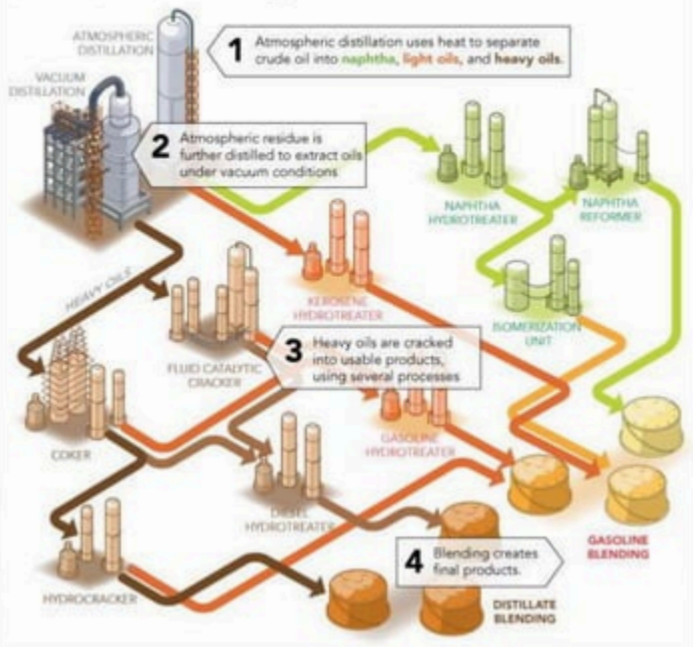
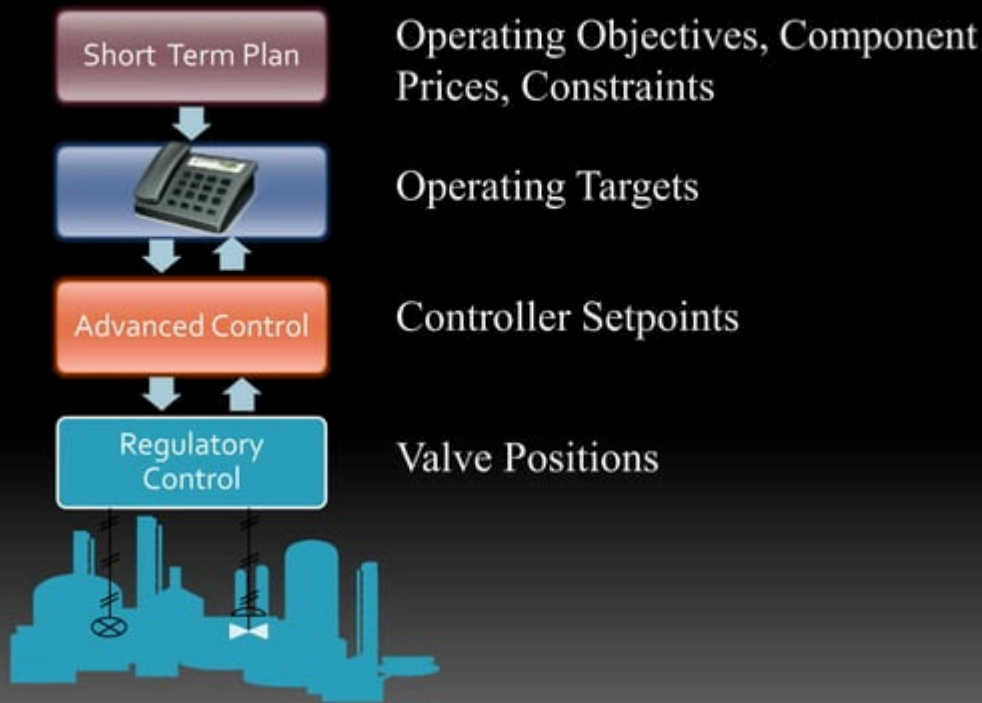


Flowsheet

Crude Oil Refining



Refining Optimization Hierarchy



RTO Approach

- Model plant with engineering equations
 - Heat + mass + hydraulic + equilibrium relationships
- Run simulation in parallel to the plant and calibrate to the plant measurements
- Optimize the model

Steady state operation

$$f(x) = 0$$

- x
 - Flow, temperatures, pressures, size
- $f(x)$
 - Nonlinear algebraic equations
 - Conservation mass, energy, chemical equilibrium

Building the simulated plant

Sequential modular

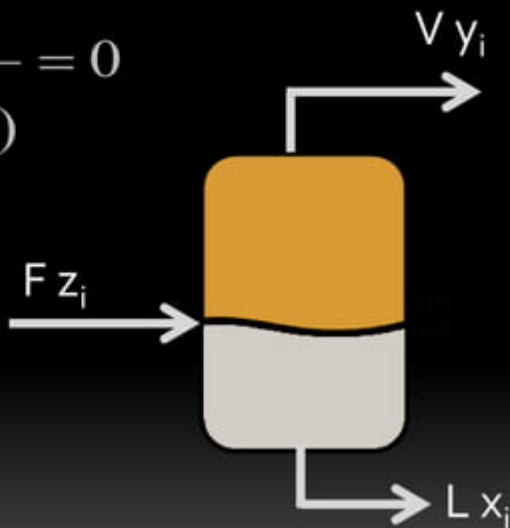
$$x_i^{out} = F_i(x_i^{in})$$



Blocks are solved in the order of material flow

Simple still

$$\sum_i \frac{Z_i(K_i - 1)}{1 + \frac{V}{F}(K_i - 1)} = 0$$



Initial Basis

- Offline design software used to fit base case
- Results used to provide initial basis for open equations
- Thereafter, converged online solutions used as starting basis for next online run

Gross error detection

- Least squares based reconciliation works well when the measurements are considered to be normally distributed around their true values with approximately known error
- Large errors (eg. instrument failures) violate these assumptions and bias reconciliation
- RTO systems include pre-screening to eliminate values obviously in error ($W_i=0$)

Optimization

- Fix instrument adjustments and other reconciled performance values
- Change objective function
 - Maximize Profit: $\sum \text{Products} - \text{Feed} - \text{Utilities}$
 - New setpoints = Old setpoints \pm rate limits

Technical challenges

- Solving 20+K non linear equations is not fool proof
- 95% convergence failures occurred during reconciliation phase
- Could have put more time trying to make constraints more linear

$$\frac{K_1}{d_1^{4.814}} + \frac{K_2}{d_2^{4.814}} + \dots \leq P_T^2 - P_0^2$$

Eg: transformations $x_i = 1 / d_i^{4.814}$

Familiarity

- Pattern recognition
- 10,000 hour rule (Gladwell)
 - Practice makes perfect
- Value proposition of advanced control is to imitate the best operator
- Value proposition of RTO is to seek out incremental, non-intuitive benefits

Technology for people

- Interactive
 - Familiarity
 - Cruise control
 - Smart phones
- Hidden
 - Out of sight



RTO Approach Rethought

- Familiar
- How best to model a plant?

Can we model a plant just from
its historical operating data?

Projection methods (PCA/PLS)

- Technique to find patterns in sets of data
- Linear algebra (singular value decomposition)

$$X = U W V^T = T P^T$$

The diagram illustrates the SVD equation $X = U W V^T$ with dimensions and properties:

- X is an $m \times n$ matrix.
- U is an $m \times n$ matrix.
- W is an $n \times n$ matrix, with diagonal elements w_1 and w_n , and zeros elsewhere.
- V^T is an $n \times n$ matrix.

Properties of the matrices are shown in callouts:

- A callout pointing to U contains the equation $U^T U = I$.
- A callout pointing to V^T contains the equation $V^T V = I$.

Projection Methods

- PCA
 - Find an optimal (least squares) approximation to a matrix X using $T_1 \dots T_k$ $k \ll n$
- PLS
 - Find a projection that approximates X well, and correlates with Y

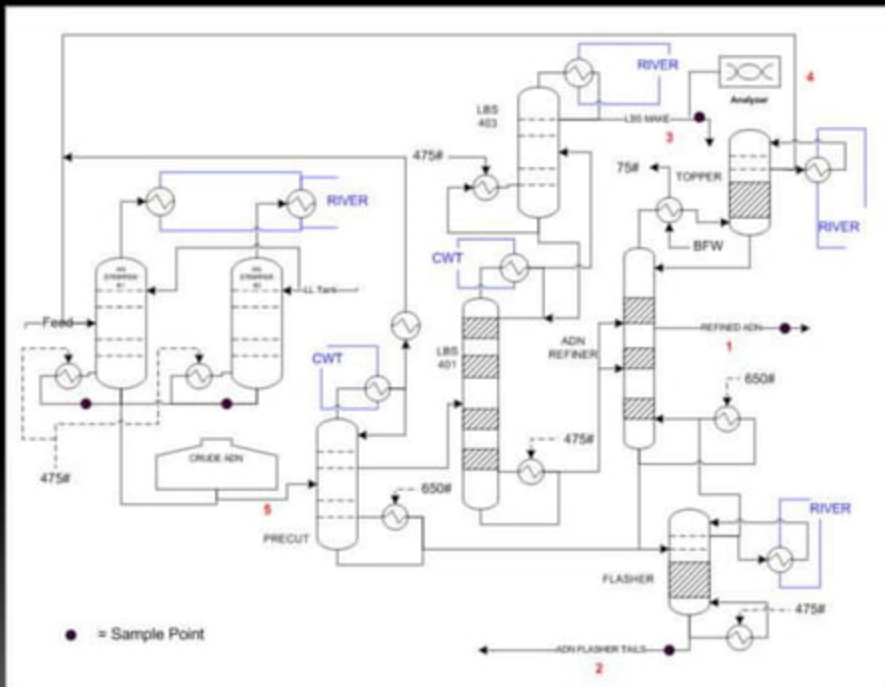
Happenstance plant data

- Number of measurements \gg rank (true dimensionality)
- Every engineering relationship removes 1 degree of freedom
- However operator rules of thumb also remove degrees of freedom

Case Study

- Chemical company
 - If we expand our feed system, what is the capacity of the downstream units?

Flowsheet



Dimensions and data

- 70 operator setpoints and valve positions
- 22 lab analyses
- 1 year of operating data (hourly averages)

Globally optimal?

- Probably not
- Better and feasible
 - Certainly

