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CRUDE SCHEDULING PACKAGE FOR AN INDIAN CROSS-COUNTRY CRUDE PIPELINE

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ABSTRACT

Transportation of crude oil and petroleum products through pipelines is the backbone of inland transportation, as it is the safest and cheapest mode for any hydrocarbon supply chain. Pipeline transport plays a vital role in sustaining the supply of crude and products across India.

However, the scheduling of pipeline operation with respect to batch formation, minimum tanker demurrage (penalty laid for not discharging the tanker), minimum transportation and inventory cost has always been a complex issue, which the pipeline scheduler must address on a monthly as well as daily basis. The scheduling problem is more complex if the pipeline is to be operated and scheduled in a manner integrated with refinery operations. Historically, these scheduling operations have required expert schedulers working on a case-by-case basis to address these issues.

The availability of pipeline scheduling tools with optimization features has made complex pipeline scheduling simpler and more cost effective. The **Crude Pipeline Scheduling (CPS)** package can improve not only pipeline operations but also refinery operations by delivering the desired crude parcel at the right time with the least transportation cost.

Recently Indian Oil Corporation Ltd (IOCL - one of the major Indian oil companies), under its ambitious **Supply Chain Management (SCM)** project, has taken up a project to develop and customize CPS in association with M/s. TataHoneywell, Pune and M/s. Energy Solutions International, Hyderabad. This solution is based on the **Batch Shipment Scheduler (BSS)** scheduling package integrated with additional modules: the **Initial Batch Plan (IBP)** automatic batch schedule generation module, the **Crude Mix module** which will give crude composition at terminals, SCADA, and the SAP R/3 package. This development takes advantage of the synergy between IOCL's vast experience in pipeline operations and the vendor's software application capability. The combined package generates a feasible batch plan which meets refinery demand while using line-balancing and terminal tanks to simultaneously satisfy several optimization goals: minimizing tanker detention, minimizing in-line batch mixing, minimizing operating cost, and maximizing direct pumping (as opposed to floating operation) at the line-balancing tanks.

INTRODUCTION

IOCL owns and operates seven of the India's seventeen refineries with a combined capacity of 38.15 Million Metric Tonnes per Annum (MMTPA) which is about 41 % of India's total refining capacity. Six of these are inland refineries and four refineries process domestic as well as imported crude. The Salaya Mathura Crude Pipeline carries imported crude from the Salaya port to three of these refineries: Mathura, Panipat, and Gujarat. These refineries process high and low sulfur imported crude and Bombay High crude. The transportation of crude from port to these refineries and products from refineries to marketing terminals or depots with minimum transportation cost is a challenge.

IOCL also has the largest network of on-land crude and products pipelines in India. This network includes 4053 miles (6523 Km) of pipe with a combined pumping capacity of 900000 bpd (43 MMTPA). The main crude and products pipelines in this network are:

Crude Pipelines

- Salaya Mathura Pipeline (SMPL)
- Haldia Barauni Crude Pipeline (HBCPL)

Products Pipelines

- Kandla Bhatinda Pipeline (KBPL)
- Mathura Jalandhar Pipeline (MJPL)
- Koyali Ahmedabad Pipeline (KAPL)
- Haldia Mourigram Rajbandh Barauni Pipeline (HMRBPL)
- Barauni Kanpur Pipeline (BKPL)
- Haldia Budge Budge Pipeline (HBBPL)
- Guwahati Siliguri Pipeline (GSPL)
- Digboi Tinsukia Pipeline (DTPL)

The main purpose of these pipelines is to supply the predetermined crude or refined-product parcels to the customers (refineries / marketing terminals) at right time with minimal quality downgrading due to interface or tank mixing, and with the least transportation cost. The pipeline operations group must schedule the system so as to handle uncertainties due to changed crude tanker arrival times and changes in the refineries' processing cycles. The operation becomes more complex if the single pipeline is transporting different types of crude or products to multiple locations.

After liberalization and the free market scenario, which has been in place in India since April 2002, the supply of crude oil to refineries with the minimum gate price has become very important.

Under the aegis of the SCM project, IOCL, in addition to implementation of SAP R/3 (Enterprise Resource Planning) software, is considering additional software packages to support strategic business decisions. These "add-on" packages are intended to help optimize the entire supply chain, including the business functions of IOCL's Marketing, Refineries, and Pipelines Divisions. Since some of these software projects are totally new to the Indian environment and are being implemented for the first time in this country, it was decided first to build confidence among the user and to assess the success of the package with a pilot project, and then to extend the software to all of the corporation's pipelines. The Salaya Mathura Crude Pipeline was chosen for this pilot project, which has been envisaged as the prototype package for subsequent extension for all other pipelines.

SMPL PIPELINE

SMPL originates at two single point moorings (SPMs) systems in the Gulf of Kutch near Salaya (Vadinar) in Gujarat. It has crucial national significance in acting as the trunk line for transportation of crude oil to three of the biggest refineries in India: Gujarat, Mathura and Panipat (located in the north-west region of the country). This 1169-mile (1881-km) pipeline is a network by itself, with nodes and tank terminals for intermediate storage of various types of crude oils at Salaya, Viramgam and Chaksu, and a series of booster stations along the line. The pipeline has been laid with the prime objective of transporting both indigenous (Bombay High) and imported crude oils (Low Sulfur & High Sulfur) from tankers at the offshore oil terminal at Salaya to the three refineries. The pipeline traverses four states: Gujarat, Rajasthan, Uttarpradesh and Haryana.

Large crude storage tanks are available at Salaya, Viramgam and Chaksu as well as smaller crude receiving tanks at the three refineries. The Salaya tanks are for receiving crude directly from the tankers and pumping to the downstream segment of the pipeline. The Viramgam and Chaksu tanks act as line-balancing tanks (LBTs) to bridge the gap between refineries' crude processing schedules and crude availability at Salaya. The present capacity of SMPL is presented in Table 1. The details of the SMPL Pipeline are provided in Figure 1.

SMPL has a Tele-supervisory Control and Data Acquisition (SCADA) system for monitoring and control of pumping operation from the central Dispatch Station (CDS) at Gauridad pump station, on the outskirt of the city of Rajkot. There are 24 Remote Tele-supervisory Units (RTUs) which are situated at various pump stations, delivery stations, booster stations, and block valve locations. The communication between CDS and the RTUs is achieved through a dedicated UHF / microwave communication system.

THE EXISTING PLANNING AND SCHEDULING OPERATION

At the monthly crude slate meeting, representatives from industry (the OCC, ONGC, SCI and pipelines) finalize the crude availability for the next month. The Shipping Corporation of India (SCI) submits the schedule of crude tanker arrivals for the next month (the "crude tanker slate") to the meeting. This slate includes for each tanker the quantity and types of crude it carries, the type of tanker, and the estimated time of arrival (ETA) of the tanker. During the following Supply Plan Meeting (SPM), refinery production numbers are finalized. The refineries subsequently prepare crude parcel requirements and their receiving plans based on allocated production numbers and their processing schedules, and then submit these requirements to refineries HQ and pipelines HQ. The refineries' receiving schedules and their daily crude parcel sizes become the basis for deciding the pumping requirements from Viramgam to Gujarat refinery and from Chaksu to Mathura and Panipat refineries.

The tanker ETAs, scheduled deliveries to each refinery, pipeline fills in each section, and stocks available in LBTs at Salaya, Viramgam and Chaksu are input to an Excel-based pipeline-scheduling system to prepare the monthly SMPL crude pumping schedule. The monthly schedule is then communicated to Central Dispatch Center at the Western Region Pipeline office at Rajkot (Gauridad) to regulate the crude flow in different sections of the pipeline by proper utilization of pumps, LBTs, etc.

The various steps followed while preparation of monthly schedules on **Excel worksheet** are as follows:

1. Manual entry of the scheduling inputs: each refinery's daily receiving plan based on parcels sizes and flow rates, the crude tanker slate, and the initial crude stocks available at Salaya, Viramgam and Chaksu LBTs and in the pipeline segments.
2. Preparation of a monthly pumping schedule from Viramgam to the Gujarat refinery (VG section) and from Chaksu to the Mathura and Panipat refineries (CM and CP sections) based on these three refineries' individual receiving schedules.
3. Preparation of a pumping plan from Viramgam to Chaksu (VC section) which takes into account the initial crude stocks and ullage (usable empty space in the tank) in LBTs at Viramgam and Chaksu and satisfies the CM and CP schedules from step 2; done via a manual trial-and-error method.
4. Preparation of the pumping plan from Salaya to Viramgam (SV section) while taking into account the initial crude stocks and ullages in LBTs at Salaya and Viramgam and satisfying the VG schedule from step 2, also using a manual trial-and-error method.
5. Frequently while performing step 3 the user finds that there is no schedule that can both keep tanks within allowed levels and meet the delivery schedules for the CM, CP, and VG sections. In such cases the user must return to step 2, find a different set of batch sequences for the CM, CP, and VG sections, and then repeat step 3. This is all done manually, and may require multiple iterations.
6. While the pumping plan is prepared for both the SV and the VC sections of the pipeline, care must be taken that none of the batches are lower than 153 kbbl (25 TKL) and the flow rates in both sections stay within the prescribed limits.
7. Once the plans are finalized, the western region manually calculates the batch arrival schedule on hourly basis to identify the requirement of direct pumping, stripping and injection from LBTs.
8. Based on this daily pumping schedule, stripping and injection from LBTs, the crude mix calculation is performed manually at all the LBTs and refinery tankages using FIFO method. Each refinery is the told the composition of the crude in its tanks on a daily basis.
9. Whenever changes are made in tanker ETAs or refinery requirements, this entire process must be repeated to produce a new schedule that includes the effects of the changes.

Steps. 2 and 3 are time-consuming, as the scheduler has to keep track of crude delivery schedules that depend on the pumping rates, line fills, and order of crude batches being pumped. Pumping rates in different line segments may vary depending on the status of LBTs, the receiving schedules of the refineries, and the availabilities of main-line pumps and/or engines.

Limitations of the Existing Planning and Scheduling System

The existing planning and scheduling are performed monthly, based on an Excel worksheet that uses a simple, non-physical fixed-rate model of the pipeline and tank-to-tank operation. This involves multiple trial-and-error iterations and is therefore very time-consuming. The fixed-rate model does not allow optimum utilization of pipeline capacity by varying flow rates. Moreover, longer schedules (e.g., a quarterly plan and schedule) are not possible due to the increased complexity and resultant requirements for many more trial-and-error iterations to be carried out manually. Also, the model does not have feature to optimize pipeline operating costs.

In addition, the manual trial-and-error based schedule does not generate information about direct pumping opportunities at the LBTs, but always assumes the less desirable tank-to-tank operation; nor does it produce the needed stripping and injection timing. Finally, the manually-calculated crude mix using the FIFO method is not a realistic of actual operation; in realoty, the crude becomes completely mixed in LBTs.

CRUDE PIPELINE SCHEDULING PACKAGE

Due to the immense complexity involved in SMPL and its strategic importance to IOCL, it is necessary that the pipeline operate in the most efficient way to maintain the supply chain and its profitability. This must be done in spite of many uncertainties, such as crude tanker delays at the upstream side or sudden changes in the refinery processing plans (due to poor product uplift, or emergency shutdown of processing units). In the event of such occurrences, the pipeline operations need to be rescheduled quickly to avoid tanker detention or a dry-out situation at refineries.

In order to improve pipeline operation and to overcome the limitations of existing scheduling process, the prototype Crude

Pipeline Scheduling package for SMPL has been developed, customized and implemented. The combined software modules have been installed and configured for SMPL at the Rajkot office and Pipelines Head Office (PLHO) in Noida. The refinery HQ in New Delhi accesses the package through a dedicated 2 MBPS lease line between PLHO and the Scope complex. The package interfaces with the SCADA system at Rajkot and with SAP R/3 for importing various crude costs and the stocks in the various tank terminals.

Features of the Base Scheduling Package (BSS)

The scheduling package provides the engineering model that simulates physical operation of various pipeline segments of the SMPL system. Engineers specify physical parameters of the pipeline, operating constraints, planned tanker ETAs, and refinery processing cycles through a GUI-based system. The package simulates the operation and automatically selects reasonable pump combinations and flow rates. The package provides as output the physical condition of the pipeline, batch locations and their ETAs at refineries and LBTs, pressure profiles, crude composition at LBTs and refinery tanks, and flows at each step, and ensures that the pipeline is operated within acceptable physical limits.

A detailed description of the algorithms used to automatically perform this scheduling is included in a later section of this article. A high-level overview of the various software modules and how the work together follows:

Base Scheduling Package

This is a standard module for detailed pipeline simulation based on a prepared batch schedule. The batch schedule output of the IBP module (described below) is imported into the Base Scheduling Module to perform the scheduling activities on an hourly basis. The Base Scheduling Package has the following sub-modules:

- **Hydraulic Model**

The flow rates of entire pipeline segments are determined by the physical properties of the crude, the physical properties of the pipe (such as roughness and elevation profile), detailed pump station models, and defined MAOP and LAOP limits.

- **Drag Reducing Agent (DRA) Modeling**

Drag reducing agent modeling is based on Conoco CDR or Backer-Hughes Flo-Improver equations. The model includes simulation of DRA breakdown.

- **Optimization features (PTO)**

The PTO module performs pump and DRA optimization. It selects which pump units to operate, sets station setpoints, and recommends DRA injection rates to meet a user-specified throughput with minimum total fuel and DRA cost. The PTO uses the Dynamic Programming optimization technique. The solution satisfies all user-provided pressure and flow constraints, and also incorporates minimization of pump switching (to save on maintenance). It minimizes total cost including driver fuel, additive injection, power costs, etc.

Software Enhancement

Before starting the customization process, the Functional Design Specifications (FDS) were finalized based on IOCL's scheduling requirements. While analyzing the functional requirements, it was observed that the standard scheduling package could not meet the entire IOCL requirements. Hence two additional modules, the **Initial Batch Plan (IBP)** and **Crude Mix Module**, having close interaction among them, were envisaged for development to cover the entire functional requirement and they were included in FDS.

In addition, certain enhancements to the Base Scheduling Package were needed. It was adapted to handle more complex scheduling operations, and to allow tanks to be reclassified for different grades of crude in the middle of a simulation run.

Standard Scheduling Module Enhancement

- **Initial Batch Plan Module (IBP)**

Typically the Base Scheduling Package requires a batch schedule as its one of the inputs. However, due to multiple types of crude pumping requirements and the complexity of operations such as direct pumping, stripping and injection at Rajkot and Chaksu, it was very labor-intensive to generate these batch schedules manually. Accordingly, it was decided to develop a separate module to generate a feasible batch sequence automatically.

The objective of this module is to prepare a feasible batch plan based on the refineries' receiving plans, tanker ETAs, and initial crude stocks in the LBTs. The module also identifies the batch formation and pumping activities, direct pumping from Salaya, Viramgam and Chaksu and the stripping and injection requirements at the LBTs.

- **Crude Mix Module**

The crude mix module has been developed to calculate realistic crude mix compositions at refinery crude tanks as well as LBTs based on perfect mixing. The hourly output generated by the Base Scheduling Package is imported into the crude mix module to generate hourly crude mix reports.

- **SCADA Connectivity**

The SCADA connectivity has been established at SMPL

Rajkot to reduce manual data entry when rescheduling is required (due to tanker detentions, refinery schedule changes, etc.) and to generate user-defined reports for Plan vs. Actual performance analysis.

The typical input data requirement and output of the scheduling packages are as follows:

INPUT

- Refinery processing and receiving plan
- Tanker ETAs (crude type, quantity and tanker arrival date)
- Inventories / ullage at LBTs and refineries tankages
- Linefill volumes and flow rates for each section
- Initial crude composition in linefill, LBTs, and refinery tanks
- Pump status (availability)
- Minimum / maximum allowable line pressure, maximum allowable station control valve throttling
- Current in-line DRA concentration

OUTPUT

- Batch formation and batch setup details
- Batch ETAs at the refineries
- Interface (transmix) size between each pair of adjacent crude batches at LBTs and refineries
- Recommended set of boosters and main line pump units to operate
- Pump station setpoints including flow rates, RPM, suction and discharge pressure
- DRA injection setpoints along with locations
- Crude composition in LBTs and refinery tankages

The schematic diagram showing the interaction of these three modules is shown in Figure 2.

BENEFITS

Although pipeline schedulers are already scheduling pipeline operations for many years, their decisions are mainly based on their skill and past experience. They may or may not make the optimal decisions, especially when unexpected changes in tanker or refinery schedules require rapid modification of the associated pipeline schedules. The availability of a standard scheduling package with built-in optimization features helps the scheduler to achieve the following:

- Quick scheduling of pipeline operations for timely delivery of the right types of crude to each refinery in line with the agreed processing plan
- Optimization of batch lengths to minimize interfacial losses and downgrading of crude quality
- Optimization of energy consumption through optimized operation of boosters and main line pumps at originating and intermediate pump stations
- Reporting of crude mix composition availability in LBTs and refinery tankages
- Overview of the entire pipeline and its planned operations through a GUI
- Checking for adequacy of the crude oil tankages at pipeline and refinery locations to match the processing capacity of each type of crude oil
- Minimization of demurrage fees incurred by IOCL for crude tankers through better inventory management
- The ability to perform case studies of facilities investment decisions and DRA usage
- Identification of bottlenecks and constraints

Method

The schedule generation is done in three phases: generation of data to drive a simplified pipeline model from the complete, detailed pipeline model; batch schedule optimization using this simplified pipeline model; and finally, pump optimization for this optimal batch sequence using the detailed model. The "detailed model" includes a complete hydraulic and thermal model, using a succession-of-steady-states approach. Pump stations are modeled using the manufacturer's pump curves, while pipes are modeled using their diameter and roughness coupled with the Colebrook-White friction factor and API correlations for crude properties. The "simplified model", on the other hand, simply assigns a maximum capacity to each segment of the pipeline based on which grade of crude is in the line.

Finding the optimal batch ordering and sizing is a combinatorial optimization process (described in more detail below) which requires very many simulations of different batch sequences. In order for these simulations to be completed quickly, each individual simulation run must be extremely fast. This necessitates the use of a simplified model for these runs.

Below, the three phases are described in more detail.

Phase I. Segment Capacity Calculation

The detailed model is used to compute the capacity of each segment of the SMPL system for a linefill of each different grade of crude. This model simulates the complete physical pipeline and pump station configuration, including detailed models of individual pumps. For each segment the maximum flow rate is found that doesn't violate MAOP or LAOP limits; this is done as follows:

At a given flow rate, the simulator turns on more pumps and reduces throttling at each station until some constraining limit is reached. This limit will either be that the pressure has reached MAOP somewhere between that pump station and the next station, or that all pumps are turned on and throttling has been reduced to zero. This process is repeated for each station in the segment. If, after this has been done for the entire segment, the pressure is everywhere above LAOP, then that flow rate is below the capacity of the segment; if the pressure is somewhere below LAOP, then that flow rate is above the capacity of the segment. A root-finding algorithm is used to zero in on the exact capacity of the segment with a succession of these simulations performed at different flow rates.

Phase I of the optimization process produces as output the capacity flow rates for each segment of the pipeline for each possible linefill. These are used as inputs for Phase II.

Phase II. Batch Sequence Optimization

This part of the optimization produces a batch ordering and set of scheduled flow rates for the entire SMPL pipeline network. This "batch plan" must meet the following constraints:

- operate segments only at flow rates found to be achievable (in Phase I) without violating MAOP or LAOP
- keep all tanks (both terminal tanks and line-balancing tanks) within their allowed level limits
- empty tankers at the Salaya terminal as quickly as possible; avoid holding them up in port and incurring demurrage charges
- meet the daily delivery schedule at the three refineries

The batch schedule must also minimize the amount of transmix generated at batch interfaces. This is done by making batches as large as possible. When possible single large batches are moved all the way from Salaya to the refineries; otherwise, large batches can be moved to LBTs where they are split up into smaller batches for movement down the branch pipelines to the refineries.

Finally, the batch schedule must minimize the amount of pumping to and from LBTs. When one batch is being delivered to an LBT and other batches are being pumped out of different tanks at the same terminal for shipment downstream, any remaining head is lost; that is, the downstream batch enters the line at tank pressure and must use booster pumps rather than passing pressure from upstream. "Tightlining", or pumping batches directly past the LBTs, is preferable (when possible) because it avoids this waste of power.

Phase II uses a heuristic combinatorial algorithm. To begin with, a batch sequence is generated for the branch lines to the refineries based on the daily refinery schedules. These three branch line batch sequences are combined at the LBT terminals to produce batch sequences along the trunk lines. This "batch plan" is used as a starting point for further optimization.

Optimization of the starting batch plan occurs by rapidly trying a large number of simple changes to the plan. Each change is evaluated by simulating the entire schedule using that batch plan under a simplified pipeline model. If the change results in constraint violations (such as overfilling tanks or failing to meet daily refinery requirements), it is rejected; if it results in improvements to the schedule (for example, fewer or smaller batch interfaces, or less use of LBTs) then it is kept in the batch plan. The permitted changes involve either moving volume from one batch to another or changing batch order in a segment.

These changes are applied repeatedly until the batch plan stops improving (by the above criteria). Then the final batch plan is used to drive Phase III.

Phase III. Pump Optimization

Pump optimization is performed using the final batch plan generated by Phase II. During this optimization, the batch plan is simulated again with the detailed pipeline model used in Phase I and pumps are selected which will complete the schedule at the specified flow rates with minimum fuel costs and without violating any MAOP or LAOP constraints.

Since in the entire pipeline there are approximately 50 pumps, optimization by a direct search over all possible combinations of pumps would require 2^{50} (about 10^{15}) simulation runs; consideration of throttling would mean that the actual number of simulation runs needed would be much greater. This is clearly not feasible with current computing technology; fortunately, there is a shortcut that makes this optimization possible.

As far as optimal pump selection at a station is concerned, the cumulative effects of all of the decisions as to pump selection at upstream stations are entirely included in a single piece of data: the suction pressure at that station. In order to select the cheapest way of achieving a given discharge pressure at a station, the only information needed about what was done upstream is the total cost of achieving each suction pressure; the details of HOW each suction pressure was reached are unimportant.

For example: if the third station in a line has a suction pressure of 150 psi, the optimal pump selection at that station is identical regardless of whether the pressure driving the line so far was generated at the first station or the second station. This means that it's not necessary to consider each pump combination at station three in conjunction with each combination at every other station, only in conjunction with each possible suction pressure at station three.

By applying this optimization at each station in sequence, it's possible to optimize the entire pipeline's pump selections in a way that is mathematically equivalent to searching for the optimum over all 2^{50} pump combinations plus throttling. This type of algorithm is called "dynamic programming", and it is widely used in the field of operations research.

The results of this pump optimization phase are a schedule of which pumps should be turned on at what times, and where throttling should be applied. By simulating the operations with these pump settings, the total fuel cost of the schedule is determined.

TABLES

PIPELINE SECTION	LENGTH (Miles)	DIAMETER (INCH)	CAPACITY	PUMPING RATE	
			Line Fill (bbl)	**(bbl /d)**	**(MMTPA)**
Salaya - Viramgam	286 (461 Km)	28 (0.71 mts)	1010000 (165000 KLs)	440000 (72000 KL/d)	21.0
Viramgam - Chaksu	445 (716 Km)	24 (0.61 mts)	1220000 (199000 KLs)	290000 (48000 KL/d)	13.5
Viramgam - Koyali	98 (158 Km)	18 (0.46 mts)	153000 (25000 KLs)	146000 (24000 KL/D)	6.5
Chaksu - Mathura	122 (197 Km)	24 (0.61 mts)	336000 (55000 KLs)	159000 (26000 KL/d)	7.5
Chaksu - Panipat	217 (349 Km)	24 (0.61 mts)	593000 (97000 KLs)	122000 (20000 KL/D)	6.0
Total	1169 (1881 Km)		**3300000 (541000 KLs)**	**21.0 MMTPA**	

Table 1 – The present capacity of SMPL

FIGURES

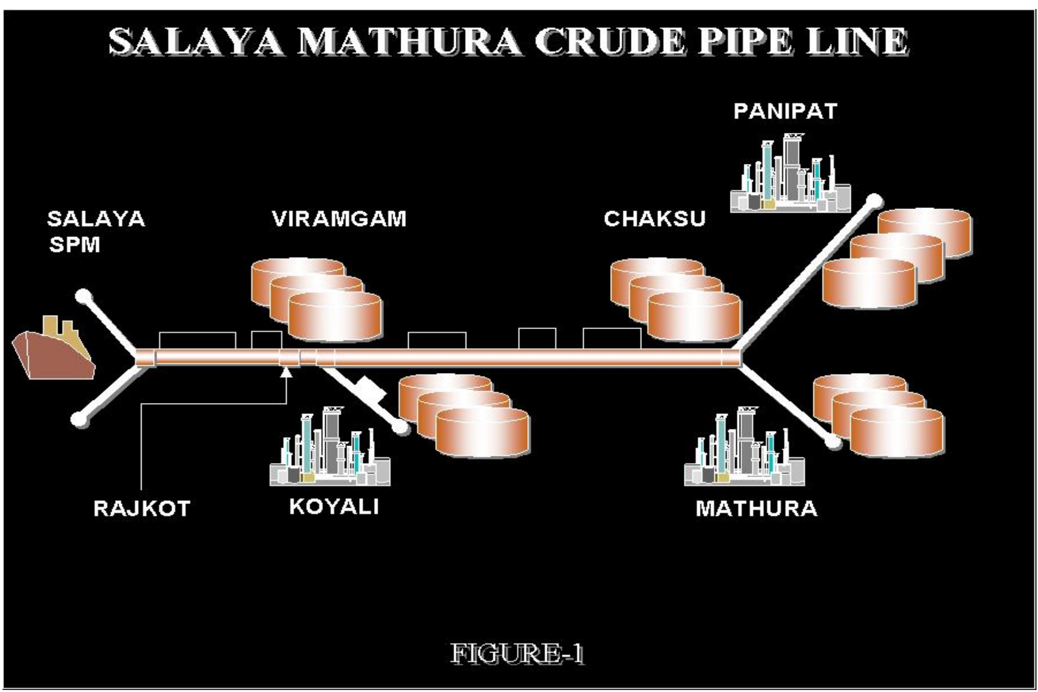

Figure 1- Details of the SMPL Pipeline

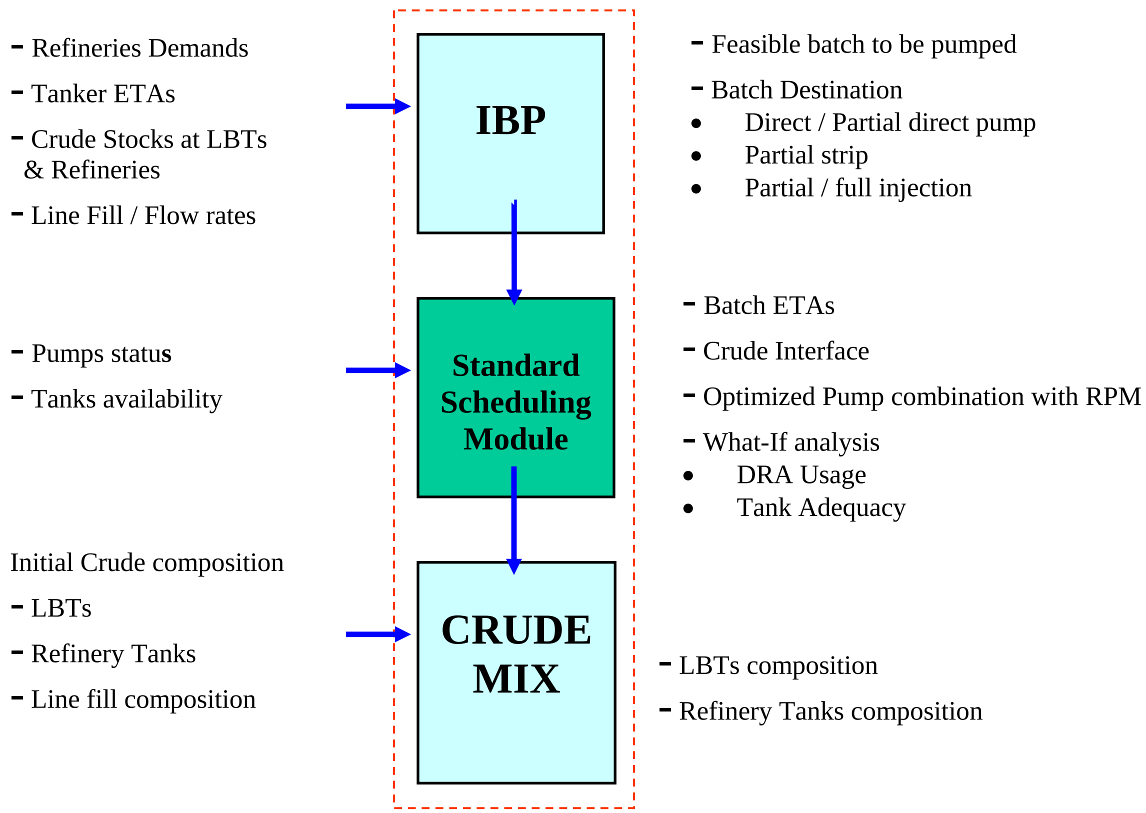

Figure 2 –SMPL CRUDE SCHEDULING PACKAGE

Appendix A – Resumes of Authors

- Appendix A (i) - Energy Solutions International
  a) Profile of Mr. TRV Krishnan
  b) Profile of Dr. Jason Modisette
  c) Profile of Mr. KV Siva Rao

- Appendix A (ii) – IndianOil Corporation Limited
  a) Profile of Mr. KM Bansal
  b) Profile of Mr. KK Jain

Appendix A (i) - Energy Solutions International

PROFILE OF Mr. TRV KRISHNAN

The late Mr. TRV Krishnan has had diversified background & experience of over 20 years in OIL and Gas Industry. He had completed MSc, DIIT Computer Science, in 1983, at the Indian Institute of Technology, Kharagpur, India. He has been responsible for establishing the Indian office of Energy Solutions. His professional experience includes thirteen years of service at Electronics Corporation of India and seven years of service at Energy Solutions. His responsibilities included resource management, client presentation and negotiation, and budgets. He was actively involved in marketing/ successfully selling multiple products & services of Energy Solutions.

PROFILE OF Mr. SIVA RAO

Siva Rao has a total experience of six years in the Oil and Gas Industry. He is a M. Tech (Computer Aided Process and Equipment Design) professional from REC Warangal. His basic degree is B. Tech (Chem) from the JNTU College of Engineering, Anantapur. Siva Rao has been with Energy Solutions for five years. During this period, he has been involved in different projects and has simultaneously grown over the years from Project Engineer to Senior Engineer & Project Manager to the post of Director. He has been associated with eight major projects at Energy Solutions. Siva Rao was employed with Electronics Corporation of India for a period of one year. He was involved in the development of Power Plant Training Simulators.

PROFILE OF Dr. JASON MODISETTE

Dr. Modisette has six years of experience in the pipeline simulation industry, most of which was spent with Energy Solutions and its parent companies. He has developed online and offline liquid and gas pipeline simulation and optimization packages, and was the primary developer of the BSS simulation and optimization tool described in this article. He has a BS in Physics from the California Institute of Technology (1992) and an MS and PhD in Physics from Rice University (1997).

Appendix A (ii) – IndianOil Corporation Limited

PROFILE OF Mr. K.M. BANSAL

Krishna Mohan Bansal, a Mechanical Engineer from the University of Pune has also received a First Class Certificate from Ministry Of Transport, Govt. of India. After a short stint at BARC, he served in Merchant Navy at M/s India Steamship Co. Pvt. Ltd. in various capacities for ten years including the post of Chief Engineer before joining Indian Oil Corporation Ltd. as Senior Manager in 1978. He has held many responsible positions in IOCL both in the Refineries and Pipelines Divisions. As General Manager he managed Human Resources and Projects functions. He is now Executive Director (Operations) of Pipelines Division, responsible for operation, maintenance, safety and environment protection and procurement functions. He is also a Director on the Board of M/s Petronet VK Limited and M/s ONGIO International Ltd. He is the Chairman, Northern Region, NACE Governing Board, Indian Section. He is member of DMA, AIMA and Life Member QCFI. He has been instrumental in organising NACE Conference in 1999. He was a member of Functional Committee of OISD on Rotary Equipment from 1987 to 1992 and is closely associated with Environment Management Group of Confederation of Indian Industry (CII).

PROFILE OF Mr. K. K. JAIN

Mr. K.K.Jain, has been a part of IOCL for the past ten years. He is a Chemical engineer from IIT Roorkee, India. Presently he holds the post of Chief Manager (Optimisation). Between 2000 & 2002, as the Senior Manager (Supply Chain Solutions) he was actively involved in implementing the Crude Scheduling Pipeline project in association with M/s ESI Hyderabad. In the year 2003, as the Chief Manager (Supply Chain Solution) he has undertaken various studies relating to Corporate Profitability, implementing Corporate Planning and scheduling systems using LP Modelling