# Crude Oil Blend Scheduling Optimization of an Industrial-sized Refinery: A Discrete Time Benchmark

**Motivation:** Replace Full Space MINLP by MILP + NLP decompositions for large problems

**Remark:** Continuous-time model cannot be easily implemented by plant operators

**Objective:** Explore to the limit discrete-time models: example 7days/2h step (84 periods)


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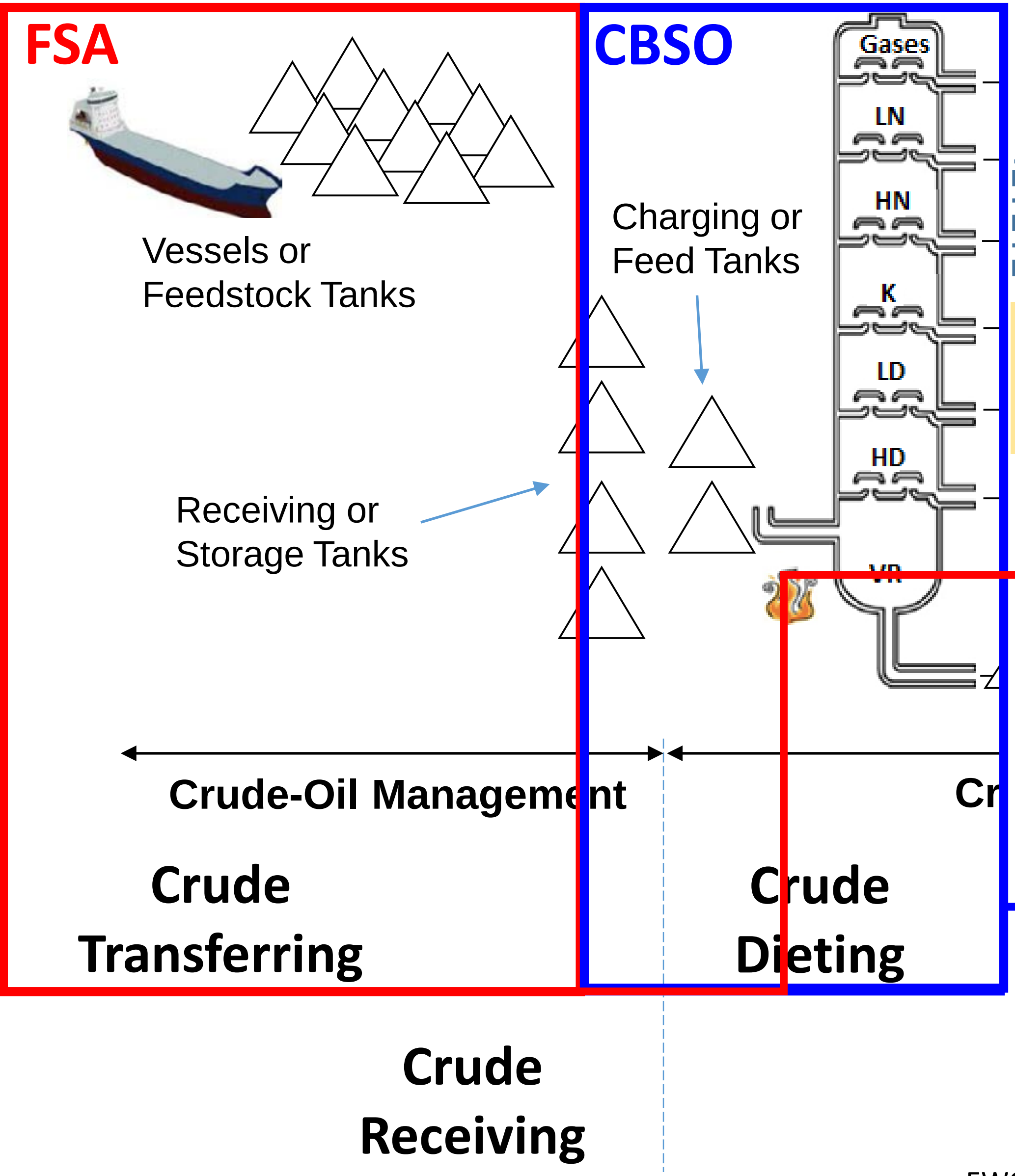
# Whole Scheduling: from Crude to Fuels

## Crude-Oil Scheduling Problem




**1996: Lee, Pinto, Grossmann and Park (MILP), discrete-time**

**2004: Randy, Karimi and Srinivasan (MILP), continuous-time**

**2009: Mouret, Grossmann and Pestiaux: MILP+NLP continuous-time**

**2014: Castro and Grossmann: MINLP ; MILP+NLP, continuous-time**

**2015: Cerda, Pautasso and Cafaro: MILP+NLP, continuous-time**
**(336h: 14 days; binary ≈ 4,000; continuous ≈ 6,000; constraints ≈ 100K; CPU(s) ≈ 500)**

**2016 Goal: solve the SK refinery scheduling for a week (34 crude, 4 pipelines, 24 storage tanks, 9 feed tanks, 5 CDUs)**

**1st Feedstock Storage Assignment (FSA)** **(MILP)**

- Improves the polyhedral space of optimization for CDU feed diet
- Reduces optimization search space for further scheduling

**2nd Crude Blend Scheduling Optimization (CSBO)** **(MILP+NLP)**

Yields (Menezes, Kelly & Grossmann, 2015)
Rates (crude diet, fuel recipes, conversion)

- Includes logistics details
- PDH Decomposition (logistics + quality problems)

# Crude Blend Scheduling Optimization (CBSO-QL)

Mixing-time | Uptime-Use | MILP(QL) + NLP(QQ) | Multi-Use | Other types | Quantity + Logic

- Key logistics details … (QL)

5th: 1 or 2 flow-in at-a-time for the CDU

1st: fill-draw-delay for storage tanks (e.g. 24h)

6th: uptime for tank-to-CDU flows (e.g. 12h)

2nd: uptime (run-length) for blend header (3h)

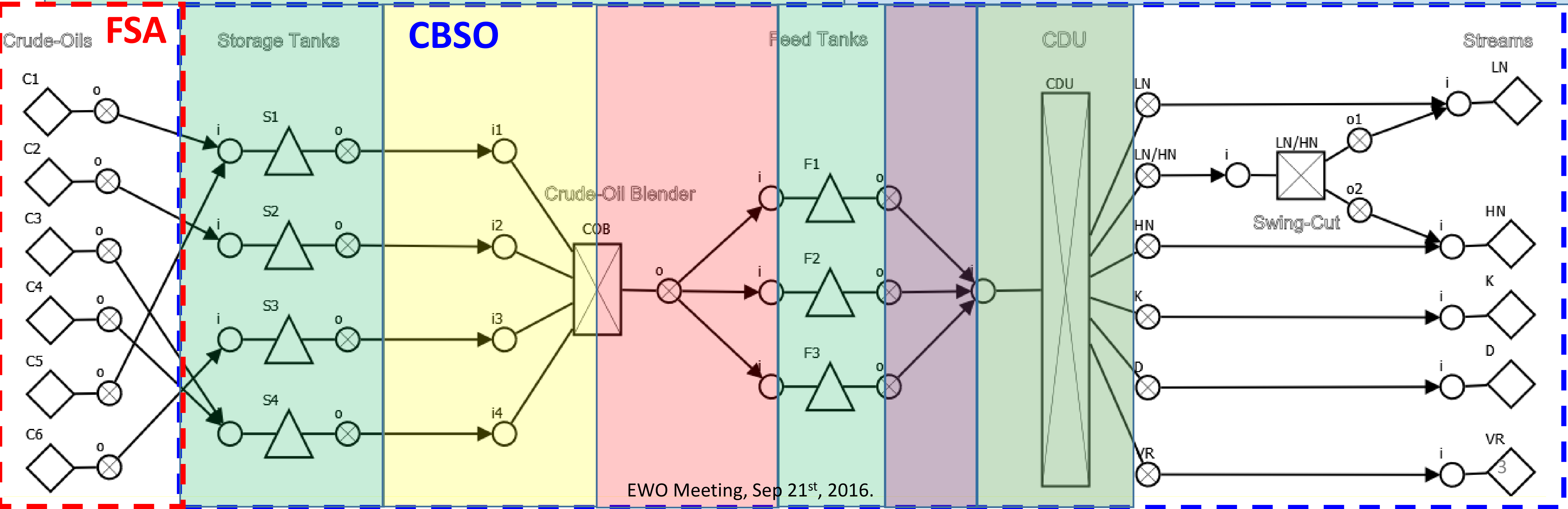
7th: 0-h downtime (continuous) for the CDU

3rd: 1 flow-out at-a-time for the blend header

8th…: Feed tank transitions

4th: fill-draw-delay for feed tanks (e.g. 3h)

Sequence-dependent (Kelly and Zyngier, 2007)



# Crude Blend Scheduling Optimization (CBSO-QQ)

Quantity + Quality

MILP(QL) + NLP(QQ)

Yields

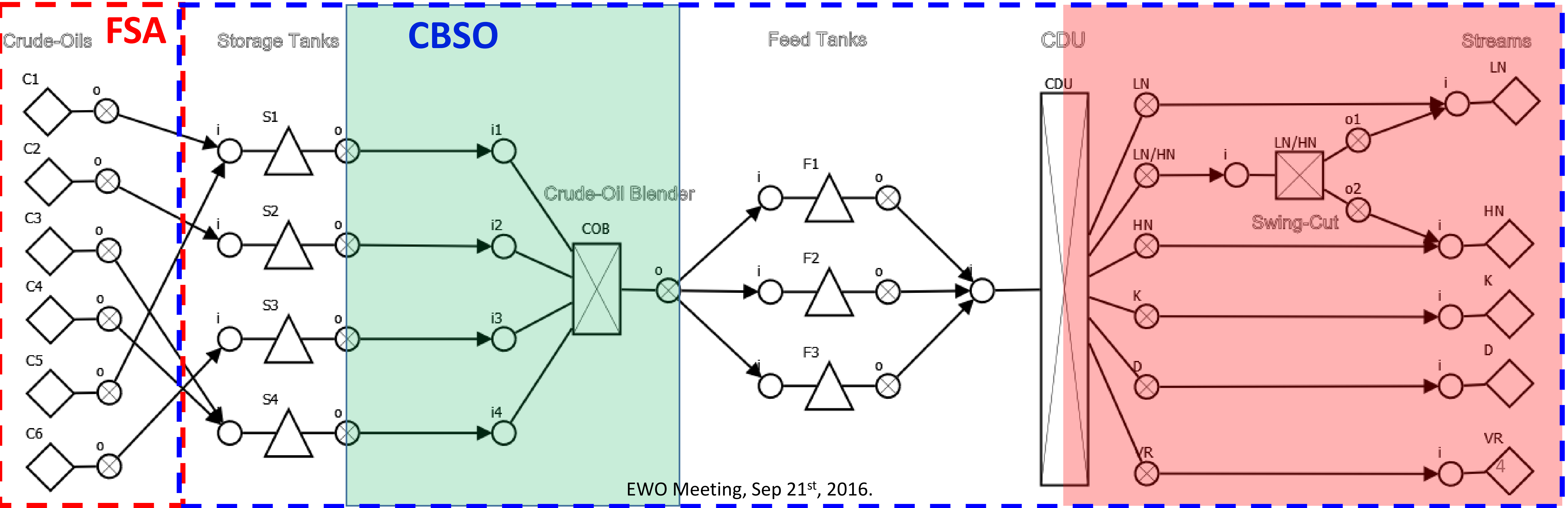
Rates (crude diet, fuel recipes, conversion)

- Key quality details… (QQ)

1st: Feed Tank diet

2nd: CDU models (modes of operations). Drawback: ↑ binary variables, Option: NLP models

Fractionation Index (Alattas et al., 2012, 2013); Improved Swing-Cut (Menezes et al., 2013), Distillation Blending (Kelly et al., 2014)

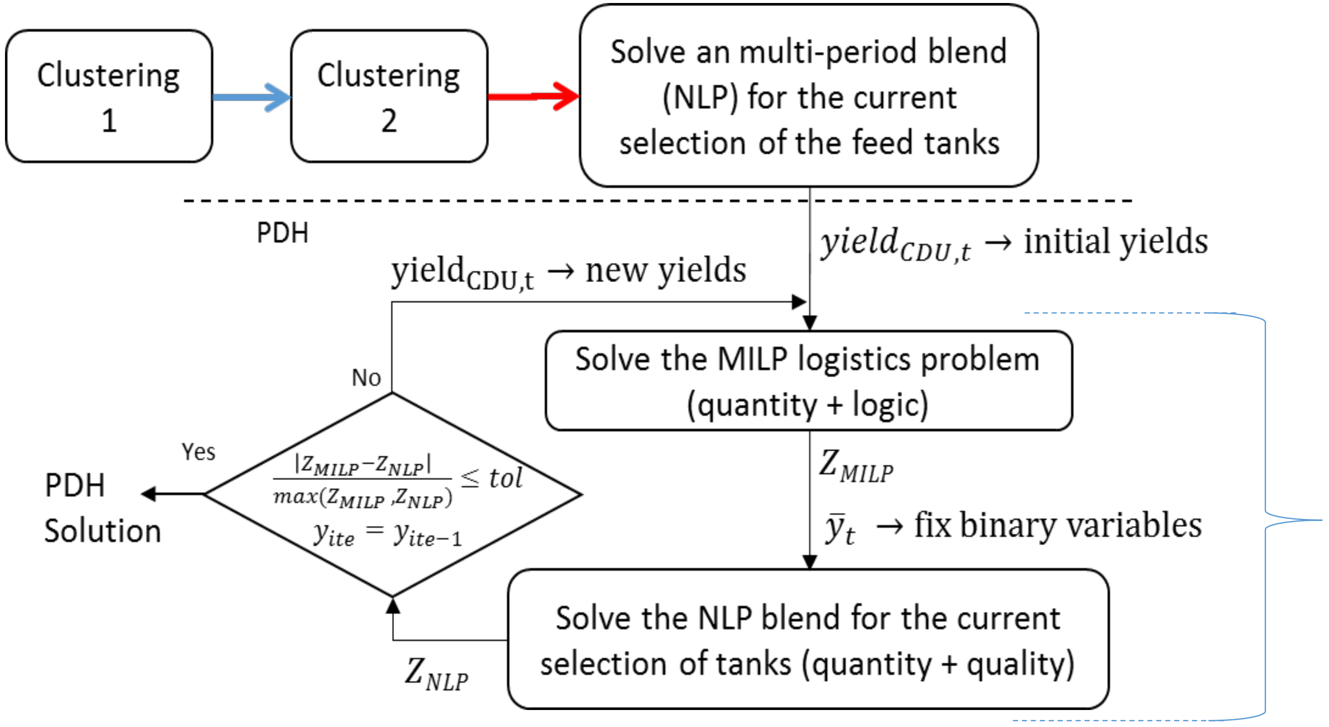


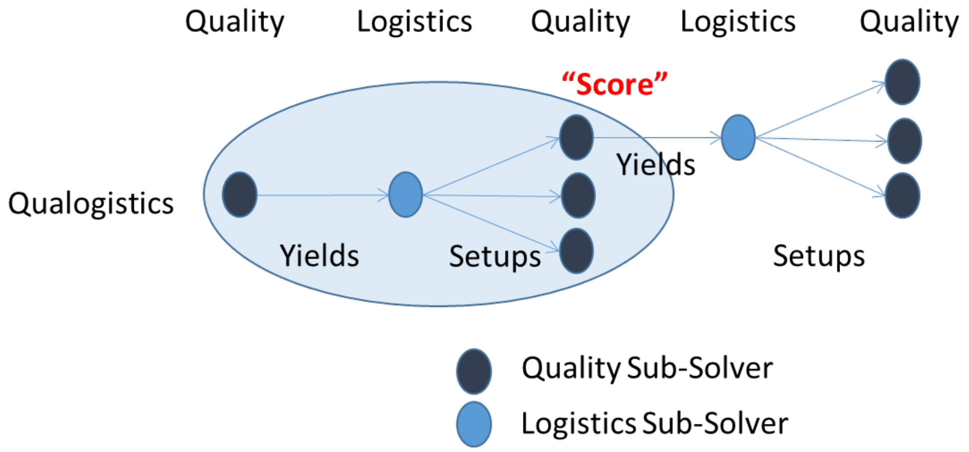
# Phenomenological Decomposition Heuristic

**MILP(QL) + NLP(QQ)**

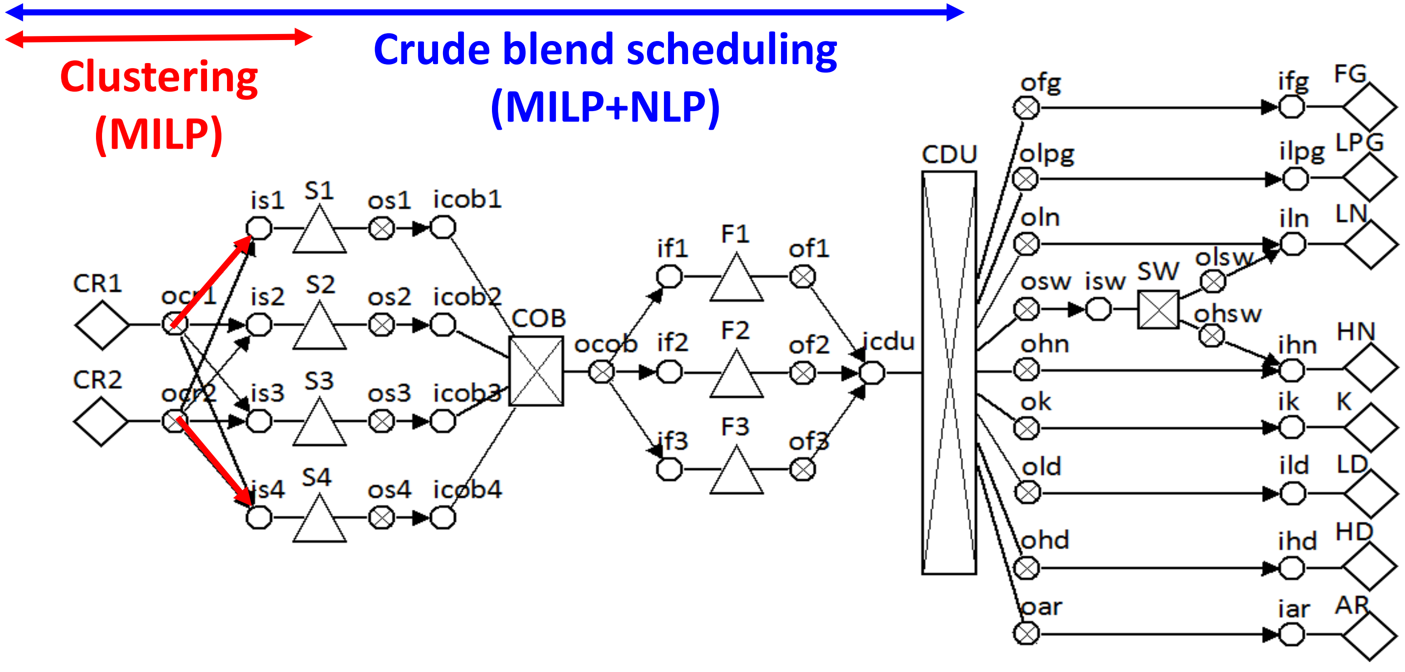
Yields

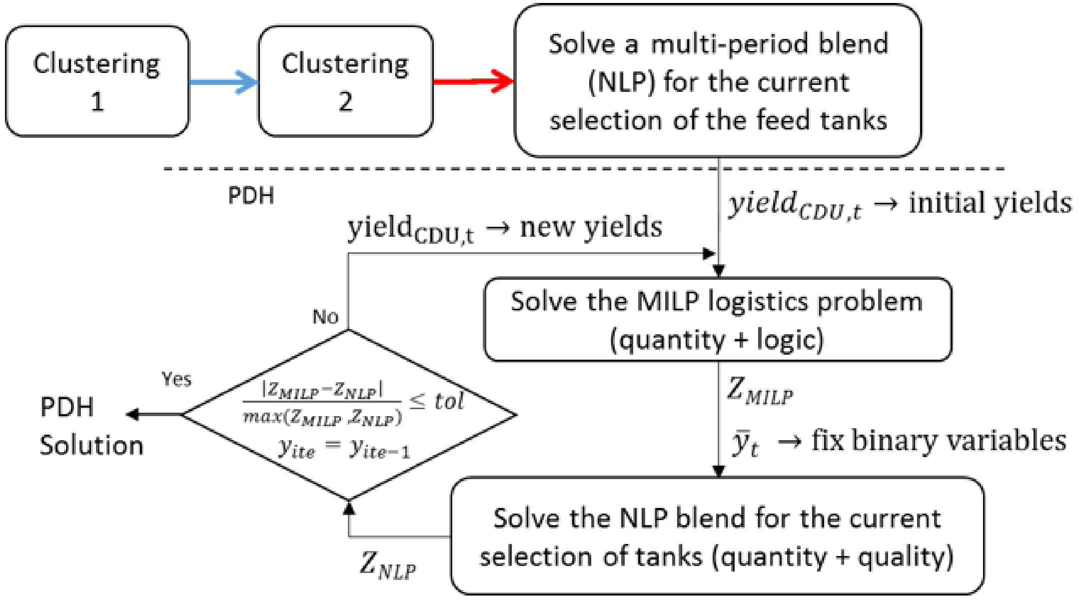
Rates (crude diet, fuel recipes, conversion)



# Crude-Oil Blend Scheduling: Illustrative Example




## 336h: 14 days discretized into 2-hour time-period durations (168 time-periods)

**The *logistics* problem (MILP): $Z_{MILP}$=695.6**

8,333 continuous + 3,508 binary variables
3,957 equality and 15,810 inequality constraints
Non-Zeros: 59,225 ; Degrees-of-freedom: 7,884
**CPU(s): 176.0 seconds** / 8 threads in CPLEX 12.6.

**The *quality* problem (NLP): $Z_{NLP}$=701.9**

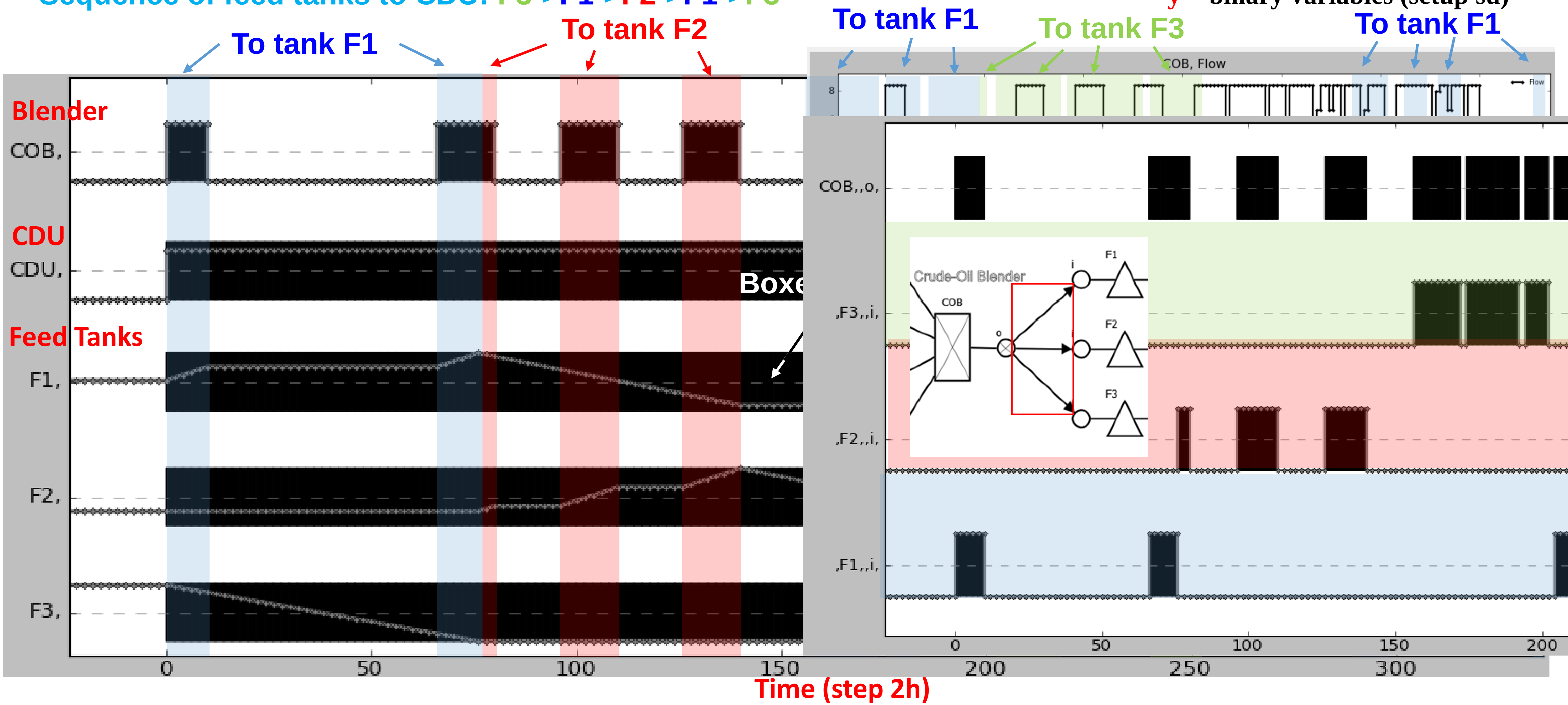
19,400 continuous variables
14,862 equality and 696 inequality constraint
Non-Zeros: 26,430 ; Degrees-of-freedom: 4,538
**CPU(s): 16.8 seconds** in the IMPL’ SLP engine linked to CPLEX 12.6.

**MILP-NLP gap**: **0.09%** with only **one PDH iteration**.

# 2nd Crude-oil Blend Scheduling Optimization (CBSO-QL)

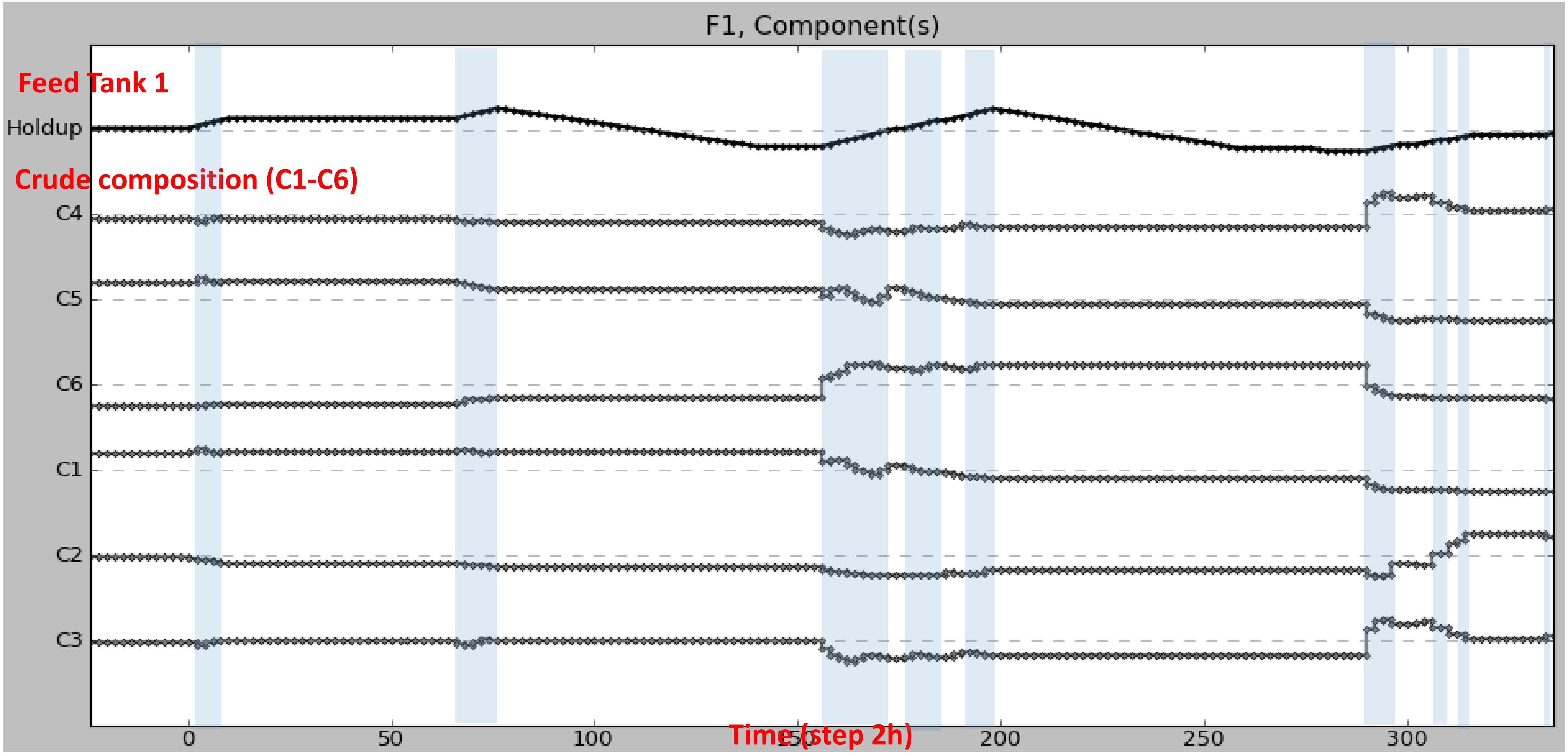
x = continuous variables (flow f)
y = binary variables (setup su)

Sequence of feed tanks to CDU: F3->F1->F2->F1->F3



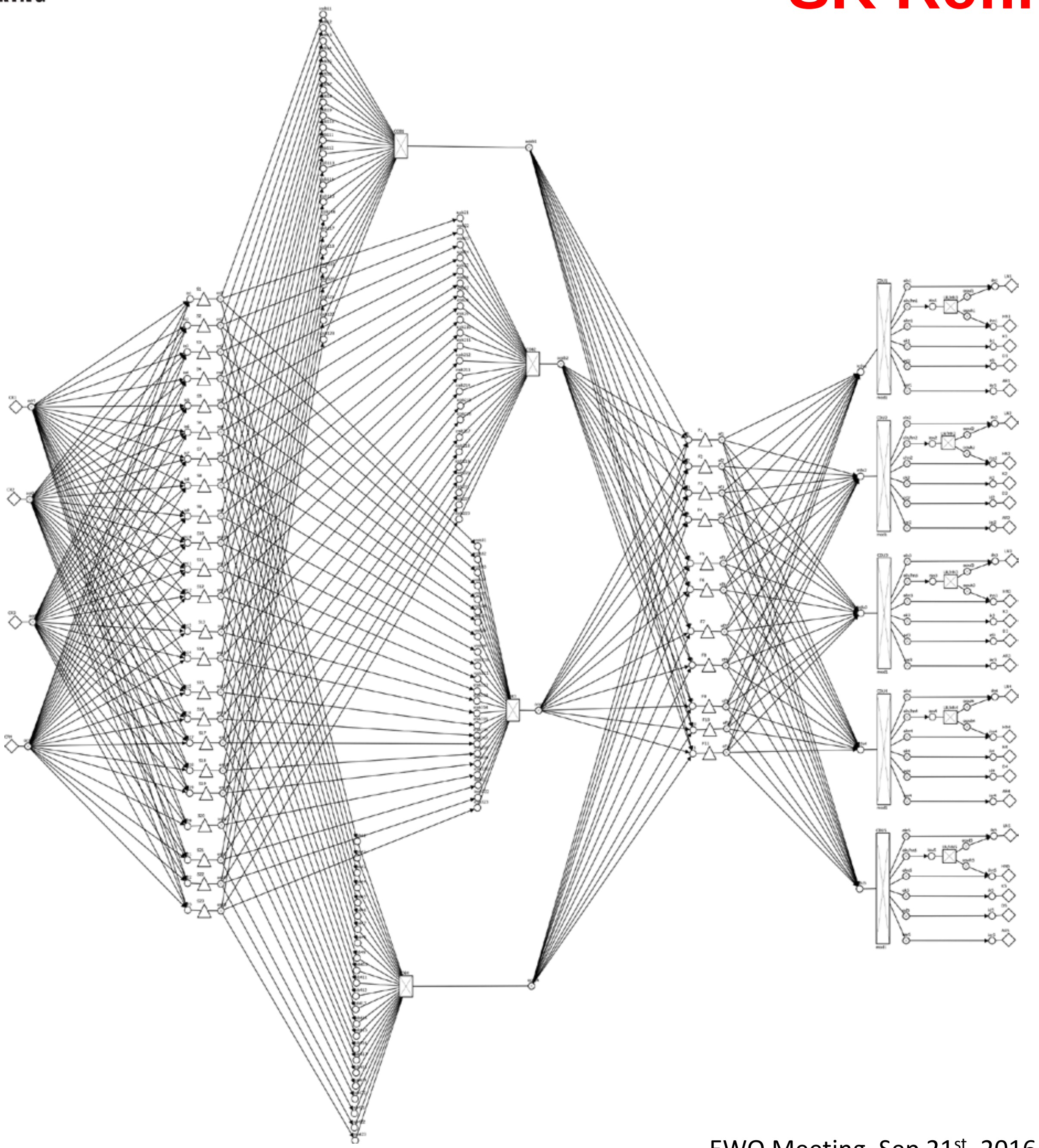

Gantt Chart: Crude blender, CDU and Feed Tanks Holdup.

# 2nd Crude-oil Blend Scheduling Optimization (CBSO-QQ)




**Gantt Chart: Feed Tank F1 Holdup and its crude composition.**

# SK Refinery Example



The proposed model is applied in an industrial-sized refinery including 5 crude-oil distillation units (CDU) in 9 modes of operation and around 35 tanks among storage and feed tanks. The past/present time-horizon has a duration of 48-hours and the future time-horizon is **168-hours discretized into 2-hour time-period durations (84 time-periods).**

The *logistics* problem (MILP):

30,925 continuous and 29,490 binary variables 6,613 equality and 79,079 inequality constraints (degrees-of-freedom = 53,802) and it is solved in 128.8 seconds using 8 threads in CPLEX 12.6.

The *quality* problem (NLP):

102,539 continuous variables and 58,019 equality and 768 inequality constraints (degrees-of-freedom = 44,520) and lasts 103.3 minutes in the IMPL' SLP engine linked to CPLEX 12.6.

The MILP-NLP gap between the two solutions is within 11% with two PDH iterations.

# Conclusion



## Novelty:

- **Segregates crude management in storage assignment and crude blend scheduling.**
- **Phenomenological decomposition in logistics (MILP) and quality (NLP) problems applied in a scheduling problem.**
- **Details all logistics relationships from practiced industrial operations.**

## Impact for industrial applications:

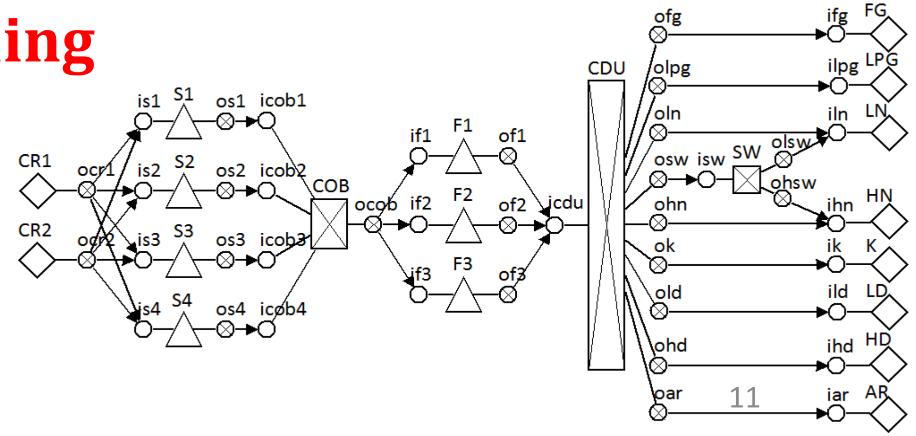
- **UOPSS modeling, pre-solving, and parallel processing permitted to solve an 2h time-step discrete-time formulation for a highly complex refinery (34 crude-oils, 24 storage tanks, 9 feed tanks, 5 CDUs):** for 7 days (84 time-periods)

# Conclusion



## Next Steps:

- Add upgrading units and their tanks (RFCC hydrotreaters, RFCC, VDU)
- Add cutpoint optimization instead of modes of operation in CDUs
- Crude-Oil Blender x Sequential Blending to prepare the Feed Tanks.
- Factors using bulk qualities as an LP between the Storage and Feed Tanks to be used in the logistics (MILP)
- Whole Scheduling: from Crude-Oils to Fuel Deliveries
- Initialization, Synchronization, Real-time Scheduling



# Thank You

# Q?&A!

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