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

- Any crude is available at the beginning of the period
- Perfect quality segregation (no crude contamination)
- Intermediates yields and quality calculated assuming the optimal crude slate.

ACTUAL CASE

- Crude availability depends on supply program
- Crude quality contamination happens.
- 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.

					0	rigin							
Sequer Type	ce Mode	Mix Crude Type	Loop	Quality Specs	Item Function	is Tar	k Farm	Lot Limit Tank Qua [m3] Tank [n	antity F n3] [n	Rate n3/d] C	rude Type	-	
E Parallel	Auto/Quantity N	IXCO		¥ ==	++	TF_H	RB_CO	Aul	to 9	H 000	TCO		
-						TF_H	RB_CO	Aul	to 18	000 H.	400		
						TF_H	RB_CO	Aul	to 18	000 H	SCO		
			_			TF_H	RB_CO	Aul	to 3	500 LA	VCO		3
		1				1	-		1				Inland Crude Supply-21_07_2016_1.mat
													Inland Crude Supply-21_07_2016_1.sol
						NZ							Inland Crude Supply-24_07_2016 23_00_00_1.m
~	~				-	-	-		1				Inland Crude Supply-24_07_2016 23_00_00_1.so
	Quality	Unit	Min	Max		Name	Code	Description	Price in	Price	Price		Inland Crude Supply-28_07_2016 13_00_00_1.m
Acidity In	KOH/al	ma KOH/a	0.000	0.600					Volume	[\$/ton]	[\$/66]		Inland Crude Supply-28_07_2016 13_00_00_1.so
BHU1 [%	/ol]	% Vol	0.000	40.000	-	AHF1	AU	Arabian Heavy		400.00	56.88		Inland Crude Supply-01 08 2016 07 00 00 1 m
СМВО [%	Vol]	% Vol	0.000	20.000		ALF1	AL	Arab Light		500.00	68.34		
ALS1 [%	'ol]	% Vol	0.000	15.000	-	ALS1	A1	AL Shaheen		300.00	41.87	_	Inland Crude Supply-01_08_2016 07_00_00_1.so
Viscosity	40°C [Cst]	Cst	1.00	35.00		ARM1	AP	Arabian Medium		450.00	62.45		Inland Crude Supply-05_08_2016 15_00_00_1.m
UMA1 [2	√ol] /-R	% Vol	0.000	30.000		ASM1	AV	Slop Crude tank 1D		200.00	27.22	-/	Inland Crude Supply-05 08 2016 15 00 00 1.so
Subbur (1	/0I] 상태 [양 14년]	% V0I % \u0	1 500	2 100	-	AXL1	AK	Arab Extra Light Crude		550.00	71.98		a Inland Crude Supply 09 09 2016 02 00 00 1 m
Acidity [15	2.5 to 193.01 [ma KOH/a]	ma KOH/a	0.000	0.120		BAN1	B5	Banoco Arab Medium		450.00	63.23		a manu crude supply-05_06_2010 02_00_00_1.m
IH21 [%\	b]	% Vol	0.000	30.000	-	BHU1	BD	Basrah Heavy 24 API		250.00	36.24		Inland Crude Supply-09_08_2016 02_00_00_1.so
Total Nitro	gen [388.0 to 560.0] [ppm]	ppm	0.0	1650.0		BL21	BA	Basrah Crude Oil		400.00	56.24		Inland Crude Supply-09_08_2016 03_00_00_1.ma
Asphalten	is C7 [560.0 to EP] [% Wt]	% Wit	0.000	18.500		BLD1	B1	Belayim Land		200.00	29.47		Inland Crude Supply-09 08 2016 03 00 00 1.so

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.

Logistics Crudes Cargoes Supply Continuous Maritime Terminals Inland Terminals Refinery Depot	Cruck Ol Sa Line Tank 1 Tank	Cost to nhand Pipeline Refinery Depot Bit CO2 Bit CO2
BR-C01 BR-C02 BR-C03 BR-C04 CDU1 CDU1 Proc Lines Proc Lines Proc Lines Proc Lines CDU1 CDU1 CDU1 CDU1 CDU1 CDU1 CDU1 CDU1	Dataston Mod. A Naturation Mod. A Tax Non-Normal Non-Normal Non-Normal Value Normal 2000 Value Normal 2000 Value Normal 2000 Value Normal 20000 Value Normal 20000 Value Normal 20000 Used normal Normal Out-Type 20000 Used normal Normal Code Type 1004 Tark Operation Presided Code Type 1004 Date Tope 1004 Out-Statem Count Presided Code Type 1004 Date Tope 1004 Out-Type 10 New Information 10 Out-Type 100 Date Tope 100 Date Tope 100 Date Tope 100 Decody Dipper Date Tope 2000 Decody Date Topic Tope 2000 Decody Date EPIpt VM <	Tark State Color (I) Court (I) <

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.

Korick Sumay Korick Sumay Codes	Event Event Olympic Spirita Nordic Mistral	Type Crude Oil Supply by Ships Crude Oil Supply by Ships	Handled Quantity [m3] 98,000 49,000 1,807 47,193 159,000 50,724 50,706 50,684 6,686	Flow Rate [m3/d] 144,000 144,007 144,027 143,999 144,002 143,998 144,002 143,998	SUPPLY CARRIER Start 05/04/2018 10:00 05/04/2018 10:00 05/04/2018 18:20 06/04/2018 19:00 07/04/2018 19:00 07/04/2018 11:54	EVENTS End 05/04/2018 02:20 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 02:20 07/04/2018 03:27 07/04/2018 11:54 07/04/2018 19:21	Drigin [farm - tank] Olympic Spirita - Tank 1 - AHF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Destination [farm - tank] Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_K Maritime Depot - TMC_M
	Event Olympic Spirita Nordic Mistral Jag Lakshita	Type Crude Oil Supply by Shipe Crude Oil Supply by Shipe	Handled Quantity [m3] 98,000 49,000 1,807 47,193 159,000 50,724 50,724 50,684 6,886	Flow Rate [m3/d] 144,000 144,000 144,002 143,999 144,002 143,998 144,002	SUPPLY CARRIER Start 05/04/2018 10:00 05/04/2018 10:00 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 19:00 06/04/2018 19:00 07/04/2018 11:54	EVENTS End 05/04/2018 02:20 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 02:20 07/04/2018 03:27 07/04/2018 11:54 07/04/2018 13:92	Origin [farm-tank] Olympic Spirka - Tank 1 - AHF1 100% [Vol] Olympic Spirka - Tank 2 - ALF1 100% [Vol] Olympic Spirka - Tank 2 - ALF1 100% [Vol] Nordic Miatral - Tank 1 - MYA1 100% [Vol] Nordic Miatral - Tank 1 - MYA1 100% [Vol]	Destination [farm - tank] Maritime Depot - TMC_B Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Pepots Crudes Event Summay Cargo Sequencing Cargo Sequencing Supply Cargines Jag Lakshita Jag Lakshita Jag Lakshita Jag Lakef Kahla Supply Continuous BUU -4 May Supply Continuous BUU -1 Transfers	Event Olympic Spinta Nordic Mistral Jag Lakshita	Type Crude Oil Supply by Ships Crude Oil Supply by Ships	Handled Quantity [m3] 98,000 49,000 1,807 47,193 159,000 50,724 50,706 50,684 6,886	Flow Rate [m3/d] 144,000 144,000 144,002 143,999 144,000 144,002 143,998	Start 05/04/2018 10:00 05/04/2018 10:00 05/04/2018 18:10 05/04/2018 18:29 06/04/2018 19:00 06/04/2018 19:20 07/04/2018 03:27 07/04/2018 11:54	End 06/04/2018 02:20 05/04/2018 18:10 05/04/2018 18:28 05/04/2018 02:20 07/04/2018 21:30 07/04/2018 03:27 07/04/2018 10:54 02/04/2018 10:54	Drigin [farm - tank] Olympic Spirita - Tank 1 - AHF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Nodic Mistral - Tank 1 - MYA1 100% [Vol]	Destination [farm - tank] Maritime Depot - TMC_B Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Event Summary Crudes Cudes Cudes Cudes Cudes Supply Carries Jag Lakshia Jag Lakshia Jag Lateef Kahla BHU - 4 May Supply Continuous	Olympic Spirita Nordic Mistral Jag Lakshita	Crude Oil Supply by Ships Crude Oil Supply by Ships	[m3] 98,000 49,000 1,807 47,193 159,000 50,724 50,706 50,684 6,886	[m3/d] 144,000 144,000 144,027 143,999 144,002 144,002 143,998 144,002 143,998	05/04/2018 10:00 05/04/2018 10:00 05/04/2018 18:10 05/04/2018 18:28 05/04/2018 18:28 06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	06/04/2018 02:20 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 02:20 07/04/2018 02:21 07/04/2018 03:27 07/04/2018 11:54 02/04/2018 20:21	[farm - tank] Olympic Spirita - Tank 1 - AHF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	[farm - tank] Maritime Depot - TMC_B Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Coudes Cardes	Olympic Spirita Nordic Mistral Jag Lakshita	Crude Oil Supply by Ships Crude Oil Supply by Ships	98,000 49,000 1,807 47,193 159,000 50,724 50,706 50,684 6,886	144,000 144,000 144,027 143,999 144,000 144,002 143,998 144,002 143,986	05/04/2018 10:00 05/04/2018 10:00 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 19:00 06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	06/04/2018 02:20 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 02:20 07/04/2018 03:27 07/04/2018 03:27 07/04/2018 11:54	Olympic Spirita - Tank 1 - AHF1 100% (Vol) Olympic Spirita - Tank 2 - ALF1 100% (Vol) Olympic Spirita - Tank 2 - ALF1 100% (Vol) Nordic Mistral - Tank 1 - MYA1 100% (Vol) Nordic Mistral - Tank 1 - MYA1 100% (Vol)	Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Cargo Sequencing Supply Carriers Uprojic Spinta Logic Spinta Logic Spinta Logic Spinta Logic Spinta Logic Spinta Logic Sector Logic S	Nordic Mistral Jag Lakshita	Crude Oil Supply by Ships	49,000 1,807 47,193 159,000 50,724 50,706 50,684 6,886	144,000 144,027 143,999 144,000 144,002 143,998 144,002 143,986	05/04/2018 10:00 05/04/2018 18:10 05/04/2018 18:28 06/04/2018 19:00 06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	05/04/2018 18:10 05/04/2018 18:28 06/04/2018 02:20 07/04/2018 03:27 07/04/2018 03:27 07/04/2018 11:54 07/04/2018 20:21	Olympic Spirita - Tank 1 - AHF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot - TMC_B Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Supply Carriers Supply Carriers Supply Carriers X_0 Unyruic Spiths X_Nordic Mistral X_Nordic Hurter	Nordic Mistral Jag Lakshita	Crude Oil Supply by Ships	1,807 47,193 159,000 50,724 50,706 50,684 6,886	144,027 143,999 144,000 144,002 143,998 144,002 143,986	05/04/2018 18:10 05/04/2018 18:28 06/04/2018 19:00 06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	05/04/2018 18:28 06/04/2018 02:20 07/04/2018 02:20 07/04/2018 03:27 07/04/2018 11:54 07/04/2018 20:21	Olympic Spirita - Tank 2 - ALF1 100% [Vol] Olympic Spirita - Tank 2 - ALF1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot - TMC_B Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Burger Supply Camers	Nordic Mistral Jag Lakshita	Crude Oil Supply by Ships	47,193 159,000 50,724 50,706 50,684 6,886	143,999 144,000 144,002 143,998 144,002 143,996	05/04/2018 18:28 06/04/2018 19:00 06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	06/04/2018 02:20 07/04/2018 21:30 07/04/2018 03:27 07/04/2018 11:54 07/04/2018 20:21	Olympic Spirita - Tank 2 - ALF1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot - TMC_K Maritime Depot - TMC_G Maritime Depot - TMC_M
Clympic Spirls Compic Spirls Compic Commission Lag Lakshita Lyag Lakshita Lynodic Humer Lyn	Nordic Mistral Jag Lakshita	Crude Oil Supply by Ships	159,000 50,724 50,706 50,684 6,886	144,000 144,002 143,998 144,002 143,986	06/04/2018 19:00 06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	07/04/2018 21:30 07/04/2018 03:27 07/04/2018 11:54 07/04/2018 20:21	Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot - TMC_G Maritime Depot - TMC_M
L Norde Mittel Lackshita	Jag Lakshita		50,724 50,706 50,684 6,886	144,002 143,998 144,002 143,986	06/04/2018 19:00 07/04/2018 03:27 07/04/2018 11:54	07/04/2018 03:27 07/04/2018 11:54 07/04/2018 20:21	Nordic Mistral - Tank 1 - MYA1 100% [Vol] Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot · TMC_G Maritime Depot · TMC_M
L Jag Lakshita L Norde Hunter Snooa L Norde Hunter Snooa L Norde Hunter Snooa Snooa Snooa Snooa	Jag Lakshita		50,706 50,684 6,886	143,998 144,002 143,986	07/04/2018 03:27 07/04/2018 11:54	07/04/2018 11:54	Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot - TMC_M
Kordio Hunter Kordio	Jag Lakshita		50,684 6,886	144,002	07/04/2018 11:54	07/04/2018 20:21	ALL DI LES LET LES LEURA ACCOUNTER	
Kotac Hunter Konoa Konoa Koha Koha Koha Koha Supply Continuous Big Transfers	Jag Lakshita		6,886	143 986		011041201020.21	Nordic Mistral - Lank T - MYAT 100% [Vol]	Maritime Depot - TMC_H
Tringa X_s Singa X_s Jag Later X_s Aihi X_s Kahia X_s BHU - 4 May Supply Continuous Gli My Transfers	Jag Lakshita				07/04/2018 20:21	07/04/2018 21:30	Nordic Mistral - Tank 1 - MYA1 100% [Vol]	Maritime Depot - TMC_N
Jag Lateri Kahla Kahla Supply Continuous Gr Transfers	-	Crude Oil Supply by Ships	158,900	144,000	09/04/2018 10:00	10/04/2018 12:29		
Kahla Septy Continuous Transfers			47,700	144,000	09/04/2018 10:00	09/04/2018 17:57	Jag Lakshita · Tank 1 · AHF1 100% [Vol]	Maritime Depot - TMC_D
BHU - 4 May Supply Continuous			3,100	144,000	09/04/2018 17:57	09/04/2018 18:28	Jag Lakshita - Tank 2 - ARM1 100% [Vol]	Maritime Depot - TMC_D
Supply Continuous			50,613	143,999	09/04/2018 18:28	10/04/2018 02:54	Jag Lakshita - Tank 2 - ARM1 100% [Vol]	Maritime Depot - TMC_L
Supply Continuous			9,787	144,005	10/04/2018 02:54	10/04/2018 04:32	Jag Lakshita - Tank 2 - ARM1 100% [Vol]	Maritime Depot - TMC_J
Transfers			41,013	143,999	10/04/2018 04:32	10/04/2018 11:22	Jag Lakshita - Tank 3 - ALF1 100% [Vol]	Maritime Depot - TMC_J
			6,687	144,007	10/04/2018 11:22	10/04/2018 12:29	Jag Lakshita · Tank 3 · ALF1 100% [Vol]	Maritime Depot - TMC_I
Deservines	Nordic Hunter	Crude Oil Supply by Ships	159,000	144,000	12/04/2018 10:00	13/04/2018 12:30		
- S Processings			50,998	144,000	12/04/2018 10:00	12/04/2018 18:29	Nordic Hunter - Tank 1 - BLT1 100% [Vol]	Maritime Depot - TMC A
🐛 CDU Processing 1			41,985	143,999	12/04/2018 18:29	13/04/2018 01:29	Nordic Hunter - Tank 1 - BLT1 100% [Vol]	Maritime Depot - TMC I
- E 🔤 Pipelines Operation Summary			40,082	144,003	13/04/2018 01:29	13/04/2018 08:10	Nordic Hunter - Tank 1 - BLT1 100% [Vol]	Maritime Depot - TMC E
Mailine > Policen			25,934	143,996	13/04/2018 08:10	13/04/2018 12:30	Nordic Hunter - Tank 1 - BLT1 100% [Vol]	Maritime Depot TMC_C
T D L : W X	Sinopa	Crude Oil Supply by Ships			16/04/2018 10:00	16/04/2018 10:00		
DOCK > Manune	Jag Lateef	Crude Oil Supply by Ships			22/04/2018 10:00	22/04/2018 10:00		
🖃 💽 Toppings Operation Summary	Kahla	Crude Oil Supply by Ships			27/04/2018 17:00	27/04/2018 17:00		
Le 🕕 cout	A COMPANY OF MALE				04/05/2010 10:00	04/05/2019 10:00		

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.

🗊 Report								
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Save XLS Print Volume Weight Date Sel All Crudes	Remarks Init Slices Qualities Exit							
+			PIPE OPERATION S	JMMARY MARITIME -	> REFINERY			
E Reports Batch No			1574	1578	1581	1583	1585	1586 ^
Date From Date F	1		05/04/2018 00:00	08/04/2018 01:55	09/04/2018 22:54	11/04/2018 20:00	13/04/2018 16:00	15/04/2018 15:00
Date I o Date I o Date I o			08/04/2018 01:55	09/04/2018 22:54	11/04/2018 20:00	13/04/2018 16:00	15/04/2018 15:00	15/04/2018 16:00
	TMC B			30.0	17.0	65.0		54
Cargo Sequencing	TMC C		28.8	5.2				
H Supply Larners	TMC_D		9.2			28.0	39.0	
Supply Continuous	TMC_E				47.9			
Transfers	TMC_F			33.5	34.3	1.2		
- A Processings	TMC I		26.2					26.7
CDU Processing 1	TMC J		35.7	10.5				27.0
Destruction Community	TMC_L						44.6	
Pipeines Operation Summary	TMC_M						12.7	30.8
Mantime -> Hetinery	TMC_N					5.7	3.7	
Crudes [2	Vol] AHF1	Arabian Heavy	1.4	3.6	17.3	52.2	33.5	3.2
😑 🙍 Toppings Operation Summary	ALF1 ADM1	Arab Light Arabian Modium	11.0	2.2	11	0.4	27.5	14.9
Le 🗍 CDU1	BHUI	Basrah Heavu 24 API	26.5	13.4	56	23	27.3	7.2
700 Ratch View	BLT1	Basrah Light	0.6	28.1	29.3	2.0	3.9	26.6
	IH21	Iranian Heavy	24.4	30.0	26.5	21.8		4.1
Daily View	JUB1	Jubarte	6.5	0.1		2.3	3.3	0.0
- E 🙆 Inventory Detail	KU21	Kuwait	7.6	1.4		0.3	0.9	
- 🖃 🚟 Maritime Terminals	MYA1	Maya Maya	20.6	20.3	20.2	14.9	28.1	29.7
Maritime Depot Propertie	Density (API)	Upper Zakum	25.19	26.59	26.66	26.09	25.64	26.91
	Density @15°C	[Ka/dm3]	0.9032	0.8951	0.8946	0.8978	0.9006	0.8936
C Defining Densel	Sulphur (Total)	[% Wt]	3.020	3.093	3.070	2.969	3.093	3.100
- President Contraction	Acidity	[mg KOH/g]	0.392	0.148	0.145	0.257	0.289	0.140
Pipelines	Viscosity @40°C	[Cst]	23.03	18.54	19.11	20.77	23.30	18.51
🖵 🎘 Overall	T otal Nitrogen [388.0[*C) to 560.0[*C]]	[ppm]	1650.0	1629.1	1567.0	1391.2	1338.0	1436.4
- E Arm Crude Oils Consumption	Acidity [152.5] U to 133.0[U]]	[mg KUH/g] [% \u01	19,500	19 500	19.453	19 500	19,500	19,500
Pipelines	Conradson Carbon (560.0) *C) to EP1	[% Wt]	26.785	28.112	28.051	26.956	26.725	27.608
Toppings	Density @15°C [15.0(°C) to 91.9(°C)]	[Kg/dm3]	0.6522	0.6521	0.6517	0.6504	0.6518	0.6528
	PC Yield [-88.6(*C) to -60.3(*C)]	[% Wt]	0.114	0.119	0.115	0.106	0.093	0.116
	PC Yield [-42.1(*C) to -0.5(*C)]	[% Wt]	0.603	0.626	0.601	0.544	0.499	0.633
	Cut Yield [15.U[*C) to 95.6(*C)]	[% Wt]	4.567	5.064	5.141	4.987	5.014	5.371
	Cut Yield [35.6] CJ to 142.0[10]	[4 W] [2 10]	5.235	5.886	5./63	5.220	4.866	5.484
	Cut Yield [152.5] *C) to 193.0[*C]]	[% Wt]	5.317	5.416	5.365	5.308	5.434	5.646
	Cut Yield [193.0(*C) to 245.0(*C)]	[% Wt]	6.734	7.106	7.080	6.885	6.672	7.077 🗸

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.

🗊 Report																	, •
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Save XLS Print Volume Weight Date Se	▲ aprile 2018 ►	Qualities Exit															
+ -	lu mame gi ve sa do	MARITIME DEPOT INVENTORY 12-04-2018 06-00															
	12 26 27 28 29 30 31 1	12/04/2018 06:00							Maritime	Denot							
	14 2 3 4 5 6 7 8	[m3]	TMC A	TMC B	TMC C	TMC D	TMC E	TMC F	TMC G	TMC H	TMC 1	TMC J	TMC K	TMC L	TMC M	TMC N	Total
🖃 🚾 Event Summary	15 9 10 11 12 13 14 15	Arabian Heavy	72	26,616		29,980	5,378	636		76		289	16,440	15,147			94,633
🖃 🖌 Crudes	16 17 19 19 20 21 22	Arab Light		314					18,247		6,687	22,766	30,753				78,767
Caron Sequencing	17 23 24 25 26 27 28 29	Arabian Medium		4,096	7,735			244				28,034		35,466	989		76,566
Supplu Carriero	18 30 1 2 3 4 5 6	Basrah Heavy 24 API	1,700		1,997	693	528				6,992	566			4,808	4,439	21,723
Supply Callers		Basrah Light	3,975		377		7,311		4,980				83	5,084			21,809
Supply Continuous	11	Iranian Heavy		15,344			1,090	5,480	74		293	4,754	6,336				33,370
- 🕀 🛃 Transfers	Hour Ub:UU V	Jubarte				4,461			753			68					5,282
Processings		Kuwait	1.400	1.005	4,929	10.000	2 01 2	1.000	22.040	57.004	1.042	1.524	050	826	E0 000	784	6,539
COUP		Maya	1,455	1,205	3,765	18,282	3,612	1,603	33,946	57,924	1,842	1,524	856	1,477	52,202	7,834	187,525
LUU Processing I	Total	opper Zakum	7 202	47 575	10 000	52.415	17 910	7 902	50 000	59 000	16.015	59 000	54 400	59 000	59,000	12 276	420 520 624
🕀 🏬 Pipelines Operation Summary	Density (API)	[*API]	26.32	27.50	27.67	23.58	26.62	26.88	25.02	20.21	27.36	30,000	30.37	29.16	20.66	22.17	25.95
Maritime -> Refinery	Density @15*C	[Ka/dm3]	0.8966	0.8895	0.8891	0.9124	0.8948	0.8933	0.9048	0.9321	0.8911	0.8707	0.8740	0.8804	0.9294	0.9206	0.8991
Dock -> Maritime	Sulphur (Total)	[% Wt]	3.441	2.827	2.991	3.139	3.211	2.681	3.133	3,759	3.126	2.379	2,421	2,794	3.763	3.754	3.072
Territor Develop Commen	Acidity	[mg KOH/g]	0.177	0.178	0.171	0.460	0.163	0.102	0.139	0.100	0.185	0.138	0.123	0.195	0.119	0.174	0.177
Toppings operation summary	Viscosity @40°C	[Cst]	21.23	14.75	14.42	42.62	20.95	16.02	31.16	115.68	14.17	7.49	9.25	10.26	93.62	52.01	22.27
= CDU1	Total Nitrogen [388.0(*C) to 560.0	0(°C)] [ppm]	1346.9	1302.6	1219.3	1492.7	1336.1	1986.6	1736.6	2137.0	1175.4	1066.6	1090.1	931.3	2034.6	1711.0	1488.3
Batch View	Acidity [152.5(*C) to 193.0(*C)]	[mg KOH/g]	0.052	0.064	0.042	0.043	0.048	0.116	0.050	0.060	0.050	0.039	0.044	0.027	0.059	0.059	0.049
Politikana (Asphaltenes C7 [560.0[°C) to EP]	[% Wt]	18.860	16.212	14.907	21.098	18.416	18.282	23.286	28.969	19.168	7.782	12.804	10.302	28.331	26.218	20.124
Daily View	Conradson Carbon (560.0(°C) to B	EP] [% Wt]	28.254	26.071	26.027	27.622	27.918	28.138	30.132	33.067	27.216	21.562	24.497	22.592	32.614	31.312	28.149
🖃 💽 Inventory Detail	Density @15°C [15.0(°C) to 91.9	(*C)] [Kg/dm3]	0.6528	0.6500	0.6527	0.6507	0.6517	0.6510	0.6533	0.6542	0.6525	0.6527	0.6514	0.6521	0.6540	0.6532	0.6523
🖂 🚟 Maritime Terminals	PC Yield [-88.6(*C) to -60.3(*C)]	[% Wt]	0.133	0.118	0.130	0.081	0.118	0.101	0.091	0.030	0.163	0.146	0.163	0.120	0.042	0.089	0.101
Maritime Depot	PU Yield [-42.1[*U] to -0.5[*U]]	[% Wt]	0.710	0.607	0.700	0.416	0.620	0.517	0.504	0.169	0.895	0.815	0.880	0.655	0.234	0.484	0.547
Walkine Depor	Lut Yield [15.0] 'C to 95.6['C]]	[% Wt]	5.336	5.363 E 701	5.683	4.348	5.373 E 401	4.716	4.731	3.393	5.488	6.436	6.3U/	6.149 E.COO	3.533	4.021	5.026
Intermediate Terminals	Cut Yield [142.0[10] to 152.5[10]	[% w()]	1.569	1.984	1.943	4.220	1.678	2.047	4.072	4.027	1.817	2.181	2.058	2.050	4.104	4.007	1.799
🖳 🔟 Refinery Depot	Cut Yield [152 5[*C) to 193 0[*C]	[2 Wh]	5.267	5 501	5 925	4 892	5 270	5 549	5.569	5 000	5.916	6.569	6.219	6.065	5.045	5 161	5 592
🕀 🏧 Pipelines	Cut Yield [193.0[*C] to 245.0[*C]	[% Wt]	6.973	7.294	7.128	6.137	6.973	7.286	6.565	5.350	7.404	8.167	8.053	7.572	5.497	5.946	6.814
Bin Overall	Cut Yield [245.0[*C] to 340.0[*C]	[% Wt]	14.135	14.679	14.177	12.992	14.206	14.417	13.363	11.309	14.693	15.901	15.875	15.045	11.547	12.285	13.802
All orona	Cut Yield [340.0[*C] to 360.0[*C]	[% Wt]	3.076	3.063	3.032	2.880	3.042	2.941	2.891	2.610	3.172	3.215	3.234	3.132	2.661	2.825	2.962
- E Am Crude Dils Consumption	Cut Yield [360.0[*C] to 388.0[*C]	[% W/t]	4.229	4.262	4.176	4.030	4.226	4.205	4.060	3.788	4.261	4.390	4.397	4.305	3.825	3.942	4.130
🕀 🎬 Pipelines	Cut Yield [388.0[*C] to 460.0[*C]	[% W/t]	10.618	11.025	10.573	10.911	10.705	11.585	10.700	10.311	10.664	11.002	11.049	10.659	10.311	10.320	10.722
- 🕀 🔂 Toppings	Cut Yield [460.0[*C] to 560.0[*C]	[% W/t]	13.543	13.040	13.017	14.213	13.372	13.504	13.790	14.735	13.078	12.461	12.370	12.806	14.627	14.227	13.520
	Cut Yield [560.0(*C) to EP]	[% W/t]	28.840	27.363	28.016	33.303	28.985	26.807	31.199	37.834	26.878	22.488	23.446	25.754	37.058	34.605	29.874
	СМВО	[% Vol]	20.200	2.532	20.021	34.226	20.159	20.125	58.528	99.869	11.503	2.627	1.572	2.547	90.004	59.008	35.608

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

					Coast to	inland Pip	eline P	ipeline Sta	itus @ 01	1/05/2	1018 06	5:00								
MXCO MXCO	MXCO		мхсо				MXCO						MXCO			MXCO				
1.000	1.0100							10100						10,000						
32700 638.5005	34335	71	7111.08					124943.6					1	6445.84				68604.	93	
IN 58 11	17 175	233	292 3	350 -	108	466	525	583	641	7	00	758	816	875	933	9	91	1050	1108	116
																			Кп	n>
			-		0		-					0		0						_
Velume	f== 21	22	700	C20 E0	6	5 24225		77111.09		124942.6 76445.94		600	1 04.02				^			
Length	[III3]	32	19	636.00	8	96.5		216.8			351.3		7044	0.04 14.9	000	192.9				
Flowrate	[m3/d]	39	240	392	40	3924	40 3		9240	39240		240	39240			39240				
Density (API)	[*API]	26	.44	28.	50	28.5	50		27.42		26.99		26.62			26.76				
Density @15°C	[Kg/dm3]	0.8	960	0.88	41	0.884	41	0.8904			0.8931		0.8951		(0.8941				
Sulphur (Total)	[% Wt]	2.	844	2.7	00	2.70	08	2.79		2.949		949	3.080			3.093	.093			
Acidity	[mg KOH/g]	0.1	136	0.1	52	0.15	59	0.162			0.124		0.125			0.127				
Viscosity @40°C	[Cst]	18	.38	11.4	40	11.5	56		14.82	2 18.29			19.96			19.57				
Total Nitrogen	[ppm]	165	0.0	1340	.4	1351	.5	1	505.8		165	0.0	16	48.5	1	1644.9				
Acidity	[mg KOH/g]	0.	071	0.0	52	0.06	63		0.067		0.0	070	0	.071		0.074				
Asphaltenes C7	[% Wt]	18.	500	12.8	27	13.04	\$1	1	6.309		18.5	500	18	.500	1	18.343				
Conradson Carbon	[% Wt]	27.	516	24.3	76	24.58	31	2	5.288		28.1	173	28	.406	2	28.390				
Density @15°C	[Kg/dm3]	0.6	520	0.65	15	0.65	15	0	6516		0.65	524	0.	526	(0.6524				
PC Yield [-88.6 to -60.3]	[% Wt]	0.1	094	0.1	15	0.11	17		0.107		0.1	13	0	.111		0.115				
PC Yield [-42.1 to -0.5]	[% Wt]	0.	499	0.6	11	0.62	22		0.570		0.6	501	0	.588		0.606				
Cut Yield [15.0 to 95.6]	[% Wt]	4.	975	5.6	27	5.62	28		5.266		5.1	96	5	.152		5.184				
Cut Yield [95.6 to 142.0]	[% Wt]	5.	536	6.0	11	6.02	23		5.768		5.7	763	5	.743		5.861				
Cut Yield [142.0 to 152.5]	[% Wt]	1.	324	2.0	35	2.06	67		1.987		1.8	313	1	769		1.737				
0.1001011010101110000	19/31/61	¢.	∿nc	E 0	nn	E 0/	~		5 700		c 0	in	-	450		e nen				×

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 Km³) 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 Km³.



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.

Benefits:

- 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.
- 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.
 - o Analysis of alternative scenarios
 - o 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.