Innovative Software Improves Crude Oil Logistics Scheduling

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1. Abstract

The generation of the refinery operation plan requires the capability to monitor and determine the quality and the composition of crude oil tanks to be processed into the Crude Unit as well as of the related availability date.

The batches fed to the CDUs must both fit the quality constraints set by the operative department (for safe, smooth and long-lasting operation) and maximise at the same time the content of “Opportunity” crude oils (providing high processing margins).

Poor scheduling can erode up to 5% of the theoretical monthly result predicted by LP planning models; can result in a higher ship demurrage cost; thus crude oil logistics optimisation is fundamental, especially when the available crude inventories are limited and it is difficult to segregate crude quality.

Prometheus has developed a tool (PRORAF™) which offers an innovative algorithm which manages concurrently crude oil logistic events (reception, transfer, and processing) and predicts the hourly evolution of the status of all the tanks of the network.

Crude data, simulation, and optimisation techniques are appropriately integrated by an algorithm which is also able to work "high-level" transfer instructions where the sequences of tank loading/unloading operations are not detailed.

The calculation engine manages the service requests associated with material transfers (according to specified priorities and selection criteria) to bring each event to completion as fast as possible.

This simulation highlights the real bottlenecks to manage to prevent operational problems.

The software is innovative because it can solve autonomously the big part of the scheduling problem requiring the user's intervention only to manage the significant issues requiring appropriate actions.

Furthermore, the proper integration of "economically driven" optimisation methods generates operation plans maximising the processing of opportunity crudes still respecting CDU feedstock quality requirements.

The dramatic saving of time resulting from its application permits to explore more alternative options resulting in a more effective and optimised scheduling plan:

This tool correctly supports in the same environment and with the same model the development of both Long and Short term scheduling tasks:

- Long term scheduling models can calculate and update in a few minutes the evolution of the status of all the tanks and pipelines of the logistic network. It is a perfect tool to define cargo arrival dates and to identify solutions in case of unforeseen operative changes. The deep integration with the crude characterisation database enables to constrain not only the bulk properties of oil batches but also the quality of the fractions exiting the CDU.
- Short term scheduling models enable to issue detailed instruction reports as well to store validated operation results (resulting from the simulation of the executed actual operations) into a centralised historical database which can provide the information to reproduce details of the past activity.

The paper describes this technology and reports a case study illustrating its implementation for the scheduling of the crude supply operations of an Indian Petrochemical Refining complex.

This operator receives into its maritime deposit a considerable variety of crude oils of extremely variable quality (in terms of sulphur content, acidity, and API degrees). The number of available tanks does not enable the proper quality segregation, and the crude scheduling team needs to track the evolving composition of each tank.

Concurrently to cargo reception some other tanks are unloaded and fed in parallel (three to five pumping channels) to a pipeline. The blend resulting from parallel pumping must respect the quality constraints required by CDU processing at the other side of the Pipeline. The batches exiting the Pipeline can either be fed directly to the crude unit or go to the Refinery deposit.

The tool automatically tracks the status (volume, composition, quality and current operation) of each tank of the logistic network identifying (basing on the high-level criteria set by the user) the tanks to use at any time for loading and unloading service.

A MIP optimisation process runs in automatic (when required) to identify origin tanks and relative pumping rate for parallel pumping service (for example when one of the tanks of the current pumping operation is emptied or becomes unavailable).

A typical long term scheduling simulation covers four months of operation and requires the generation of about 30/40 different blends to model pipeline intake. With this system, this calculation is performed in less than three minutes while before this tool, this task required hours for a single Long Term Scheduling Run.

However, the user can always influence and orientate the solution proposed by the tool and always has full control of the results.

Last but not least: the economic structure of the algorithm’s objective function applied to calculate the blends tends intrinsically to maximise the use of low-cost material (opportunity crude oils). Assuming an average increment in the use of opportunity Crude oils of 5% (conservative), the pay-out resulting from the use of this tool is equal to a few months.

2. Prometheus Technologies

Prometheus has more than 30 years of experience in the oil refining industry. The company provide specialised consulting and optimisation software.

In Prometheus vision, helpful and practical optimisation tools must be user-friendly, reliable, flexible end task-oriented. These goals demand an in-depth understanding of both the industry requirements and modelling techniques.

On this purpose, Prometheus has developed a set of exclusive technologies for crude oil characterisation, plant simulation and blending calculation and has integrated them into five modules, designed to support the most relevant planning and scheduling tasks.

These modules can work stand-alone to perform a specific set of scheduling tasks or share data and processes in case of extended solutions.

- CUTS™: crude assay data elaboration for characterisation database building and re-cutting. This module provides crude oil data to all the other modules.
- SIMRAF™: refinery LP optimisation, integrated with Process Plant Simulation Models for yield and quality calculation. This module supports ordinary and strategic planning tasks.
- PRORAF™: modelling and optimisation of logistics.
- PROLAV™: modelling and optimisation of processing operations.
- OTTMIX™: LP optimisation of blending operations.

These modules support short-term scheduling tasks.

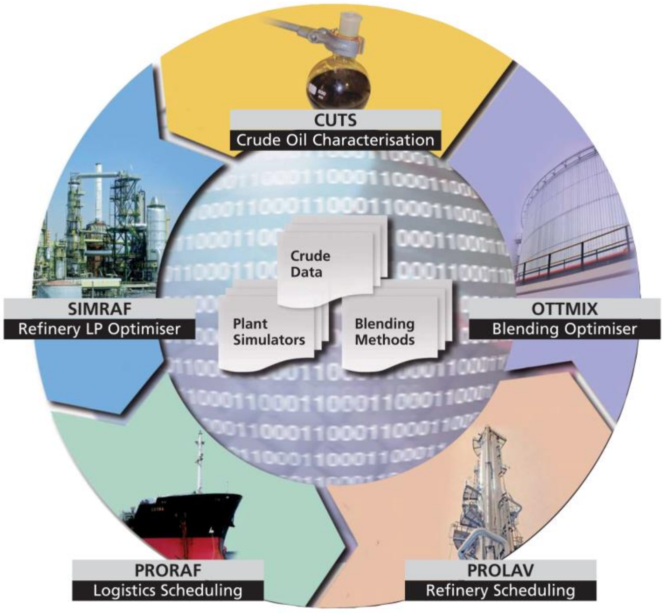


Figure 1 – Prometheus DSS Modules

The Crude scheduling model described in this paper applies CUTS™ and PRORAF™ modules. Further integration with other DSS Modules to model Crude Oil Processing and Finished Product Blending operations is in the design phase.

3. Crude Scheduling

Figure 2 summarises the finding of a study carried out to identify the refining operations mostly impacting the difference between the theoretical result expected from Business Plan and the actual result.

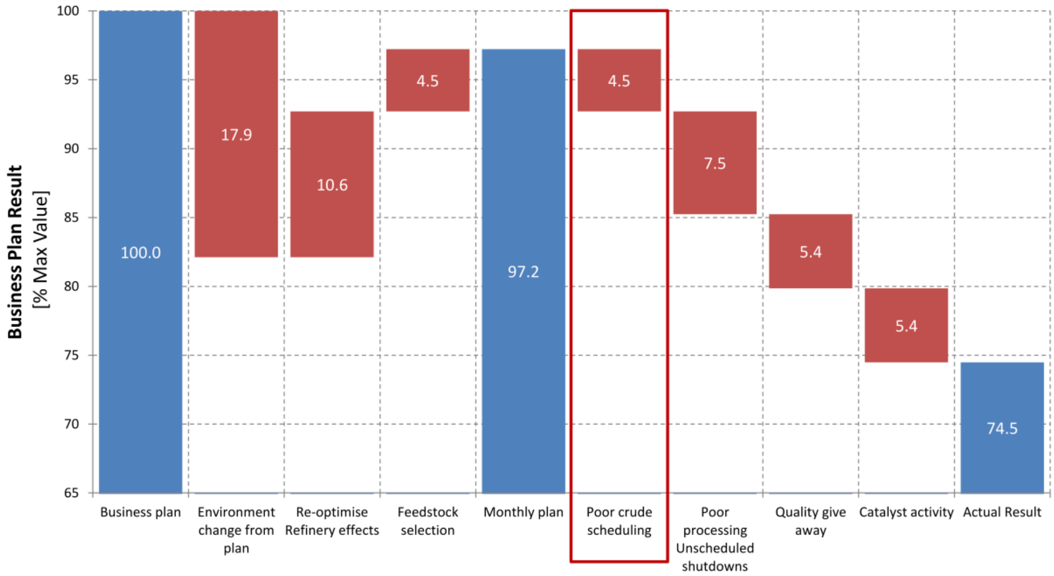


Figure 2 – Actual refinery result versus the original business plan

Compared to planning result, actual refinery margin can decrease up to 25% for various reasons :

- Poor crude scheduling impacts 4 to 5%.
- Suboptimal processing impacts 7 to 8%
- Quality give-away in blending operation impacts 5 to 6%
- Reduced catalyst activity impacts 5 to 6%

According to these results, the improper management crude logistics (reception facilities, deposits and pipelines) can involve for a mid-size refinery a 15-20 M$/Year loss: this is particularly true when feedstocks variability forces operators to monitor the quality of crude refinery tanks or to store different crude types in separately to prevent quality contamination.

Typically the average residence time of crude oil in refinery inventories is too low to enable proper quality segregation, and it is fundamental to improve the intelligence of the tools dedicated to the scheduling of the logistic assets to manage the quality of the stocks finally fed to the refinery Crude Units. In these cases, the Crude Scheduling process becomes critical, and a lot of efforts and investments are realised by refining operators to improve the performance of this area.

Figure 3 lists the leading causes for the economic losses involved by the poor scheduling of crude oil logistics: in practice, the LP models – which are useful to select the refinery feedstock and to produce the operative plans – assume the capability to process optimal crude mixes in refinery crude units for all the period while in the actual case the feedstock availability depends on the supply schedule and the logistic constraints involve unforeseen quality contaminations.

MONTHLY PLAN	ACTUAL CASE
➡ Any crude is available at the beginning of the period	➡ Crude availability depends on supply program
➡ Perfect quality segregation (no crude contamination)	➡ Crude quality contamination happens.
➡ Intermediates yields and quality calculated assuming the optimal crude slate.	➡ Different mixes with different yield and quality of intermediates.

Figure 3 – Monthly Plan vs Actual case

In this scenario, the Refiner must exploit all the degrees of freedom available during the Operation Planning and Scheduling process to maximise the final result: the crude batches fed to the CDUs must both fit the quality constraints set by the operative department (for safe, smooth and long-lasting operation) and maximise the content of opportunity crude oils (providing high processing margins).

Even if each operator has its specific business processes, typically in this framework, Crude quality and Cargo size is input from the Planning while the Scheduling can define the arrival dates of the cargoes and the handling operations throughout the logistic network up to the Crude Unit.

- In case of the definition of Cargoes arrival dates the scheduler must be able to foresee the impact of this material intake on the Crude Logistics.
- Given the supply program, it is fundamental to plan handling operations to avoid undesired contamination (especially in case of different operating modes based on different crude quality) and optimise batches (maximising the use of opportunity crude oils).

It is possible to split the crude scheduling activities into two main classes differing for the specific objective and the time horizon: Long Term Scheduling and Short Term Scheduling. The proper execution of both activities require the capability to simulate the evolution over time of the status of crude logistic assets (tanks, tank farms, pipelines) as depending on Supply Program, Transfer Operations and Processing Runs.

3.1. Long Term Scheduling

Long Term Scheduling is an exercise aimed to assess the feasibility of Crude reception and transfer Operation (in terms of blend quality and reliability) within a few months time horizon for a given schedule of crude cargo arrivals. The goal is to assure an ordered cargo arrival plan, timely unloading of cargoes at Maritime Terminal with no demurrage cost, blending to maximize heavy/opportunity crudes consumption. The typical time horizon for Long Term Scheduling is between three to four months (90-120 days).

Given:

- **M**: current month, day 0 to 30 (Short term horizon). During this period, Crude arrivals gates are fixed (with three days variability); the scheduler has no degree of freedom to change these dates, which are not under his control. He may need to update them and re-run the simulation once the actual cargo reception date and time is available.
- **M+1**: next month, day 31 to 60 (nomination horizon). Of this period, the scheduler knows quality, size and number of cargoes (nominated cargoes) but the arrival gates are unknown: the task is to define the contractual arrival dates.
- **M+2/M+3**: following month(s), day 61 to 90-120 (buy horizon). In this case, no information is available and the scheduler in co-ordination with the refinery planning team responsible for crude oil selection provides suggestions about the quality and the size of the cargoes to be purchased.

With this activity, the Scheduler defines the arrival dates of the crude cargos to be nominated (typically at M+1) and finalizes cargo grades, quantity, and arrival dates for the month M+2 and M+3.

For these purposes, the scheduler set-up a model of the logistic network and uses it to:

- Simulate the evolution in time of tanks content considering arrivals, pipeline dispatches and processing. The simulation aims to check the feasibility of cargoes reception schedule considering the status of the tanks at reception dates (volume and quality) and the contemporary ongoing of transfer and processing activities.
- Plan the composition of the crude batches (pipelines and crude units). The scheduler must track the composition of the batches fed to pipelines and Crude units to prevent issues during the processing steps.
- Define contractual arrival dates for “nominated” cargos: for the four months covered by the simulation.
- Estimate arrival dates for “to buy” cargos, providing feedback to the planning department and trading departments charged of the purchase of new cargos.

The long term simulation of crude logistics operation is a time-consuming activity and, the availability of a fast simulation tool is fundamental to enable the evaluation of alternative scenarios.

3.2. Short Term Scheduling

Short Term Scheduling is an exercise aimed to update the status of the tanks during the current month, taking into account the deviations occurred in the period from the original schedule. Actual operations are set in the model and recalculated to align to reality the status of the tanks and to check the feasibility of the scheduled blends.

Short Term Scheduling supports the publication of daily operative instructions as well as the historicisation of the actual movements. The typical time horizon for Sort Term Scheduling is one month (30 days).

In this case, the Scheduler uses a model to:

- Re-schedule short-term operations to handle unexpected events (minor changes, delays or unforeseen shutdowns) and to update the simulation baseline accordingly.

- Calculate the status of the tanks based on actual operation accounting for schedule deviations: in most cases, the logistic model is used to keep track of the crude composition of the content of the tanks, a piece of information made available to others applications of refinery IT infrastructure.
- Reconcile operations: for each planned transfer, the scheduler adjusts the planned quantity to the actual one. Due to the high quantities handled, the actual transfers of a day usually differs from the scheduled ones, and even in case of minor deviations, it is necessary to update the model to avoid errors in the calculation of the status of the tanks.
- Store the results of the past operation (after Reconciliation) to data Historian. The information of the past operation can be retrieved to support future scheduling activities (for example, the operative issues associated with the processing of a given crude oil mix).
- Publication of operative instructions: after updating the baseline with the operations executed, the Scheduler updates the plan and publishes the operative instructions for a horizon of about ten days.

Even though the horizon is shorter than in the case of Long Term Scheduling, also this activity is time-consuming, mainly because the input required is much more detailed than in the case of long term simulations. In this case, it is particularly useful to dispose of tools supporting the reconciliation activities.

4. Logistic Simulation

4.1. Requirements

Both Long Term and Short term scheduling activities requires the availability of a model able to calculate the evolution of the status of the logistics assets depending on the events occurring in the simulation period.

To prevent inconsistencies between Long Term and Short Term scheduling results (both activities start from the same baseline), the model applied to support both tasks should be the same, but especially in the case of long term horizons, the modelling phase is time-consuming because - with the tools available in the market - the user must input to the software all the details related to each transfer.

Furthermore, any deviation from the plan requires to update the model re-checking the modelling of all the transfer event following the deviation: with this scenario, the Scheduler spends most of his time in running and updating the model and cannot evaluate alternative scenarios resulting from different decisions.

To overcome this difficulty, Prometheus focused the research on realising a real paradigm change: implementing an algorithm able to process “high level” instructions useful to select the origin and destination tanks for a given service and enabling the software to propose a solution autonomously.

Setting the criteria for tanks selection in different situations is much faster than getting in the detail of every transfer, and this potentially reduces the time for modelling tremendously. On the other side, the tool must provide the user with the flexibility to “orientate” the solution to account also for the constraints which are not explicit in the model but which he takes into account while generating the schedule.

To enable the software to propose reliable and feasible solutions, Prometheus made available in the same environment Crude Characterisation Data and a MIP Optimisation and developed a Simulation Algorithm able to exploit these tools to generate the schedule automatically.

The research phase has been challenging and, the underlying assumptions went through many revisions following to various end-users feedback. At the end of this process, Prometheus was able to develop a fast and effective algorithm based on:

- Deep integration of crude assay data (bulk and fraction properties, economics)
- Sophisticate Simulation Engine enabling at the same time:
    - High-level setup of transfer events
    - Flexibility to change and orientate the solution
    - Economic driven MIP optimisation models automatically run to optimise batches.

This simulation engine suggests the sequence of handling operations accounting both for operative and quality constraints. The elaboration of Long term scheduling solution (4 months horizon) takes only a few minutes.

4.2. Crude assay data

CUTS™ is the Prometheus module dedicated to the construction and the management of the crude oil characterisation database. This application makes available to its users a proprietary technology (multidimensional regression) specifically developed to elaborate Crude Assay data to produce a library of consistent data that can provide data for all the properties of any fraction of any crude blend, irrespective of the source, form and consistency of the input assay.

CUTS™ characterises every Crude Oil as a mix of pure components (C5 minus) and "pseudo-components" (C6 plus), which overall cover the entire crude boiling range. Each pseudo component envelops pure components boiling in a narrow range of 10°C.

Creating a distribution curve by multidimensional regression on assay data, CUTS calculates the values of appropriate quality characteristics for each pseudo component. The software distributes properties of the original assay, finding the best agreement between the natural curve shape and the input data. The crude assay data regression algorithm can calculate consistent values for contiguous pseudo components, while individual operating parameters are available to harmonise the shape of the resulting curve, if necessary.

The multidimensional regression defines the property distribution curve accounting for the reliability assigned to each property value, applying endorsed blending rules (using blending indexes when necessary), considering the crude oil components yields and the shape of the resulting distribution.

Table 1 lists the fundamental properties (e.g. with property values estimated for each pseudo component through the methods as mentioned earlier) managed by the current release, the relative blending rule and meaningful boiling range:

CUTS FUNDAMENTAL PROPERTIES			
PROPERTY	**UNIT**	**Blending Rule**	**Boiling Range**
Weight TBP Yield	% weight	Linear weight	Whole Crude
Volume TBP Yield	% volume	Linear volume	Whole Crude
Density@15°C	kg/dm3	Linear volume	Whole Crude
Sulphur Content	% weight	Linear weight	Whole Crude
Mercaptan Sulphur Content	% weight	Linear weight	Whole Crude
Kinematic Viscosity @50°C	CST	Index weight	Whole Crude
Kinematic Viscosity @100°C	CST	Index weight	Whole Crude
Acidity	mg KOH/gr	Linear weight	Whole Crude
Aromatics Content [FIA]	% volume	Linear volume	Gasoline
Naphthenic Content [FIA]	% volume	Linear volume	Gasoline
Paraffin Content [FIA]	% volume	Linear volume	Gasoline
Aromatics Content [Gas chromatography]	% weight	Linear weight	Gasoline
Naphthenic Content [Gas chromatography]	% weight	Linear weight	Gasoline
Paraffin Content [Gas chromatography]	% weight	Linear weight	Gasoline
Octane Number Motor Method (MON)		Linear volume	Gasoline
Octane Number Research Method (RON)		Index volume	Gasoline
RON + Tetra Ethyl Lead 0.5		Index volume	Gasoline
RON + Tetra Methyl Lead 0.5		Index volume	Gasoline
Reid Vapour Pressure	PSIA	Index volume	Gasoline
Cyclopentane Content	% weight	Linear weight	Gasoline
Cyclohexane Content	% weight	Linear weight	Gasoline
i-Hexanes Content	% weight	Linear weight	Gasoline
n-Hexane Content	% weight	Linear weight	Gasoline
Benzene Content	% weight	Linear weight	Gasoline
Methylcyclopentane Content	% weight	Linear weight	Gasoline
Naphthalenes	% volume	Linear volume	Mid Distillates
Freezing Point	°C	Index volume	Mid Distillates
Cloud Point	°C	Index volume	Mid Distillates
CFPP	°C	Index volume	Mid Distillates
Pour Point	°C	Index volume	Mid Distillates
Refraction Index @20°C		Index volume	Mid Distillates
Refraction Index @70°C		Index volume	Mid Distillates
Aniline Point	°C	Linear weight	Mid Distillates
Total Nitrogen Content	ppm weight	Linear weight	Mid Distillates and Residua
Basic Nitrogen Content	ppm weight	Linear weight	Mid Distillates and Residua
Ash Content	ppm weight	Linear weight	Mid Distillates and Residua
Asphaltenes C5 Content	% weight	Linear weight	Mid Distillates and Residua
Asphaltenes C7 Content	% weight	Linear weight	Mid Distillates and Residua
Conradson Carbon Residue	% weight	Linear weight	Mid Distillates and Residua
Nickel Content	ppm weight	Linear weight	Mid Distillates and Residua
Vanadium Content	ppm weight	Linear weight	Mid Distillates and Residua
Wax Content	% weight	Linear weight	Mid Distillates and Residua

Table 1 – CUTS fundamental properties

The system enables to define the list of Quality specifications to be considered within the Logistic Simulation to track the tanks content quality or to set-up quality constraints for tanks or crude blends (in case of quality-controlled parallel sequences).

The association with CUTS™ library enable to consider almost any possible characterisation property, but it is recommendable to find a good trade-off between the amount of information used to characterise the content of the refinery tanks and the calculation resources used to simulate the logistic network. Indeed, a high number of quality specifications involves longer computation time.

PRORAF™ foresees four types of quality specifications, for each type, it is necessary to define a specific set of parameters to enable their retrieval from CUTS™ library.

- Bulk: a property which refers to the whole Crude. It can be either a generic property (like Density, Sulphur, Viscosity) or the yield of a fraction.
- Cut: a property which refers to a fraction of the Crude Oil (for example, the acidity of the fraction boiling between 150 and 250).
- Crude: the amount of a given Crude Oil in the mix.
- Crude Type: the amount of a given Crude Type in the mix.

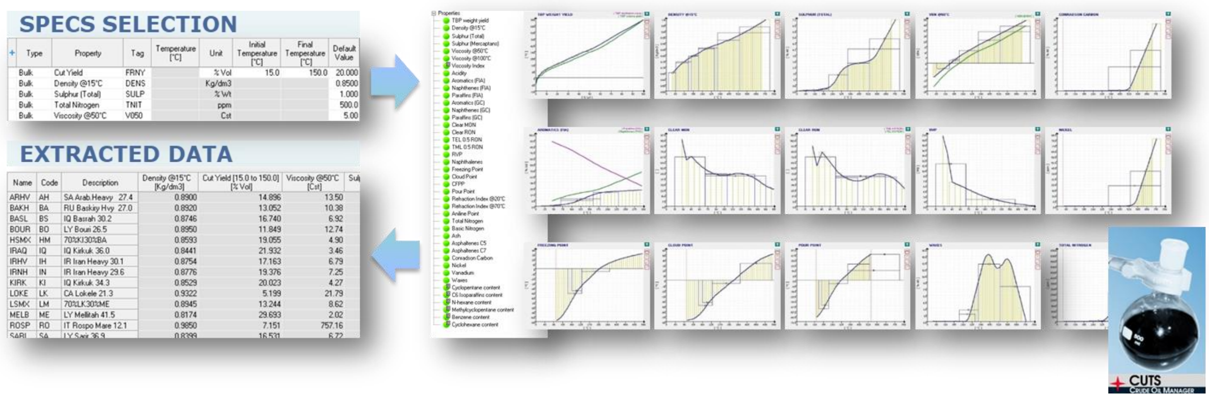


Figure 4 – Crude oil library data query

4.1. The simulation algorithm

PRORAF™ differentiates from other scheduling tools because of the existence if this simulation step: in this case, the detailed list of operations associated to each transfer event is an output of the simulation while other Tools require to input this information.

While other systems simulate the impact of the set of transfer operations inputted by the user on the status of the tanks, PRORAF™ can generate the set of transfer operations based on the high-level instructions provided by the User.

This difference reduces tremendously the time needed to produce or update the scheduling plan, both for long and short term scheduling exercises.

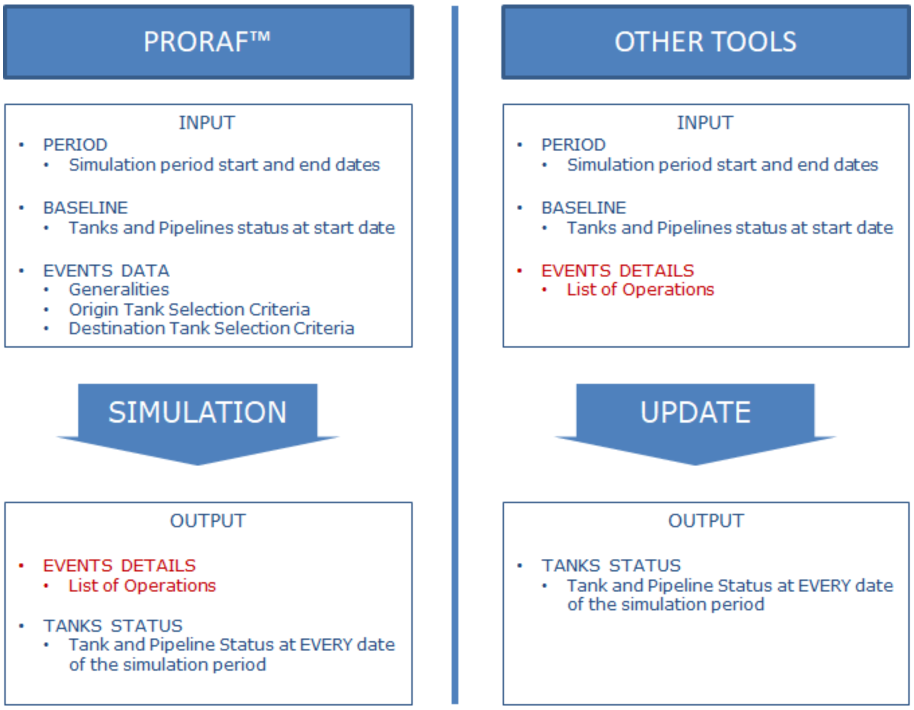


Figure 5 – PRORAF™ approach vs other tools

The simulation algorithm of PRORAF™ is innovative because it can handle "high level" instructions and to propose a solution without requiring to specify in detail the sequences of origin and destination tanks involved by a transfer.

The user can specify in detail origin, destination quantity and flow rate (like in the case of other scheduling tools) but can also delegate to the algorithm the selection of the tanks to use in a given moment from a set of tanks (called Sequence). In this case, PRORAF™ suggests (basing on the user criteria) the best tank for the requested service.

The algorithm splits the simulation period in "time slots" and elaborates them in series from the first to the last one. For each transfer event, the engine generates the list of service requests to the connected objects (tanks, tank farms, pipelines) represented in the logistic structure and manages these requests (according to specified priorities and selection criteria) to bring each event to completion as fast as possible.

The system manages various types of transfer events (carrier and pipeline crude reception, transfers, processing).

The following set of information defines each event:

- General data (start date, flow rate, quantity, calendars)
- Origin and destination sequences (set of tanks and selection criteria)
- Linking pipes.

The algorithm selects the origin and destination tanks from the specified sequences and defines the transfer flow rate based on :

- Volume and pumping (load/unload) constraints,
- Status (volume and content) and availability,
- Handling operations (drainage, measurements),
- Quality specifications (quality constraints set for the receiving tank),
- Batch quality targets (in case of parallel pumping),
- Pipeline quality tracking,
- Tank selection logics and exceptions.

The calculation run generates the details of the operations associated with each transfer event as well as the time evolution of the status of any asset in the logistic network.

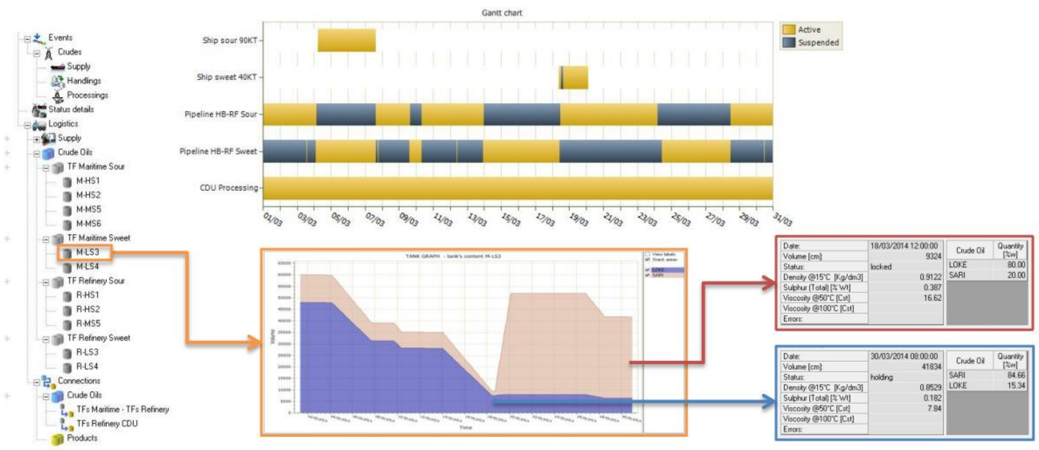


Figure 6 – Oil movement simulation engine

4.2. Batch Optimisation Engine

PRORAF™ disposes of an Optimised Blending functionality enabling to determine the origin tanks and the blending ratios in case of Automatic Parallel Origin sequences.

When required by the simulation engine, the algorithm automatically formalises a Mixed Integer Programming Optimisation problem applying the constraints set by the user and solves it to find the origin tank of each pumping channel and the related pumping flow rate.

The simulation algorithm then uses this result to elaborate on the transfer event until when the solution is applicable. When for some reason the solution becomes not feasible (for example one of the origin tanks empties) a new problem is formalised based on the updated scenario.

The objective function bases on economic data: in the space of the solutions respecting the quality constraints, the system selects the one using the tanks whose content has a lower value. In this context, the value of each tank is determined by the composition of the crude oil of the tank and by the selected price scenario. When the optimisation process runs, the system excludes the tanks which are not available (with loading status, not available for an operation or empty) and looks for a feasible solution using the remaining ones. The algorithm can select only one tank per channel.

In this context, the user disposes of various tools enabling to constrain the optimisation problem:

- Pumping Channel constraints: for each channel, it is possible to specify the Minimum and Maximum Flow Rates and to specify the subset of tanks of the tank farm to be considered.
- Quality constraints: it is possible to constrain the bulk quality of the mix, the quality of mix fractions, the composition of crude oils and crude types.
- Optimisation Parameters: provide further flexibility to orientate the solution, for example, to finalise the emptying use of the tanks used by the previous pumping set.

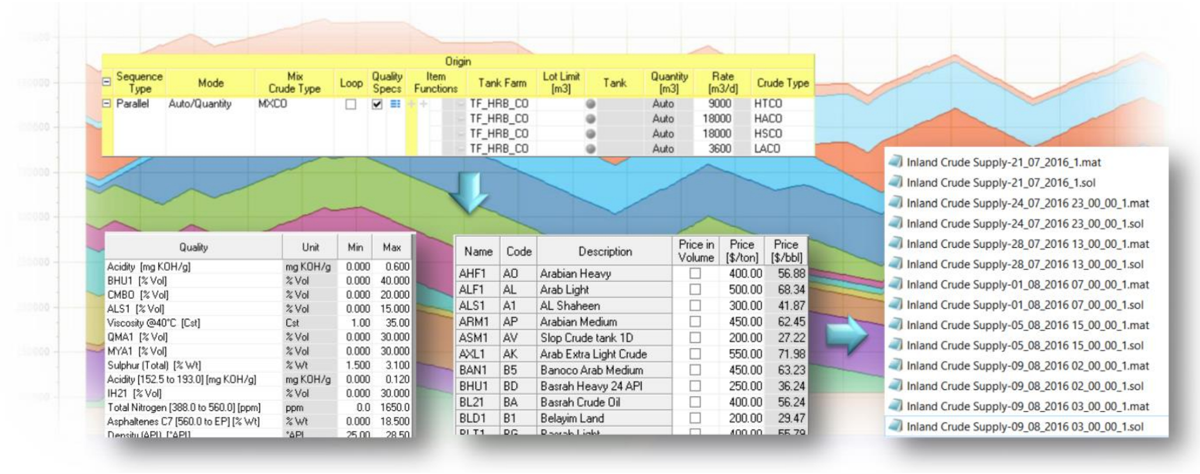


Figure 7 – Batch Optimisation Engine

5. Model Setup

The simulation model foresees the preliminary set-up of a logistic network; PRORAF™ disposes of various objects useful to model the elements of the logistic network:

- Tank: modelled with their actual geometrical properties, pumping constraints and quality specifications.
- Pipeline: connecting tanks can be one way, two ways or a simple connection.
- Tank Operations: to model operations triggered by loading or unloading.
- Docks: modelling cargoes mooring points
- Ships Templates: different types of available crude carriers.
- Crude Types: crude oil associations
- Quality Specifications: modelling the quality of crude oil batches
- Calendars: defining timetables for tank operations or events.

The logistic network groups tanks in tank farms which can be actual or logic depending on simulation needs:

- Cargos (dynamic tank farms)
- Maritime terminals (tank farms linked to mooring points)
- Inland terminals
- Refineries (processing material)

The Logistic Network is easy to modify and update: PRORAF™ GUI enables to customise the behaviour of each object of the logistic net (tank, pipeline, cargo) to reproduce the actual operative procedures.

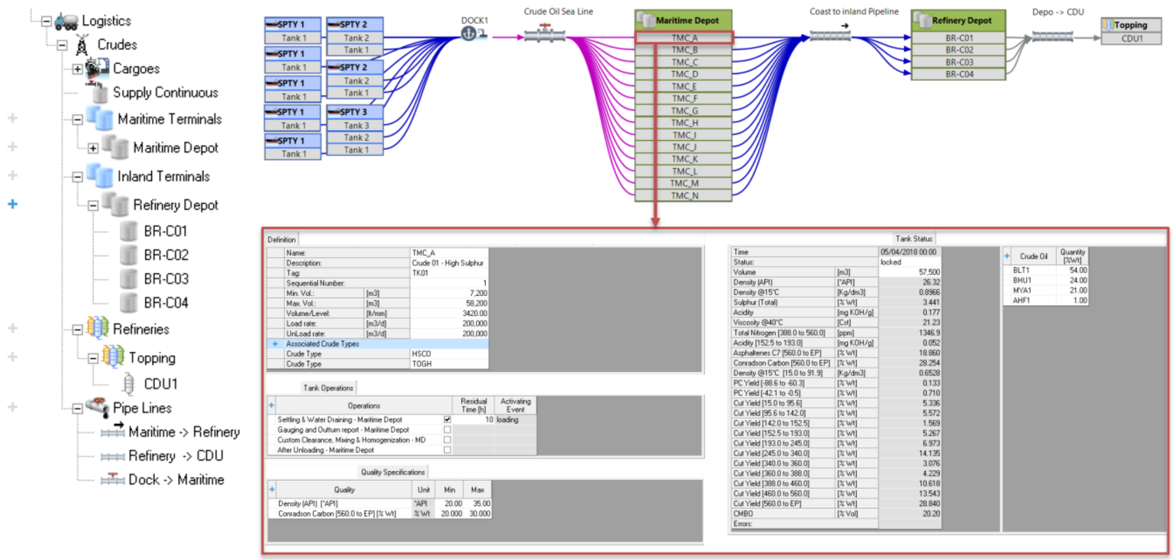


Figure 8 – Logistic Network Setup

Once the Logistics is defined, it is necessary to define the transfer events occurring during the simulation period. For this purpose, PRORAF™ makes available four types of events enabling the modelling of all types of operation, from reception to processing; each event is defined by :

- General information (start date, flow rate, quantity, calendars)
- Origin sequence (set of origin tanks and selection criteria)
- Destination sequence (set of destination tanks and selection criteria)
- Linking pipes (see here how to establish pipe links).

Figure 9 – Event Structure

The algorithm uses this information to select, for each elaborated time slot, the origin and destination tanks as well as transfer flow rate (the lower between event, event element, origin, connection and destination).

The Events Editor enables the definition of each transfer as well as the related parameters (type, calculation mode, origin, destination, volume, flow rate and quality constraints).

In this environment, it is also possible to set "high-level" transfer instructions where the sequences of tank loading/unloading operations are not thoroughly detailed.

An input like "transfer material at flowrate X between tank farms Y and Z" is allowed.

Each transfer event has four bars, two for the origin sequence (input elements and output operations) and two for the destination sequence.

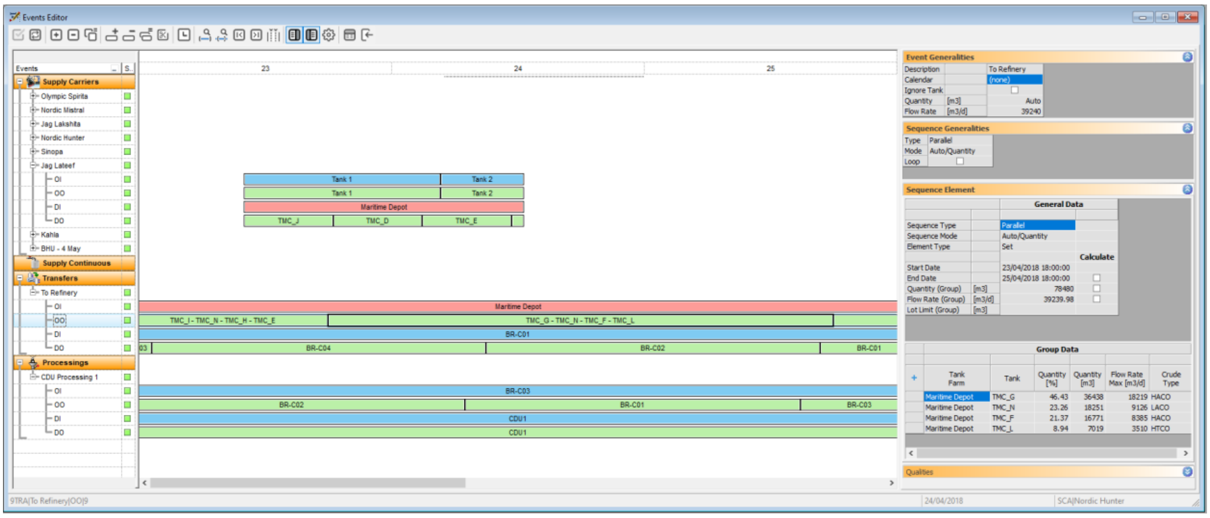


Figure 10 – Events Editor

6. Results

The simulation calculates, with an hourly resolution, the evolution of the status of all the tanks as well as the detail of material transfers. This information is made available throughout exhaustive reports sharable between various refinery services.

We report below examples of the different types of reports generated by the simulation.

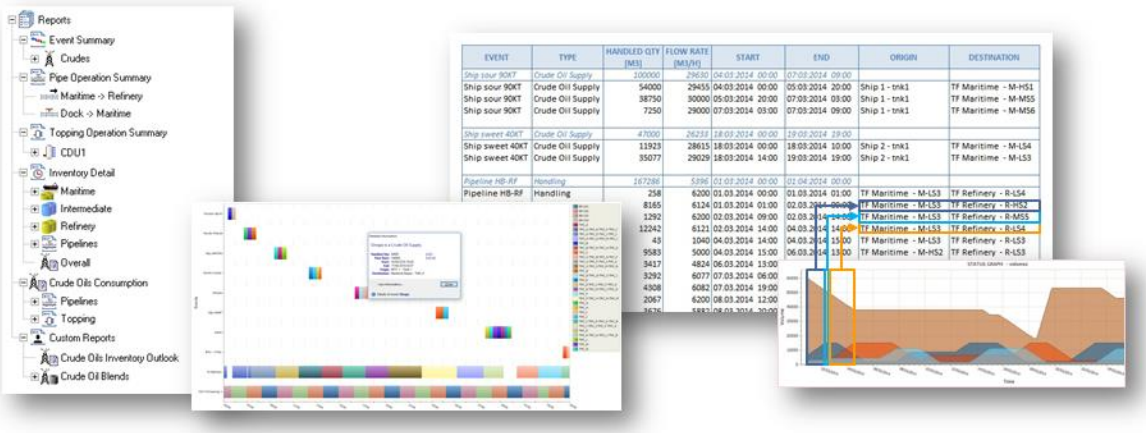


Figure 11 – Simulation Reports

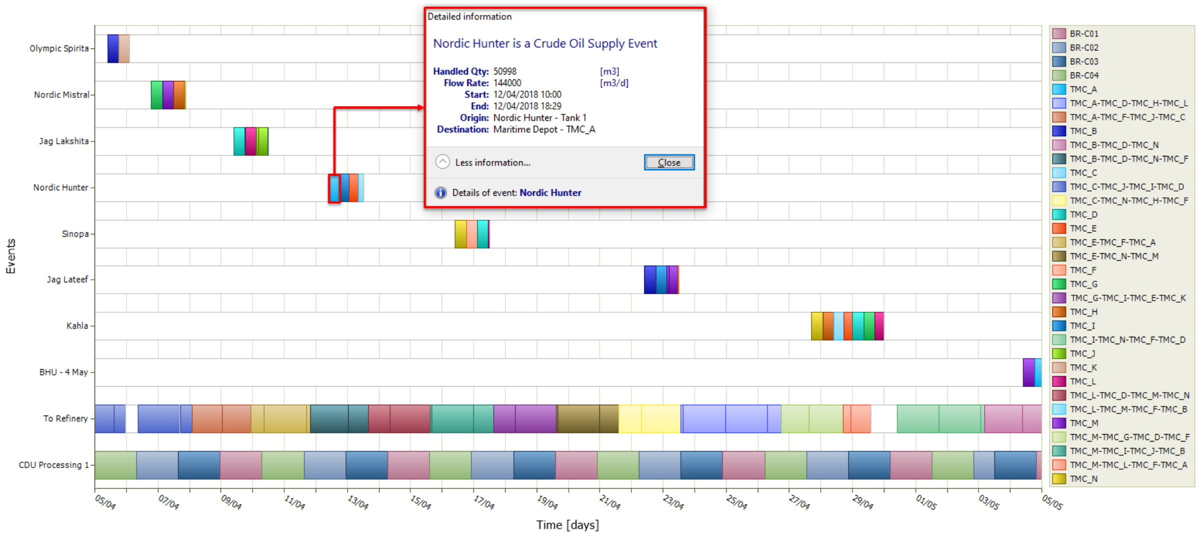


Figure 12 – Events Chart

Gantt chart reporting the events with transfers origin and destination details and highlighting transfers issues of any kind.

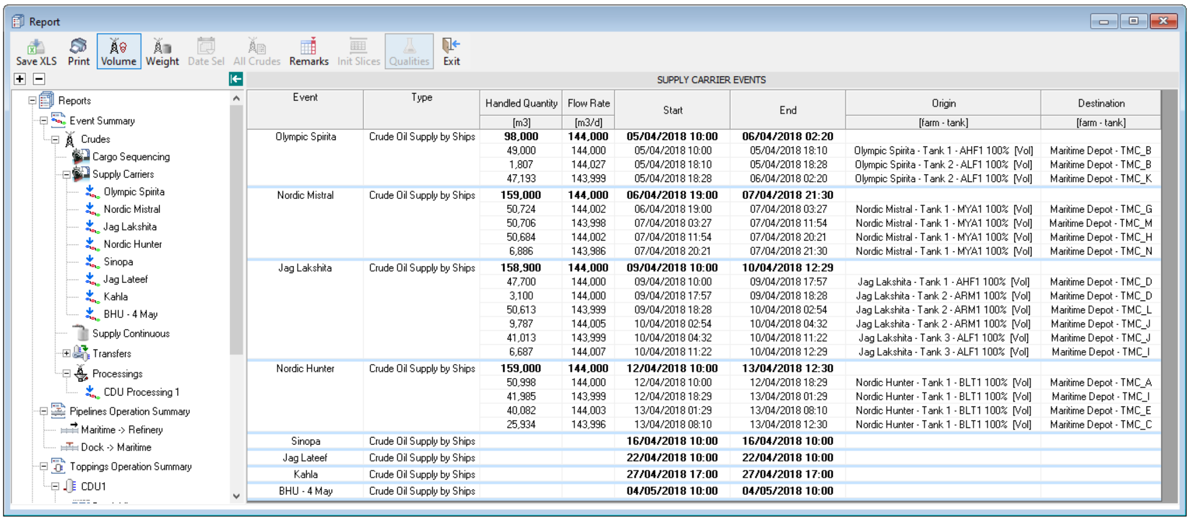


Figure 13 – Supply Events Summary

These reports contain the calculated details of each transfer operation (supply, material transfer, processing) in tabular format. Any report is exportable to MS Excel™ environment.

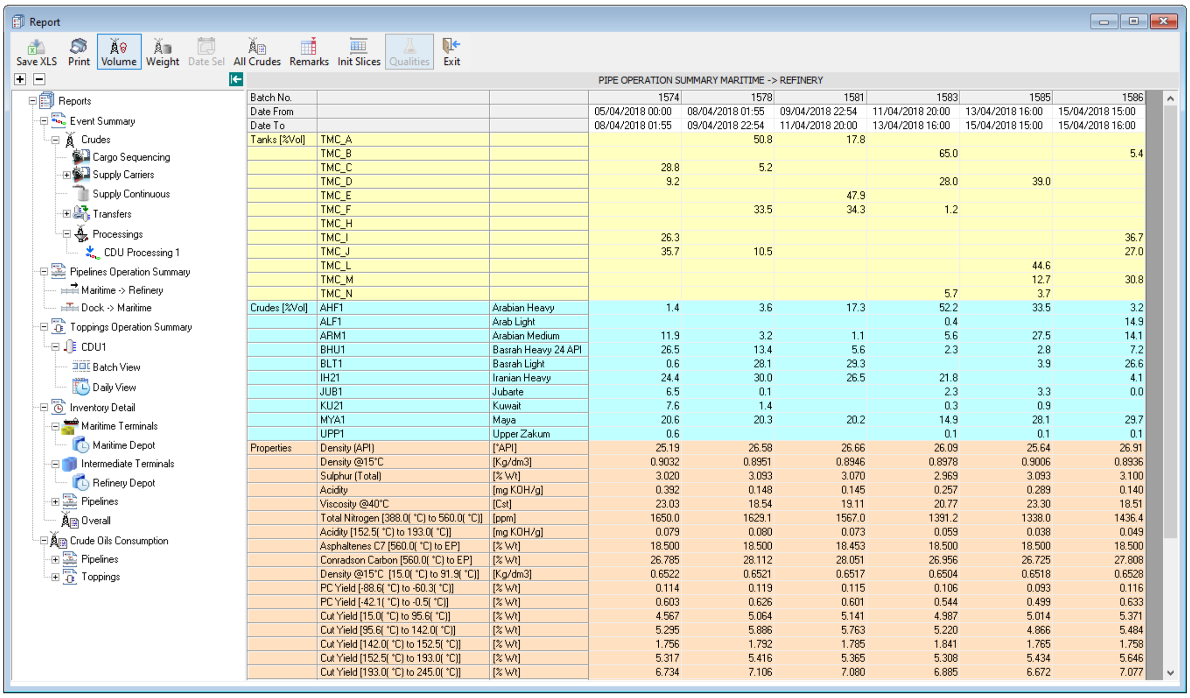


Figure 14 – CDU-Pipeline Operation

Quality, composition and origin tanks of all the crude oil batches fed to the pipelines and CDUs during the simulated period, both on daily average and on batch base.

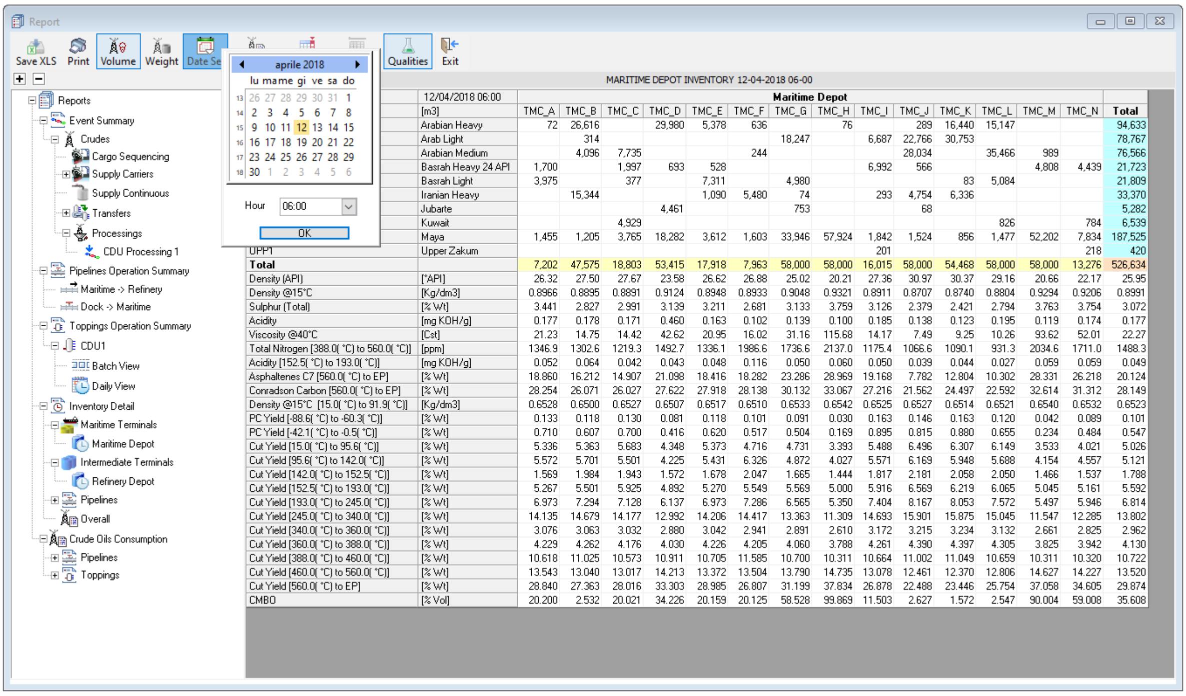


Figure 15 – Inventory Detail

Status (volume, composition and quality) of all the Inventories at selected Date/Time (with hourly resolution).

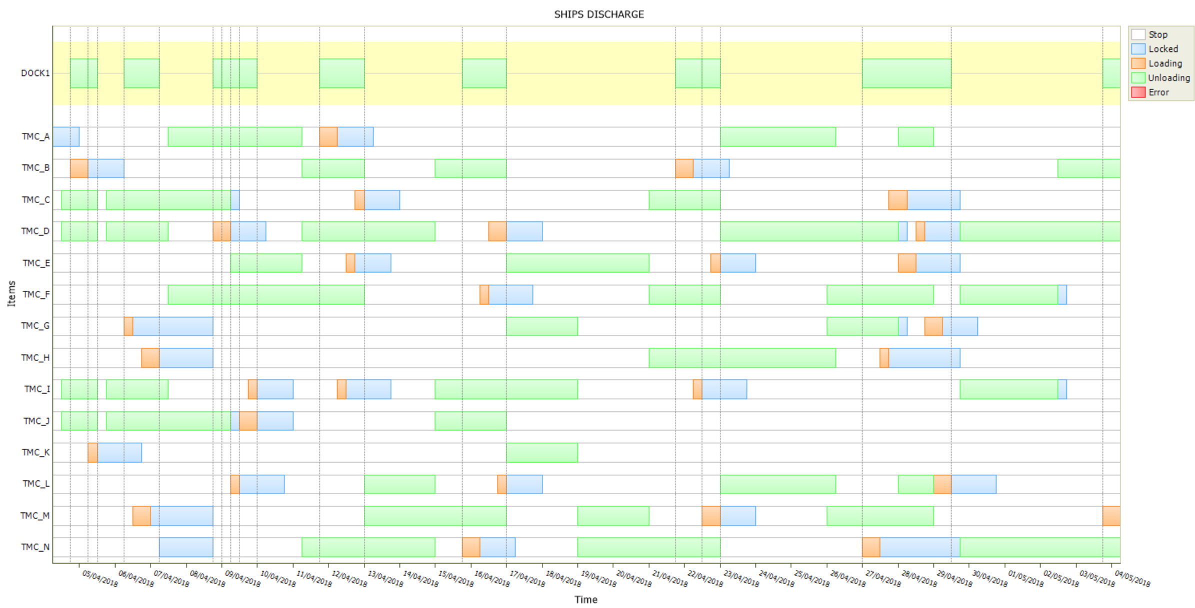


Figure 16 – Ship Discharge Summary

Graphical representation of ship discharge event with the detail of the activity (loading, unloading, locked, on hold) of the receiving tanks.

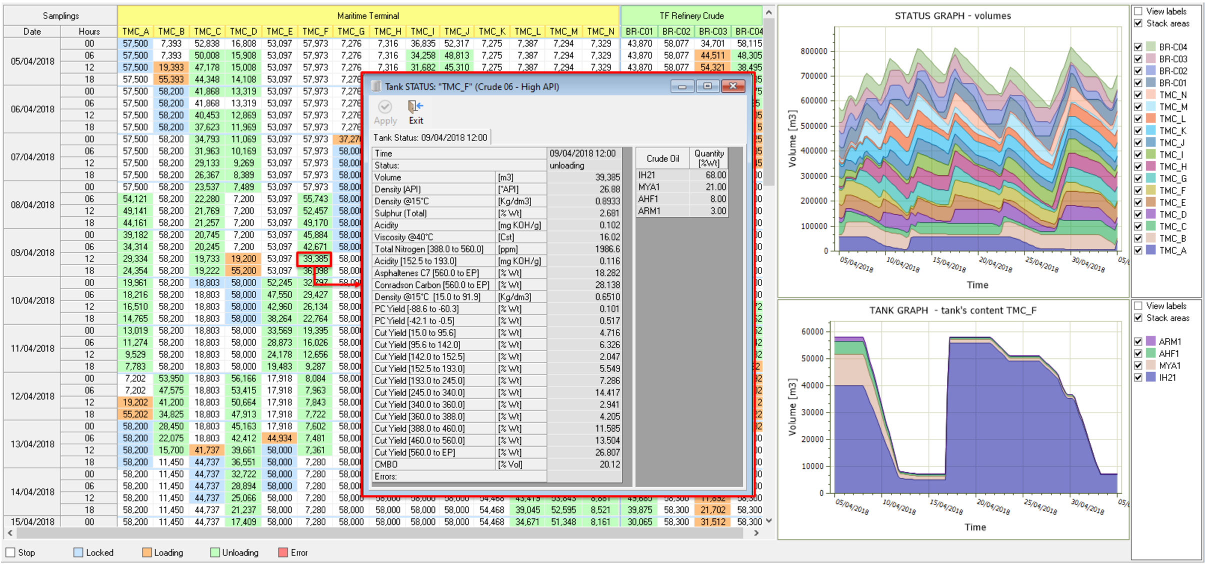


Figure 17 – Tank Status Table

Tank Status table with graphical and tabular evolution of the status of all the tanks.

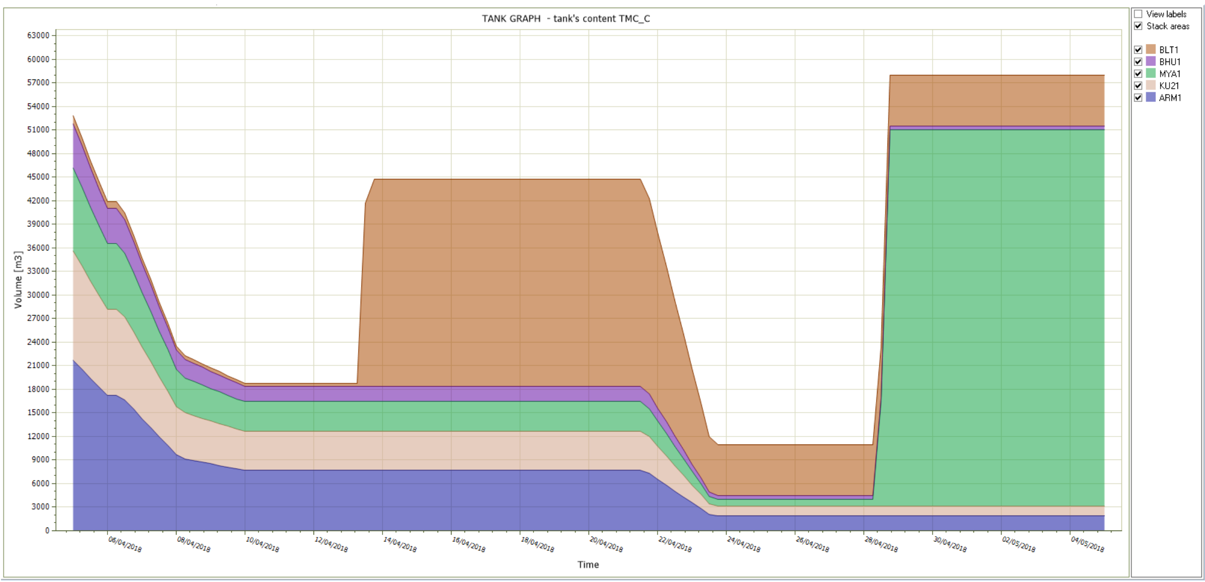
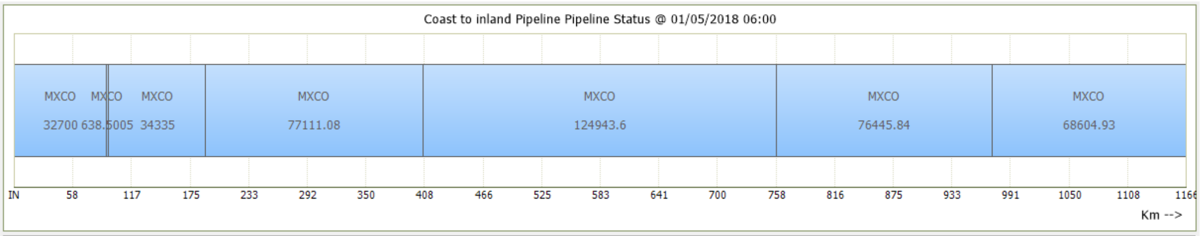


Figure 18 – Tank Graph

Tank Graph (Quality Detail) overall evolution of the composition of the selected tank



		7	6	5	4	3	2	1
Volume	[m3]	32700	638.5005	34335	77111.08	124943.6	76445.84	68604.93
Length	[Km]	91.9	1.8	96.5	216.8	351.3	214.9	192.9
Flowrate	[m3/d]	39240	39240	39240	39240	39240	39240	39240
Density (API)	[°API]	26.44	28.50	28.50	27.42	26.99	26.62	26.76
Density @15°C	[Kg/dm3]	0.8960	0.8841	0.8841	0.8904	0.8931	0.8951	0.8941
Sulphur (Total)	[% Wt]	2.944	2.700	2.708	2.794	2.949	3.080	3.093
Acidity	[mg KOH/g]	0.136	0.162	0.159	0.162	0.124	0.125	0.127
Viscosity @40°C	[Cst]	18.38	11.40	11.56	14.82	18.29	19.96	19.57
Total Nitrogen	[ppm]	1650.0	1340.4	1351.5	1505.8	1650.0	1648.5	1644.9
Acidity	[mg KOH/g]	0.071	0.062	0.063	0.067	0.070	0.071	0.074
Asphaltenes C7	[% Wt]	18.500	12.827	13.041	16.309	18.500	18.500	18.343
Conradson Carbon	[% Wt]	27.616	24.376	24.581	26.288	28.173	28.406	28.390
Density @15°C	[Kg/dm3]	0.6520	0.6515	0.6515	0.6516	0.6524	0.6526	0.6524
PC Yield [-88.6 to -60.3]	[% Wt]	0.094	0.115	0.117	0.107	0.113	0.111	0.115
PC Yield [-42.1 to -0.5]	[% Wt]	0.499	0.611	0.622	0.570	0.601	0.588	0.606
Cut Yield [15.0 to 95.6]	[% Wt]	4.975	5.627	5.628	5.266	5.196	5.152	5.184
Cut Yield [95.6 to 142.0]	[% Wt]	5.636	6.011	6.023	5.768	5.763	5.743	5.861
Cut Yield [142.0 to 152.5]	[% Wt]	1.924	2.085	2.067	1.987	1.813	1.769	1.737

Figure 19 – Pipeline Linefill

Pipeline linefill at any selected time during the simulation period.

7. Case Study

Guru Gobind Singh Refinery (GGSR) is a refinery owned by HPCL-Mittal Energy Limited (HMEL) a joint venture between HPCL and Mittal Energy Investment Pte Ltd and is located in village Phulokhari, Bathinda, Punjab, India.

The current crude oil processing capacity of 11.3 MTon/Year (225 kbbl/sd) and became operational in 2012.

The refinery gets its crude oil supply from Crude Oil Terminal situated at Mundra, a coastal town in Gujarat, through a pipeline where the oil is imported from abroad and serves the domestic market providing motor fuels (Euro-VI Specifications) and petrochemical products.

The refinery has a complex configuration with the following facilities: CDU/VDU, NHT, CCR, ISOM, DHDT, VGO-HDT, FCCU, PPU, DCU, HGU, SRU Block, Utilities & Offsites, Cross Country Pipeline, Crude Oil Terminal and Marine facilities.

The crude supply logistics enables the reception of Crude Oil Feedstocks from world market: cargoes are unloaded into the tanks of the maritime terminal (the storage volume is of 840 Km^3) and then pumped to the refinery crude oil tankfarm with an 1000 Km pipeline. The volume of the refinery crude oil tankfarm is equal to 240 Km^3.

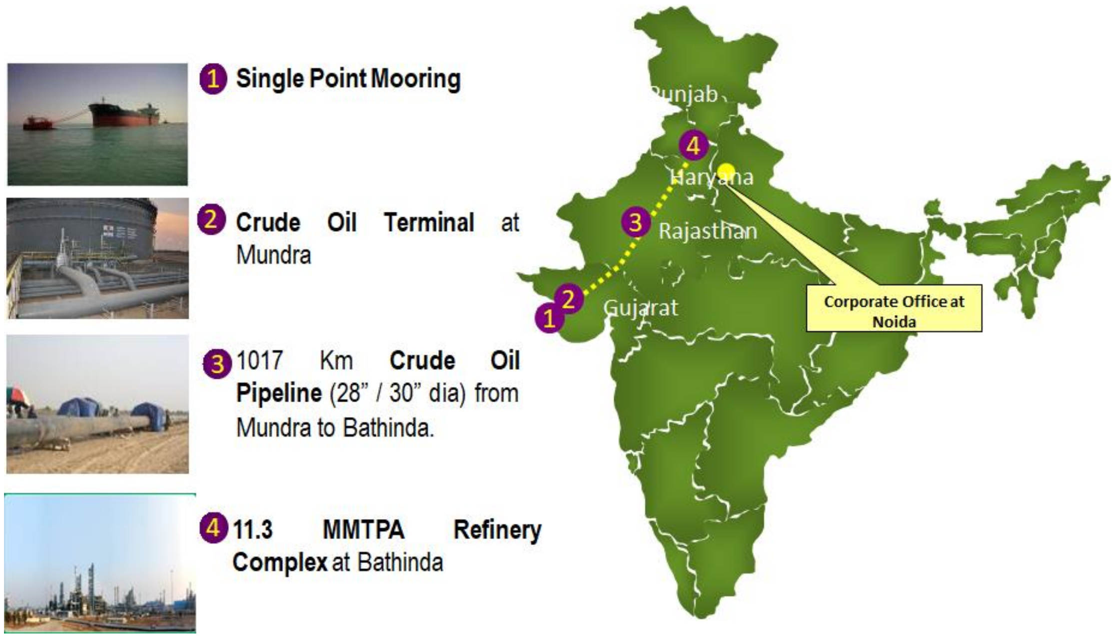


Figure 20 – HMEL Overview

The Refinery gets crude oils with highly variable quality in terms of Sulphur, API density, Acidity, Asphaltenes which must be blended appropriately to respect the quality constraints set by the operations department to assure the smooth and reliable operation in the processing units.

The blending operation is made in the maritime terminal, and the goal of the crude scheduling process consists in respecting the quality requirements set by the operations (to assure plant integrity and smooth operation) and by the planning department (LP Business Plan) maximising at the same time the use of "Heavy/Opportunity" crude oils (Low API and High Acidity) providing higher margins compared to "Light" crude oils.

The blending is realised through parallel feeding of more tanks (typically four/five channels but not obligatory) to the pipeline; therefore, for every crude oil batch fed to the pipeline, the Scheduler must decide the "pumping composition" (which tank for each channel and with which flowrate).

The scheduling tool must track the quality of the tanks as well as their availability at the moment in which it is necessary to generate a new crude blend and identify the most economical recipe.

Even though HMEL was already using a Crude Scheduling tool to support its Scheduling activities, in 2017 it started to co-operate with Prometheus to develop a new tool better fitting its requirements and aiming to:

- Fasten the development of the scheduling plan, especially for long term scheduling exercises (to automate manual scheduling tasks).
- Support the scheduler for better control of the quality of blended crude-mix batches entering pipeline as feedstock for CDU (to maximise the use of Heavy/Opportunity crude oils).
- A quick analysis of alternate scenarios for an early response plan to manage an unexpected event viz. cargo arrival delay.

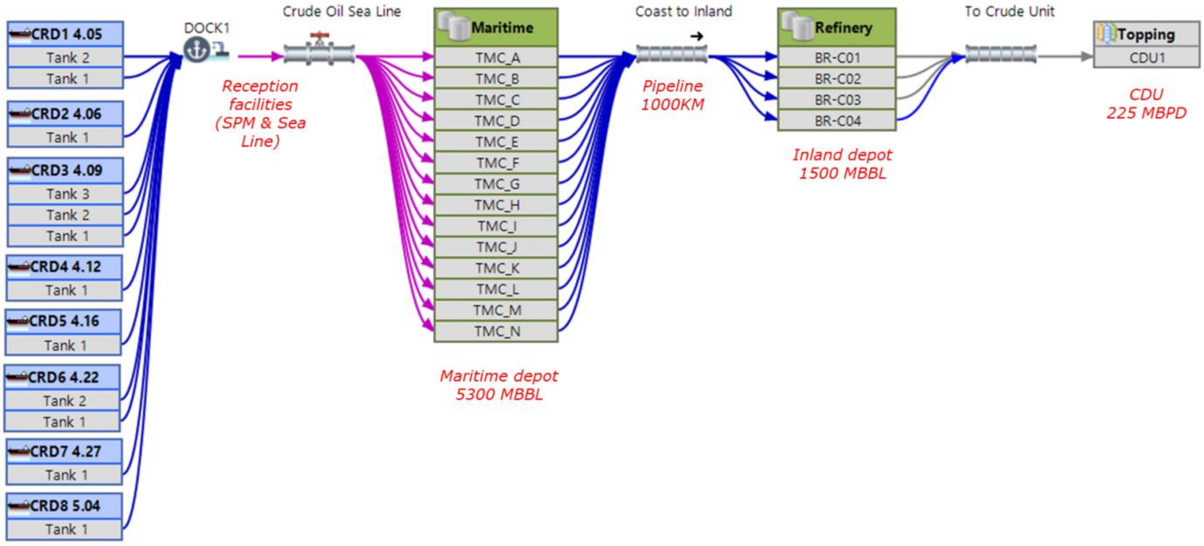


Figure 21 – HMEL Refinery Crude Reception Scheme

The implementation project started in November 2018, and the last module (Short Term Scheduling and historicisation database) was delivered in August 2019.

<u>Benefits:</u>

1. The economic objective function applied by the automatic optimisation engine available in PRORAF™ tends to maximise the use of low value Opportunity crude oils, in this case, corresponds to an increase in Refinery Margin by 1-2 cents/bbl.
2. The automatic calculation algorithm enables the update of the scheduling plan in a few minutes enabling:
   - a precise cargo arrival sequencing plan (for cargo loading dates nominations) for uniteruppted crude availability in optimum cargo parcels.
   - a quick analysis of different scenarios for an effective response to unexpected events viz a cargo arrival delay/ supplier confirms for a loading date different than the nominated one. This helps in minimizing demurage cost by 1-2 days every quarter.
   - A quick blend feasibility check for timely decision on spot/opportunity cargo purchase.

8. Conclusions

Integrating Crude Characterisation, Simulation and Optimisation technologies PRORAF™ offers an innovative Decision Support System for:

- Optimise ship discharge and coastal storage tanks management automatically with minimum user intervention.
- Assess optimal crude blends for pipeline or CDU, maximising the use of "heavy/opportunity" crude oils in compliance with feed quality constraints.
- The system enables:
    - CDU/Pipeline feed quality tracking (extendable to any specification).
    - Automatic calculation of scheduling solution and CDU products yields and qualities.
    - Get the solution of crude scheduling problems in less time.
    - Analysis of alternative scenarios
    - Better economics also compared to other established scheduling tools.
    - The same tool and the same model can be used both for Long and Short term scheduling activities.
- HMEL - Guru Gobind Singh refinery has successfully implemented this tool in 2019 and now uses it to support its crude oil scheduling activities.