# On-Line Optimization

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Acknowledgments
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Monsanto Enviro-Chem Company

# INTRODUCTION

- Status of on-line optimization
- Results of a theoretical and numerical evaluation of the best way to conduct on-line optimization
- An optimal procedure for on-line optimization
- Application to a Monsanto contact process
- Interactive Windows program incorporating these methods

Mineral Processing Research Institute
web site
www.leeric.lsu.edu/mpri/

# On-Line Optimization

Automatically adjust operating conditions with the plant's distributed control system

Maintains operations at optimal set points

Requires the solution of three NLP's

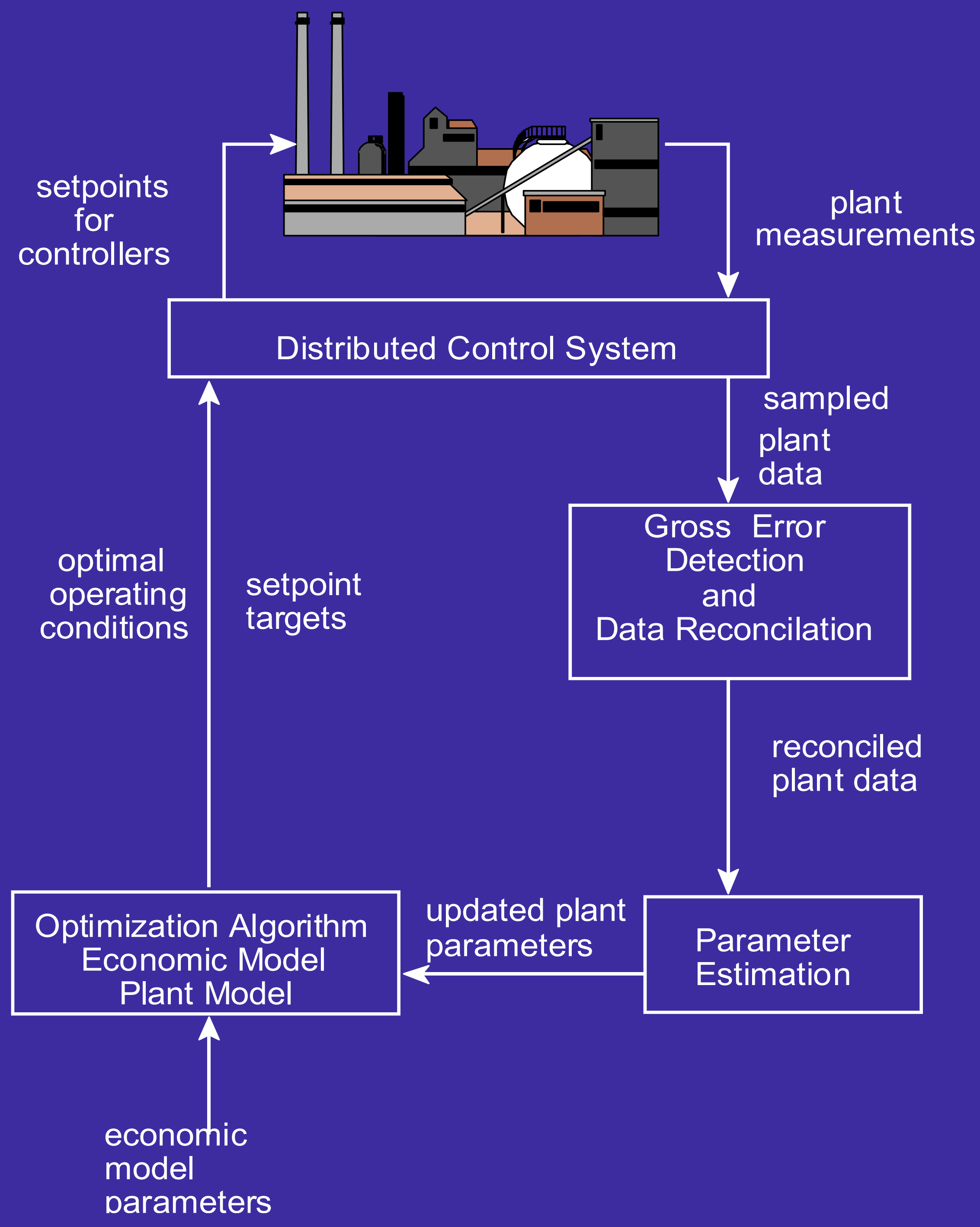
- gross error detection and data reconciliation
- parameter estimation
- economic optimization

## BENEFITS

Improves plant profit by 3-5%

Waste generation and energy use are reduced

Increased understanding of plant operations


setpoints for controllers
plant measurements
Distributed Control System
sampled plant data
Gross Error Detection and Data Reconcilation
optimal operating conditions
setpoint targets
reconciled plant data
Optimization Algorithm
Economic Model
Plant Model
updated plant parameters
Parameter Estimation
economic model parameters

## Some Companies Using On-Line Optimization

| United States | Europe |
|---|---|
| Texaco | OMV Deutschland |
| Amoco | Dow Benelux |
| Conoco | Shell |
| Lyondel | OEMV |
| Sunoco | Penex |
| Phillips | Borealis AB |
| Marathon | DSM-Hydrocarbons |
| Chevron | |
| Pyrotec/KTI | |
| NOVA Chemicals (Canada) | |
| British Petroleum | |

## Applications

mainly crude units in refineries and ethylene plants

## Companies Providing On-Line Optimization

Aspen Technology - RT-OPT
- DMC Corporation
- Setpoint

Simulation Science - ROM
- Shell - Romeo

Profimatics - On-Opt
- Honeywell

Litwin Process Automation - FACS

Hyprotech Ltd.

DOT Products, Inc. - NOVA

# Status of Industrial Practice for On-Line Optimization

Steady state detection by time series screening

Gross error detection by time series screening

Data reconciliation by least squares

Parameter estimation by least squares

Economic optimization by standard methods

## Key Elements

Gross Error Detection

Data Reconciliation

Parameter Estimation

Economic Model
(Profit Function)

Plant Model
(Process Simulation)

Optimization Algorithm

# DATA RECONCILIATION

Adjust process data to satisfy material and energy balances.

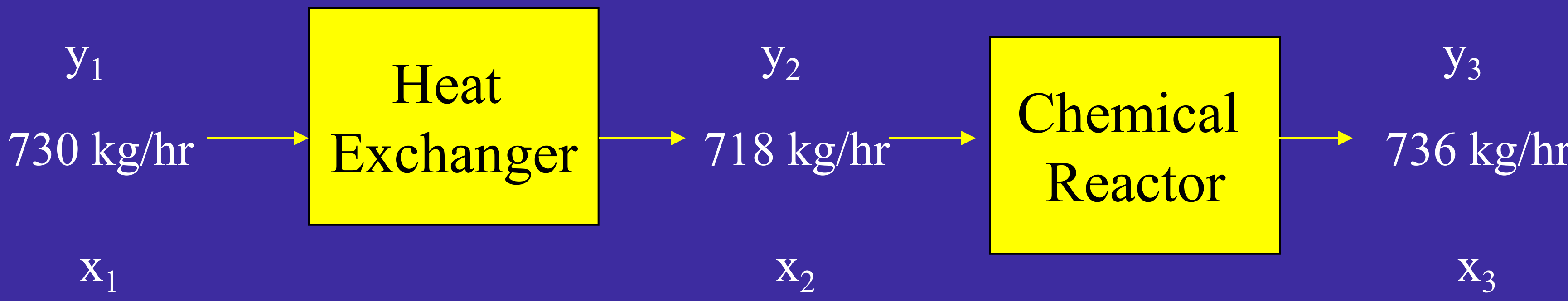
Measurement error - **e**

$$\mathbf{e = y - x}$$

**y** = measured process variables
**x** = true values of the measured variables

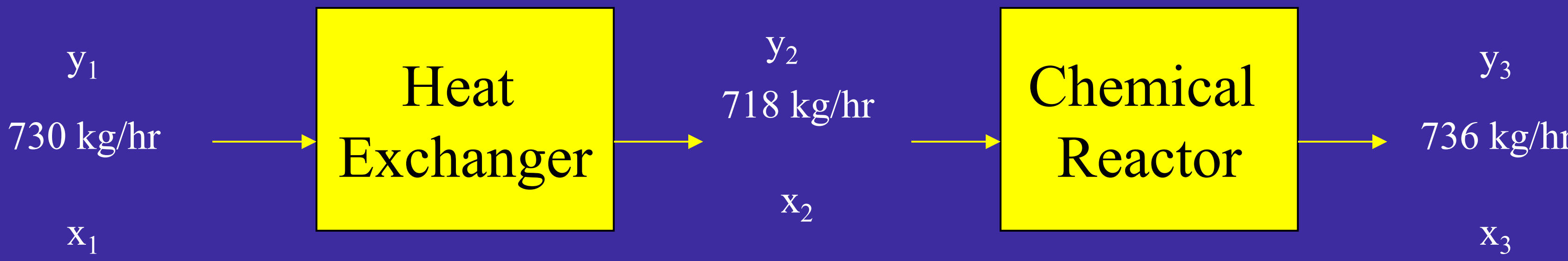
$$\tilde{\mathbf{x}} = \mathbf{y + a}$$

a - measurement adjustment



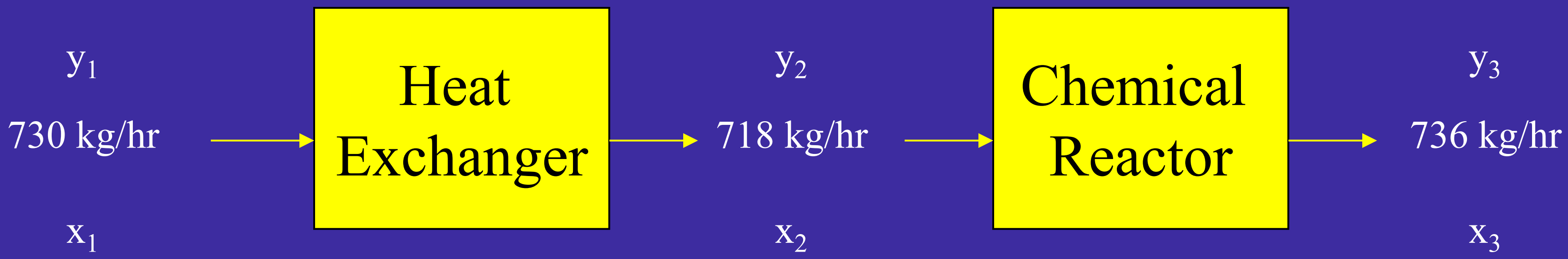

Material Balance $\quad x_1 = x_2 \quad\quad x_1 - x_2 = 0$

Steady State $\quad x_2 = x_3 \quad\quad x_2 - x_3 = 0$




$$\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Ax = 0$$




$$\min_{x}: \sum_{i=1}^{3} \left( \frac{y_i - x_i}{\sigma_i} \right)^2$$

$$y = \begin{bmatrix} 730 \\ 718 \\ 736 \end{bmatrix}$$

Subject to:

$$\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = 0$$

$$\sigma = \begin{bmatrix} 12 & 0 & 0 \\ 0 & 12 & 0 \\ 0 & 0 & 12 \end{bmatrix}$$

min:
x

$$\sum_{i=1}^{n}\left(\frac{y_i - x_i}{\sigma_i}\right)^2 = \min\,(y-x)^T Q^{-1}(y-x)$$

Subject to: $Ax = 0$

Analytical solution using LaGrange Multipliers

$$\hat{x} = y - QA^T(AQA^T)^{-1}Ay$$

$$\hat{x} = \begin{bmatrix}728 & 728 & 728\end{bmatrix}^T$$

# Nonlinear Process Model

Min: $(y-x)^T Q^{-1} (y-x)$

Subject to:

$$f_i(x) = 0$$

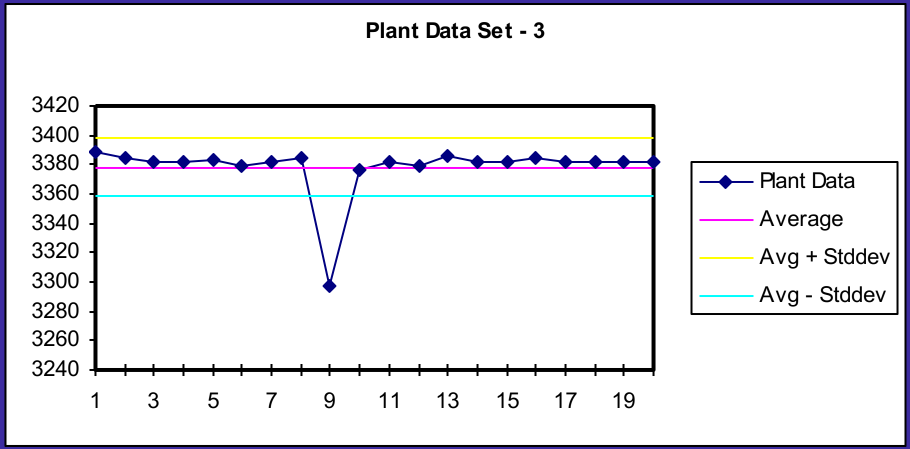
$$f_i(x) \le 0$$

material and energy balances
capacities of process units
demand for product
availability of raw materials

Requires the solution of a nonlinear programming problem

# Gross Error Detection Methods

Time series
screening




Statistical testing

- many methods
- can include data reconciliation

# Combined Gross Error Detection and Data Reconciliation

Measurement Test Method - least squares

*Minimize*: $(\mathbf{y} - \mathbf{x})^T \Sigma^{-1} (\mathbf{y} - \mathbf{x}) = \mathbf{e}^T \mathbf{\Sigma}^{-1} \mathbf{e}$

$\mathbf{x}, \mathbf{z}$

*Subject to*: $\mathbf{f}(\mathbf{x}, \mathbf{z}, \boldsymbol{\theta}) = 0$

$\mathbf{x}^L \quad \mathbf{x} \quad \mathbf{x}^U$

$\mathbf{z}^L \quad \mathbf{z} \quad \mathbf{z}^U$

Test statistic:

if $e_i / \sigma_i \geq C$ measurement contains a gross error

Least squares is based on only random errors being present

Gross errors cause numerical difficulties

Need methods that are not sensitive to gross errors

# Methods Insensitive to Gross Errors

## Tjao-Biegler's Contaminated Gaussian Distribution

$$P(y_i \quad x_i) = (1-\eta)P(y_i \quad x_i, R) + \eta\, P(y_i \quad x_i, G)$$

$P(y_i \quad x_i, R)$ = probability distribution function for the random error
$P(y_i \quad x_i, G)$ = probability distribution function for the gross error.
Gross error occur with probability $\eta$

Gross Error Distribution Function

$$P(y \quad x, G) \qquad \frac{1}{\sqrt{2\pi} b \sigma} \; e^{\frac{(y \quad x)^2}{2b^2\sigma^2}}$$

# Tjao-Biegler Method

Maximizing this distribution function of measurement errors or minimizing the negative logarithm subject to the constraints in plant model, i.e.,

Minimize: $\mathbf{x}$

$$_{i}\left\{\ln\left[(1 \quad )e^{\frac{(y_i \; x_i)^2}{2 \; _i^2}} \quad \frac{}{b} e^{\frac{(y_i \; x_i)^2}{2b^2 \; _i^2}}\right] \ln\left[\sqrt{2} \quad _i\right]\right\}$$

Subject to: $\mathbf{f}(\mathbf{x}) = 0$ — plant model

$\mathbf{x}^L \quad \mathbf{x} \quad \mathbf{x}^U$ — bounds on the process variables

A NLP, and values are needed for and b

# Test for Gross Errors

If P($y_i$ $x_i$, G) (1- )P($y_i$ $x_i$, R), gross error

probability of a gross error — probability of a random error

$$_i \quad \frac{y_i \quad x_i}{_i} > \sqrt{\frac{2b^2}{b^2 \quad 1}\ln\left[\frac{b(1 \quad )}{}\right]}$$

# Robust Function Methods

Minimize: - $[\rho(y_i, x_i) \quad ]$

$\mathbf{x}$ $\quad$ ii

Subject to: $\mathbf{f}(\mathbf{x}) = 0$

$\mathbf{x}^L \quad \mathbf{x} \quad \mathbf{x}^U$

## Lorentzian distribution

$$\rho(\varepsilon_i) \quad \frac{1}{1 \quad \frac{1}{2}\varepsilon_i^2}$$

## Fair function

$$\rho(\varepsilon_i, c) \quad c^2\left[\frac{\varepsilon_i}{c} \quad \log\left(1 \quad \frac{\varepsilon_i}{c} \mathrm{I}\right)\right]$$

c is a tuning parameter

## Test statistic

$$\varepsilon_i = (y_i - x_i \quad )/\sigma_i$$

# Parameter Estimation
# Error-in-Variables Method

Least squares

$$\underset{\boldsymbol{\theta}}{\textit{Minimize}}: \quad (\mathbf{y} - \mathbf{x})^T \boldsymbol{\Sigma}^{-1} (\mathbf{y} - \mathbf{x}) = \mathbf{e}^T \boldsymbol{\Sigma}^{-1} \mathbf{e}$$

$$\textit{Subject to}: \quad \mathbf{f}(\mathbf{x}, \boldsymbol{\theta}) = 0$$

$\boldsymbol{\theta}$ - plant parameters

Simultaneous data reconciliation and parameter estimation

$$\underset{\mathbf{x},\, \boldsymbol{\theta}}{\textit{Minimize}}: \quad (\mathbf{y} - \mathbf{x})^T \boldsymbol{\Sigma}^{-1} (\mathbf{y} - \mathbf{x}) = \mathbf{e}^T \boldsymbol{\Sigma}^{-1} \mathbf{e}$$

$$\textit{Subject to}: \quad \mathbf{f}(\mathbf{x}, \boldsymbol{\theta}) = 0$$

another nonlinear programming problem

# Three Similar Optimization Problems

*Optimize:* **Objective function**
*Subject to:* **Constraints are the plant model**

Objective function

data reconciliation - distribution function
parameter estimation - least squares
economic optimization - profit function

Constraint equations

material and energy balances
chemical reaction rate equations
thermodynamic equilibrium relations
capacities of process units
demand for product
availability of raw materials

# Theoretical Evaluation of Algorithms for Data Reconciliation

Determine sensitivity of distribution functions to gross errors

Objective function is the product or sum of distribution functions for individual measurement errors

$P = \quad p(\varepsilon) \qquad \ln p(\varepsilon) \qquad \rho(\varepsilon)$

# Three important concepts

in the theoretical evaluation
of the robustness and precision
of an estimator from a distribution function

## Influence Function

Robustness of an estimator is unbiasedness (insensitivity) to the presence of gross errors in measurements. The sensitivity of an estimator to the presence of gross errors can be measured by the influence function of the distribution function. For M-estimate, the influence function is defined as a function that is proportional to the derivative of a distribution function with respect to the measured variable,
( ρ/ x)

# Relative Efficiency

The precision of an estimator from a distribution is measured by the relative efficiency of the distribution. The estimator is precise if the variation (dispersion) of its distribution function is small

# Breakdown Point

The break-down point can be thought of as giving the limiting fraction of gross errors that can be in a sample of data and a valid estimation of the estimator is still obtained using this data. For repeated samples, the break-down point is the fraction of gross errors in the data that can be tolerated and the estimator gives a meaningful value.

# Influence Function

proportional to the derivative of the distribution function, IF  ρ/ x

represents the sensitivity of reconciled data to the presence of gross errors

## Normal Distribution

$$IF_{MT} \quad \frac{\rho_i}{x_i} \quad \frac{y_i \;\; x_i}{\sigma_i^2} \quad \frac{\varepsilon_i}{\sigma_i}$$

## Contaminated Gaussian Distribution

$$IF \quad \frac{\rho_i}{x_i} \quad \frac{\dfrac{\varepsilon_i}{\sigma_i}\left| (1 \;\; \eta) e^{\frac{\varepsilon_i^2}{2}\left(1 \;\; \frac{1}{b^2}\right)} \;\; \dfrac{\eta}{b^3} \right|}{(1 \;\; \eta) e^{\frac{\varepsilon_i^2}{2}\left(1 \;\; \frac{1}{b^2}\right)} \;\; \dfrac{\eta}{b}}$$

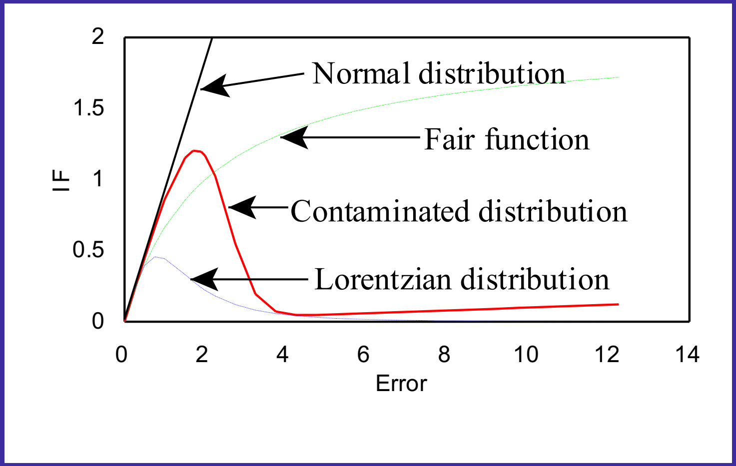
## Lorentzian Distribution

$$IF_{Lorentzian} \quad \frac{\rho_i}{\varepsilon_i} \quad \frac{\varepsilon_i}{\left(1 \;\; \frac{1}{2}\varepsilon_i^2\right)^2}$$

## Fair Function

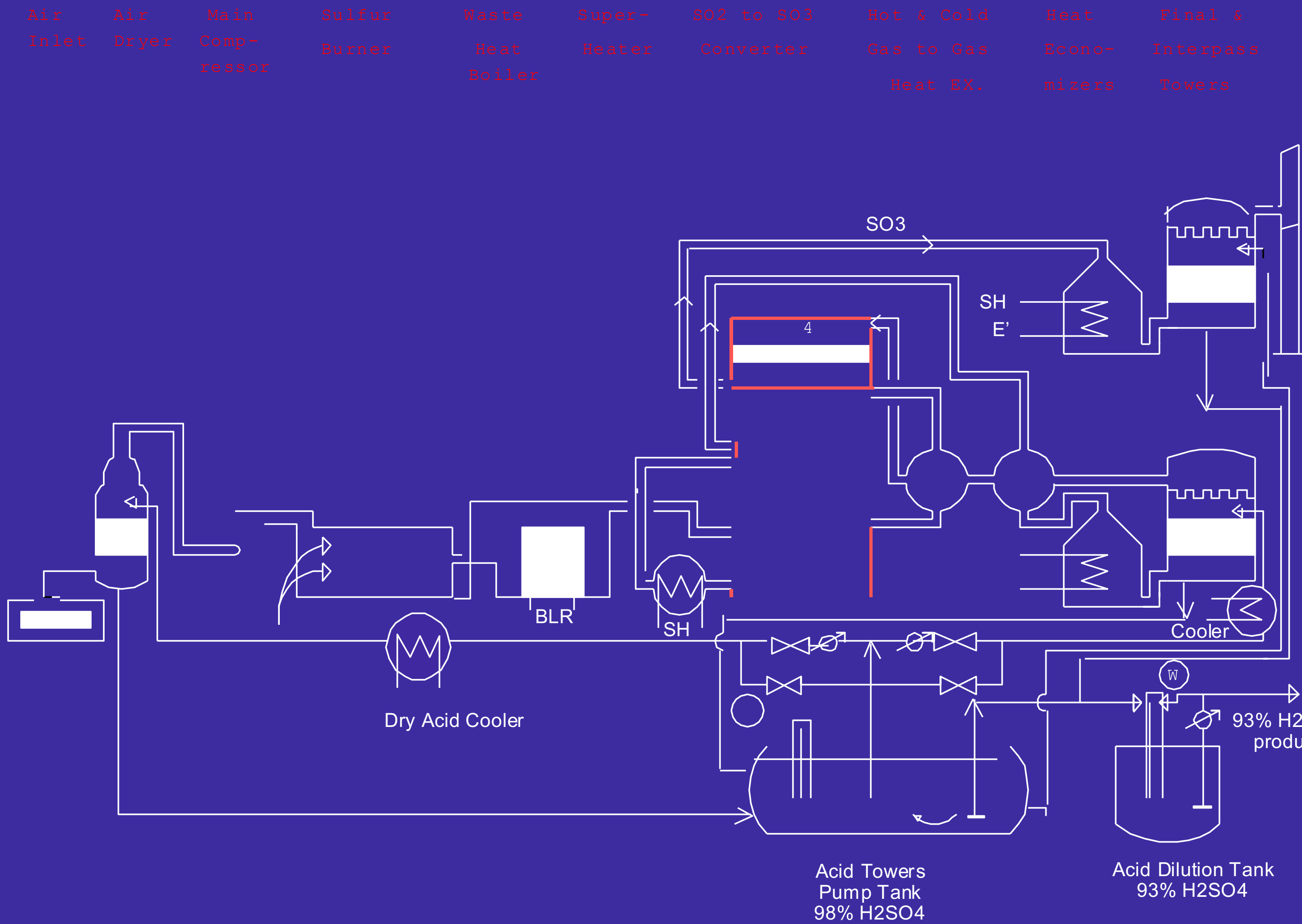
$$IF_{Fair} \quad \frac{\rho_i}{\varepsilon_i} \quad c^2\left(\frac{1}{c} \quad \frac{\frac{1}{c}}{1 \;\; \frac{\varepsilon_i}{c}}\right) \quad \frac{1}{\frac{1}{\varepsilon_i} \;\; \frac{1}{c}}$$

# Comparison of Influence Functions




Effect of Gross Errors on Reconciled Data - Least to Most

Lorentzian Contaminated Gaussian Fair Normal



Air Inlet
Air Dryer
Main Comp-ressor
Sulfur Burner
Waste Heat Boiler
Super-Heater
SO2 to SO3 Converter
Hot & Cold Gas to Gas Heat EX.
Heat Econo-mizers
Final & Interpass Towers
SO3
SH
E'
4
BLR
SH
Cooler
W
Dry Acid Cooler
93% H2SO4 product
Acid Towers Pump Tank 98% H2SO4
Acid Dilution Tank 93% H2SO4

# Numerical Evaluation of Algorithms

Simulated plant data is constructed by

$$\mathbf{y} = \mathbf{x} + \mathbf{e} + a$$

**y** - simulated measurement vector for measured variables

**x** - true values (plant design data) for measured variables

**e** - random errors added to the true values

a - magnitude of a gross error added to one of measured variables

- a vector with one in one element corresponding to the measured variable with gross error and zero in other elements

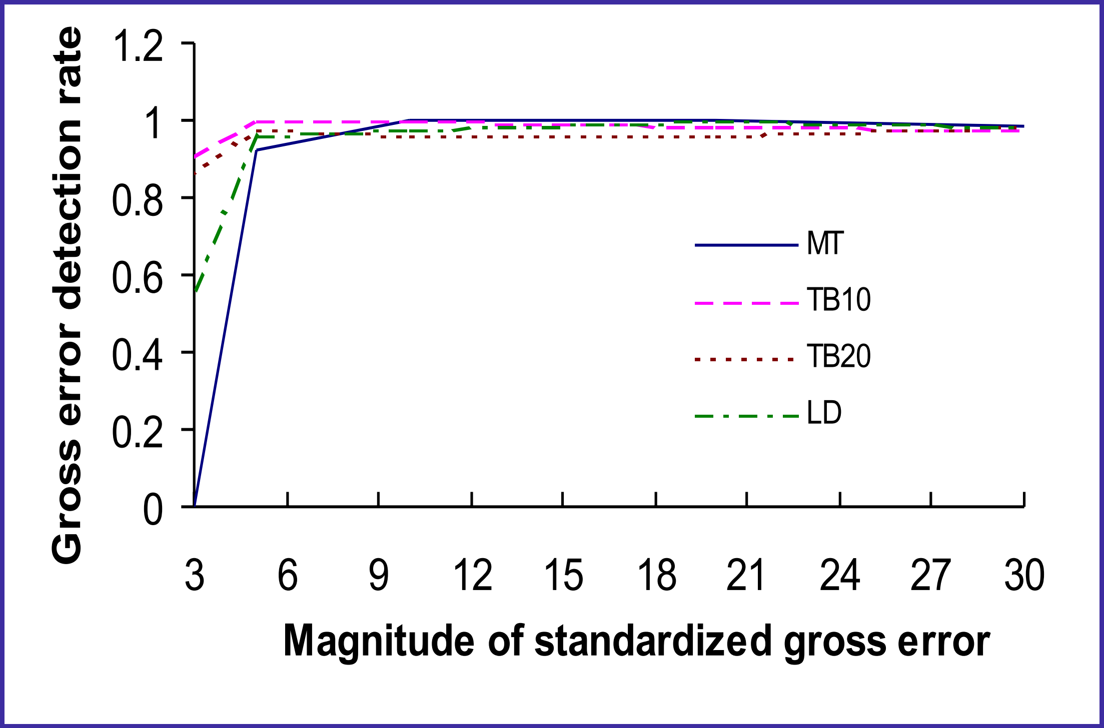
# Criteria for Numerical Evaluation

**Gross error detection rate** - ratio of number of gross errors that are correctly detected to the total number of gross errors in measurements

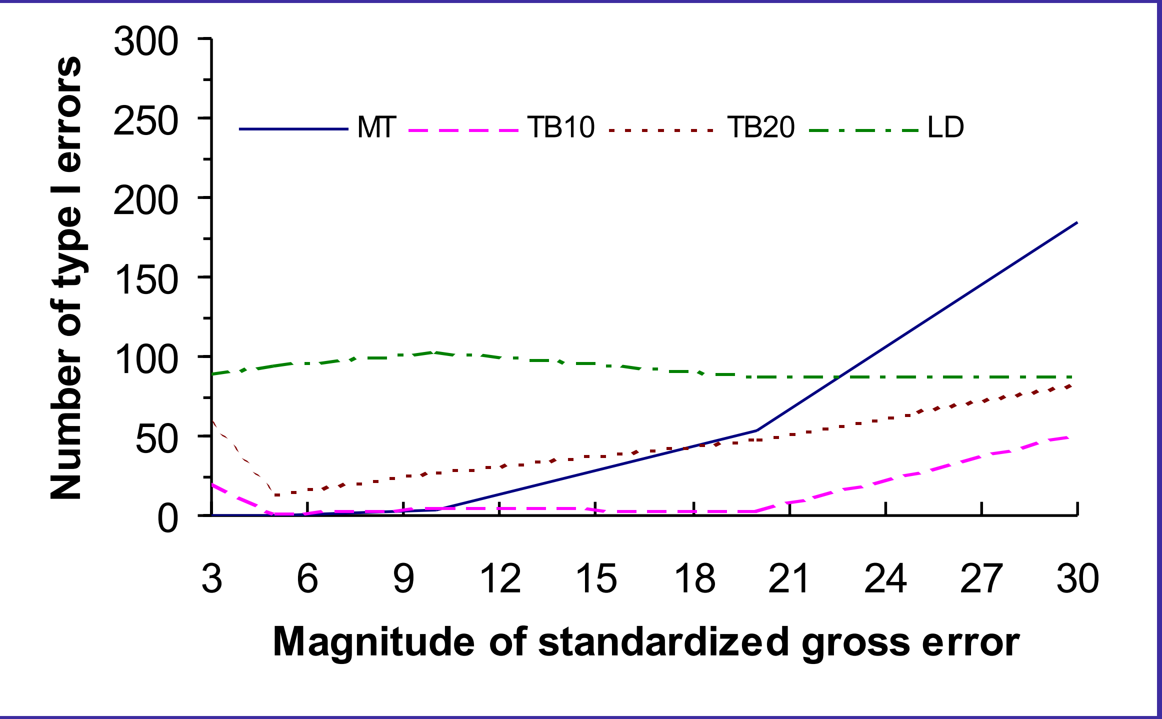
**Number of type I errors** - If a measurements does not contain a gross error and the test statistic identifies the measurement as having a gross error, it is called a type I error

**Random and gross error reduction** - the ratio of the remaining error in the reconciled data to the error in the measurement

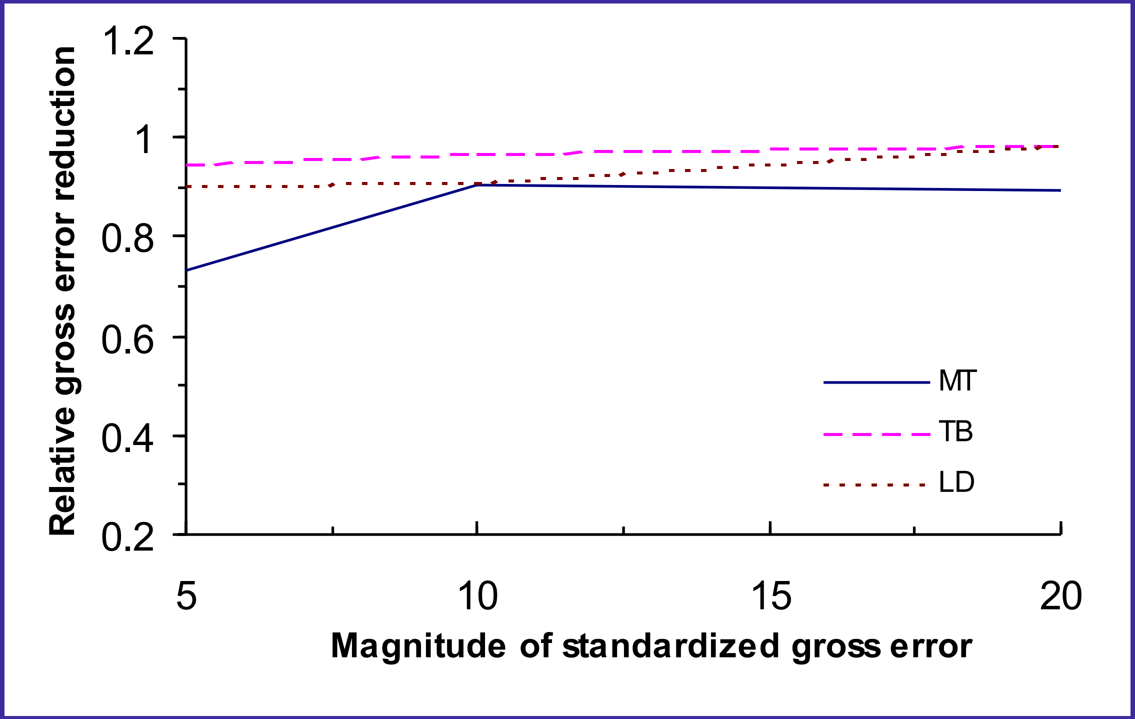
# Comparison of Gross Error Detection Rates
## 390 Runs for Each Algorithm



# Comparison of Numbers of Type I Errors
## 390 Runs for Each Algorithm



# Comparison of Relative Gross Error Reductions
## 645 Runs for Each Algorithm



## Results of Theoretical and Numerical Evaluations

Tjoa-Biegler's method has the best performance for measurements containing random errors and moderate gross errors (3σ-30σ)

Robust method using Lorentzian distribution is more effective for measurements with very large gross errors (larger than 30σ)

Measurement test method gives a more accurate estimation for measurements containing only random errors. It gives significantly biased estimation when measurements contain gross errors larger than 10σ

# Interactive On-Line Optimization Program

1. Conduct combined gross error detection and data reconciliation to detect and rectify gross errors in plant data sampled from distributed control system using the Tjoa-Biegler's method (the contaminated Gaussian distribution) or robust method (Lorentzian distribution).

**This step generates a set of measurements containing only random errors for parameter estimation.**

2. Use this set of measurements for simultaneous parameter estimation and data reconciliation using the least squares method.

**This step provides the updated parameters in the plant model for economic optimization.**

3. Generate optimal set points for the distributed control system from the economic optimization using the updated plant and economic models.

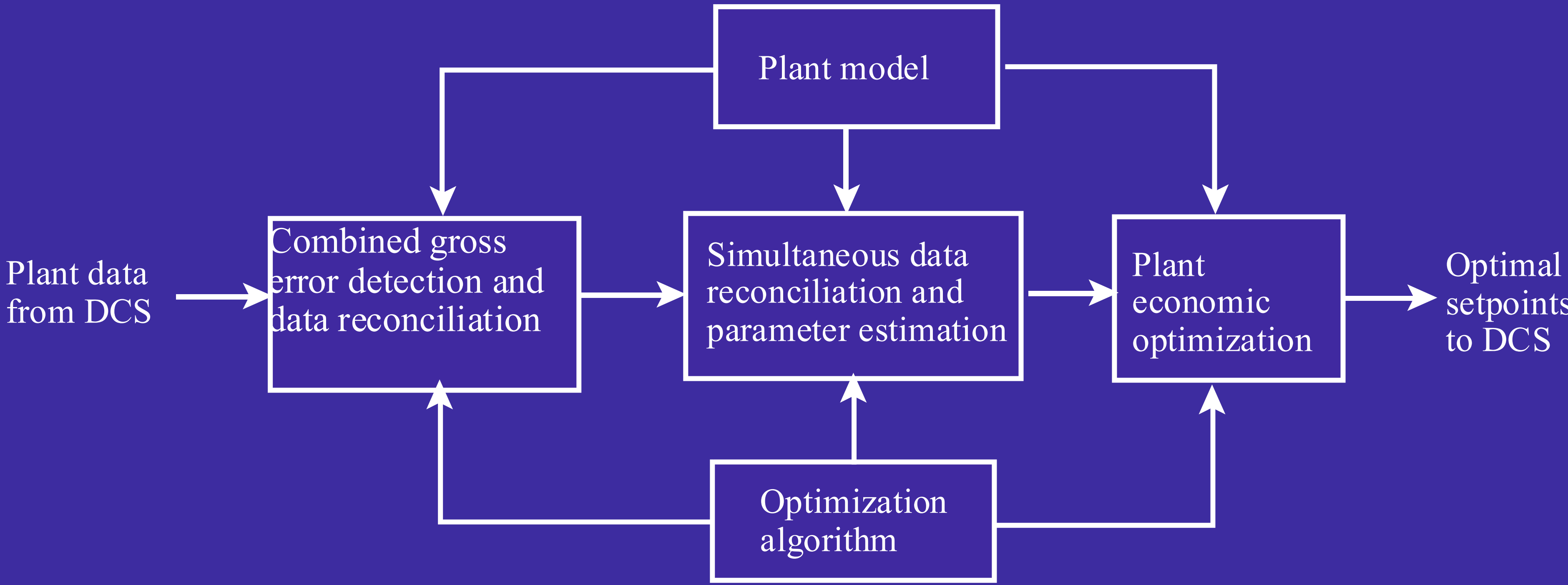
# Economic Optimization

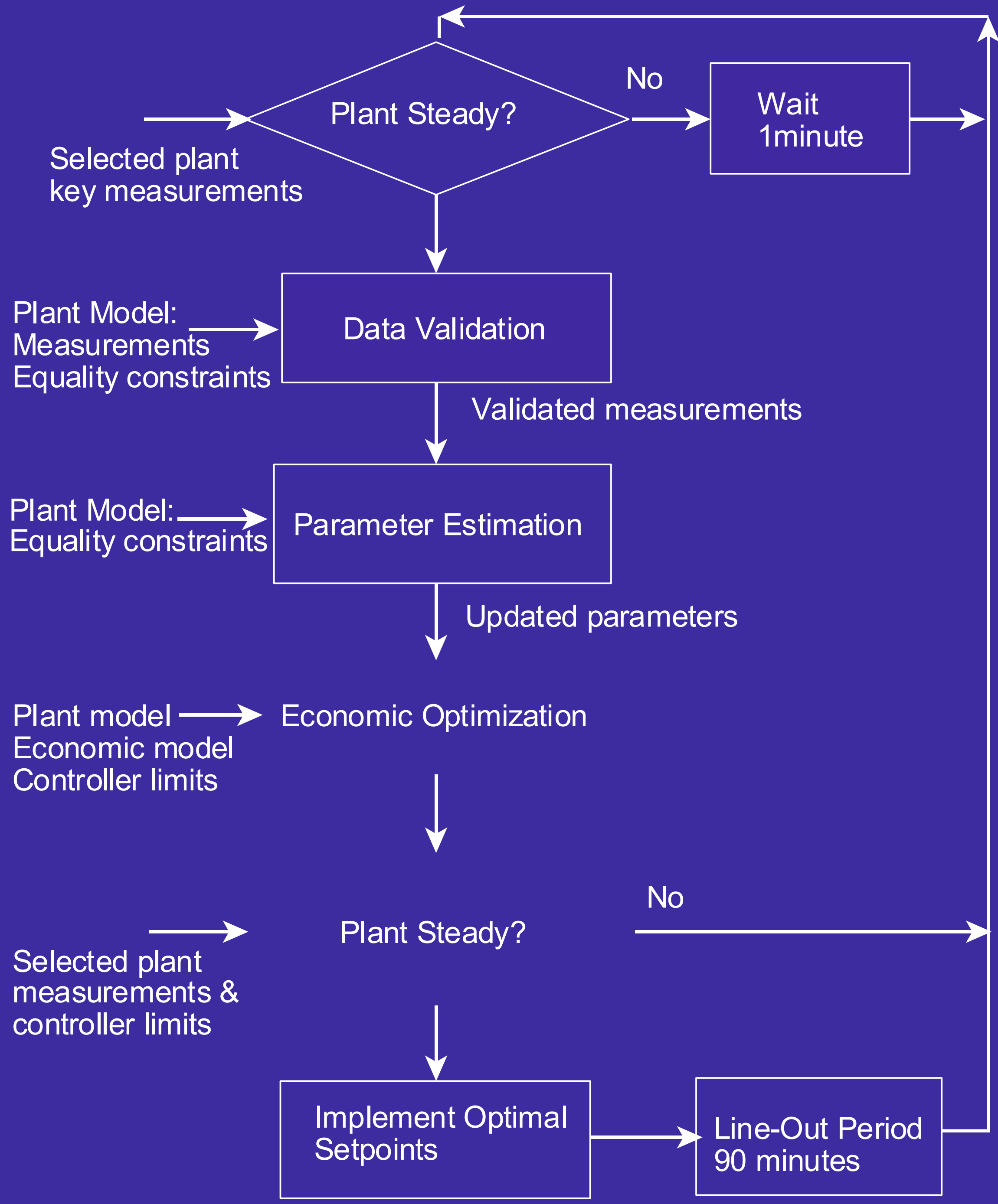
## Value Added Profit Function

$$s_{F64}F_{64} + s_{FS8}F_{S8} + s_{FS14}F_{S14} - c_{F50}F_{50} - c_{FS1}F_{S1} - c_{F65}F_{65}$$

On-Line Optimization Results

| Date | Current ($/day) | Profit Optimal ($/day) | Improvement |
|---|---|---|---|
| 6-10-97 | 37,290 | 38,146 | 2.3% $313,000/yr |
| 6-12-97 | 36,988 | 38,111 | 3.1% $410,000/yr |


Plant model
Plant data
from DCS
Combined gross
error detection and
data reconciliation
Simultaneous data
reconciliation and
parameter estimation
Plant
economic
optimization
Optimal
setpoints
to DCS
Optimization
algorithm


Plant Steady?
No
Wait
1minute
Selected plant
key measurements
Plant Model:
Measurements
Equality constraints
Data Validation
Validated measurements
Plant Model:
Equality constraints
Parameter Estimation
Updated parameters
Plant model
Economic model
Controller limits
Economic Optimization
No
Plant Steady?
Selected plant
measurements &
controller limits
Implement Optimal
Setpoints
Line-Out Period
90 minutes

# Interactive On-Line Optimization Program

Process and economic models are entered as equations in a form similar to Fortran

The program writes and runs three GAMS programs.

Results are presented in a summary form, on a process flowsheet and in the full GAMS output

The program and users manual (120 pages) can be downloaded from the LSU Minerals Processing Research Institute web site

URLhttp://www.leeric.lsu.edu/mpri/

# Some Other Considerations

Redundancy

Observeability

Variance estimation

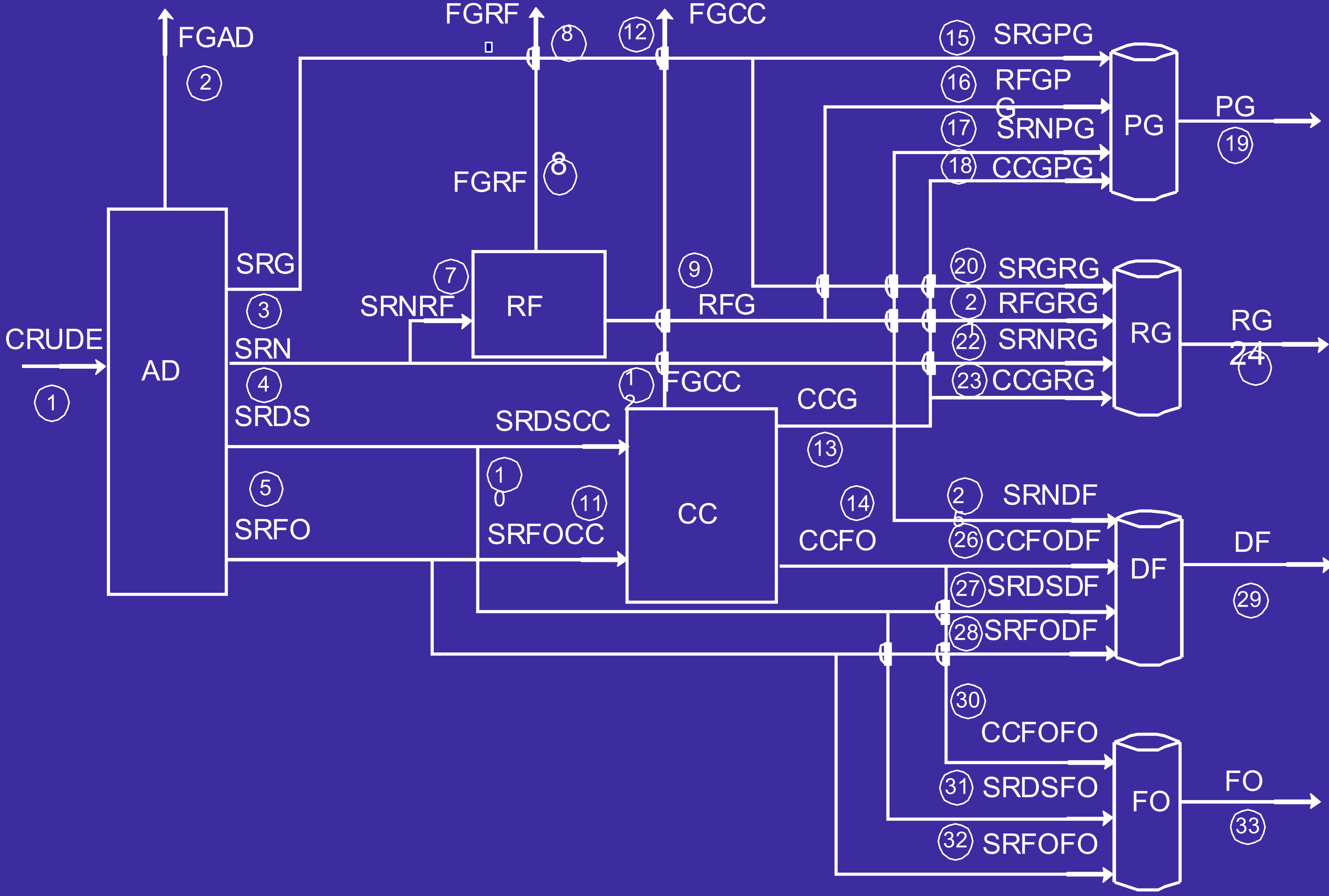
Closing the loop

Dynamic data reconciliation
and parameter estimation

## Summary

Most difficult part of on-line optimization is developing and validating the process and economic models.

Most valuable information obtained from on-line optimization is a more thorough understanding of the process



FGAD
2
FGRF
8
12
FGCC
15
SRGPG
16
RFGP
G
17
SRNPG
PG
PG
19
18
CCGPG
FGRF
8
SRG
7
RF
9
RFG
20
SRGRG
2
1
RFGRG
3
SRNRF
CRUDE
AD
SRN
22
SRNRG
RG
RG
24
1
2
FGCC
23
CCGRG
4
SRDS
CCG
SRDSCC
1
13
1
0
5
11
14
2
5
SRNDF
SRFO
CC
CCFO
26
CCFODF
DF
DF
SRFOCC
27
SRDSDF
29
28
SRFODF
30
CCFOFO
31
SRDSFO
FO
FO
33
32
SRFOFO

Table 20 Description and Plant Data for Process Variables of the Refinery

| | Name | Definition (Flow rates are in barrels per day) | Plant Data | Standard Deviation |
|---|---|---|---|---|
| Measured Variables | CRUDE | Crude oil flow rate to atmospheric distillation column (AD) | 99686.7 | 1000.0 |
| | FGAD | Fuel gas flow rate from AD | 3553606 | 35420.0 |
| | SRG | Straight run gasoline flow rate from AD | 27125.2 | 270.0 |
| | SRN | Straight run naphtha flow rate from AD | 23266.3 | 237.0 |
| | SRDS | Straight run distillate flow rate from AD | 8636.35 | 87.0 |
| | SRFO | Straight run fuel oil flow rate from AD | 36838.6 | 372.0 |
| | SRNRF | Straight run naphtha feed rate to reformer (RF) | 23606.6 | 237.0 |
| | FGRF | Fuel gas flow rate from the reformer | 3796351 | 37612.0 |
| | RFG | Reformer gasoline flow rate | 21826.6 | 219.9 |
| | SRDSCC | Straight run distillate flow rate to the catalytic cracking unit (CCU) | 0.004 | 10.0 |
| | SRFOCC | Straight run fuel oil flow rate to the CCU | 29727.3 | 300.0 |
| | FGCC | Fuel gas flow rate from the CCU | 1.2212E+7 | 115920.0 |
| | CCG | Gasoline flow rate from CCU | 20503.3 | 206.4 |
| | CCFO | Fuel oil flow rate from CCU | 6567.9 | 66.0 |
| | SRGPG | Straight run gasoline flow rate for premium gasoline (PG) blending | 17394.8 | 170.7 |
| | RFGPG | Reformer gasoline flow rate for PG blending | 21835.1 | 219.9 |
| | SRNPG | Straight run naphtha flow rate for PG blending | 12.99 | 10.0 |
| | CCGPG | CCU gasoline flow rate for PG blending | 7935.7 | 80.5 |
| | PG | Premium gasoline flow rate | 47263.8 | 471.1 |
| | SRGRG | Straight run gasoline flow rate for regular gasoline (RG) blending | 10044.6 | 99.3 |
| | RFGRG | Reformer gasoline flow rate for RG blending | 11.532 | 10.0 |
| | SRNRG | Straight run naphtha flow rate for RG blending | 7.100 | 10.0 |
| | CCGRG | CCU gasoline flow rate for RG blending | 12721.8 | 125.9 |
| | RG | Regular gasoline flow rate | 22357.3 | 225.2 |
| | SRNDF | Straight run naphtha flow rate for diesel fuel (DF) blending | 9.994 | 10.0 |
| | CCFODF | CCU fuel oil flow rate for DF blending | 3270.1 | 32.7 |
| | SRDSDF | Straight run distillate flow rate for DF blending | 8613.5 | 87.0 |
| | SRFODF | Straight run fuel oil flow rate for DF blending | 525.34 | 5.3 |
| | DF | No. 2 diesel fuel flow rate | 12582.8 | 125.0 |
| | CCFOFO | CCU fuel oil flow rate for fuel oil (FO) blending | 3382.5 | 33.3 |
| | SRDSFO | Straight run distillate flow rate for FO blending | 22.13 | 10.0 |
| | SRFOFO | Straight run fuel oil flow rate for FO blending | 6628.2 | 66.7 |
| Unmeasured Variables | FO | No. 6 fuel oil flow rate | | |

Table 21 Capacities, Operating Costs and Volumetric Yields for the Refinery Process Units

| Unit | Capacity (bbl/day) | Operating Cost ($/bbl) | Input | Output | Mass Yield of Output Stream | Volumetric Yield of Output Stream |
|---|---|---|---|---|---|---|
| Crude oil Atmospheric Distillation Column | 100,000 | 1.00 | CRUDE | FGAD | 0.029 | 35.42 |
| | | | | SRG | 0.236 | 0.270 |
| | | | | SRN | 0.223 | 0.237 |
| | | | | SRDS | 0.087 | 0.087 |
| | | | | SRFO | 0.426 | 0.372 |
| Catalytic Reformer | 25,000 | 2.50 | SRNRF | FGRF | 0.138 | 158.7 |
| | | | | RFG | 0.862 | 0.928 |
| Catalytic Cracking Unit | 30,000 | 2.20 | SRDSCC | FGCC | 0.273 | 336.9 |
| | | | | CCG | 0.536 | 0.619 |
| | | | | CCFO | 0.191 | 0.189 |
| | | | SRFOCC | FGCC | 0.277 | 386.4 |
| | | | | CCG | 0.527 | 0.688 |

Table 22 Names and Definition of Parameters for the Refinery

| Units of Parameters | Names of Parameters | Initial Values | Definitions of parameters Volumetric yields (BBL output/BBL input) |
|---|---|---|---|
| Crude Oil Atmospheric Distillation Column | VFGAD | 35.42 | BBLs of fuel gas per BBL crude |
| | VSRG | 0.27 | BBLs of straight-run gasoline per BBL crude |
| | VSRN | 0.237 | BBLs of straight-run naphtha per BBL crude |
| | VSRDS | 0.087 | BBLs of straight-run distillate per BBL crude |
| | VSRFO | 0.372 | BBLs of Straight-run fuel oil per BBL crude |
| Catalytic Reformer | VSRNFGRF | 158.7 | BBLs of reformer fuel gas per BBL of straight-run naphtha |
| | VSRNRFG | 0.928 | BBLs reformer gasoline per BBL straight-run naphtha |
| Catalytic Cracking | VSRDSFGCC | 336.9 | BBLs of fuel gas per BBL straight-run distillate |
| | VSRDSCCG | 0.619 | BBLs of gasoline from CC per BBL straight-run distillate |
| | VSRDSCCFO | 0.189 | BBLs of fuel oil per BBL of straight-run distillate |
| | VSRFOFGCC | 386.4 | BBLs of fuel gas per BBL straight-run fuel oil |
| | VSRFOCCG | 0.688 | BBLs of gasoline from CC per BBL of straight-run fuel oil |
| | VSRFOCCFO | 0.220 | BBLs of fuel oil per BBL straight-run fuel oil |

Table 23 Quality Specifications and Physical Properties for Products and Intermediate Streams for the Refinery

| Stream | Motor Octane Number | Vapor pressure (mmHg) | Density (lb/bbl) | Sulfur Content (lb/bbl) |
|---|---|---|---|---|
| Premium Gasoline | 93.0 | 12.7 | - | - |
| Regular Gasoline | 87.0 | 12.7 | - | - |
| Diesel Fuel | - | - | 306.0 | 0.5 |
| Fuel Oil | - | - | 352.0 | 3.0 |
| SRG | 78.5 | 18.4 | - | - |
| RFG | 104.0 | 2.57 | - | - |
| SRN | 65.0 | 6.54 | 272.0 | 0.283 |
| CCG | 93.7 | 6.90 | - | - |
| CCFO | - | - | 294.4 | 0.353 |
| SRDS | - | - | 292.0 | 0.526 |
| SRFO | - | - | 295.0 | 0.980 |

Table 24  Crude Oil Cost and Product Sales Prices for the Refinery

| | Prices |
|---|---|
| Gulf Cost Crude | $32.00/bbl |
| Premium Gasoline | $45.36/bbl |
| Regular Gasoline | $43.68/bbl Names |
| No.2 Diesel Fuel | $40.32/bbl |
| No.6 Fuel Oil | $13.14/bbl |
| Fuel Gas | $0.01965/bbl |

# Table 25 Refinery Objective Function and Constraint Equations

| | | Atmospheric Distillation | | | | | | Reformer | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CRUDE | FGAD | SRG | SRN | SRDS | SRFO | SRNRF | FGRF | RFG | |
| Objective Function | -33.0 | .01965 | | | | | -2.50 | .01965 | | |
| Crude Availability | 1.0 | | | | | | | | | |
| Products | | | | | | | | | | |
| Premium Gasoline | | | | | | | | | | |
| Min. PG Prod. | | | | | | | | | | |
| PG Blending | | | | | | | | | | |
| PG Octane Rating | | | | | | | | | | |
| Regular Gasoline | | | | | | | | | | |
| Min. RG Prod. | | | | | | | | | | |
| RG Blending | | | | | | | | | | |
| RG Octane Rating | | | | | | | | | | |
| RG Vapor Press. | | | | | | | | | | |
| Diesel Fuel | | | | | | | | | | |
| Min. DF Prod. | | | | | | | | | | |
| DF Blending | | | | | | | | | | |
| DF Density Spec. | | | | | | | | | | |
| DF Sulfur Spec. | | | | | | | | | | |
| Fuel Oil | | | | | | | | | | |
| Min. FO Prod. | | | | | | | | | | |
| FO Blending | | | | | | | | | | |
| FO Density Spec. | | | | | | | | | | |
| FO Sulfur Spec. | | | | | | | | | | |
| Process Units | | | | | | | | | | |
| Atm. Distillation | | | | | | | | | | |
| AD Capacity | | 1.0 | | | | | | | | |
| FGAD Yield | | 35.42 | -1.0 | | | | | | | |
| SRG Yield | | 0.270 | | -1.0 | | | | | | |
| SRN Yield | | 0.237 | | | -1.0 | | | | | |
| SRDS Yield | | 0.087 | | | | -1.0 | | | | |
| SRFO Yield | | 0.372 | | | | | -1.0 | | | |
| Reformer | | | | | | | | | | |
| RF Capacity | | | | | | | | 1.0 | | |
| FGRF Yield | | | | | | | | 158.7 | -1.0 | |
| RFG Yield | | | | | | | | 0.928 | | -1.0 |
| Catalytic Cracker | | | | | | | | | | |
| CC Capacity | | | | | | | | | | |
| FGCC Yield | | | | | | | | | | |
| CCG Yield | | | | | | | | | | |
| CCFO Yield | | | | | | | | | | |
| Stream Splits | | | | | | | | | | |
| SRG | | | 1.0 | | | | | | | |
| SRN | | | | 1.0 | | | -1.0 | | | |
| SRDS | | | | | 1.0 | | | | | |
| SRFO | | | | | | 1.0 | | | | |
| RFG | | | | | | | | | 1.0 | |
| CCG | | | | | | | | | | |
| CCFO | | | | | | | | | | |

# Table 25 Refinery Objective Function and Constraint Equations (continued)

| | | Catalytic Cracker | | | | | Premium Gasoline Blending | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SRDSCC | SRFOCC | FGCC | CCG | CCFO | SRGPG | RFGPG | SRNPG | CCGPG | PG |
| Objective Function | -2.20 | -2.20 | -.01965 | | | | | | | 45.36 |
| Crude Availability | | | | | | | | | | |
| Products | | | | | | | | | | |
| Premium Gasoline | | | | | | | | | | |
| Min. PG Prod. | | | | | | | | | | 1.0 |
| PG Blending | | | | | | | 1.0 | 1.0 | 1.0 | 1.0 |
| 1.0 | | | | | | | | | | |
| PG Octane Rating | | | | | | 78.5 | 104.0 | 65.0 | 93.7 | -93.0 |
| PG Vapor Press. | | | | | | 18.4 | 2.57 | 6.54 | 6.90 | -12.7 |
| Regular Gasoline | | | | | | | | | | |
| Min. RG Prod. | | | | | | | | | | |
| RG Blending | | | | | | | | | | |
| RG Octane Rating | | | | | | | | | | |
| RG Vapor Press. | | | | | | | | | | |
| Diesel Fuel | | | | | | | | | | |
| Min. DF Prod. | | | | | | | | | | |
| DF Blending | | | | | | | | | | |
| DF Density Spec. | | | | | | | | | | |
| DF Sulfur Spec. | | | | | | | | | | |
| Fuel Oil | | | | | | | | | | |
| Min. FO Prod. | | | | | | | | | | |
| FO Blending | | | | | | | | | | |
| FO Density Spec. | | | | | | | | | | |
| FO Sulfur Spec. | | | | | | | | | | |
| Process Units | | | | | | | | | | |
| Atm. Distillation | | | | | | | | | | |
| AD Capacity | | | | | | | | | | |
| FGAD Yield | | | | | | | | | | |
| SRG Yield | | | | | | | | | | |
| SRN Yield | | | | | | | | | | |
| SRDS Yield | | | | | | | | | | |
| SRFO Yield | | | | | | | | | | |
| Reformer | | | | | | | | | | |
| RF Capacity | | | | | | | | | | |
| FGRF Yield | | | | | | | | | | |
| RFG Yield | | | | | | | | | | |
| Catalytic Cracker | | | | | | | | | | |
| CC Capacity | | 1.0 | 1.0 | | | | | | | |
| FGCC Yield | | 336.9 | 386.4 | -1.0 | | | | | | |
| CCG Yield | | 0.619 | 0.688 | | -1.0 | | | | | |
| CCFO Yield | | 0.189 | 0.220 | | | -1.0 | | | | |
| Stream Splits | | | | | | | | | | |
| SRG | | | | | | -1.0 | | | | |
| SRN | | | | | | | | -1.0 | | |
| SRDS | -1.0 | | | | | | | | | |
| SRFO | | -1.0 | | | | | | | | |
| RFG | | | | | | | -1.0 | | | |
| CCG | | | | 1.0 | | | | | -1.0 | |
| CCFO | | | | | 1.0 | | | | | |

# Table 25 Refinery Objective Function and Constraint Equations (continued)

| Regular Gasoline Blending | | | | | Diesel Fuel Blending | | | | | Fuel Oil BLending | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SRGRG | RFGRG | SRNRG | CCGRG | RG | SRNDF | CCFODF | SRDSDF | SRFODF | DF | CCFOFO | SRDSFO | SRFOFO | FO | | |
| | | | | 43.68 | | | | | 40.32 | | | | 13.14 | Maximum | OBJ |
| | | | | | | | | | | | | | | ≤ 110,00 | CRDAVAIL |
| | | | | | | | | | | | | | | ≥ 10,000 | PGMIN |
| | | | | | | | | | | | | | | 0 | PGBLEND |
| | | | | | | | | | | | | | | ≥ 0 | PGOCTANE |
| | | | | | | | | | | | | | | ≤ 0 | PGVAPP |
| | | | | 1.0 | | | | | | | | | | ≥ 10,000 | RGMIN |
| 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | | | | | | | 0 | RGBLEND |
| 78.5 | 104.0 | 65.0 | 93.7 | 87.0 | | | | | | | | | | ≥ 0 | RGOCTANE |
| 18.4 | 2.57 | 6.54 | 6.90 | 12.7 | | | | | | | | | | ≤ 0 | RGVAPP |
| | | | | | | | | | 1.0 | | | | | ≥ 10,000 | DFMIN |
| | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | | | | 0 | DFBLEND |
| | | | | | 272.0 | 294.4 | 292.0 | 295.0 | 306.0 | | | | | ≤ 0 | DFDENS |
| | | | | | 0.283 | 0.353 | 0.526 | 0.980 | 0.50 | | | | | ≤ 0 | DFSULFUR |
| | | | | | | | | | | | | | 1.0 | ≥ 10,000 | FOMIN |
| | | | | | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 0 | FOBLEND |
| | | | | | | | | | | 294.4 | 292.0 | 295.0 | 352.0 | ≤ 0 | FODENS |
| | | | | | | | | | | 0.353 | 0.526 | 0.980 | 3.0 | ≤ 0 | FOSULFUR |
| | | | | | | | | | | | | | | ≥ 100,000 | ADCAP |
| | | | | | | | | | | | | | | 0 | ADFGYLD |
| | | | | | | | | | | | | | | 0 | ADSRGYLD |
| | | | | | | | | | | | | | | 0 | ADNYLD |
| | | | | | | | | | | | | | | 0 | ADDSYLD |
| | | | | | | | | | | | | | | 0 | ADFOYLD |
| | | | | | | | | | | | | | | ≤ 25,000 | RFCAP |
| | | | | | | | | | | | | | | 0 | RFFGYLD |
| | | | | | | | | | | | | | | 0 | RFRFGYLD |
| | | | | | | | | | | | | | | ≤ 30,000 | CCCAP |
| | | | | | | | | | | | | | | 0 | CCFGYLD |
| | | | | | | | | | | | | | | 0 | CCGYLD |
| | | | | | | | | | | | | | | 0 | CCFOYLD |
| 1.0 | | | | | | | | | | | | | | 0 | SRGSPLIT |
| | 1.0 | | | | 1.0 | | | | | | | | | 0 | SRNSPLIT |
| | | | | | | | 1.0 | | | | 1.0 | | | 0 | SRDSSPLIT |
| | | | | | | | | 1.0 | | | | 1.0 | | 0 | SRFOPLIT |
| | 1.0 | | | | | | | | | | | | | 0 | RFGSPLIT |
| | | | 1.0 | | | | | | | | | | | 0 | CCGSPLIT |
| | | | | | | 1.0 | | | | 1.0 | | | | 0 | CCFOSPLT |

Table 26 Quantity and Quality Constraints of the Refinery Products

| | | | | | | |
|---|---|---|---|---|---|---|
| **Premium Gasoline** | | | | | | |
| | SRGPG | RFGPG | SRNPG | CCGPG | PG | RHS |
| Min. P.G. Production | | | | | 1.0 | ≥10,000 |
| PG Blending | 1.0 | 1.0 | 1.0 | 1.0 | -1.0 | = 0 |
| PG Octane Rating | 78.5 | 104.0 | 65.0 | 93.7 | -93.0 | ≥ 0 |
| PG Vapor Pressure | 18.4 | 2.57 | 6.54 | 6.90 | -12.7 | ≤ 0 |
| **Regular Gasoline** | | | | | | |
| | SRGRG | RFGRG | SRNRG | CCGRG | RG | RHS |
| Min R.G. Production | | | | | 1.0 | ≥ 10,000 |
| RG Blending | 1.0 | 1.0 | 1.0 | 1.0 | -1.0 | = 0 |
| RG Octane Rating | 78.5 | 104.0 | 65.0 | 93.7 | -87.0 | ≥ 0 |
| RG Vapor Pressure | 18.4 | 2.57 | 6.54 | 6.90 | -12.7 | ≤ 0 |
| **Diesel Fuel** | | | | | | |
| | SRNDF | CCFODF | SRDSDF | SRFODF | DF | RHS |
| Min D.F. Production | | | | | 1.0 | >10,000 |
| DF Blending | 1.0 | 1.0 | 1.0 | 1.0 | -1.0 | = 0 |
| DF Density Spec. | 272.0 | 294.4 | 292.0 | 295.0 | -306.0 | ≤ 0 |
| DF Sulfur Spec. | 0.283 | 0.353 | 0.526 | 0.980 | -0.50 | ≤ 0 |
| **Fuel Oil** | | | | | | |
| | | CCFOFO | SRDSFO | SRFOFO | FO | RHS |
| Min. FO Production | | | | | 1.0 | ≥ 10,000 |
| FO Blending | | 1.0 | 1.0 | 1.0 | -1.0 | = 0 |
| FO Density Spec. | | 294.4 | 292.0 | 295.0 | -352.0 | ≤ 0 |
| FO Sulfur Spec. | | 0.353 | 0.526 | 0.980 | -3.0 | ≤ 0 |

## Table 27 Process Unit Material Balances Using Volumetric Yields

Crude Oil Atmospheric Distillation Column:

| | CRUDE | FGAD | SRG | SRN | SRDS | SRFO | RHS |
|---|---|---|---|---|---|---|---|
| AD Capacity | 1.0 | | | | | | ≤ 100,000 |
| FGAD Yield | 35.42 | -1.0 | | | | | = 0 |
| SRG Yield | 0.270 | | -1.0 | | | | = 0 |
| SRN Yield | 0.237 | | | -1.0 | | | = 0 |
| SRDS Yield | 0.087 | | | | -1.0 | | = 0 |
| SRFO Yield | 0.372 | | | | | -1.0 | = 0 |

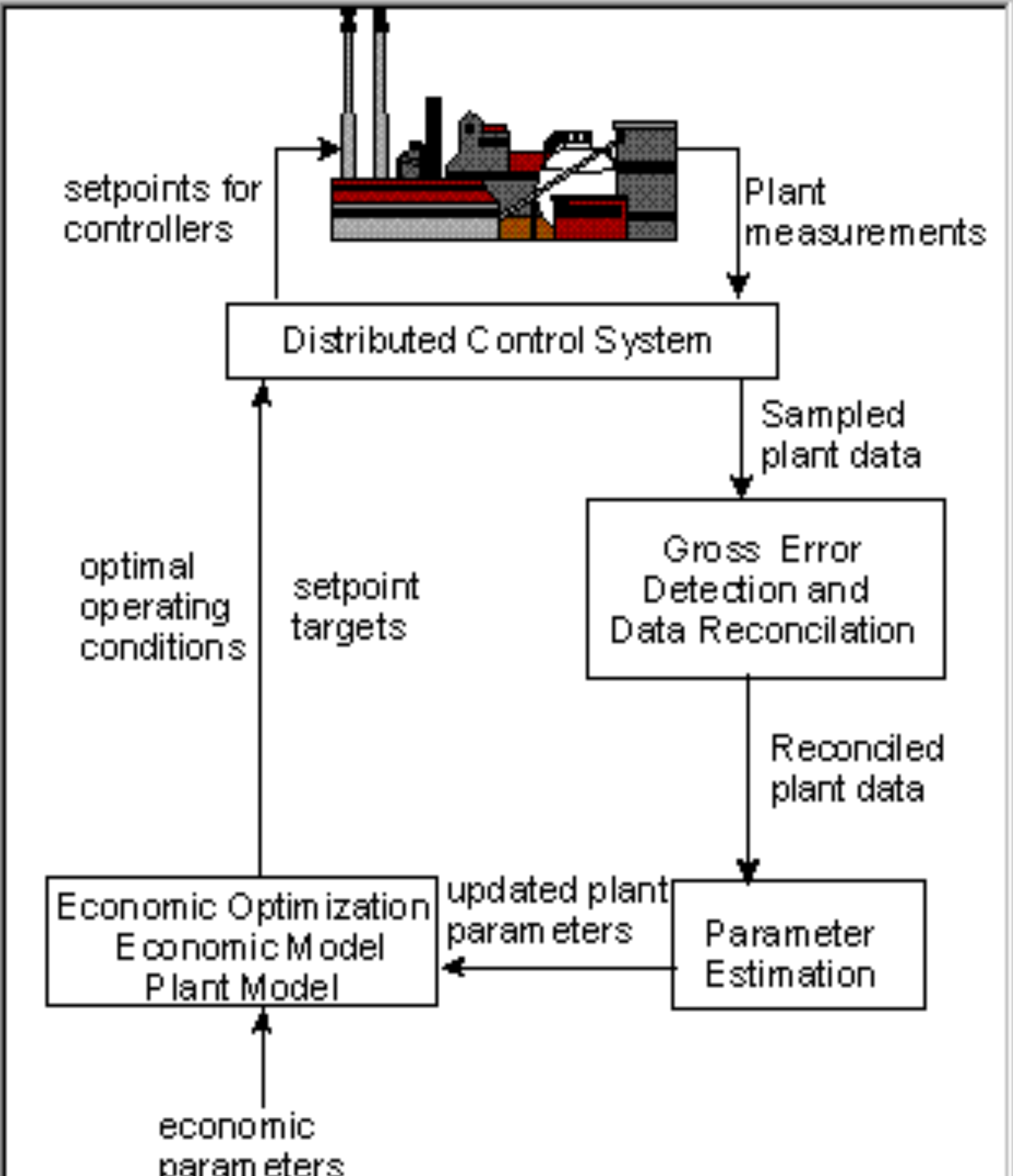
Catalytic Reformer:

| | SRNRF | FGRF | RFG | RHS |
|---|---|---|---|---|
| RF Capacity | 1.0 | | | ≤ 25,000 |
| FGRF Yield | 158.7 | -1.0 | | = 0 |
| RFG Yield | 0.928 | | -1.0 | = 0 |

Catalytic Cracking Unit:

| | SRDSCC | SRFOCC | FGCC | CCG | CCFO | RHS |
|---|---|---|---|---|---|---|
| CC Capacity | 1.0 | 1.0 | | | | ≤ 30,000 |
| FGCC Yield | 336.9 | 386.4 | -1.0 | | | = 0 |
| CCG Yield | 0.619 | 0.688 | | -1.0 | | = 0 |
| CCFO Yield | 0.189 | 0.220 | | | -1.0 | = 0 |

## Instructions

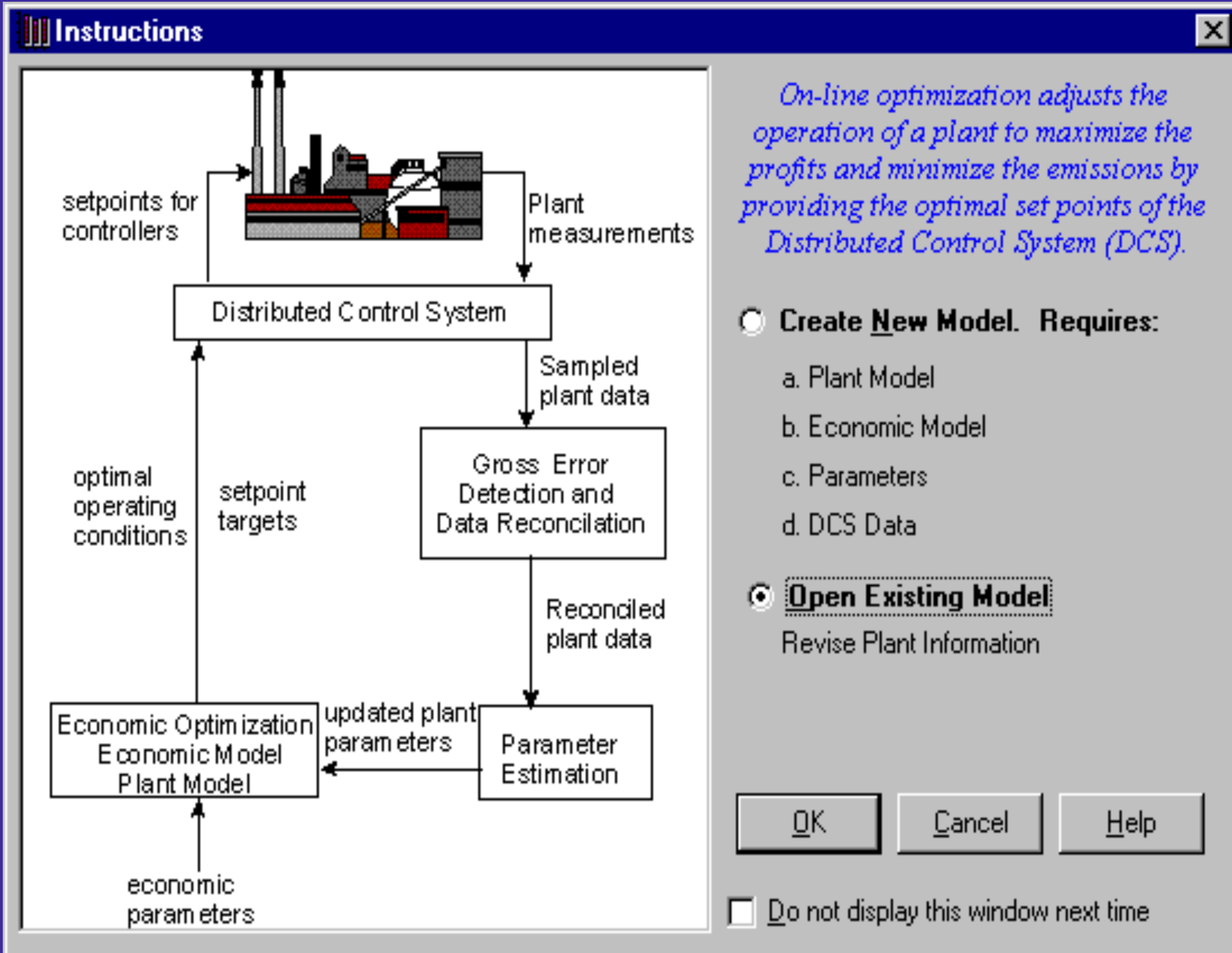



*On-line optimization adjusts the operation of a plant to maximize the profits and minimize the emissions by providing the optimal set points of the Distributed Control System (DCS).*

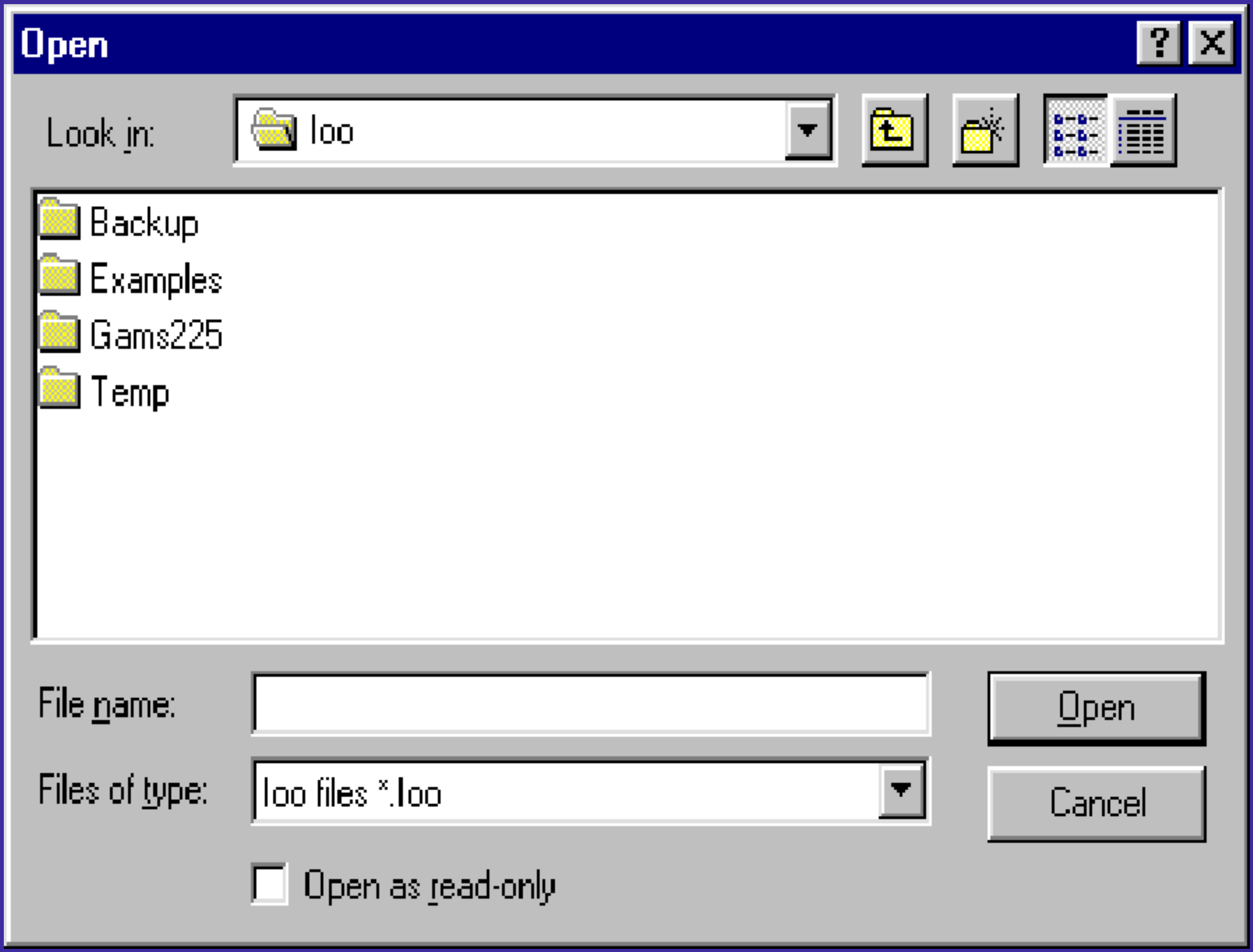
- (•) **Create New Model. Requires:**
  - a. Plant Model
  - b. Economic Model
  - c. Parameters
  - d. DCS Data
- ( ) **Open Existing Model**
  - Revise Plant Information

OK | Cancel | Help

☐ Do not display this window next time



Instructions
setpoints for controllers
Plant measurements
Distributed Control System
Sampled plant data
Gross Error Detection and Data Reconcilation
optimal operating conditions
setpoint targets
Reconciled plant data
Economic Optimization Economic Model Plant Model
updated plant parameters
Parameter Estimation
economic parameters
On-line optimization adjusts the operation of a plant to maximize the profits and minimize the emissions by providing the optimal set points of the Distributed Control System (DCS).
Create New Model. Requires:
a. Plant Model
b. Economic Model
c. Parameters
d. DCS Data
Open Existing Model
Revise Plant Information
OK
Cancel
Help
Do not display this window next time



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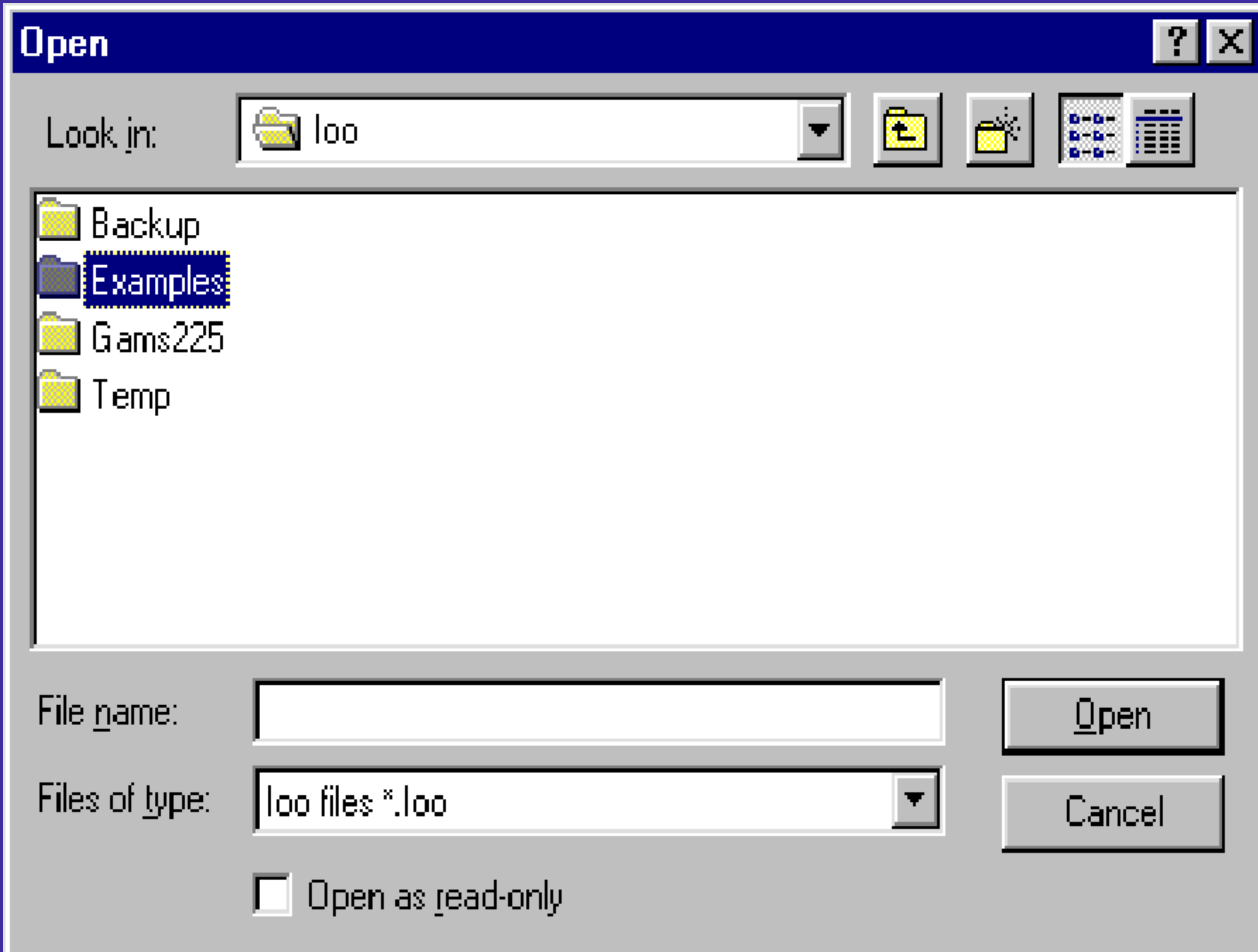
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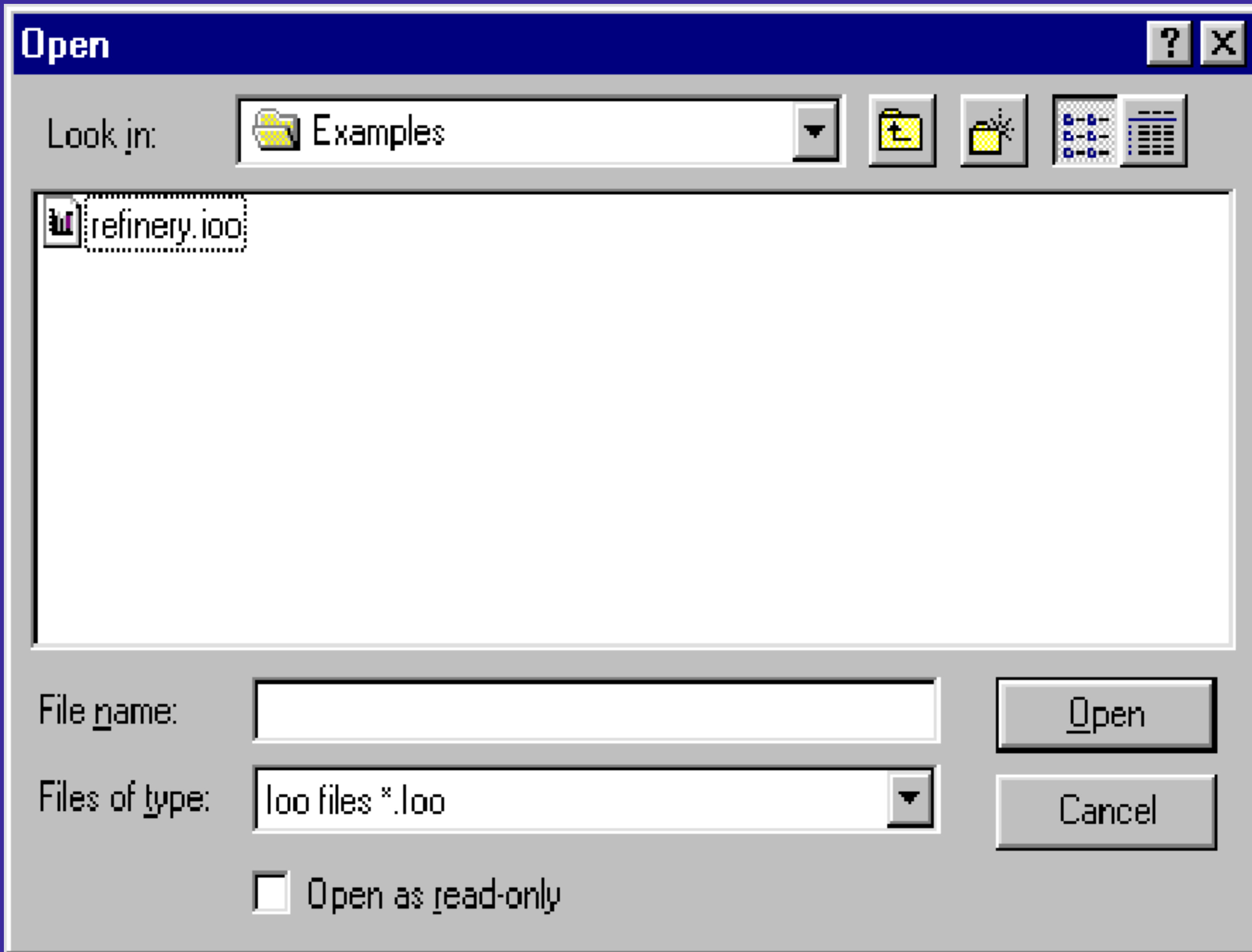

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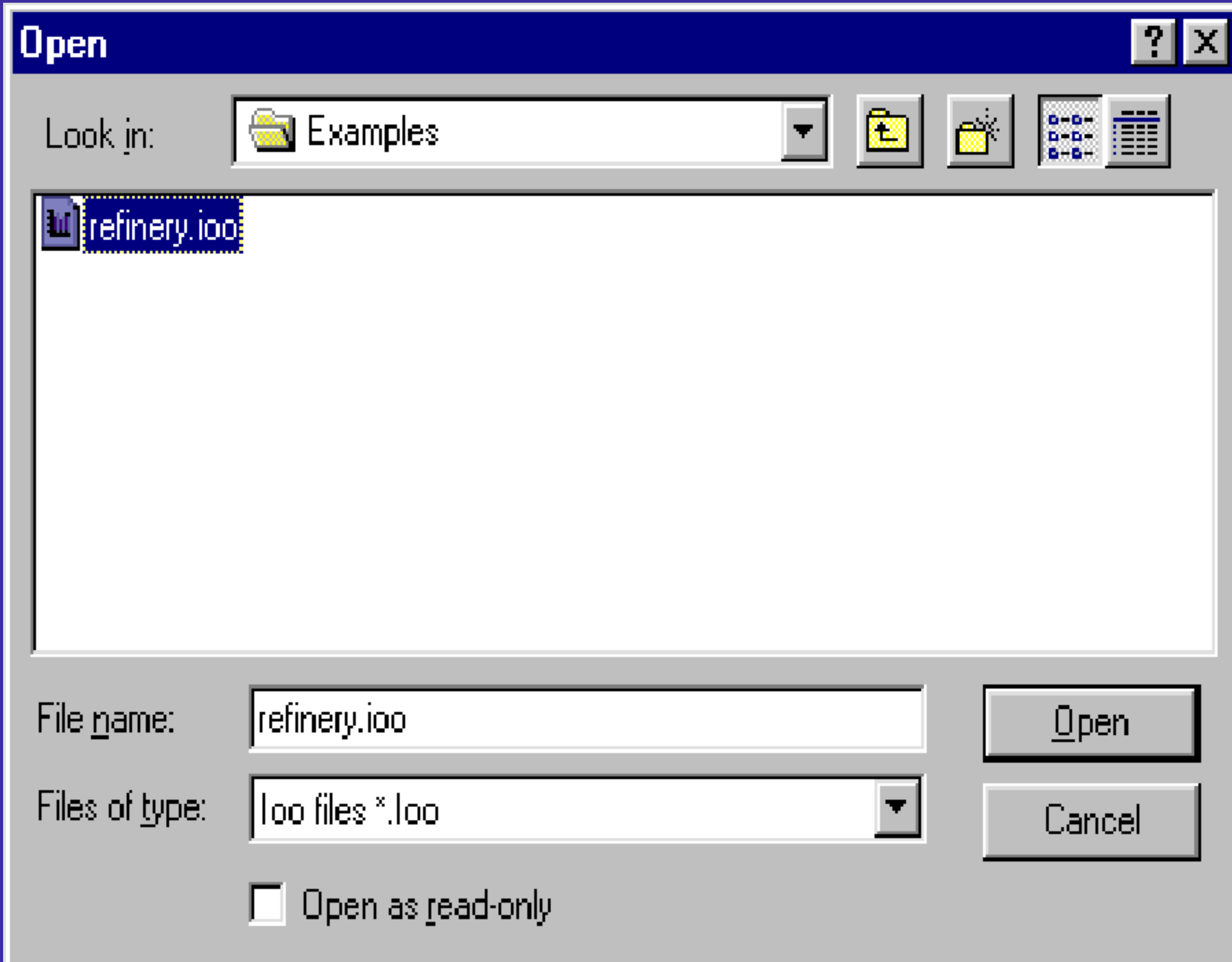
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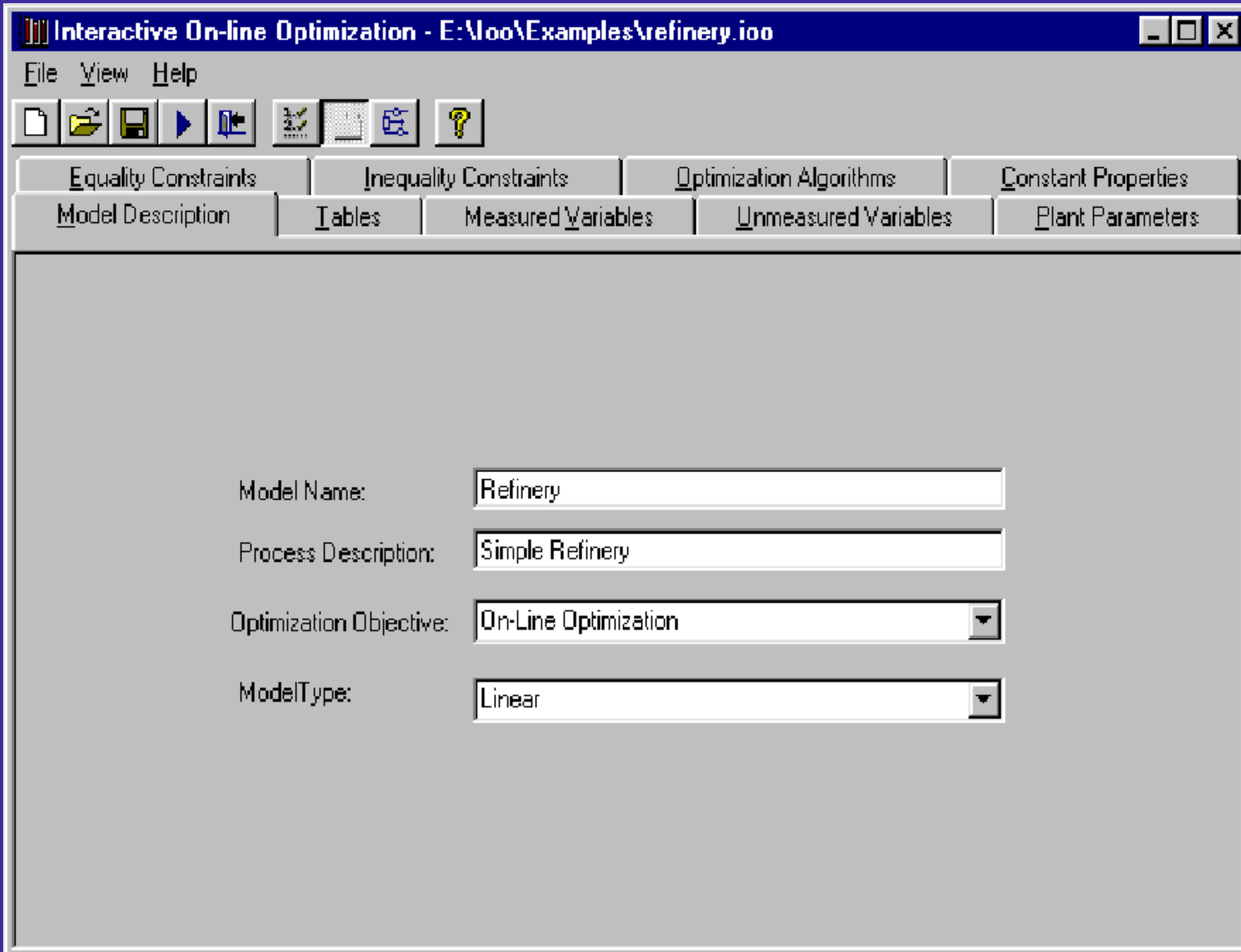
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Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Model Description
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Model Name:
Refinery
Process Description:
Simple Refinery
Optimization Objective:
On-Line Optimization
ModelType:
Linear

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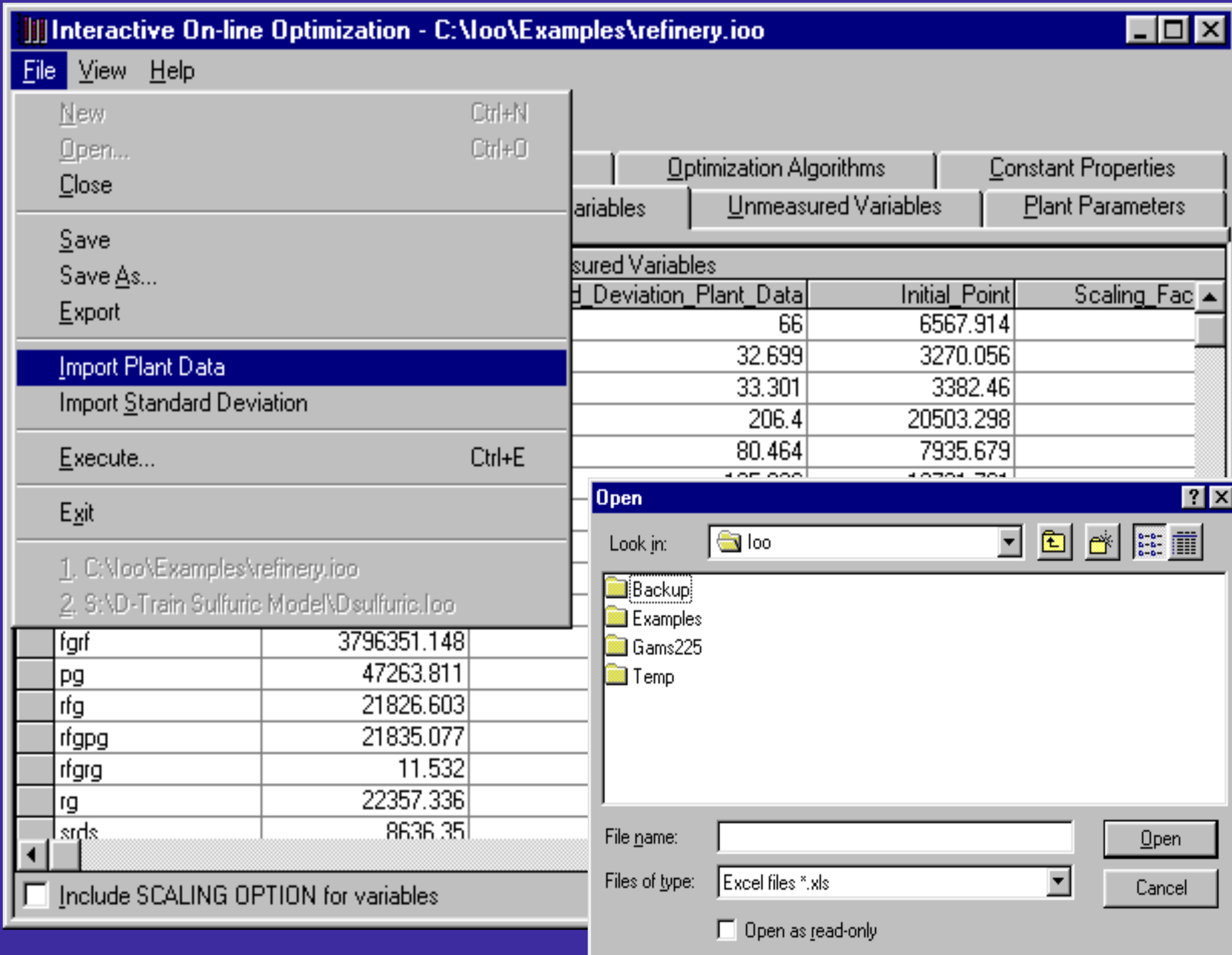
Equality Constraints | Inequality Constraints | Optimization Algorithms | Constant Properties

Model Description | Tables | Measured Variables | Unmeasured Variables | Plant Parameters

Measured Variables

| Name | Plant_Data | Standard_Deviation_Plant_Data | Initial_Point | Scaling_Fac |
|---|---|---|---|---|
| ccfo | 6567.914 | 66 | 6567.914 | |
| ccfodf | 3270.056 | 32.699 | 3270.056 | |
| ccfofo | 3382.46 | 33.301 | 3382.46 | |
| ccg | 20503.298 | 206.4 | 20503.298 | |
| ccgpg | 7935.679 | 80.464 | 7935.679 | |
| ccgrg | 12721.761 | 125.936 | 12721.761 | |
| crude | 99686.657 | 1000 | 99686.657 | 10 |
| df | 12582.842 | 125 | 12582.842 | |
| fgad | 3553606.242 | 35420 | 3553606.242 | 3 |
| fgcc | 12211460 | 115920 | 12211460 | 10 |
| fgrf | 3796351.148 | 37612 | 3796351.148 | 4 |
| pg | 47263.811 | 471.132 | 47263.811 | |
| rfg | 21826.603 | 219.936 | 21826.603 | |
| rfgpg | 21835.077 | 219.936 | 21835.077 | |
| rfgrg | 11.532 | 10 | 11.532 | |
| rg | 22357.336 | 225.204 | 22357.336 | |
| srds | 8636.35 | 87 | 8636.35 | |

☑ Include SCALING OPTION for variables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Save
Save As...
Export
Import Plant Data
Import Standard Deviation
Execute... Ctrl+E
Exit
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Optimization Algorithms
Constant Properties
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Unmeasured Variables
Plant Parameters
sured Variables
d_Deviation_Plant_Data
Initial_Point
Scaling_Fac
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6567.914
32.699
3270.056
33.301
3382.46
206.4
20503.298
80.464
7935.679
fgrf
3796351.148
pg
47263.811
rfg
21826.603
rfgpg
21835.077
rfgrg
11.532
rg
22357.336
srds
8636.35
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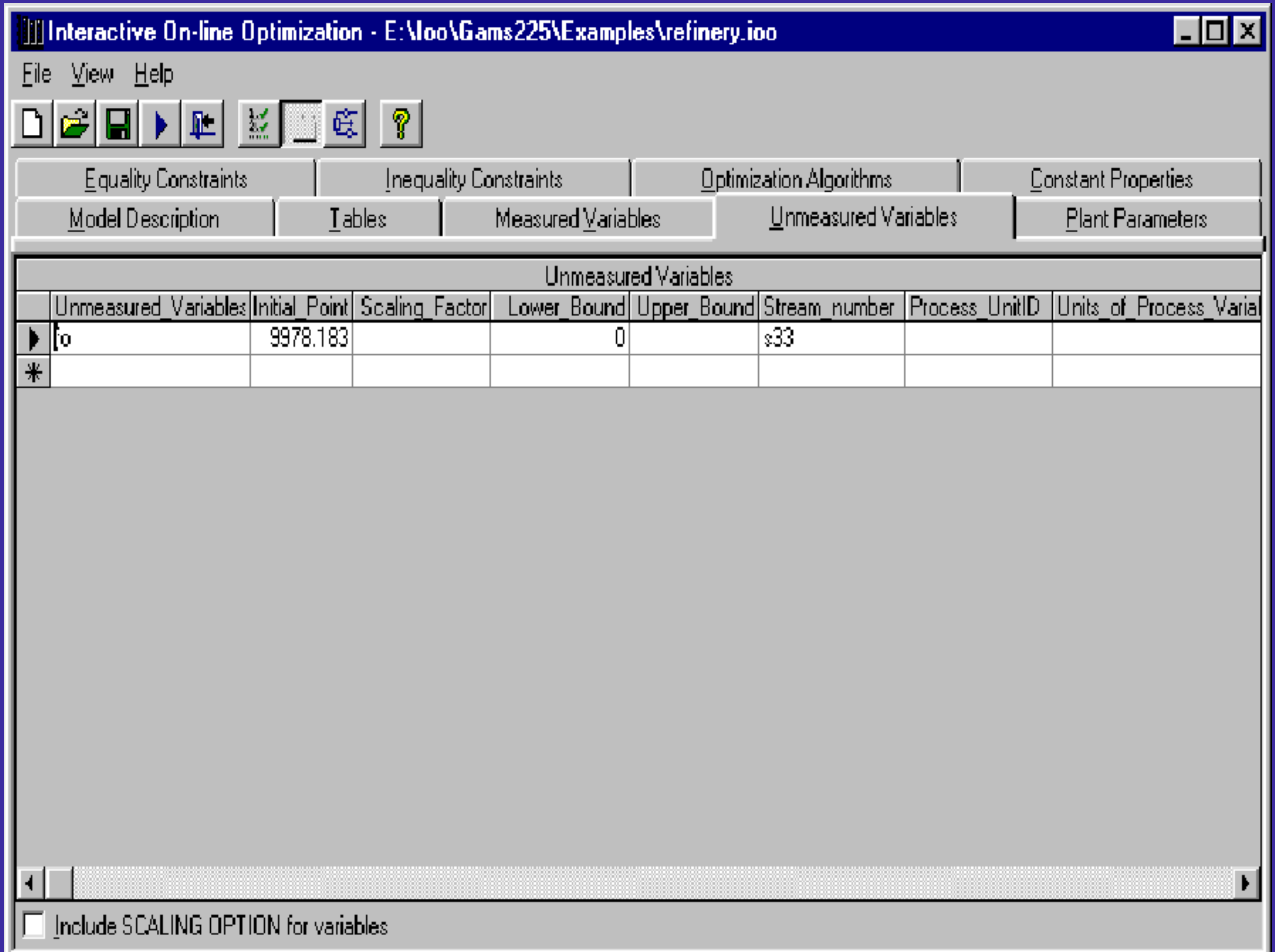
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Measured Variables
Unmeasured Variables
Plant Parameters
Unmeasured Variables
Unmeasured_Variables
Initial_Point
Scaling_Factor
Lower_Bound
Upper_Bound
Stream_number
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Equality Constraints | Inequality Constraints | Optimization Algorithms | Constant Properties

Model Description | Tables | Measured Variables | Unmeasured Variables | Plant Parameters

Plant Parameters

| Plant_Parameter | Initial_Point | Lower_Bound | Upper_Bound | Process_UnitID | Unit_of_parameter |
|---|---|---|---|---|---|
| vfgad | 35.42 | 10 | 100 | AD | BBL/BBL |
| vsrds | 0.087 | 0 | 1 | AD | |
| vsrdsccfo | 0.189 | 0.15 | 0.2 | CC | |
| vsrdsccg | 0.619 | 0 | 0.7 | CC | |
| vsrdsfgcc | 336.9 | 300 | 400 | CC | |
| vsrfo | 0.372 | 0 | 3 | AD | |
| vsrfoccfo | 0.22 | 0 | 5 | CC | |
| vsrfoccg | 0.688 | 0 | 5 | CC | |
| vsrfofgcc | 386.4 | 100 | 1000 | CC | |
| vsrg | 0.27 | 0 | 5 | AD | |
| vsrn | 0.237 | 0 | 5 | AD | |
| vsrnfgrf | 158.17 | 0 | 1000 | RF | |
| vsrnrfg | 0.928 | 0 | 10 | RF | |

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File View Help

Model Description | Tables | Measured Variables | Unmeasured Variables | Plant Parameters

Equality Constraints | Inequality Constraints | Optimization Algorithms | Constant Properties

Equality Constraints

| Equality_Constraints | Scaling_Factor | Process_UnitID | Stream_Number |
|---|---|---|---|
| SRGPG + RFGPG + SRNPG + CCGPG - PG =E=0 | | PG | |
| SRGRG + RFGRG + SRNRG + CCGRG - RG =E= 0 | | RG | |
| SRNDF + CCFODF + SRDSDF + SRFODF - DF =E= 0 | | DF | |
| CCFOFO + SRDSFO + SRFOFO - FO =E= 0 | | FO | |
| VFGAD*CRUDE - FGAD =E= 0 | 300 | AD | |
| VSRG*CRUDE - SRG =E= 0 | 100 | AD | |
| VSRN*CRUDE - SRN =E= 0 | 100 | AD | |
| VSRDS*CRUDE - SRDS =E= 0 | 100 | AD | |
| VSRFO*CRUDE - SRFO =E= 0 | 100 | AD | |
| VSRNFGRF*SRNRF - FGRF =E= 0 | | RF | |
| VSRNRFG*SRNRF - RFG =E= 0 | | RF | |
| VSRDSFGCC*SRDSCC + VSRFOFGCC*SRFOCC - FGCC =E= 0 | | CC | |
| VSRDSCCG*SRDSCC + VSRFOCCG*SRFOCC - CCG =E= 0 | | CC | |
| VSRDSCCFO*SRDSCC + VSRFOCCFO*SRFOCC - CCFO =E= 0 | | CC | |
| SRG- SRGPG - SRGRG =E= 0 | | Split2 | |
| SRN - SRNRF - SRNPG - SRNRG - SRNDF =E= 0 | | Split1 | |
| SRDS - SRDSCC - SRDSDF - SRDSFO =E= 0 | | Split4 | |

Include SCALING OPTION for equations

Interactive On-line Optimization - E:\OFFICE\PRWIN\FILES\Ioo\Examples\refinery.ioo

File View Help

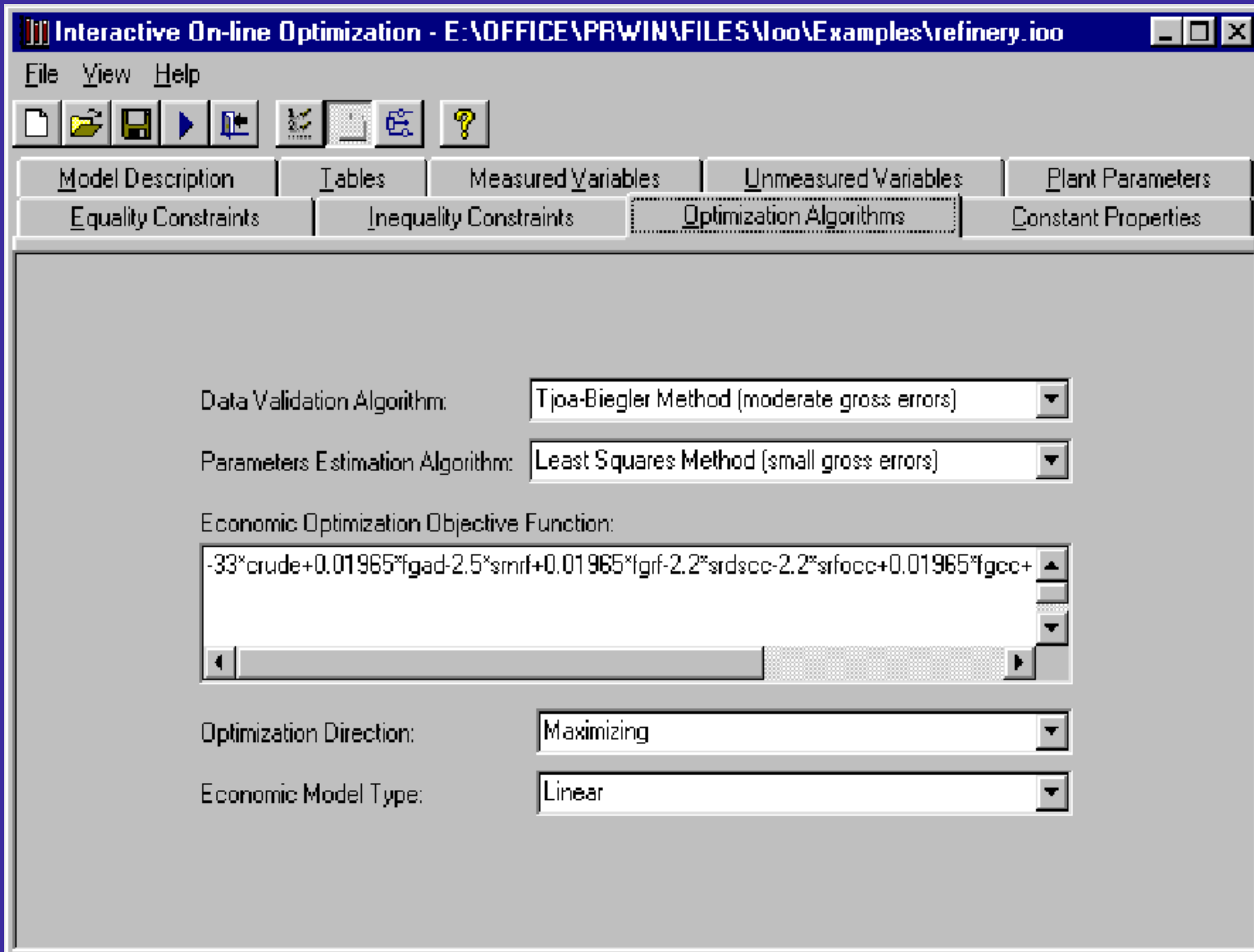
Model Description | Tables | Measured Variables | Unmeasured Variables | Plant Parameters

Equality Constraints | Inequality Constraints | Optimization Algorithms | Constant Properties

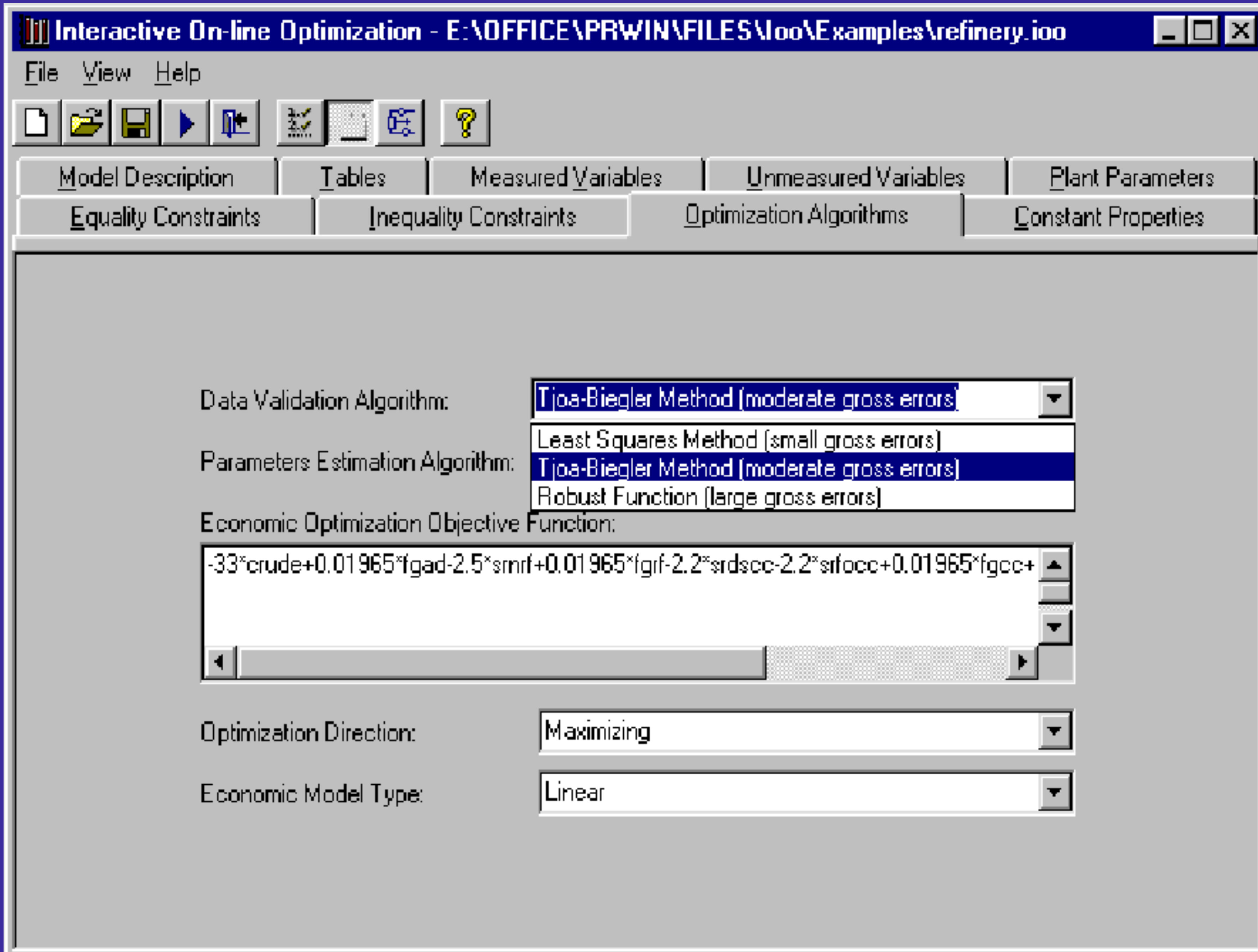
**Inequality Constraints**

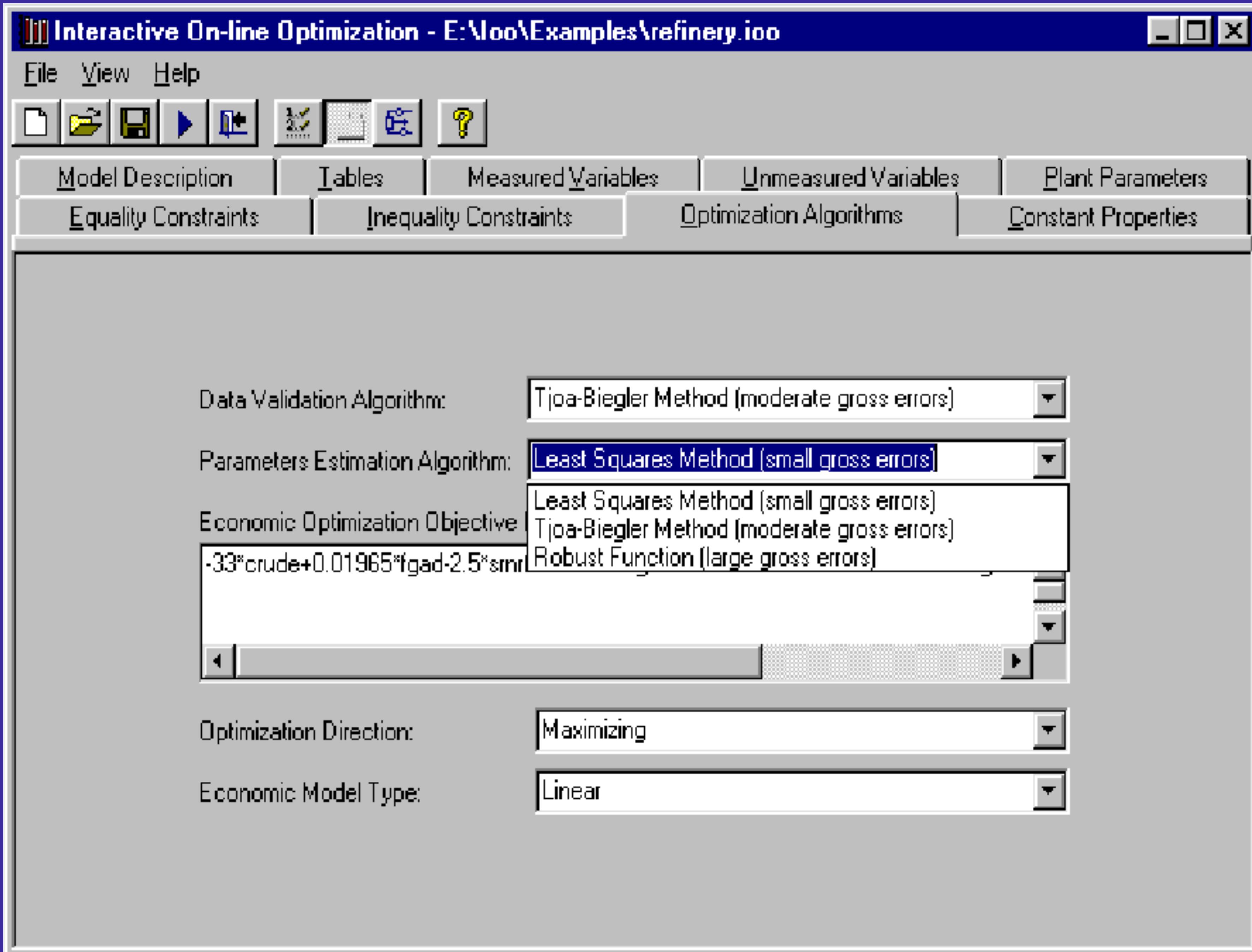
| Inequality_Constraints | Scaling_Factor |
|---|---|
| CRUDE=L=100000 | |
| CRUDE=L=110000 | |
| 78.5*SRGPG + 104*RFGPG + 65*SRNPG + 93.7*CCGPG - 93*PG =G= 0 | |
| 18.4*SRGPG + 2.57*RFGPG + 6.54*SRNPG + 6.9*CCGPG - 12.7*PG=L= 0 | |
| 78.5*SRGRG + 104*RFGRG + 65*SRNRG + 93.7*CCGRG - 87*RG =G= 0 | |
| 18.4*SRGRG + 2.57*RFGRG + 6.54*SRNRG + 6.9*CCGRG - 12.7*RG =L= 0 | |
| 272*SRNDF + 294.4*CCFODF + 292*SRDSDF + 295*SRFODF - 306*DF =L= 0 | |
| 0.283*SRNDF + 0.353*CCFODF + 0.526*SRDSDF + 0.98*SRFODF - 0.5*DF =L= 0 | |
| 294.4*CCFOFO + 292*SRDSFO + 295*SRFOFO - 352*FO =L= 0 | |
| 0.353*CCFOFO + 0.526*SRDSFO + 0.98*SRFOFO - 3*FO =L= 0 | |
| SRDSCC + SRFOCC =L= 30000 | |
| pg =g= 10000 | |
| rg =g= 10000 | |
| df =g= 10000 | |
| fo =g= 10000 | |

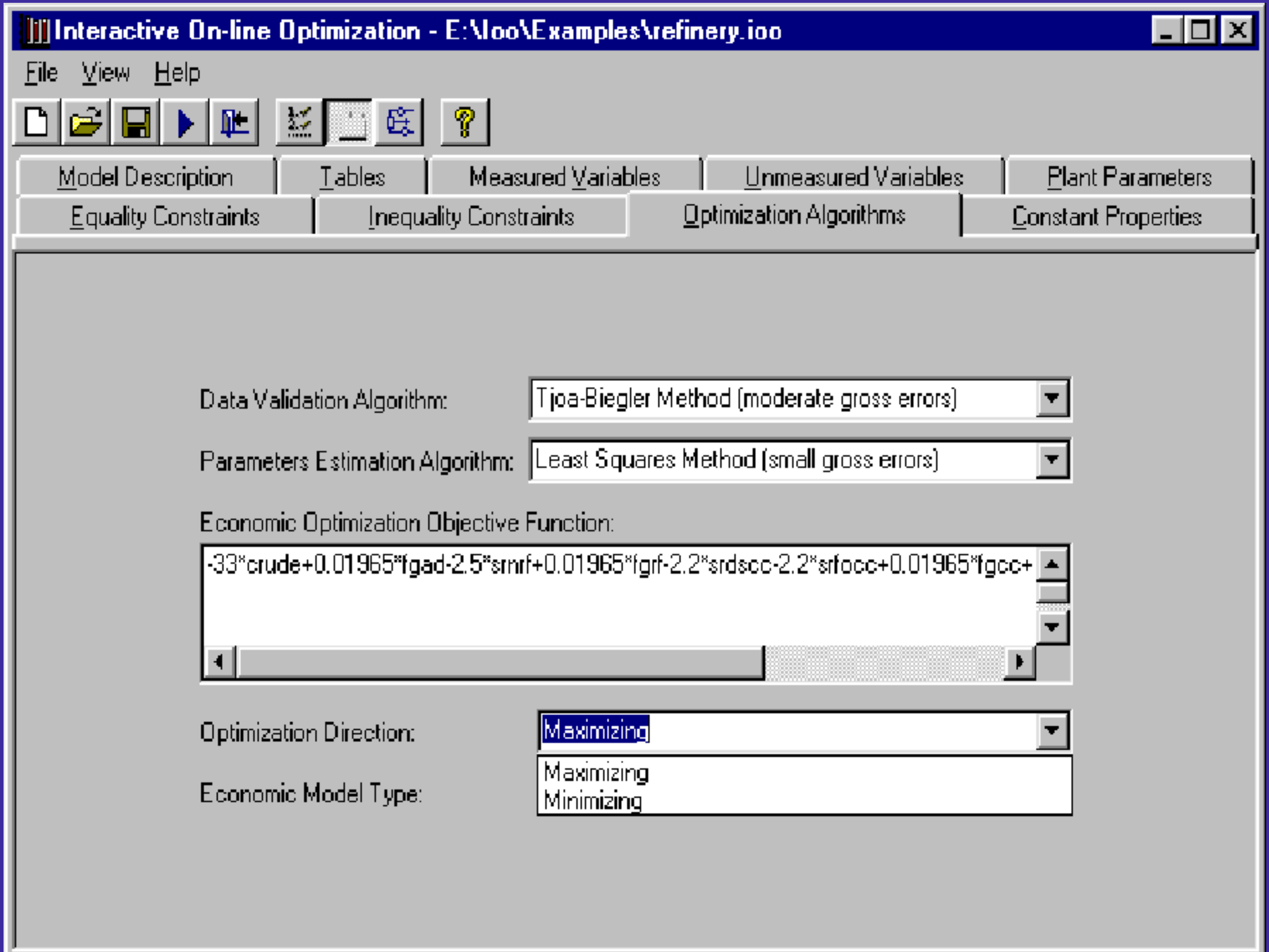
☑ Include SCALING OPTION for equations

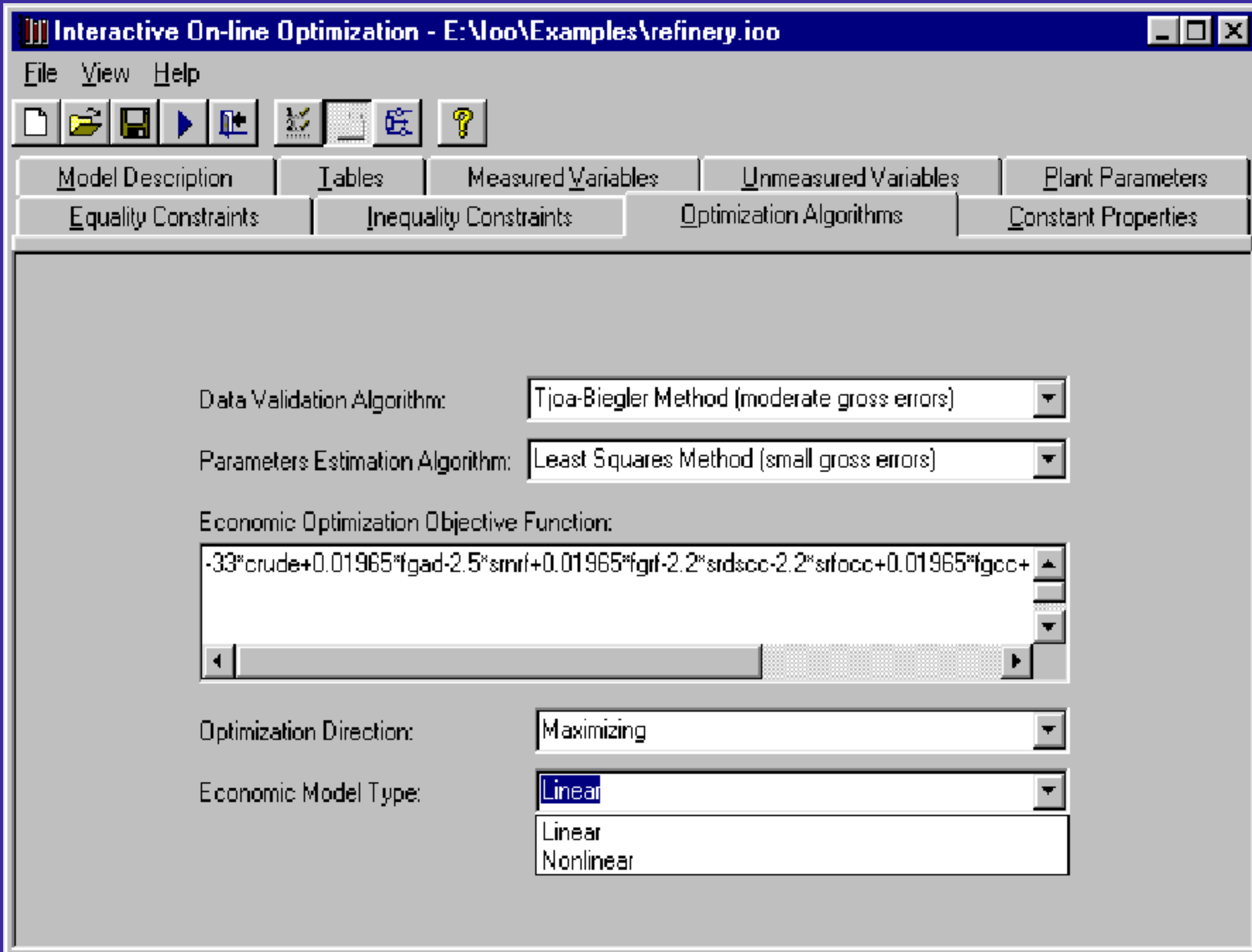


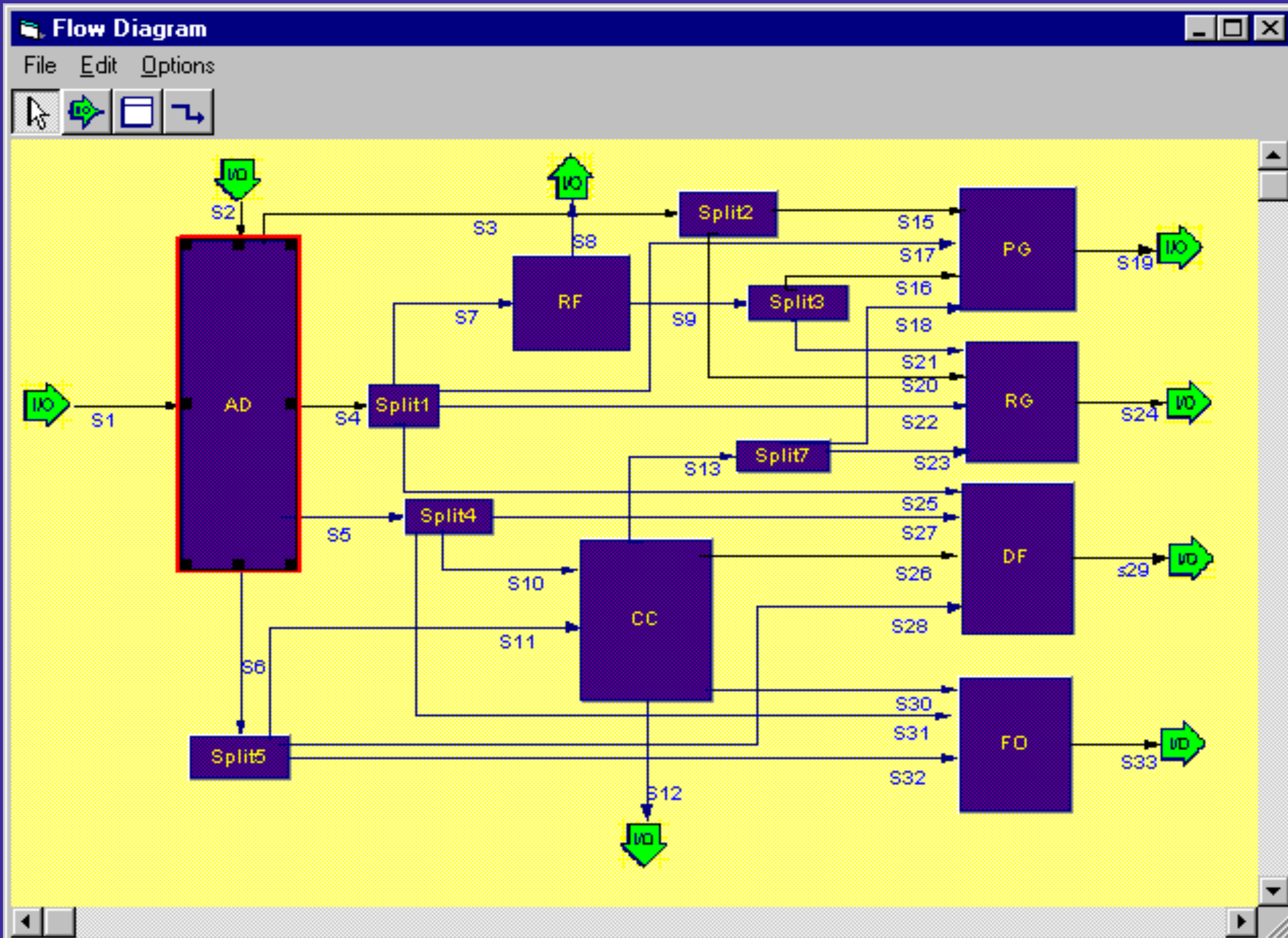
Interactive On-line Optimization - E:\OFFICE\PRWIN\FILES\Ioo\Examples\refinery.ioo
File View Help
Model Description
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Data Validation Algorithm:
Tjoa-Biegler Method (moderate gross errors)
Parameters Estimation Algorithm:
Least Squares Method (small gross errors)
Economic Optimization Objective Function:
-33*crude+0.01965*fgad-2.5*smrf+0.01965*fgrf-2.2*srdscc-2.2*srfocc+0.01965*fgcc+
Optimization Direction:
Maximizing
Economic Model Type:
Linear


Interactive On-line Optimization - E:\OFFICE\PRWIN\FILES\Ioo\Examples\refinery.ioo
File View Help
Model Description
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Data Validation Algorithm:
Tjoa-Biegler Method (moderate gross errors)
Least Squares Method (small gross errors)
Tjoa-Biegler Method (moderate gross errors)
Robust Function (large gross errors)
Parameters Estimation Algorithm:
Economic Optimization Objective Function:
-33*crude+0.01965*fgad-2.5*smrf+0.01965*fgrf-2.2*srdscc-2.2*srfocc+0.01965*fgcc+
Optimization Direction:
Maximizing
Economic Model Type:
Linear


Interactive On-line Optimization - E:\Ioo\Examples\refinery.ioo
File View Help
Model Description
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Data Validation Algorithm:
Tjoa-Biegler Method (moderate gross errors)
Parameters Estimation Algorithm:
Least Squares Method (small gross errors)
Least Squares Method (small gross errors)
Tjoa-Biegler Method (moderate gross errors)
Robust Function (large gross errors)
Economic Optimization Objective
-33*crude+0.01965*fgad-2.5*smr
Optimization Direction:
Maximizing
Economic Model Type:
Linear


Interactive On-line Optimization - E:\Ioo\Examples\refinery.ioo
File View Help
Model Description
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Data Validation Algorithm:
Tjoa-Biegler Method (moderate gross errors)
Parameters Estimation Algorithm:
Least Squares Method (small gross errors)
Economic Optimization Objective Function:
-33*crude+0.01965*fgad-2.5*srnrf+0.01965*fgrf-2.2*srdscc-2.2*srfocc+0.01965*fgcc+
Optimization Direction:
Maximizing
Economic Model Type:
Maximizing
Minimizing


Interactive On-line Optimization - E:\Ioo\Examples\refinery.ioo
File View Help
Model Description
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Data Validation Algorithm:
Tjoa-Biegler Method (moderate gross errors)
Parameters Estimation Algorithm:
Least Squares Method (small gross errors)
Economic Optimization Objective Function:
-33*crude+0.01965*fgad-2.5*smrf+0.01965*fgrf-2.2*srdscc-2.2*srfocc+0.01965*fgcc+
Optimization Direction:
Maximizing
Economic Model Type:
Linear
Linear
Nonlinear



Flow Diagram
File
Edit
Options
I/O
S1
S2
S3
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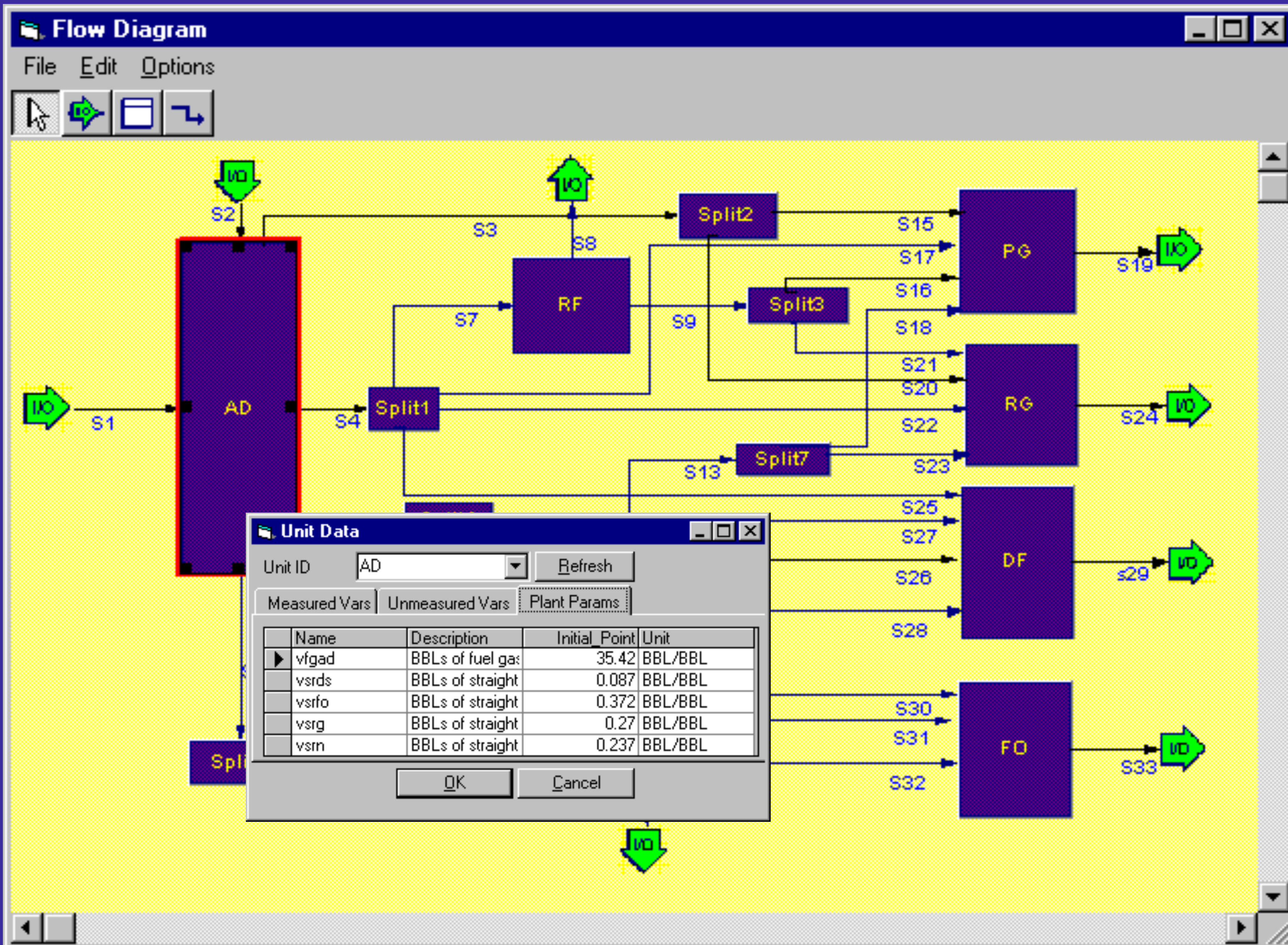
S25
S26
S27
S28
s29
S30
S31
S32
S33
AD
RF
CC
PG
RG
DF
FO
Split1
Split2
Split3
Split4
Split5
Split7


Flow Diagram
File
Edit
Options
I/O
S1
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S4
S7
S8
S9
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S15
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S18
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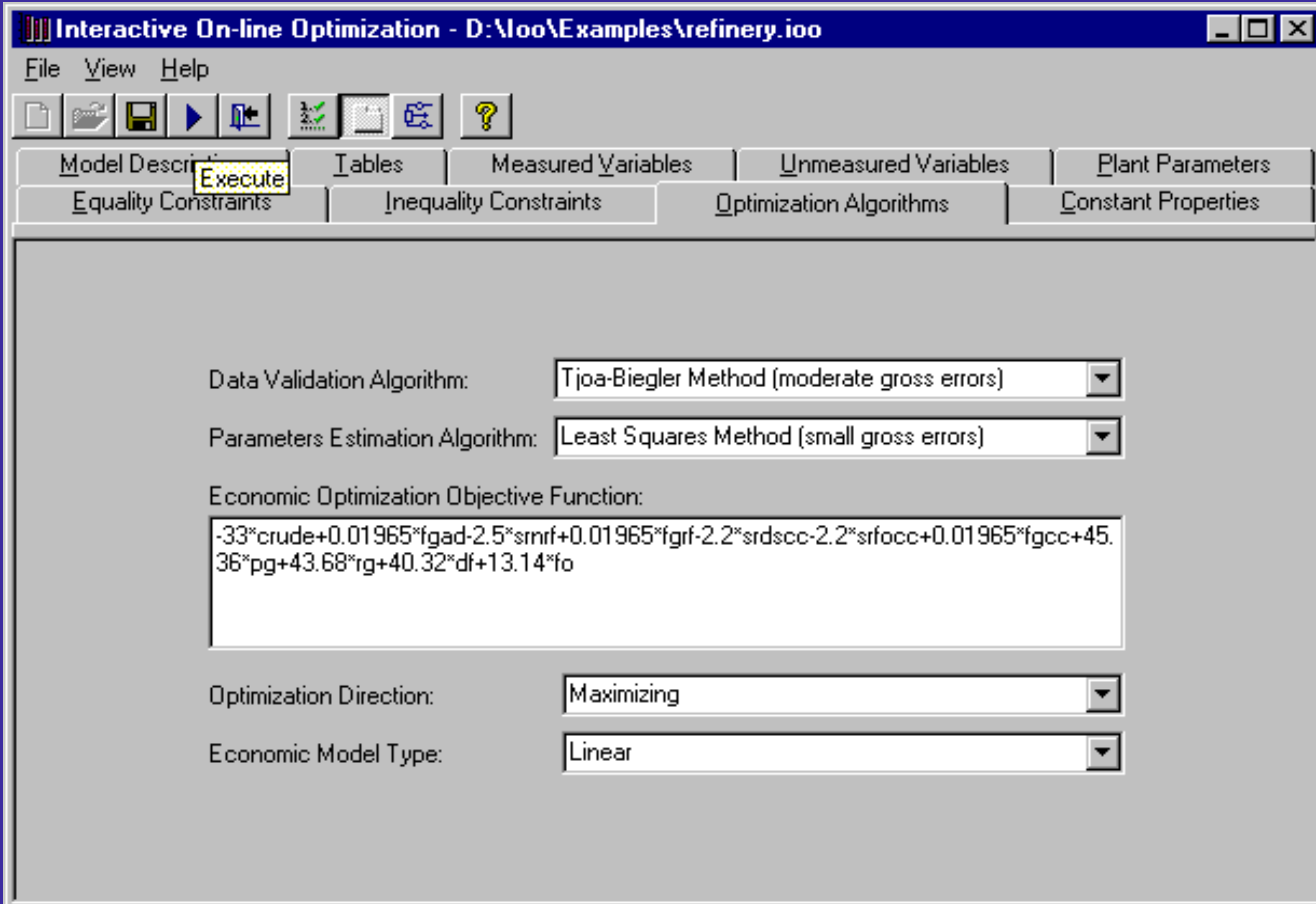
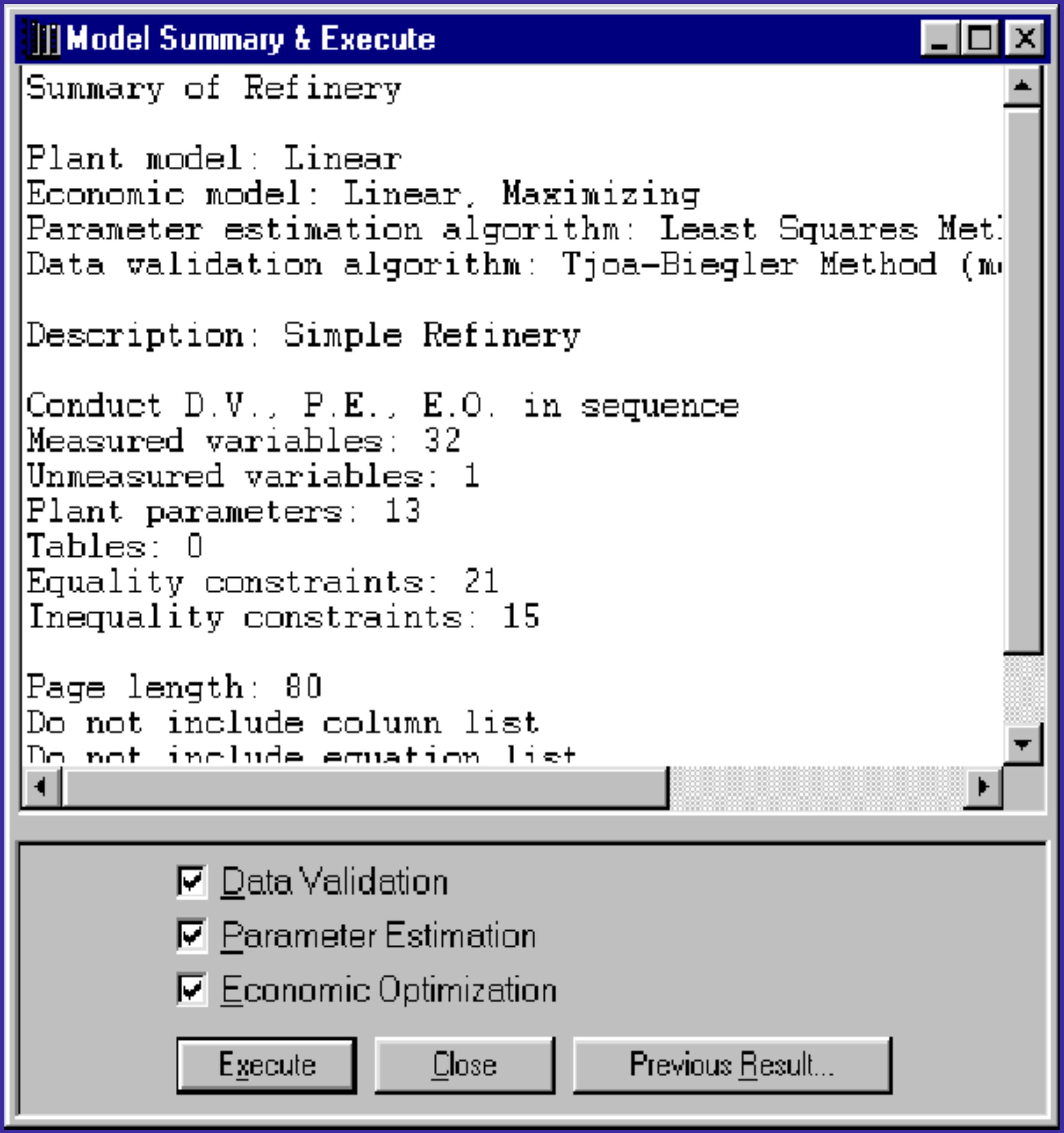
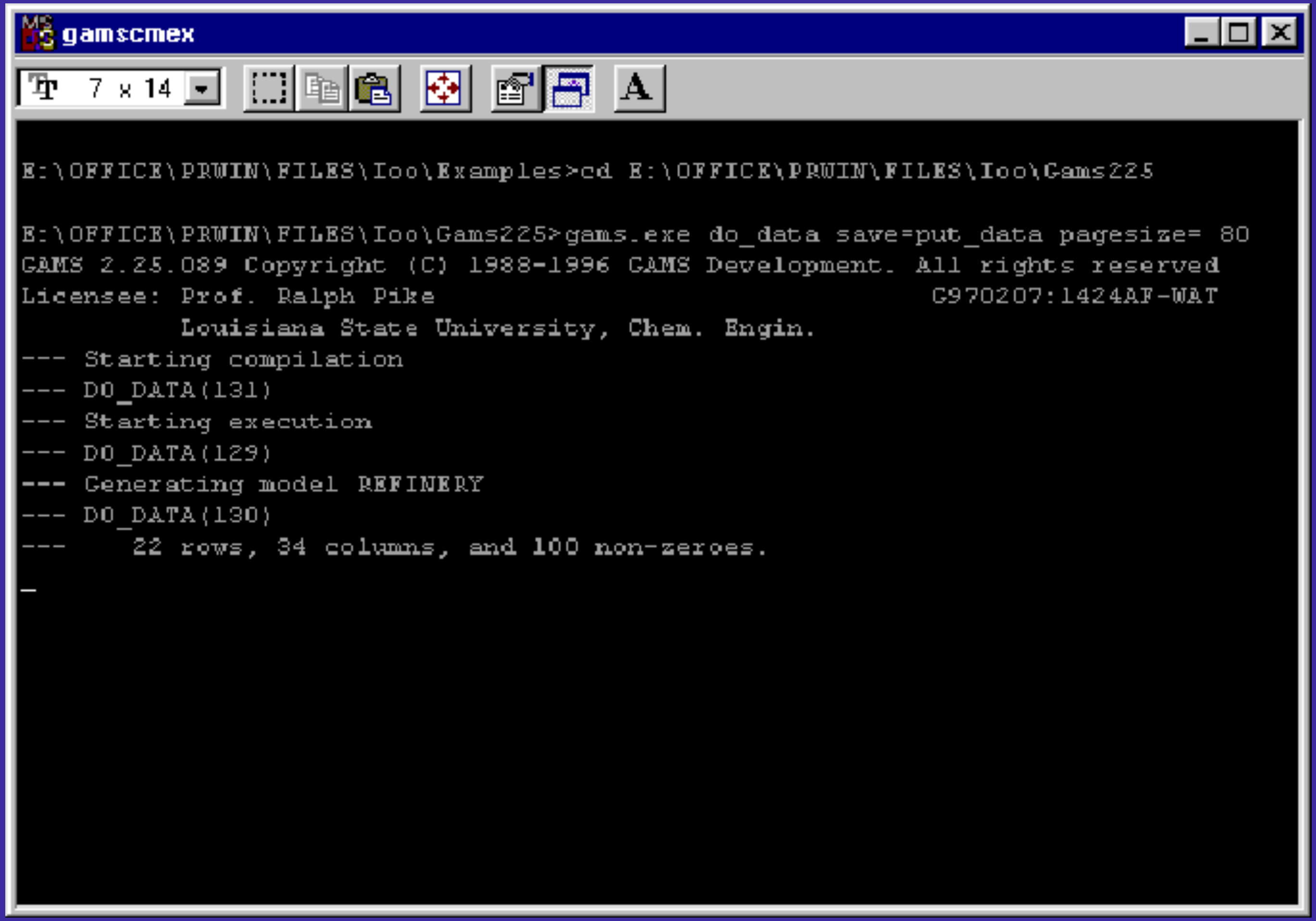
S21
S22
S23
S24
S25
S26
S27
S28
s29
S30
S31
S32
S33
AD
RF
Split1
Split2
Split3
Split7
PG
RG
DF
FO
Unit Data
Unit ID
AD
Refresh
Measured Vars
Unmeasured Vars
Plant Params
Name
Description
Initial_Point
Unit
vfgad
BBLs of fuel gas
35.42
BBL/BBL
vsrds
BBLs of straight
0.087
BBL/BBL
vsrfo
BBLs of straight
0.372
BBL/BBL
vsrg
BBLs of straight
0.27
BBL/BBL
vsrn
BBLs of straight
0.237
BBL/BBL
OK
Cancel


Interactive On-line Optimization - D:\Ioo\Examples\refinery.ioo
File View Help
Model Descri
Execute
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Equality Constraints
Inequality Constraints
Optimization Algorithms
Constant Properties
Data Validation Algorithm:
Tjoa-Biegler Method (moderate gross errors)
Parameters Estimation Algorithm:
Least Squares Method (small gross errors)
Economic Optimization Objective Function:
-33*crude+0.01965*fgad-2.5*srnrf+0.01965*fgrf-2.2*srdscc-2.2*srfocc+0.01965*fgcc+45.36*pg+43.68*rg+40.32*df+13.14*fo
Optimization Direction:
Maximizing
Economic Model Type:
Linear


Model Summary & Execute
Summary of Refinery
Plant model: Linear
Economic model: Linear, Maximizing
Parameter estimation algorithm: Least Squares Met
Data validation algorithm: Tjoa-Biegler Method (m
Description: Simple Refinery
Conduct D.V., P.E., E.O. in sequence
Measured variables: 32
Unmeasured variables: 1
Plant parameters: 13
Tables: 0
Equality constraints: 21
Inequality constraints: 15
Page length: 80
Do not include column list
Data Validation
Parameter Estimation
Economic Optimization
Execute
Close
Previous Result...


gamscmex
7 x 14
E:\OFFICE\PRWIN\FILES\Ioo\Examples>cd E:\OFFICE\PRWIN\FILES\Ioo\Gams225
E:\OFFICE\PRWIN\FILES\Ioo\Gams225>gams.exe do_data save=put_data pagesize= 80
GAMS 2.25.089 Copyright (C) 1988-1996 GAMS Development. All rights reserved
Licensee: Prof. Ralph Pike G970207:1424AF-WAT
Louisiana State University, Chem. Engin.
--- Starting compilation
--- DO_DATA(131)
--- Starting execution
--- DO_DATA(129)
--- Generating model REFINERY
--- DO_DATA(130)
--- 22 rows, 34 columns, and 100 non-zeroes.

Output

File View

***Economic Objective = 700734.61975***

9/28/98 3:48:00 PM

| Name | Gross_Error |
|---|---|
| ccfo | |
| ccfodf | |
| ccfofo | |
| ccg | |
| ccgpg | |
| ccgrg | |
| crude | |
| df | |
| fgad | |
| fgcc | -5.33387149396135 |
| fgrf | |
| pg | |
| rfg | |
| rfgpg | |
| rfgrg | |
| rg | |
| srds | |
| srdscc | |
| srdsdf | |
| srdsfo | |

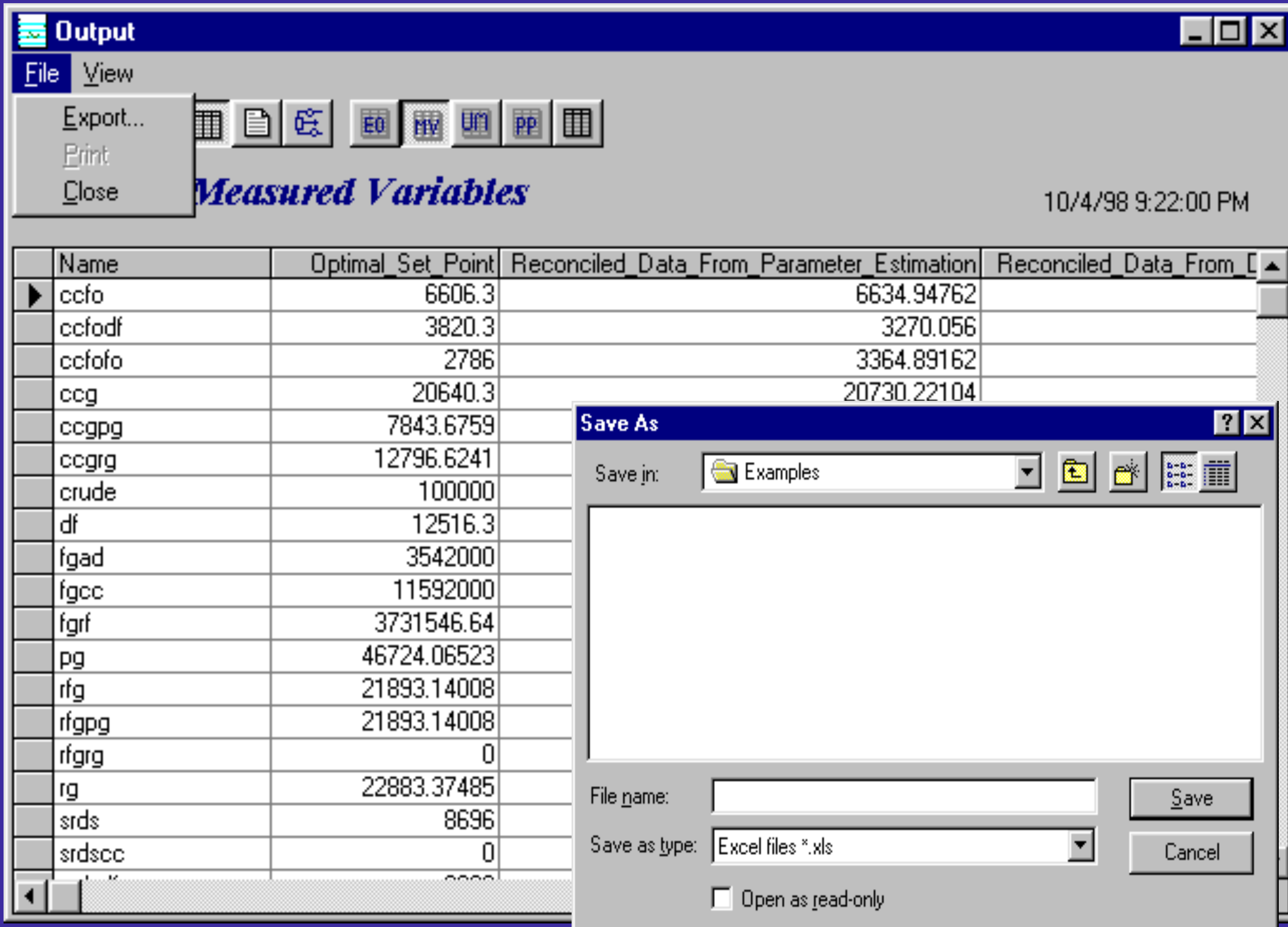
Output

File View

# *Values of Measured Variables*

9/28/98 3:48:00 PM

| Name | Optimal_Set_Point | Data_From_Parameter_Estimation | Reconciled_Data_From_Data_Validation |
|---|---|---|---|
| ccfo | 6606.3 | 6634.94762 | 6600.65902 |
| ccfodf | 3442.80193 | 3270.056 | 3249.28602 |
| ccfofo | 3163.49807 | 3364.89162 | 3351.37301 |
| ccg | 20640.3 | 20730.22104 | 20642.06169 |
| ccgpg | 10491.06299 | 7935.679 | 7956.28167 |
| ccgrg | 10149.23701 | 12794.54204 | 12685.78001 |
| crude | 100000 | 100188.95139 | 99908.29873 |
| df | 12516.3 | 12495.89361 | 12455.40653 |
| fgad | 3542000 | 3548692.68012 | 3538751.94089 |
| fgcc | 11592000 | 11642423.34337 | 11593157.61642 |
| fgrf | 3731546.64 | 3733862.09383 | 3740432.58444 |
| pg | 46724.06523 | 47238.72121 | 46996.68208 |
| rfg | 21893.14008 | 21906.75821 | 21945.51077 |
| rfgpg | 20315.08974 | 21895.22621 | 21934.31875 |
| rfgrg | 1578.05034 | 11.532 | 11.19202 |
| rg | 22883.37485 | 22543.89309 | 22585.6082 |
| srds | 8696 | 8712.64461 | 8692.02199 |
| srdscc | 0 | 0.004 | 0.02644 |
| srdsdf | 8673.867 | 8690.50761 | 8669.90103 |


Output
File
View
Export...
Print
Close
EO
MV
UM
PP
Measured Variables
10/4/98 9:22:00 PM
Name | Optimal_Set_Point | Reconciled_Data_From_Parameter_Estimation | Reconciled_Data_From_D
ccfo | 6606.3 | 6634.94762
ccfodf | 3820.3 | 3270.056
ccfofo | 2786 | 3364.89162
ccg | 20640.3 | 20730.22104
ccgpg | 7843.6759
ccgrg | 12796.6241
crude | 100000
df | 12516.3
fgad | 3542000
fgcc | 11592000
fgrf | 3731546.64
pg | 46724.06523
rfg | 21893.14008
rfgpg | 21893.14008
rfgrg | 0
rg | 22883.37485
srds | 8696
srdscc | 0
Save As
Save in:
Examples
File name:
Save as type:
Excel files *.xls
Save
Cancel
Open as read-only

Output

File View

# *Values of Unmeasured Variables*

9/28/98 3:48:00 PM

| | Unmeasured_Variables | Value_From_Data_Validation | Value_From_Parameter_Estimation | Value_From_Economic_Op |
|---|---|---|---|---|
| ▶ | fo | 10010.77225 | 10015.20862 | |

Output

File View

EO MV UM PP

## Values of Plant Parameters

9/28/98 3:

| Plant_Parameter | Initial_Point | Estimated_Value | Process_UnitID | Unit_of_Parameter |
|---|---|---|---|---|
| vfgad | 35.42 | 35.42 | AD | BBL/BBL |
| vsrds | 0.087 | 0.08696 | AD | BBL/BBL |
| vsrdsccfo | 0.189 | 0.189 | CC | BBL/BBL |
| vsrdsccg | 0.619 | 0.619 | CC | BBL/BBL |
| vsrdsfgcc | 336.9 | 336.9 | CC | BBL/BBL |
| vsrfo | 0.372 | 0.37214 | AD | BBL/BBL |
| vsrfoccfo | 0.22 | 0.22021 | CC | BBL/BBL |
| vsrfoccg | 0.688 | 0.68801 | CC | BBL/BBL |
| vsrfofgcc | 386.4 | 386.4 | CC | BBL/BBL |
| vsrg | 0.27 | 0.27074 | AD | BBL/BBL |
| vsrn | 0.237 | 0.23592 | AD | BBL/BBL |
| vsrnfgrf | 158.17 | 158.17 | RF | BBL/BBL |
| vsrnfg | 0.928 | 0.92799 | RF | BBL/BBL |

Output

File Edit View

DV PE EO

## *Data Validation Output file*

```
GAMS 2.25.089  DOS Extended/C            09/28/98 15:48:48  PAGE      1
Data Validation Program



   2
   5
   6  * The following are the Measured Variables
   7  VARIABLES
   8  ccfo, ccfodf, ccfofo, ccg, ccgpg, ccgrg, crude, df,
   9  fgad, fgcc, fgrf, pg, rfg, rfgpg, rfgrg, rg,
  10  srds, srdscc, srdsdf, srdsfo, srfo, srfocc, srfodf, srfofo,
  11  srg, srgpg, srgrg, srn, srndf, srnpg, srnrf, srnrg;
  12
  13  * The following are the Unmeasured Variables
  14  VARIABLES
  15  fo;
  16
  17  * The following are the Parameters in the Model
  18  SCALARS
  19  vfgad       / 35.42 /
  20  vsrds       / 0.087 /
  21  vsrdsccfo       / 0.189 /
  22  vsrdsccg       / 0.619 /
  23  vsrdsfgcc       / 336.9 /
  24  vsrfo       / 0.372 /
  25  vsrfoccfo       / 0.22 /
  26  vsrfoccg       / 0.688 /
```

Output

File Edit View

DV PE EO

# *Parameter Estimation Output file*

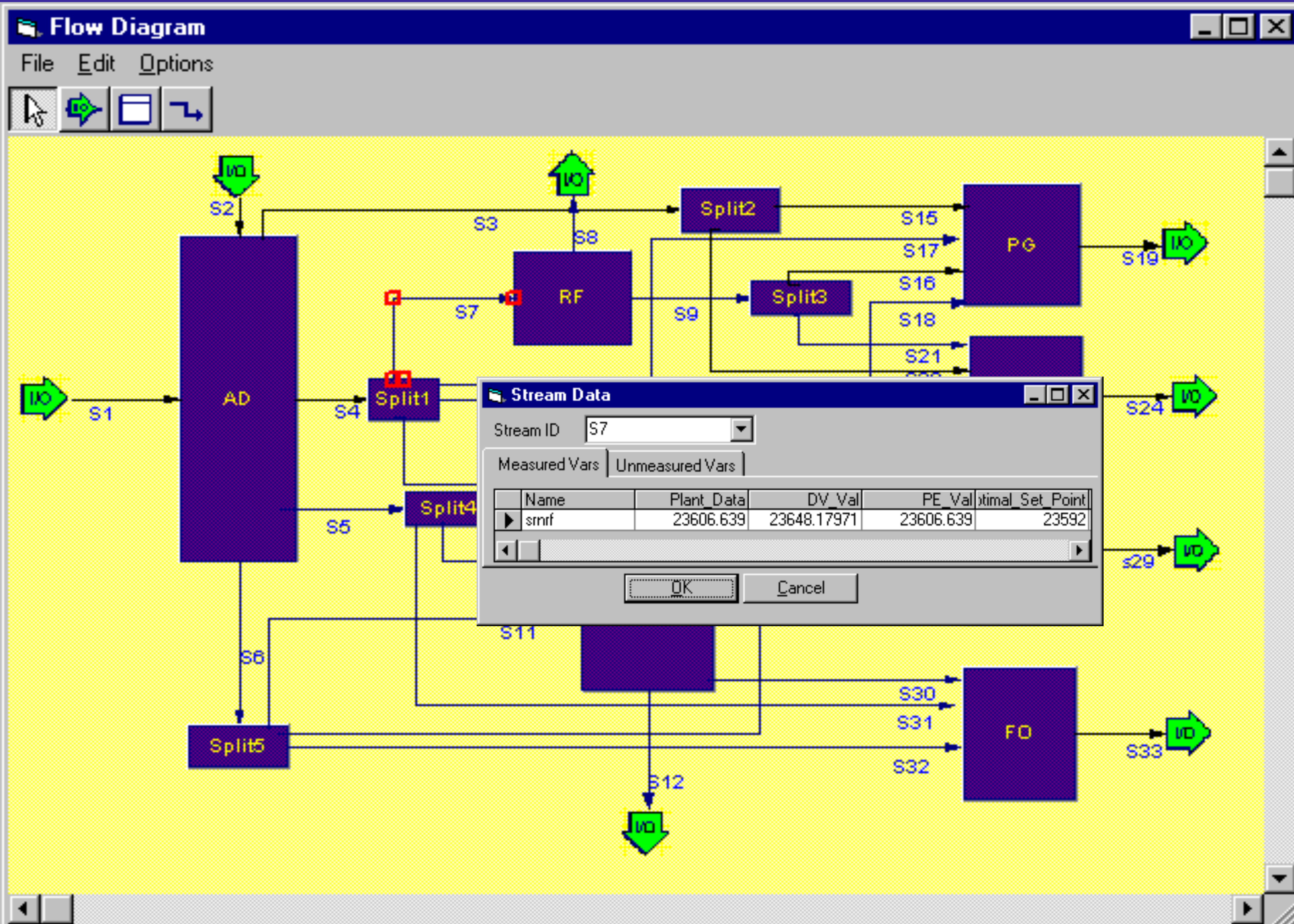
```
GAMS 2.25.089  DOS Extended/C              09/28/98 15:48:50  PAGE      1
Parameter Estimation Program




   2
   5
   6  * The following are the Measured Variables
   7  VARIABLES
   8  ccfo, ccfodf, ccfofo, ccg, ccgpg, ccgrg, crude, df,
   9  fgad, fgcc, fgrf, pg, rfg, rfgpg, rfgrg, rg,
  10  srds, srdscc, srdsdf, srdsfo, srfo, srfocc, srfodf, srfofo,
  11  srg, srgpg, srgrg, srn, srndf, srnpg, srnrf, srnrg;
  12
  13  * The following are the Unmeasured Variables
  14  VARIABLES
  15  fo;
  16
  17  VARIABLE ObjVar Objective function using ' ' algorithm
  18  vfgad, vsrds, vsrdsccfo, vsrdsccg, vsrdsfgcc, vsrfo, vsrfoccfo, vsrfoccg,
  19  vsrfofgcc, vsrg, vsrn, vsrnfgrf, vsrnrfg;
  20
  21  EQUATIONS
  22  * The Constraints
  23  EQU1, EQU2, EQU3, EQU4, EQU5, EQU6,
  24  EQU7, EQU8, EQU9, EQU10, EQU11, EQU12,
  25  EQU13, EQU14, EQU15, EQU16, EQU17, EQU18,
  26  EQU19, EQU20, EQU21, ObjName;
  27
```

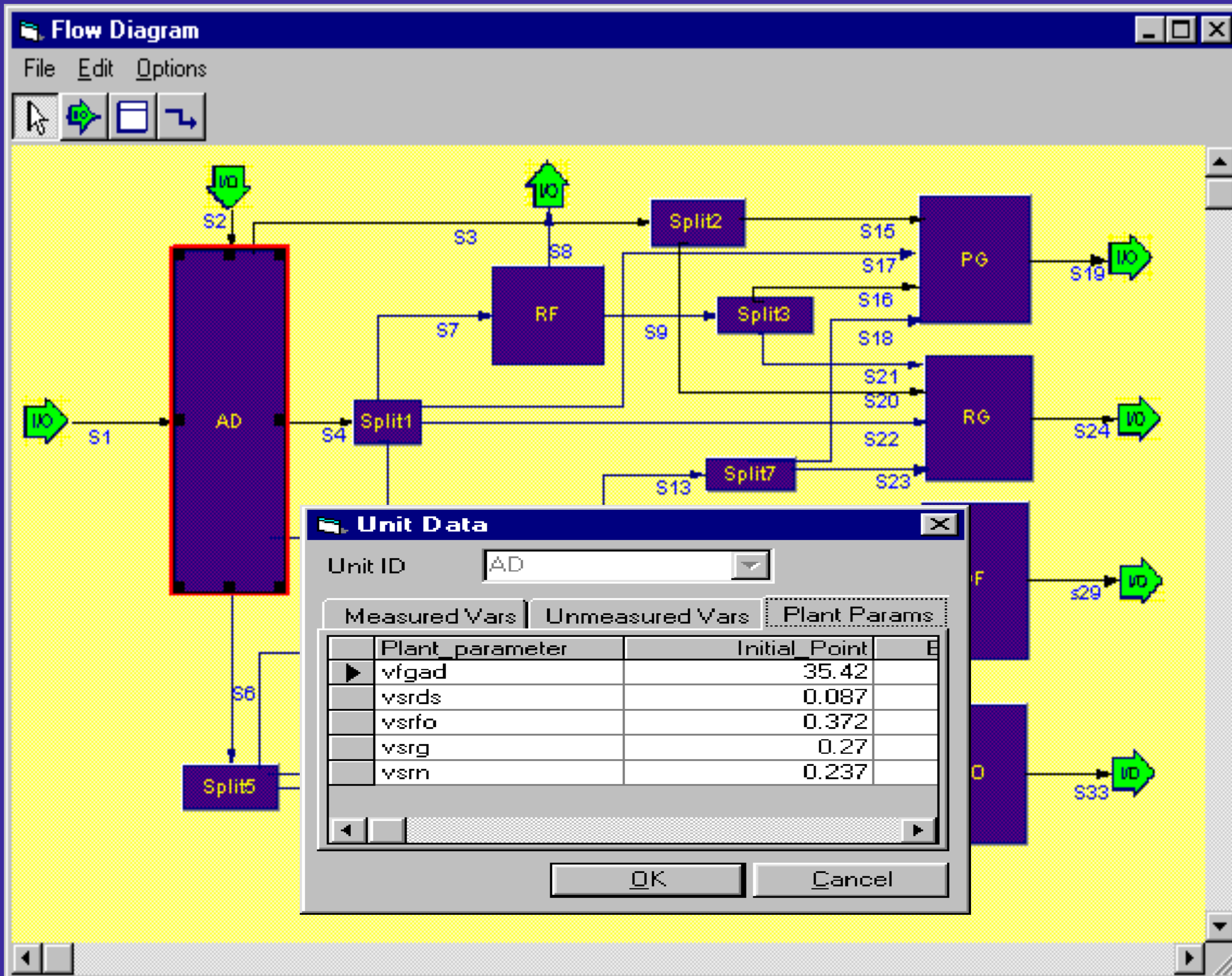
Output

File Edit View

# *Economic Optimization Output file*

```
        S O L V E     S U M M A R Y

   MODEL   REFINERY          OBJECTIVE  OBJVAR
   TYPE    LP               DIRECTION  MAXIMIZE
   SOLVER  CONOPT            FROM LINE  123

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE          700734.6198

 RESOURCE USAGE, LIMIT          0.109      1000.000
 ITERATION COUNT, LIMIT        11          1000


    C O N O P T   386/486 Watcom  version 2.041H-017
    Copyright (C) ARKI Consulting and Development A/S
              Bagsvaerdvej 246 A
              DK-2880 Bagsvaerd, Denmark


 ** Optimal solution. Reduced gradient less than tolerance.


 Function calls:        0     Gradient calls:        0
 CONOPT Time:           0.109     Interpreter:       0.000 =  0.0%

 Work length =   6071 double words  = 0.05 Mbytes
   Estimate =   6071 double words  = 0.05 Mbytes
```


Flow Diagram
File
Edit
Options
I/O
S1
S2
S3
S4
S5
S6
S7
S8
S9
S11
S12
S15
S16
S17
S18
S19
S21
S24
s29
S30
S31
S32
S33
AD
RF
PG
FO
Split1
Split2
Split3
Split4
Split5
Stream Data
Stream ID
S7
Measured Vars
Unmeasured Vars
Name
Plant_Data
DV_Val
PE_Val
ptimal_Set_Point
smrf
23606.639
23648.17971
23606.639
23592
OK
Cancel



Flow Diagram
File
Edit
Options
I/O
S1
S2
AD
S3
S4
Split1
S6
Split5
S7
RF
S8
S9
Split2
Split3
Split7
S13
S15
S16
S17
S18
S19
S20
S21
S22
S23
S24
PG
RG
s29
S33
Unit Data
Unit ID
AD
Measured Vars
Unmeasured Vars
Plant Params
Plant_parameter
Initial_Point
vfgad 35.42
vsrds 0.087
vsrfo 0.372
vsrg 0.27
vsrn 0.237
OK
Cancel

Output

File View

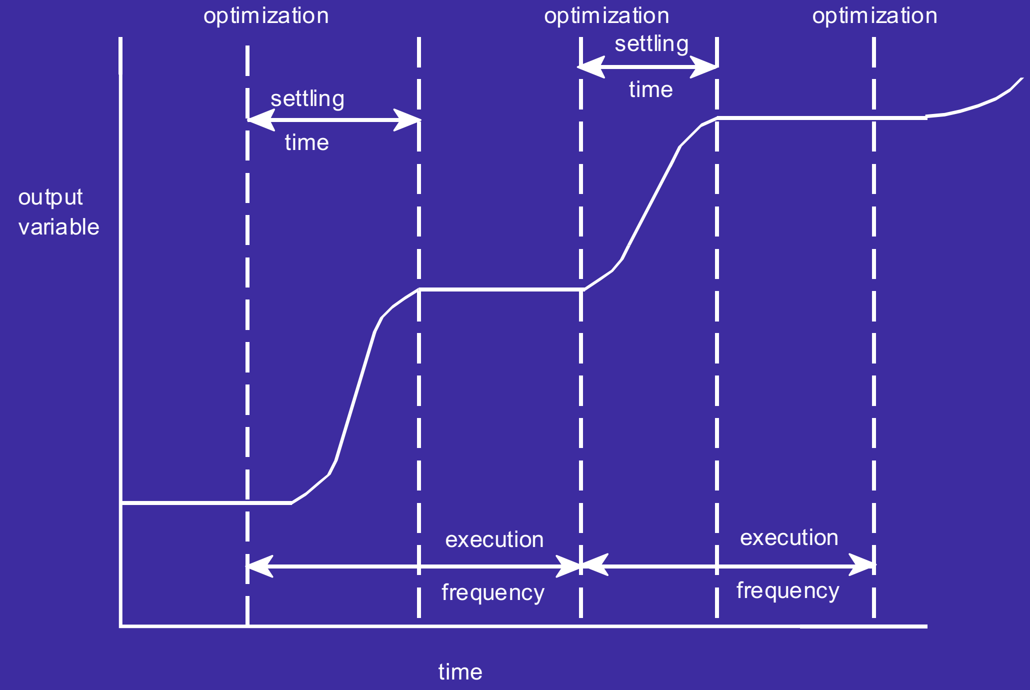
EO MV UM PP

*Values of Measured Variables*

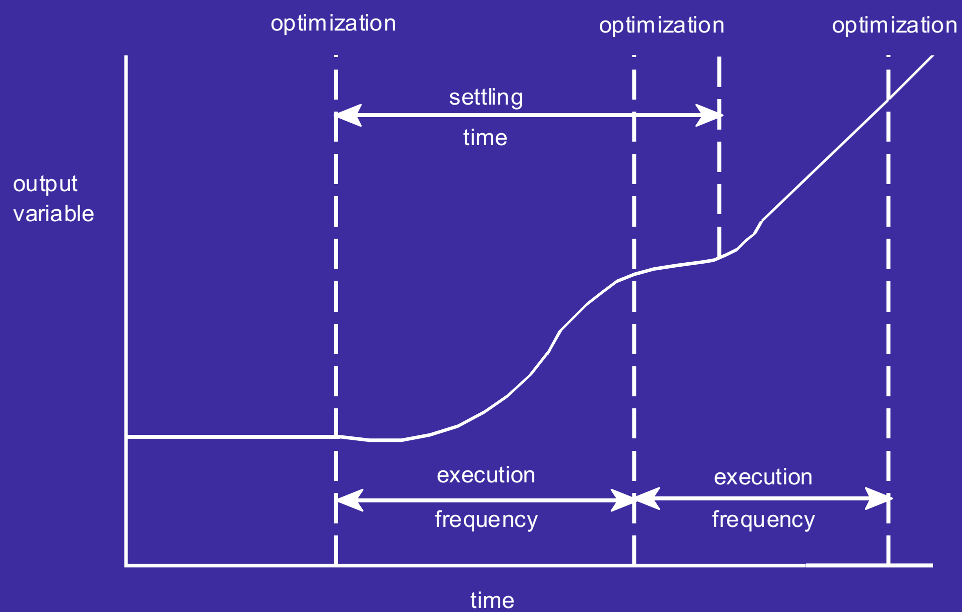
Stream Number

9/28/98 3:

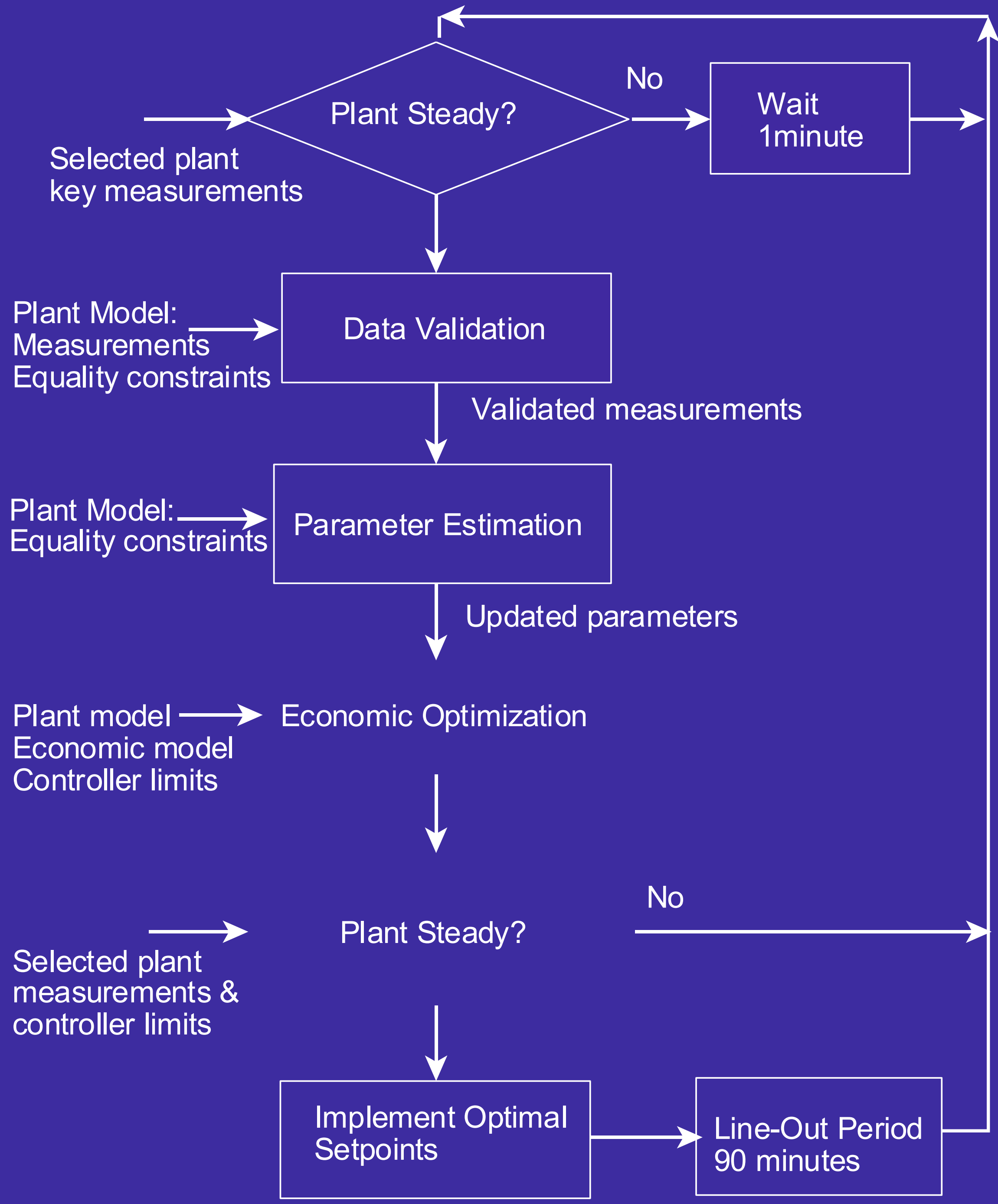
| | Name | Optimal_Set_Point | Reconciled_Data_From_Parameter_Estimation | Reconciled |
|---|---|---|---|---|
| ▶ | ccfo | 6606.3 | 6634.94762 | |
| | ccfodf | 3442.80193 | 3270.056 | |
| | ccfofo | 3163.49807 | 3364.89162 | |
| | ccg | 20640.3 | 20730.22104 | |
| | ccgpg | 10491.06299 | 7935.679 | |
| | ccgrg | 10149.23701 | 12794.54204 | |
| | crude | 100000 | 100188.95139 | |
| | df | 12516.3 | 12495.89361 | |
| | fgad | 3542000 | 3548692.68012 | |
| | fgcc | 11592000 | 11642423.34337 | |
| | fgrf | 3731546.64 | 3733862.09383 | |
| | pg | 46724.06523 | 47238.72121 | |
| | rfg | 21893.14008 | 21906.75821 | |
| | rfgpg | 20315.08974 | 21895.22621 | |
| | rfgrg | 1578.05034 | 11.532 | |
| | rg | 22883.37485 | 22543.89309 | |
| | srds | 8696 | 8712.64461 | |
| | srdscc | 0 | 0.004 | |
| | srdsdf | 8673.867 | 8690.50761 | |
| | srdsfo | 22.133 | 22.133 | |
| | srfo | 37214 | 37284.01171 | |
| | srfocc | 30000 | 30130.49171 | |
| | srfodf | 399.63107 | 525.336 | |
| | [illegible] | [illegible] | [illegible] | |




a. Time between optimizations is longer than settling time




b. Time between optimizations is less than settling time


Plant Steady?
No
Wait
1minute
Selected plant
key measurements
Plant Model:
Measurements
Equality constraints
Data Validation
Validated measurements
Plant Model:
Equality constraints
Parameter Estimation
Updated parameters
Plant model
Economic model
Controller limits
Economic Optimization
No
Plant Steady?
Selected plant
measurements &
controller limits
Implement Optimal
Setpoints
Line-Out Period
90 minutes

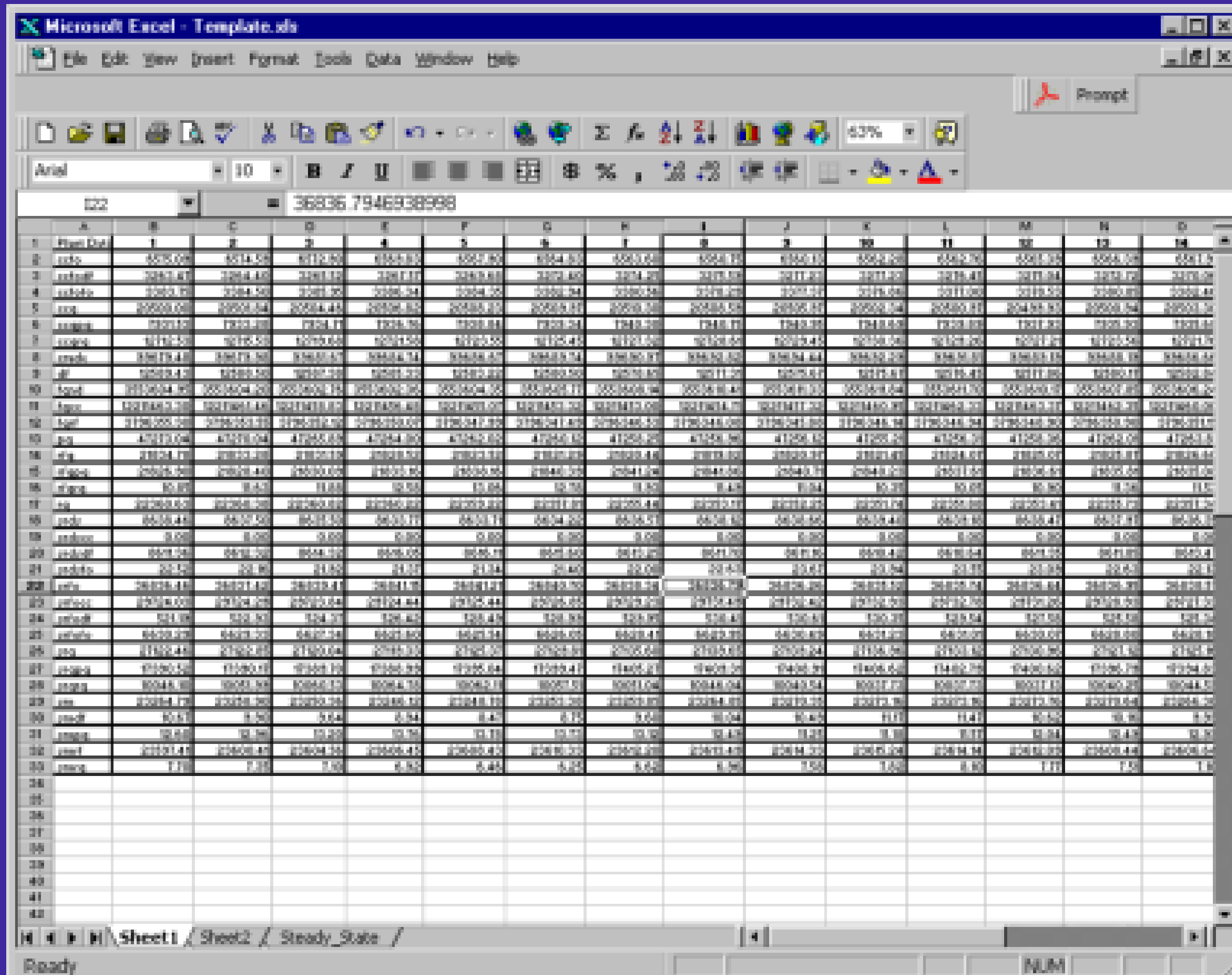



Figure 33 Excel Spreadsheet of Simulated Plant Data for the Simple Refinery

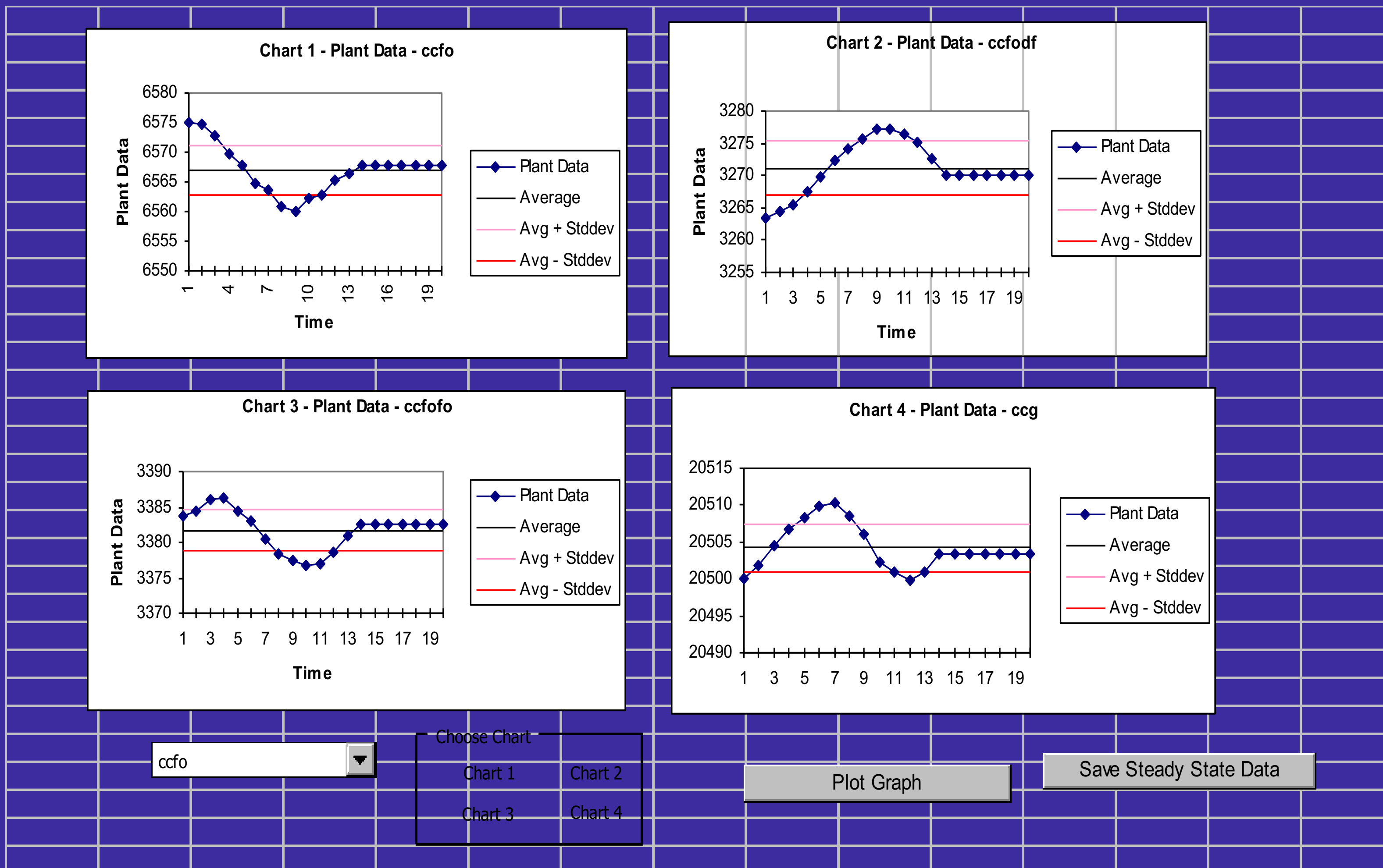


Chart 1 - Plant Data - ccfo
Plant Data
Time
Chart 2 - Plant Data - ccfodf
Chart 3 - Plant Data - ccfofo
Chart 4 - Plant Data - ccg
Plant Data
Average
Avg + Stddev
Avg - Stddev
ccfo
Choose Chart
Chart 1
Chart 2
Chart 3
Chart 4
Plot Graph
Save Steady State Data

| |
|---|
| 6567.914 |
| 3270.056 |
| 3382.46 |
| 20503.3 |
| 7935.679 |
| 12721.76 |
| 99686.66 |
| 12582.84 |
| 3553606 |
| 12211460 |
| 3796351 |
| 47263.81 |
| 21826.6 |
| 21835.08 |
| 11.532 |
| 22357.34 |
| 8636.35 |
| 0.004 |
| 8613.47 |
| 22.133 |
| 36838.57 |
| 29727.33 |
| 525.336 |
| 6628.184 |
| 27125.16 |
| 17394.83 |
| 10044.59 |
| 23266.3 |
| 9.994 |
| 12.99 |
| 23606.64 |
| 7.1 |

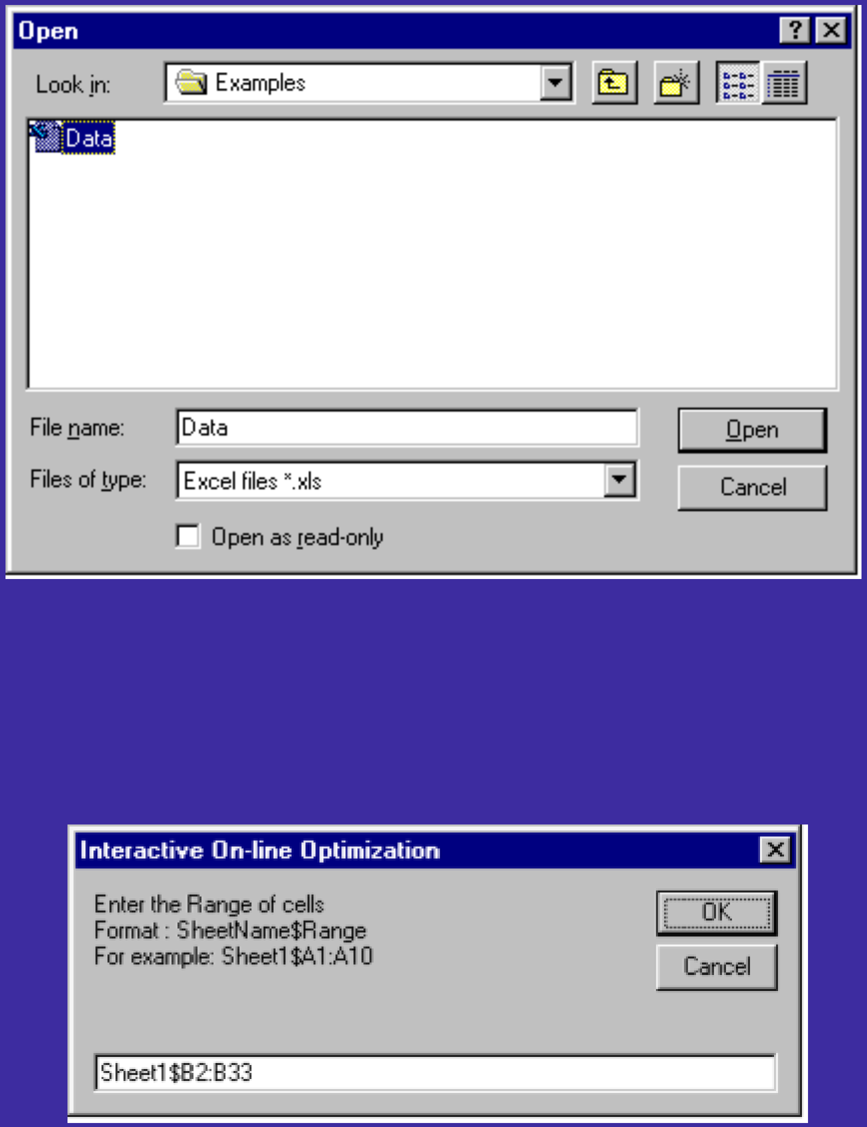



Figure 37 The Screen to Enters the Excel Sheet Name and Range

# Data from Contact Process DCS

| Plant Data | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F06 | 1.72 | 1.74 | 1.72 | 1.72 | 1.72 | 1.68 | 1.68 | 1.72 | 1.74 | 1.76 | 1.66 | 1.76 | 1.72 | 1.74 |
| f50 | 0.245 | 0.245 | 0.248 | 0.245 | 0.248 | 0.245 | 0.24 | 0.245 | 0.249 | 0.245 | 0.245 | 0.245 | 0.25 | 0.245 |
| fsbfw | 1.93 | 1.93 | 1.965 | 1.93 | 1.93 | 1.93 | 1.965 | 1.89 | 1.93 | 1.958 | 1.93 | 1.93 | 1.93 | 1.93 |
| O2percent | 6 | 6.03 | 6.01 | 6 | 5.9 | 6 | 6.01 | 6.06 | 5.7 | 5.9 | 6.1 | 5.97 | 6 | 6.07 |
| Pshp1 | 614.7 | 610 | 614.7 | 614.7 | 614.7 | 612 | 614.7 | 614.7 | 610 | 614.7 | 614.7 | 608 | 614.7 | 614.7 |
| Pshp2 | 614.7 | 610 | 614.7 | 614.7 | 614.7 | 608 | 614.7 | 614.7 | 610 | 614.7 | 614.7 | 608 | 614.7 | 614.7 |
| Pss2 | 709.7 | 708.8 | 709.7 | 709.7 | 709.7 | 709.7 | 709.7 | 709.7 | 709.7 | 709.7 | 709.7 | 709.7 | 712 | 709.7 |
| SO2ppm | 349 | 355 | 359 | 355 | 355 | 357 | 360 | 355 | 355 | 360 | 355 | 355 | 351 | 355 |
| T06 | 359.67 | 359.67 | 361.89 | 362.44 | 362.44 | 362.44 | 360.78 | 359.67 | 360.22 | 359.00 | 359.67 | 360.22 | 362.44 | 363.00 |
| T07 | 1321.5 | 1323.2 | 1321.5 | 1321.5 | 1324.2 | 1319.4 | 1321.5 | 1318.9 | 1321.5 | 1321.5 | 1320 | 1321.5 | 1321.5 | 1321.5 |
| T09 | 646.5 | 646.2 | 646.5 | 646.5 | 646.5 | 645.8 | 646.5 | 646.5 | 646.8 | 646.5 | 645.5 | 646.5 | 646.5 | 646.5 |
| T10 | 708 | 708.5 | 708 | 708.3 | 708 | 707.6 | 708 | 708 | 708.1 | 708 | 708 | 707.9 | 708 | 708 |
| T11 | 893.56 | 894.11 | 893.56 | 893.00 | 892.44 | 893.56 | 894.11 | 894.67 | 893.56 | 893.00 | 892.44 | 893.00 | 893.56 | 893.56 |
| T12 | 689.3 | 689.3 | 689.1 | 689.3 | 689.3 | 690.1 | 689.3 | 689.3 | 689 | 689.3 | 689.5 | 689.3 | 689.2 | 689.3 |
| T13 | 785.7 | 785.9 | 785.9 | 785.8 | 785.9 | 786.1 | 785.9 | 785.9 | 786.3 | 785.9 | 786 | 785.9 | 785.9 | 785.6 |
| T15 | 501.5 | 501.2 | 501.5 | 501.5 | 501.6 | 501.5 | 501.4 | 502 | 501.5 | 501.5 | 501.1 | 501.5 | 501 | 501.5 |
| T16 | 349.8 | 349.8 | 349.5 | 349.7 | 349.8 | 349.8 | 349.9 | 350 | 349.8 | 349.8 | 349.6 | 349.8 | 350 | 349.8 |
| T19 | 549.3 | 549.1 | 549.3 | 549.3 | 549.6 | 549.3 | 549.2 | 549.3 | 549.4 | 549.3 | 549.3 | 549.6 | 549.3 | 549.3 |
| T20 | 690.9 | 691 | 690.9 | 691.1 | 690.9 | 690.8 | 690.9 | 690.8 | 690.7 | 690.6 | 690.9 | 691 | 690.9 | 690.9 |
| T21 | 737 | 737.2 | 737 | 737.3 | 737 | 736.9 | 737 | 737.1 | 737 | 737 | 737.2 | 737 | 737.1 | 737 |
| T22 | 683.5 | 683.5 | 683.3 | 683.5 | 683.5 | 683.6 | 683.5 | 683.5 | 683.6 | 683.6 | 683.5 | 683.5 | 683.4 | 683.5 |
| T23 | 692.6 | 692.6 | 692.7 | 692.6 | 692.5 | 692.6 | 692.6 | 692.4 | 692.6 | 692.6 | 692.7 | 692.6 | 692.7 | 692.6 |
| T235 | 673.2 | 673.2 | 673.3 | 673.2 | 673.1 | 673.2 | 673.2 | 673.3 | 673.2 | 673.4 | 673.2 | 673.3 | 673.2 | 673.2 |
| T24 | 504.8 | 504.6 | 504.8 | 504.8 | 504.7 | 504.8 | 504.8 | 504.9 | 504.8 | 504.7 | 504.8 | 504.8 | 504.8 | 504.8 |
| T25 | 350.4 | 350.6 | 350.4 | 350.4 | 350.2 | 350.4 | 350.4 | 350.5 | 350.4 | 350.5 | 350.4 | 350.4 | 350.6 | 350.4 |
| TSBFW | 225 | 225 | 225.1 | 225 | 225.2 | 225 | 224.9 | 225 | 225 | 225.1 | 225.2 | 225 | 225 | 225 |
| TSHP1 | 665 | 664.8 | 665 | 665.2 | 665 | 665 | 664.9 | 665 | 665.1 | 665 | 665.1 | 665 | 665 | 665 |
| TSHP2 | 650 | 650.2 | 650 | 649.7 | 650 | 650.2 | 650 | 650.1 | 650 | 649.8 | 650 | 650.3 | 650 | 650 |
| TSW1 | 340 | 339.6 | 340 | 340 | 340.4 | 340 | 340.1 | 340 | 339.9 | 340 | 340 | 340.6 | 340 | 340 |

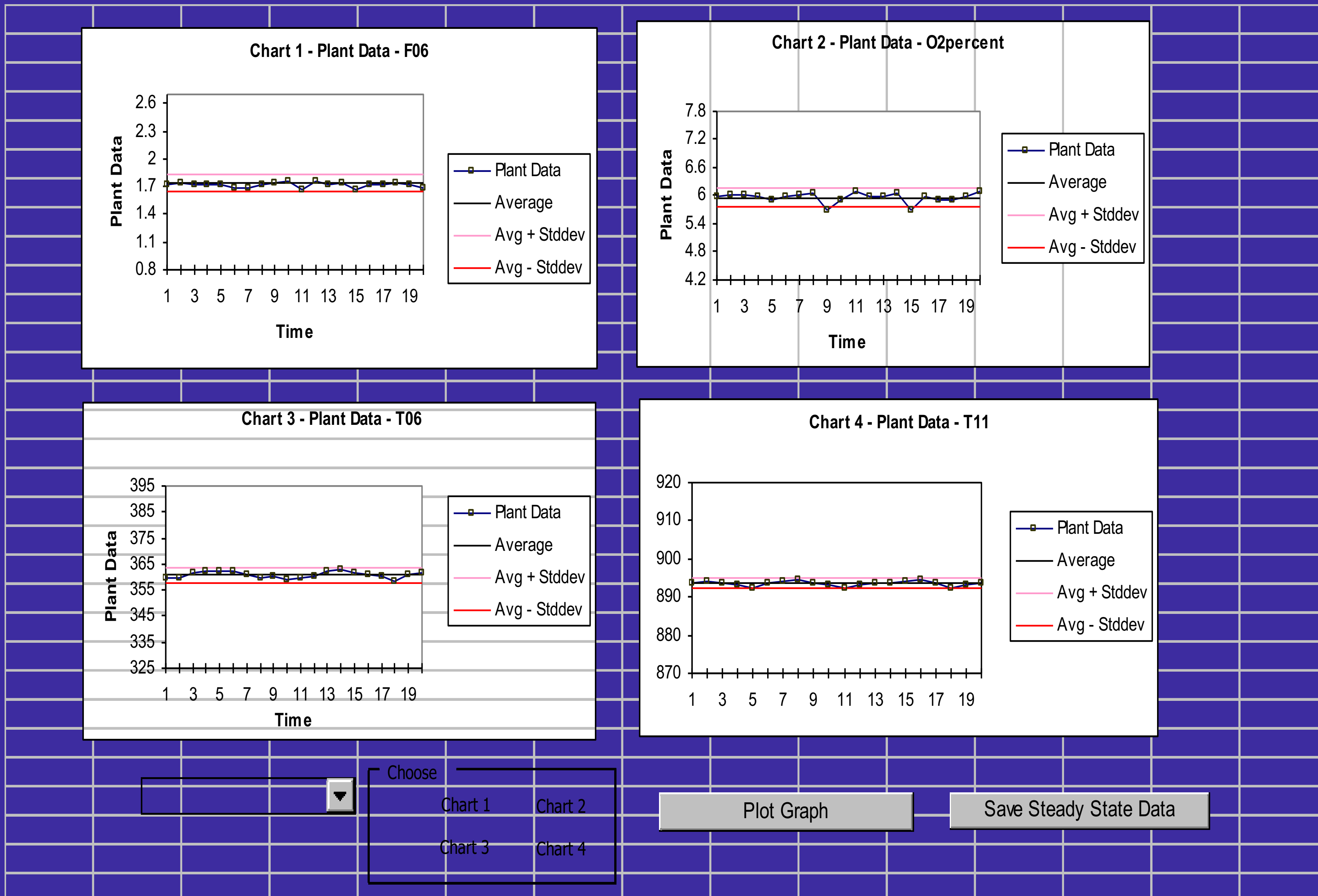


Chart 1 - Plant Data - F06
Plant Data
2.6
2.3
2
1.7
1.4
1.1
0.8
1 3 5 7 9 11 13 15 17 19
Time
Plant Data
Average
Avg + Stddev
Avg - Stddev
Chart 2 - Plant Data - O2percent
Plant Data
7.8
7.2
6.6
6
5.4
4.8
4.2
1 3 5 7 9 11 13 15 17 19
Time
Plant Data
Average
Avg + Stddev
Avg - Stddev
Chart 3 - Plant Data - T06
Plant Data
395
385
375
365
355
345
335
325
1 3 5 7 9 11 13 15 17 19
Time
Plant Data
Average
Avg + Stddev
Avg - Stddev
Chart 4 - Plant Data - T11
920
910
900
890
880
870
1 3 5 7 9 11 13 15 17 19
Plant Data
Average
Avg + Stddev
Avg - Stddev
Choose
Chart 1
Chart 2
Chart 3
Chart 4
Plot Graph
Save Steady State Data

| |
|---|
| 6567.234 |
| 3271.247 |
| 3384.938 |
| 20542.59 |
| 7940.337 |
| 12711.45 |
| 99673.84 |
| 12572.05 |
| 3548524 |
| 12235392 |
| 3791338 |
| 47302.53 |
| 21818.31 |
| 21838.05 |
| 12.78068 |
| 22350.21 |
| 8640.12 |
| 0.00429 |
| 8624.112 |
| 21.24542 |
| 36835.25 |
| 29725.27 |
| 525.4783 |
| 6630.703 |
| 27123.65 |
| 17412.39 |
| 10062.55 |
| 23275.79 |

# DATA RECONCILIATION

measurements having only random errors - least squares

***Minimize:*** $e^T\Sigma^{-1}e = (y - x)^TQ^{-1}(y - x)$
x

***Subject to:*** $f(x) = 0$

$\boldsymbol{\Sigma}$ = variance matrix = $\{\sigma^2_{ij}\}$.

$\sigma_i$ =standard deviation of $e_i$.

**f**(**x**) - process model
- linear or nonlinear

# DATA RECONCILIATION

Linear Constraint Equations - material balances only

$$\mathbf{f}(\mathbf{x}) = \mathbf{A}\mathbf{x} = \mathbf{0}$$

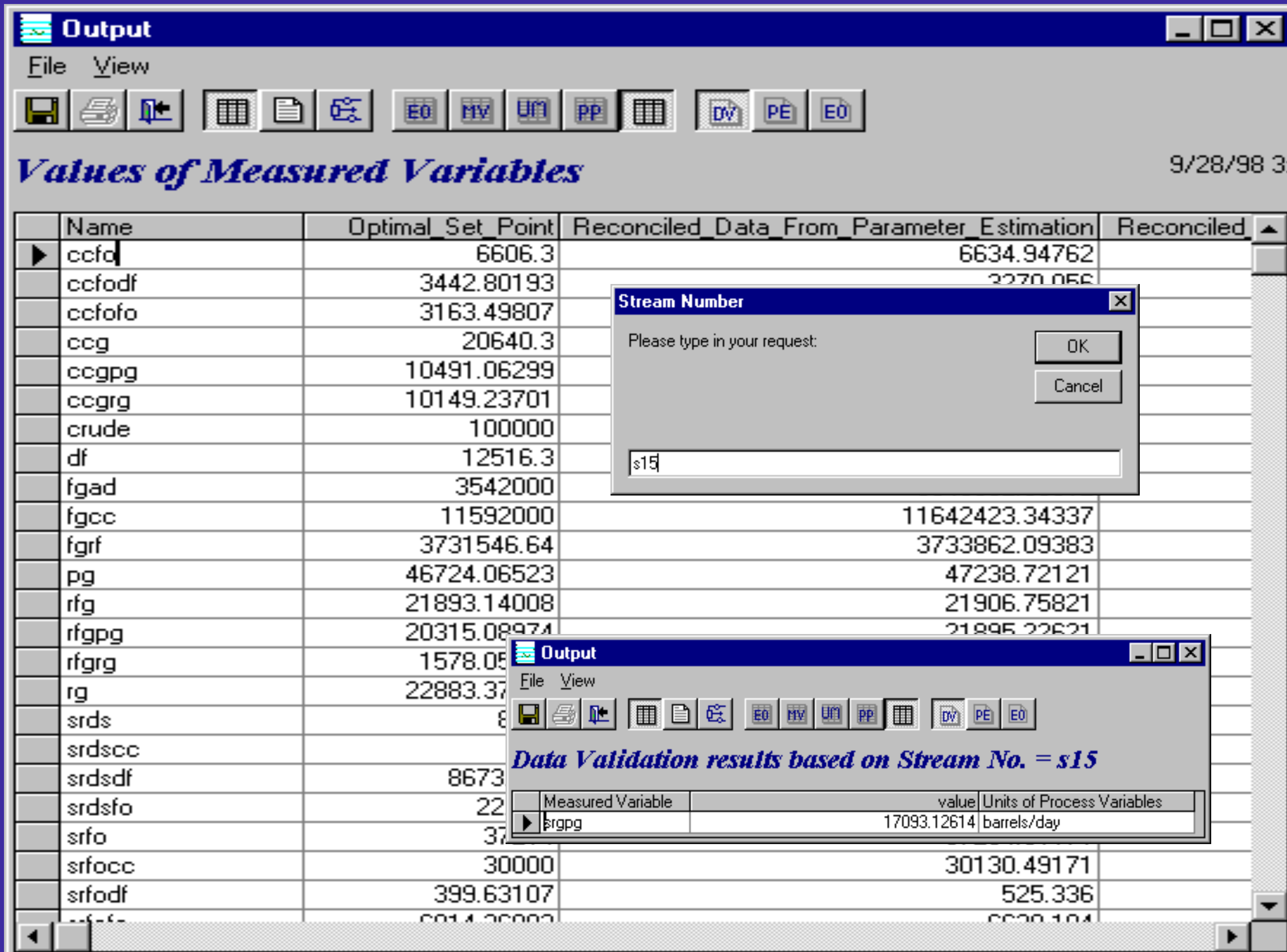
analytical solution - $\tilde{\mathbf{x}} = \mathbf{y} - \boldsymbol{\Sigma}\mathbf{A}^T(\mathbf{A}\boldsymbol{\Sigma}\mathbf{A}^T)^{-1}\mathbf{A}\mathbf{y}$

Nonlinear Constraint Equations

$\mathbf{f}(\mathbf{x})$ includes material and energy balances, chemical reaction rate equations, thermodynamic relations

nonlinear programming problem

GAMS and a solver, e.g. MINOS


Output
File View
Values of Measured Variables
9/28/98 3:
Name
Optimal_Set_Point
Reconciled_Data_From_Parameter_Estimation
Reconciled
ccfo 6606.3 6634.94762
ccfodf 3442.80193
ccfofo 3163.49807
ccg 20640.3
ccgpg 10491.06299
ccgrg 10149.23701
crude 100000
df 12516.3
fgad 3542000
fgcc 11592000 11642423.34337
fgrf 3731546.64 3733862.09383
pg 46724.06523 47238.72121
rfg 21893.14008 21906.75821
rfgpg
rfgrg
rg
srds
srdscc
srdsdf
srdsfo
srfo
srfocc 30000 30130.49171
srfodf 399.63107 525.336
Stream Number
Please type in your request:
OK
Cancel
s15
Output
File View
Data Validation results based on Stream No. = s15
Measured Variable
value
Units of Process Variables
srgpg 17093.12614 barrels/day

Output

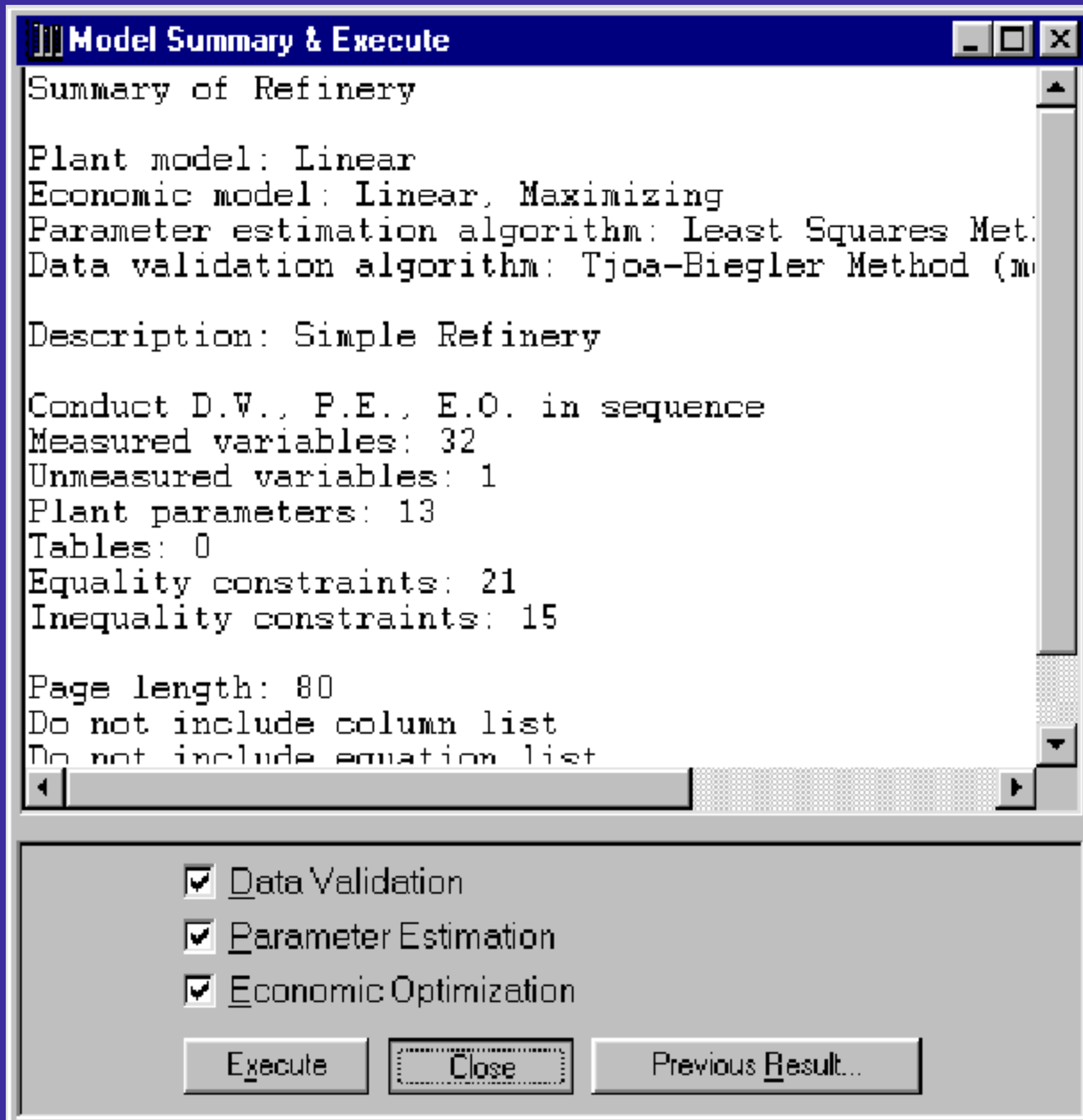
File View

Export...
Print
Close

EO MV UM PP

ective = 700734.61975

| Name | Gross_Error |
|---|---|
| ccfo | |
| ccfodf | |
| ccfofo | |
| ccg | |
| ccgpg | |
| ccgrg | |
| crude | |
| df | |
| fgad | |
| fgcc | -5.33387149396135 |
| fgrf | |
| pg | |
| rfg | |
| rfgpg | |
| rfgrg | |
| rg | |
| srds | |
| srdscc | |
| srdsdf | |
| srdsfo | |
| srfo | |
| srfocc | |
| srfodf | |
| srfofo | |
| srg | |
| srgpg | |
| srgrg | |


Model Summary & Execute
Summary of Refinery
Plant model: Linear
Economic model: Linear, Maximizing
Parameter estimation algorithm: Least Squares Met
Data validation algorithm: Tjoa-Biegler Method (m
Description: Simple Refinery
Conduct D.V., P.E., E.O. in sequence
Measured variables: 32
Unmeasured variables: 1
Plant parameters: 13
Tables: 0
Equality constraints: 21
Inequality constraints: 15
Page length: 80
Do not include column list
Data Validation
Parameter Estimation
Economic Optimization
Execute
Close
Previous Result...

Interactive On-line Optimization - C:\Ioo\Examples\refinery.ioo

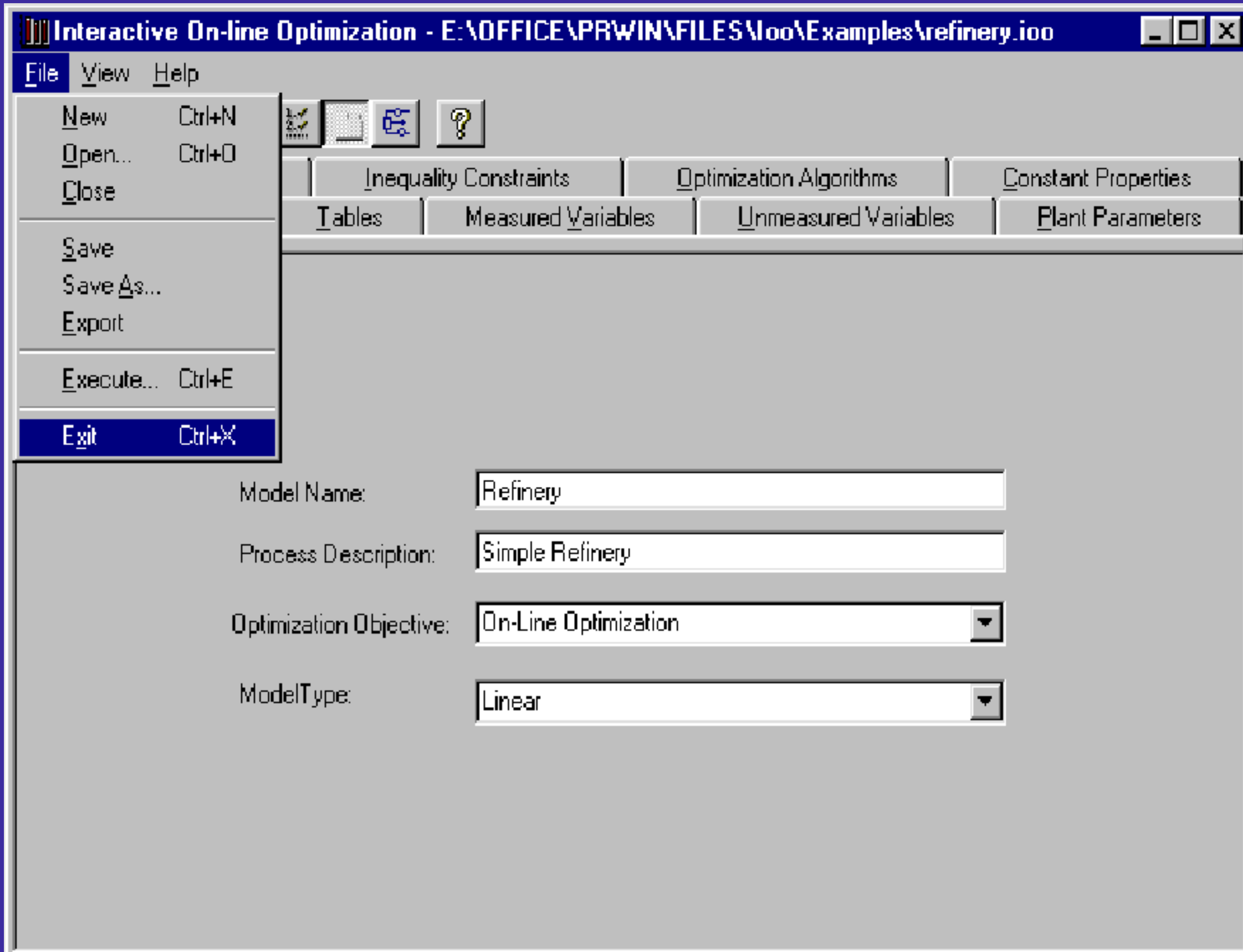
File View Help

- New Ctrl+N
- Open... Ctrl+O
- Close
- Save
- Save As...
- Export
- Import Plant Data
- Import Standard Deviation
- Execute... Ctrl+E
- Exit
- 1. C:\Ioo\Examples\refinery.ioo
- 2. C:\kedar\Data Validation\sulfuric42.Ioo

...asured Variables | Plant Parameters | Equality Constraints | Inequality Constr...

Measured Variables

| | | | Plant_Data | Initial_Point | Scaling_Factor | Lower_Bound | Upper_Bound |
|---|---|---|---|---|---|---|---|
| | | | 66 | 6567.914 | | 0 | |
| | | | 32.699 | 3270.056 | | 0 | |
| | | | 33.301 | 3382.46 | | 0 | |
| | | | 206.4 | 20503.298 | 1 | 0 | |
| | | | 80.464 | 7935.679 | | 0 | |
| | | | 125.936 | 12721.761 | 1 | 0 | |
| | | | 1000 | 99686.657 | 1000 | 0 | |
| | | | 125 | 12582.842 | 1 | 0 | |
| | | | 35420 | 3553606.242 | 300 | 0 | |
| fgcc | 12211460 | | 115920 | 12211460 | 1000 | 0 | |
| fgrf | 3796351.148 | | 37612 | 3796351.148 | 400 | 0 | |
| pg | 47263.811 | | 471.132 | 47263.811 | 1 | 0 | |
| rfg | 21826.603 | | 219.936 | 21826.603 | 1 | 0 | |
| rfgpg | 21835.077 | | 219.936 | 21835.077 | 1 | 0 | |
| rfgrg | 11.532 | | 10 | 11.532 | | 0 | |
| rg | 22357.336 | | 225.204 | 22357.336 | 1 | 0 | |
| srds | 8636.35 | | 87 | 8636.35 | 1 | 0 | |



Interactive On-line Optimization - E:\OFFICE\PRWIN\FILES\Ioo\Examples\refinery.ioo
File
View
Help
New Ctrl+N
Open... Ctrl+O
Close
Save
Save As...
Export
Execute... Ctrl+E
Exit Ctrl+X
Inequality Constraints
Optimization Algorithms
Constant Properties
Tables
Measured Variables
Unmeasured Variables
Plant Parameters
Model Name:
Refinery
Process Description:
Simple Refinery
Optimization Objective:
On-Line Optimization
ModelType:
Linear