland refineries and 18 ports. In addition, a (dummy) super source has been used in the formulation to deal with infeasibilities arising either from inadequacy of supplies or from non-connectivity. Given these, two characters were reserved for identifying the sources. The code thus can accommodate up to 676 sources. It would therefore be quite adequate for future additions to sources, since the total number of sources as of now is only 39. Since Petronet had been using a three-character code for source, we had to provide for mapping of our two-character codes to the three-character codes of Petronet. An illustrative list of sources is presented in Table 3.

Table 3 : The Code for Sources

No.	Code-2	Code-3	Name
1	AA	BAR	BARAUNI
2	AB	BIN	BINA
3	AC	BON	BONGAIGAON
4	AD	BTD	BHATINDA
5	AE	BUD	CALCUTTA
6	AF	COC	COCHIN REFINERY
7	AG	COP	COCHIN PORT
8	AH	CRE	CUDDALORE
9	AI	DAH	DAHEJ
10	AJ	DEO	DEOGARH

The current number of depots is 141. We used 2-character code to represent depots. This code too therefore can accommodate up to 676 depots, much larger than the present number of depots. The code therefore provides adequate room for expanding the list of depots. An illustrative list of depots is presented in Table 4. Code-2 is our code and Code-3 is the code used currently by Petronet.

Table 4 : The Code for Depots

No.	Code-2	Code-3	Name
1	AA	AGR	AGRA
2	AB	AJM	AJMER
3	AC	AKO	AKOLA
4	AD	ALH	ALLAHABAD
5	AE	AMB	AMBALA
6	AF	AMR	AMRITSAR
7	AG	AUR	AURANGABAD
8	AH	BAD	BADNERA
9	AI	BAL	BALASORE
10	AJ	BAN	BANGALORE

There are currently 467 districts in the country. We employed a 3-character code to represent districts. The third character was added to provide for the possibility that the number of districts could become larger than 676 sometime in the future (!). The code can thus handle up to 17576 districts without modifications. The following table gives the district code for the first ten districts. An illustrative list of districts is presented in Table 5. Code –3a is our 3-character code and Code-3n is the 3-digits numeric code used by Petronet.

Table 5 : The Code for Districts

No.	Code-3a	Code-3n	Name
1	AAA	001	SRIKAKULAM
2	AAB	002	VIZIANAGARAM
3	AAC	003	VISAKHAPATNAM
4	AAD	004	EASTGODAVARI
5	AAE	005	WESTGODAVARI
6	AAF	006	KRISHNA
7	AAG	007	GUNTUR
8	AAH	008	PRAKASAM
9	AAI	009	NELLORE
10	AAJ	010	CHITTOOR

After detailed discussions with Petronet, eight different mode combinations were used for the model.

1   Pipeline, Road
2   Coastal, Road
3   Rail, Road
4   Road, Road
5   Coastal, Pipeline, Road
6   Coastal, Pipeline, Rail, Road
7   Rail, Road, Road
8   Pipeline, Rail, Road

As is evident from the above description, the last mode of transportation (from the final depot to district) is always by road. The depots can be reached from the source either directly or through one or two depots. The first four mode combinations represent use of pure modes for reaching the depots from the sources. The last four mode combinations represent use of mixed modes for reaching the depots from the sources. For example, mode combination 5 represents transportation by ship (coast) from source to depot, by pipeline from depot to depot and finally by road from depot to district.

The products were divided into two groups, the Light end comprising MS and Naphtha, are represented by L and the middle end comprising HSD, SKO and ATF are represented by P. A single character is adequate to capture the product category.

The final length of the code is 9, 11 or 13 characters. These respectively represent use of 1, 2 or 3 depots for transportation from a source to a district.

Since each path of reaching a district from a source through depot(s) defines a variable, the path name and the variable name are the same. The name should capture the full details – the names of source, depots, district, mode combination and product group. For example, an illustrative list for mode combination 1 would be as follows:

Table 6: 9-Character Variable Names

BLEKAAE1L
BLEKAAF1L
BLEKAAT1L
BLEKAAU1L
BLEKAAV1L
BLFKAAE1L
BLFKAAF1L
BLFKAAG1L
BLFKAAH1L
BLFKAAI1L

The first two characters identify the source, the next two characters identify the depot, the next three characters identify the district, the digit 1 identifies the mode and the last character L represents the product group

An illustrative list of 11 character codes is as follows:

Table 7: 11-Character Variable Names

AZDMCZAGI5L
AZDMCZAGP5L
AZDMCZAJP5L
AZDMCZAJQ5L
AZDMCZAJR5L
AZDMCZAJS5L
AZDMCZAJT5L
AZDMCZAJU5L
AZDMCZAJY5L
AZDMCZAJZ5L

For the first code in the list AZ is the source, DM is the first depot; CZ is the second depot, AGI is the district; 5 is the mode, L denotes light ends.

An illustrative list of 13 character codes is as follows:

Table 8: 13-Character Variable Name

AZDMCZBXAAP6L
AZDMCZBXAGK6L
AZDMCZBXAGL6L
AZDMCZBXAGQ6L
AZDMCZCFAAF6L
AZDMCZCFAAG6L
AZDMCZCFAAI6L
AZDMCZCFAAK6L
AZDMCZCFAAL6L
AZDMCZCFAAM6L

For the first code in the list AZ is the source, DM is the first depot; CZ is the second depot, BX is the third depot, AAP is the district; 6 is the mode, L denotes light ends.

The software developed by us enumerates all feasible paths based on the data on connectivity. For each path thus enumerated, the total cost of transportation is computed on the basis of cost data.

Model Generator

The preceding section described the process of enumerating all the paths/variables. These variables thus generated along with the associated unit costs are used to construct the objective function and the constraints for the optimization model. The constraints are generated by sorting the lists of variable by source, or by district or by pipeline segment or by port. These are converted into text files to be used as inputs for the CPLEX software. The content of these files would appear as follows:

Min
2117.5 AABEFJAAA7L + 11517.5   AEFJAAA3L + 11665.6 AHFJAAA3L   +
20174.8 ALFJAAA4L + 1403.9 AOBEFJAAA7L   + 1970.9 APBEFJAAA7L   +
… **+**
s.t.
   - L001   +ABEFJAAA7L+AEFJAAA3L+AHFJAAA3L+ALFJAAA4L+
      AOBEFJAAA7L+APBEFJAAA7L+ASFJAAA3L+ … **+**

Generation of Reports from Optimal Solutions

The optimal solution reached by CPLEX is in the form of a text file. This file contains the the list of variables in the optimal solution and their corresponding values and the value of the obejective function. This output requires further processing for meaningful interpretation. We therefore developed a post-processor software in VBA to generate summary reports based on the optimal solutions. The software consists of about 3000 lines of coding. Before generating these reports, the values of variables are disaggregated into the five different products. The Light end product variables are split into MS and

Naphtha and Middle end prodcut variables are split into HSD, SKO and ATF. The disaggregation is done on the basis of the proportion of demand for a product within the product group it belongs to computed for the district. The proportion varies from year to year.

The summary reports generated are described in the following sections.

District Report

This report provides details about the manner in which each district receives its requirement from different sources. The quantity, the cost, the mode and the complete path from each source to the district are displayed in the report. The report is contained in the workbook named DISTXXXX, where XXXX represents the year. For example DIST2007 would be the district flow report for year 2006-2007. Each workbook has five worksheet, one each for MS, Naphtha, SKO, HSD and ATF. An excerpt from such a report for year 2006-7 is presented in Table 9.

Table 9: Districtwise, Productwise, Receipts for MS for 2007

No	District	Qty	Source	Mode	Depot1	Depot2	Depot3
1	SRIKAKULAM	5.93	VIZAG REFINERY	4	VISAKHAPATNAM		
2	VIZIANAGARAM	6.60	VIZAG REFINERY	2	VISAKHAPATNAM		
3	VISAKHAPATNAM	46.34	VIZAG REFINERY	4	VISAKHAPATNAM		
4	EASTGODAVARI	33.42	VIZAG REFINERY	4	VISAKHAPATNAM		
5	WESTGODAVARI	29.10	VIZAG REFINERY	5	VISAKHAPATNAM	R'MUNDRY	
6	KRISHNA	39.15	VIZAG REFINERY	5	VISAKHAPATNAM	VIJAYAWADA	
7	GUNTUR	25.59	VIZAG REFINERY	5	VISAKHAPATNAM	VIJAYAWADA	
8	PRAKASAM	10.25	MADRAS REFINERY	2	MADRAS		
9	NELLORE	10.23	MADRAS REFINERY	4	MADRAS		
10	CHITTOOR	20.27	MADRAS REFINERY	4	MADRAS		

Source Reports

There are two reports on sources. This first report provides details about the manner in which each source supplies products to different districts. The quantity, the cost, the mode and the complete path to the districts that are supplied by the source are displayed in the report. The report is contained in the workbook named SOU1XXXX, where XXXX represents the year. For example SOU12007 would be the source flow report for year 2006-2007. Each workbook has five worksheet, one each for MS, Naphtha, SKO, HSD and ATF. An excerpt from such a report for year 2006-7 is presented in Table 10.

Table 10: Sourcewise, Productwise, Despatches for MS for 2007

No	Source	Qty	District	Mode	Depot1	Depot2	Depot3
1	BARAUNI	29.20	ALLAHABAD	1	ALLAHABAD		
1	BARAUNI	6.81	DARBHANGA	4	BARAUNI		
1	BARAUNI	5.14	PRATAPGARH	1	ALLAHABAD		
1	BARAUNI	4.90	SHAHDOL	1	ALLAHABAD		
1	BARAUNI	4.15	MADHUBANI	4	BARAUNI		
1	BARAUNI	4.13	BHAGALPUR	4	BARAUNI		
1	BARAUNI	3.95	SIDHI	1	ALLAHABAD		
1	BARAUNI	3.61	ROHTAS(SASARAM	4	BARAUNI		
1	BARAUNI	3.44	SARAN	4	BARAUNI		
1	BARAUNI	3.40	SAMASTIPUR	4	BARAUNI		

The second report on sources named SOU2XXXX contains details about the quantities evacuated through different modes from each source. The report is contained in the workbook named SOU2XXXX, where XXXX represents the year. For example SOU22007 would be the mode-wise flow report for year 2006-2007. Each workbook has five worksheet, one each for MS, Naphtha, SKO, HSD and ATF. An excerpt from such a report for year 2006-7 is presented Table 11.

Table 11: Sourcewise, Modewise, Distribution for MS for 2007

	Mode								
Source	1	2	3	4	5	6	7	8	Tot.Qty
BARAUNI	43.88			45.65					89.54
BINA	89.71		76.60	55.57					221.89
BONGAIGAON				6.76					6.76
BHATINDA	274.42		101.78	574.19				6.00	956.39
COCHIN REFINERY	7.32	266.70	54.70	245.55	231.86				806.13
DIGBOI				18.37					18.37
GAUHATI	36.51			69.25					105.76
HALDIA REFINERY	61.90	50.62	138.86	31.08	69.99		67.74		420.19
KOYALI	199.00		57.75	85.28				20.29	362.32
MADRAS REFINERY		156.53	23.80	168.52	45.88				394.73

Pipeline Report

This report provides information on the thruput for each pipeline segment. The report is contained in workbook PIPEXXXX, where XXXX represents the year. For example PIPE2007 would be the report for year 2006-2007 on pipeline utilization. An excerpt from the pipeline report for 2006-7 is presented Table 12.

Table 12: Pipeline Utilisation

Segment	Quantity ('000 tons)
VIZRRY	267.28
VIZVWD	1,593.05
VIZHYD	1,641.60
PARCTK	1,254.68
PARRLA	377.55
PARRAN	573.22
HALMOU	37.04
HALRAJ	291.27
GAUSIL	434.01
BARALH	3,000.00

The section VIZRRY (Vizag Rajamundry) has carried 267.28 (i.e 2,67,280 metric tonnes). The other figures can be interpreted in a similar manner.

Statewise Demand and Supply of Products

This report provides information on demand and supply for each state. The report is contained in workbook STATXXXX, where XXXX represents the year. For example, STAT2007 would be report for year 2006-07. The workbook has five worksheets, one for each product. The report for year 2006-7 for MS is presented in Table 13.

Table 13: Statewise Supply and Demand Position for MS for 2007

('000 tons)

	Demand	Supply	Difference
ANDHRA PRADESH	649.17	758.39	109.22
ANDMAN&NIKOBAR	4.47		-4.47
ARUNACHAL PRAD.	15.61		-15.61
ASSAM	56.73	264.99	208.26
BHUTAN	4.08		-4.08
BIHAR	200.43		-200.43
CHANDIGARH	83.82		-83.82
DADRA&NAGARHAV.	9.24		-9.24
DAMAN & DIU	8.29		-8.29
DELHI	756.17		-756.17
GOA	49.32		-49.32
GUJARAT	736.27	918.78	182.51
HARYANA	248.41	1,102.26	853.86
HIMACHAL PRADES	44.56		-44.56
JAMMU & KASHMIR	88.87		-88.87
KARNATAKA	542.29	1,106.62	564.33
KERALA	443.70	806.13	362.43

LAKSHADEEP	.01		-.01
MADHYA PRADESH	385.31	221.89	-163.42
MAHARASHTRA	1,247.49	776.50	-470.99
MANIPUR	10.08		-10.08
MEGHALAYA	23.81		-23.81
MIZORAM	8.57		-8.57
NAGALAND	10.45		-10.45
ORISSA	134.02	110.54	-23.48
PONDICHERRY	28.64		-28.64
PUNJAB	596.02	956.39	360.38
RAJASTHAN	366.69		-366.69
SIKKIM	11.05		-11.05
TAMILNADU	710.78	428.08	-282.70
TRIPURA	8.36		-8.36
UTTAR PRADESH	618.23	421.88	-196.36
WEST BENGAL	191.71	420.19	228.48
	8,292.63	8,292.63	

The figures in the table indicate that Andhra Pradesh, Assam, Gujarat, Haryana, Karnataka, Kerala, Punjab and West Bengal do not consume all the MS they refine/import. They are surplus states, while all others are deficit states.

Depot Report

A depot receives products either from a source or from another depot. This report provides depot-wise details on amonut received from sources and amount received from other depots. The report is contained in the workbook named DEPOXXXX, where XXXX represents the year. For example DEPO2007 would be the flow report for year 2006-2007. Each workbook has five worksheet, one each for MS, Naphtha, SKO, HSD and ATF. An excerpt from such a report for year 2006-7 is presented in Table 14.

Table 14: Depotwise Movement of Products for MS for 2007

('000 tons)

DEPOT	From Source	From Other Depots	Total
AGRA	47.22		47.22
AJMER	28.56		28.56
AKOLA		23.79	23.79
ALLAHABAD	43.88		43.88
AMRITSAR	80.03		80.03
AURANGABAD		52.81	52.81
BADNERA		59.56	59.56
BANGALORE	264.44		264.44
BARAUNI	45.65		45.65
BAST1	9.01		9.01

Financial Evaluation of Projects

The rate that would prevail for trnasportation of products by pipeline after dismantling of APM (Administered Pricing Mechanism) was unclear at the time of the study (it is unclear even today!). Petronet was therefore using three rate-regimes for financial evaluation of pipeline projects. The three regimes were : a) Rs 0.12 per ton-km, b) 45% of the corresponding rail fare for the segment, c) 70% of the corresponding rail fare for the segment. The financial evaluation software developed by us uses these three regimes for evaluation of financial viability of projects.

The net cash flows to Petronet is from setting up and operating the pipeline are determined for the pipeline project life of 35 years. The rate of return is then computed, using this benefits stream and the cost of the project. The procedure first determines the optimal solutions, with and without the pipeline, for each of the eleven years (from 2000-2010) using CPLEX. There are thus 22 runs of the model (2 for each year). The revenue received from the project for each year is stored in a separate text file. These figures are then read into an excel workbook. The benefit stream to Petronet is extended beyond the eleventh year at the rate of of 6% per period. The return for the project is computed using the IRR-function available in Excel. The sensitivity of the rate of return to changes in the project cost is also carried out by the software. The wokbook that has the VBA routines for financial evaluation is FIN-ANA. The software consists of about 200 lines of coding.

Identification of New Pipeline Projects

The search for profitable routes for new pipelines should begin by examining the utilization of mode combinations that do not use pipelines. These combinations are 2, 3, 4 and 7. The software developed by us therefore ranks the paths for these modes in descending order of flows. The new pipline projects should essentially be based on a combination of these paths, since these are the paths that are heavily used and are therefore the best candidates for use of pipelines instead of other modes of transport. An illustrative list of paths that can be considered for new pipeline projects are presented in Tables 15 & 16.

Table 15: Non Pipeline Movements

Path	Quantity ('000 tons)
AYDMAJH4P	1513.09
BEBHARS4P	1164.81
AZDMAJJ4L	1129.91
ASDBANN4P	993.84
ARCVAEL4L	898.15
BLFJAAD4L	846.17
BJELAEI3P	758.22
BEBHARS4L	756.17
ARCCAEN3L	735.80
BJDMAJI2P	678.08

Table 16: Non Pipeline Movements (Decoded)

Source	Depot	District	Mode	Group	Quantity
MUMBAI HPCL	BOMBAY	GREATERBOMBAY	4	P	1,513.09
PANIPAT	DELHI	DELHI	4	P	1,164.81
MUMBAI BPCL	BOMBAY	RAIGAD	4	L	1,129.91
MADRAS REFINERY	MADRAS	CHINGELPET	4	P	993.84
KOYALI	KOYALI (baroda)	VADODARA	4	L	898.15
VIZAG REFINERY	VISAKHAPATNAM	EASTGODAVARI	4	L	846.17
VADINAR REFINERY	AHMEDABAD	AHMEDABAD	3	P	758.22
PANIPAT	DELHI	DELHI	4	L	756.17
KOYALI	SURAT	SURAT	3	L	735.80
VADINAR REFINERY	BOMBAY	THANA	2	P	678.08

A Case Study: Evaluation of Central India Pipeline

The section of Central India Pipeline Project evaluated starts at Koyali and end at Gwalior. The section consists of the following segments: koyali-ratlam, ratlam-indore, indore-bhopal, bhopal-itarsi, itarsi-nagpur, nagpur-hyderabad, ratlam-udaipur, udaipur-kota and kota-gwalior. The total length of the section is 2411 km.

The financial evaluation has been done assuming : a) the tariff for pipeline transportation is 70% of the corresponding rail fare, b) there is a 6% annual growth in tariff, to account for inflation, c) the cost of laying the pipeline varies from Rs. 1.50 crores to 3.00 crores per kilometer. Table 17 presents the internal rate of return (IRR) for the above project for different investment costs.

Table 17: Sensitivity to Change in Cost of Laying the Pipeline

Unit Cost (Rs. Crore/km)	1.50	1.80	2.00	2.20	2.40	2.60	2.80	3.00
IRR	14.01%	12.34%	11.46%	10.71%	10.05%	9.48%	8.96%	8.50%

The capacity specified for each segment is 99.999 million tons per year. The throughputs for optimal production and distribution plan for different segments for various years are presented in Table 18.

Table 18 : Throughput in Pipeline Segments

(in '000 tons)

Year	KOYRAT	RATIND	INDBHP	BHPITA	ITANGP	NGPHYD	RATUDA	UDAKOT	KOTGWA
2,000	1,881	771	277	284	38		734		147
2,001	2,115	828	293	290			786		663
2,002	1,795	884	433	297			728		1,365
2,003	2,003	945	517	313			780		1,662
2,004	2,117	1,045	545	321			823		1,820
2,005	2,230	1,341	572	328			870		2,483
2,006	2,476	1,109	376	323			1,046		15
2,007	2,326	1,166	393	330			964		472
2,008	2,560	1,229	626	349			1,011		1,032
2,009	2,683	1,410	728	359			1,058		1,363
2,010	3,179	1,335	443	350			1,254		546

Since products supplied to Indore from Koyali would necessarily flow through Ratlam, the total flow in the Koyali-Ratlam segment should take into account all the flows meant for other destinations that are further from Ratlam. The aggregate segment-wise flow using the above reasoning is presented in Table 19.

Table 19 : Aggregate Throughput in Pipeline Segments

(in '000 tons)

Year	KOYRAT	RATIND	INDBHP	BHPITA	ITANGP	NGPHYD	RATUDA	UDAKOT	KOTGWA
2,000	4,132	1,370	598	322	38		881	147	147
2,001	4,975	1,411	583	290			1,449	663	663
2,002	5,502	1,614	730	297			2,093	1,365	1,365
2,003	6,220	1,776	831	313			2,442	1,662	1,662
2,004	6,670	1,911	865	321			2,643	1,820	1,820
2,005	7,824	2,241	900	328			3,353	2,483	2,483
2,006	5,346	1,809	700	323			1,061	15	15
2,007	5,651	1,888	723	330			1,436	472	472
2,008	6,807	2,203	975	349			2,043	1,032	1,032
2,009	7,601	2,498	1,087	359			2,421	1,363	1,363
2,010	7,106	2,127	792	350			1,799	546	546

Concluding Remarks

The software developed has been automated to an extent where an uninitiated user can learn to meaningfully use the software very quickly. The software has the features of a full-fledged decision support system (DSS). The DSS automatically adjusts to changes in the basic data including the size of the problem, that is, can without modifications, cope with changes in the number of sources, depots, districts, ports and pipeline segments.

The time for one run of the DSS depends (in addition to the speed of the machine) on the conditions under which the run is taken. The three conditions could be broadly described as follows: a) no change in data, b) change in data other than for pipeline segments, c) change in data including changes in the pipeline segments. The times taken for these on a Pentium-II machine with 64 MB RAM are about 15 minutes, 60 minutes and 120 minutes respectively. Since most of the runs would belong to the first category, the time taken for evaluation of a pipeline project would be just 15 minutes.