

# HMI<sup>3</sup> Optimization Approach for Pulp & Paper Industry

Added Value by Optimal Process Control

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# Optimization Targets

- Production Costs & Savings
- Safety of operation
- Production Capacity (of existing assets)
- Product Quality
- Energy Efficiency
- Raw material yield
- Robustness of operation
- Flexibility of production

# HMI<sup>3</sup> Optimizers Overview

## A systematic and modular large scale approach

### Available Optimizations Modules:

- Site-Balance Optimization
- O<sub>2</sub>-Delignification + Bleaching Plant
- Continuous Digester (Kamyr)
- Steam & Electricity Production (Forecast and short term optimization intraday)
- Paper Machine Settings for Grade & Quality Control
- Evaporator Washing Strategy
- Recovery Boiler Operation at full load
- Drying Cost & Energy Efficiency Optimization of Yankee PMs

# Optimization Approach

1. Development of a **robust process model**
2. **Degrees of Freedom** analysis (to manipulate the process)
3. Definition of **objectives**
4. Definition of **constraints**
5. Definition of **weights**
6. Definition of a **objective function**
7. Definition of **Jacoby function** (Performance boost)
8. Selection of **appropriate solver**

# Optimization Approach – Large Scale

1. Up to 1000's degrees of freedom (DoF \* Time Horizon)
2. Up to 20 terms in objective function (very flexible)
3. Up to 1000's of weights, constraints, setpoints (in horizon)
4. Up to 15min calculation time for large scale optimization problem solution

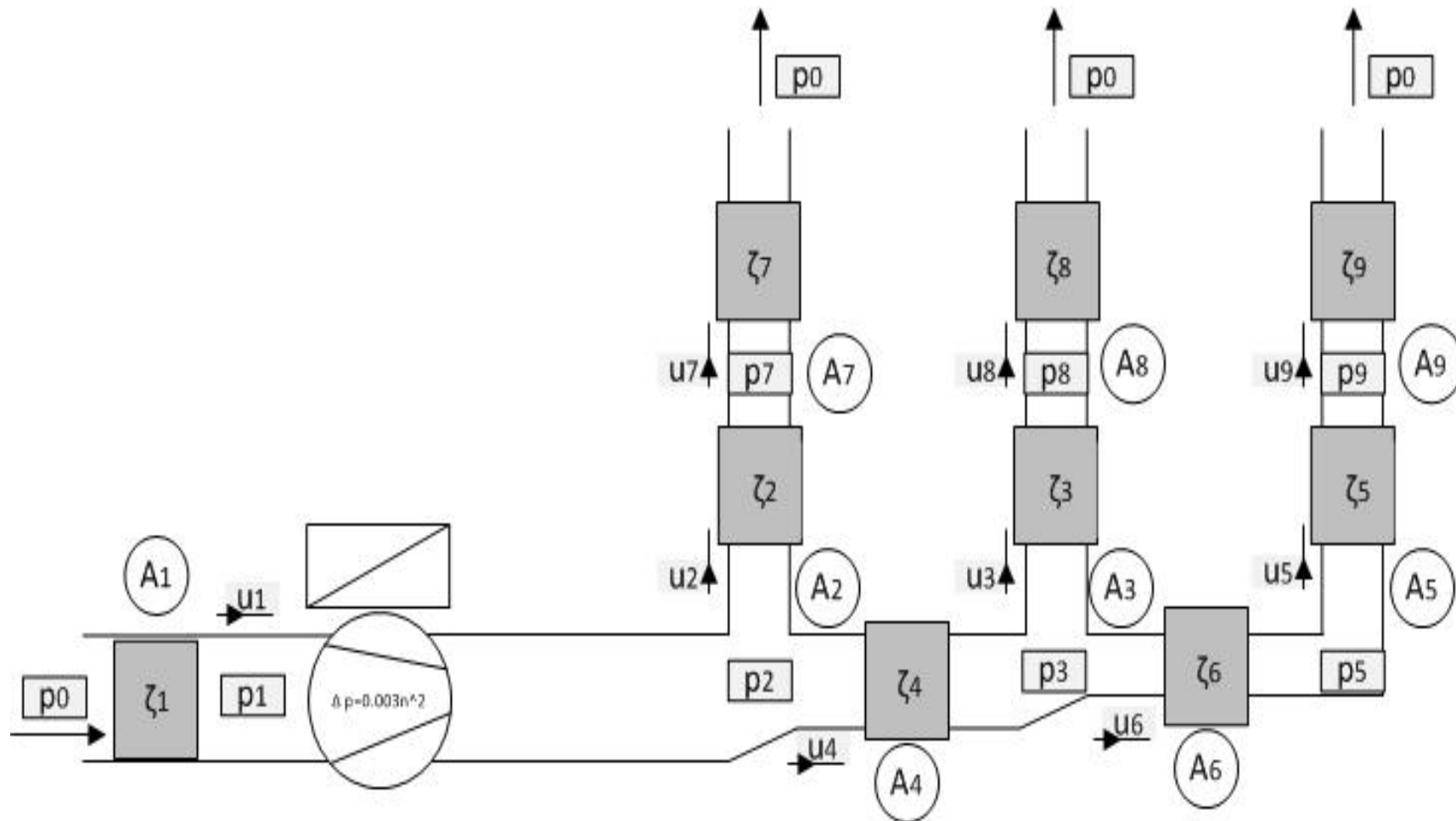
Much Experience and know-how required for setup of high performance large scale optimization solutions.

# Optimization Toolset

The screenshot displays the Optimization Tool interface, which is divided into several sections:

- Problem Setup and Results:** This section contains a list of solvers and algorithms. The selected solver is `fmincon - Constrained nonlinear minimization`. Other options include `fminimax - Minimax optimization`, `fminsearch - Unconstrained nonlinear minimization`, `fminunc - Unconstrained nonlinear minimization`, `fsemif - Semi-infinite minimization`, `fsolve - Nonlinear equation solving`, `fzero - Single-variable nonlinear equation solving`, and `ga - Genetic Algorithm`. Below this list are input fields for constraints: Linear inequalities (A, b), Linear equalities (Aeq, beq), Bounds (Lower, Upper), Nonlinear constraint function, and Derivatives (set to "Approximated by solver").
- Options:** This section is titled "Stopping criteria" and includes several parameters with radio buttons for "Use default" and "Specify":
  - Max iterations: Use default: 400
  - Max function evaluations: Use default: 100\*numberC
  - X tolerance: Use default: 1e-6
  - Function tolerance: Use default: 1e-6
  - Nonlinear constraint tolerance: Use default: 1e-6
  - SQP constraint tolerance: Use default: 1e-6
  - Unboundedness threshold: Use default: -1e20
- Function value check:** This section is currently collapsed.
- Quick Reference:** A sidebar on the right provides a quick reference for the **fmincon Solver**. It includes a description: "Find a minimum of a constrained nonlinear multivariable function." and a list of links to expand sections: [Problem Setup and Results](#), [Solver and Algorithm](#), [Problem](#), [Constraints](#), [Run solver and view results](#), **Options**, [Stopping criteria](#), [Function value check](#), [User-supplied derivatives](#), [Approximated derivatives](#), [Algorithm settings](#), [Inner iteration stopping criteria](#), [Plot functions](#), and [Output function](#).
- Run solver and view results:** This section contains buttons for **Start**, **Pause**, and **Stop**. Below these buttons is a field for "Current iteration:" and a **Clear Results** button.

# Optimization for Solving Large Balance Networks



# Optimization for Solving Large Balance Networks

```
function [F,J] = pipesystem(x,c)
%c=[p0 zeta1 zeta2 zeta3 zeta4 zeta5 zeta6 zeta7 zeta8 zeta9 rho1 rho2 n];
% c(1) c(2) c(3) c(4) c(5) c(6) c(7) c(8) c(9) c(10) c(11) c(12) c(13)
% x = [p1 p2 p3 p5 p7 p8 p9 u1 u2 u3];
```

```
F=[c(1)-x(1)-c(2)*c(11)*0.5*x(8)^2;
   x(1)-x(2)+0.003*c(13)^2;
   x(5)-x(2)+c(3)*c(11)*0.5*x(9)^2;
   x(6)-x(3)+c(4)*c(11)*0.5*x(10)^2;
   x(3)-x(2)+c(5)*c(11)*0.5*(x(8)-x(9))^2;
   x(7)-x(4)+c(6)*c(11)*0.5*(x(8)-x(9)-x(10))^2;
   x(4)-x(3)+c(7)*c(11)*0.5*(x(8)-x(9)-x(10))^2;
   c(1)-x(5)+c(8)*c(11)*0.5*x(9)^2;
   c(1)-x(6)+c(9)*c(11)*0.5*x(10)^2;
   c(1)-x(7)+c(10)*c(11)*0.5*(x(8)-x(9)-x(10))^2]
```

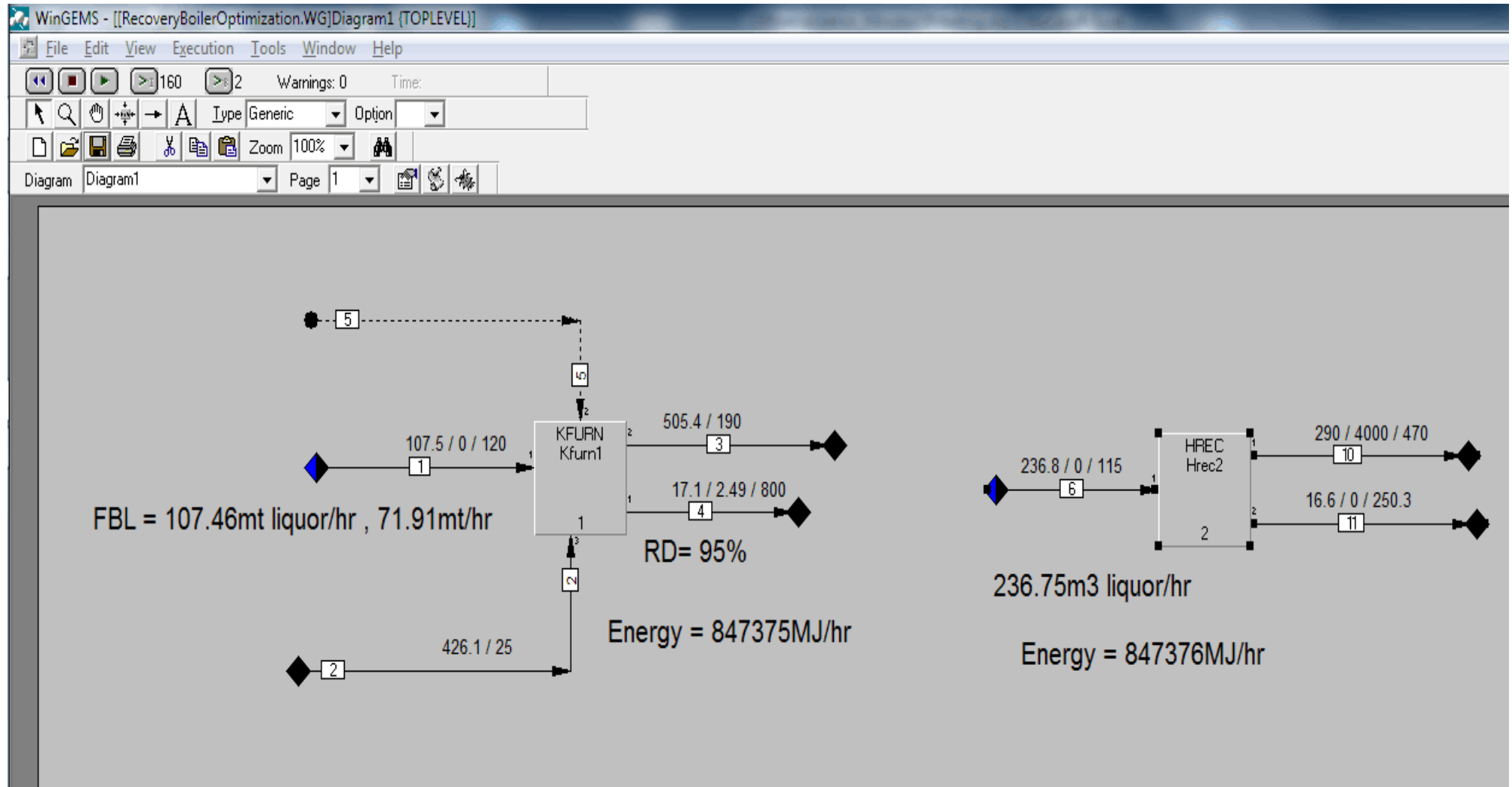
Equation system solved in 0.67s

```
J=[-1 0 0 0 0 0 0 -c(2)*c(11)*x(8) 0 0;
    1 -1 0 0 0 0 0 0 0 0;
    0 -1 0 0 1 0 0 0 c(3)*c(11)*x(9) 0;
    0 0 -1 0 0 1 0 0 0 c(4)*c(11)*x(10);
    0 -1 1 0 0 0 0 c(5)*c(11)*(x(8)-x(9)) c(5)*c(11)*(x(9)-x(8)) 0;
    0 0 0 -1 0 0 1 c(6)*c(11)*(x(8)-x(9)-x(10)) c(6)*c(11)*(x(9)+x(10)-x(8)) c(6)*c(11)*(x(10)+x(9)-x(8));
    0 0 -1 1 0 0 0 c(7)*c(11)*(x(8)-x(9)-x(10)) c(7)*c(11)*(x(9)+x(10)-x(8)) c(7)*c(11)*(x(10)+x(9)-x(8));
    0 0 0 0 -1 0 0 0 c(8)*c(11)*x(9) 0;
    0 0 0 0 0 -1 0 0 0 c(9)*c(11)*x(10);
    0 0 0 0 0 0 -1 c(10)*c(11)*(x(8)-x(9)-x(10)) c(10)*c(11)*(x(9)+x(10)-x(8)) c(10)*c(11)*(x(10)+x(9)-x(8))];
```

```
% Optimization
options=optimset('Jacobian','on');
[x,fval,exitflag,output] = fsolve(@x)pipesystem(x,c),x0);
```



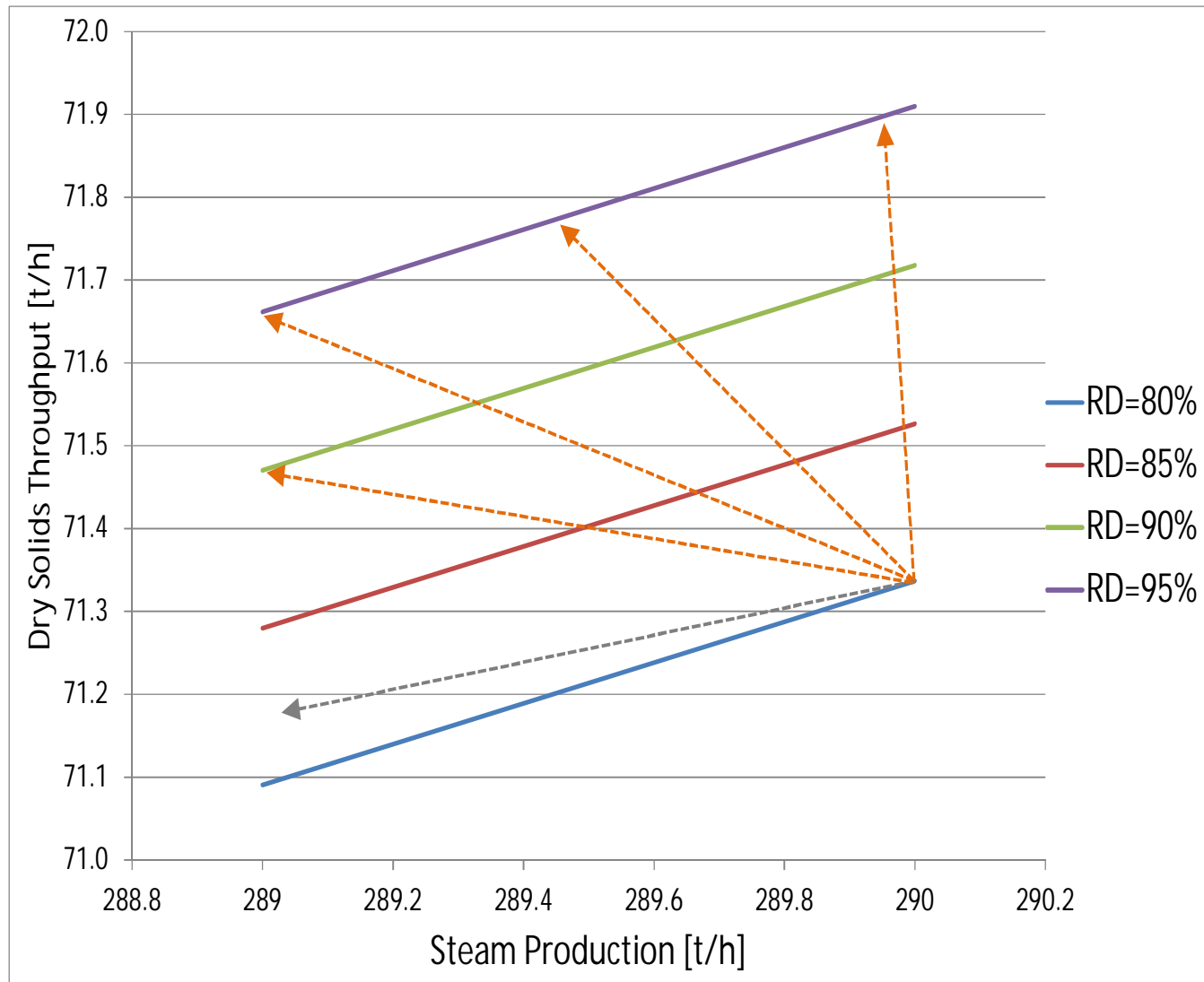
# Recovery Boiler Optimization



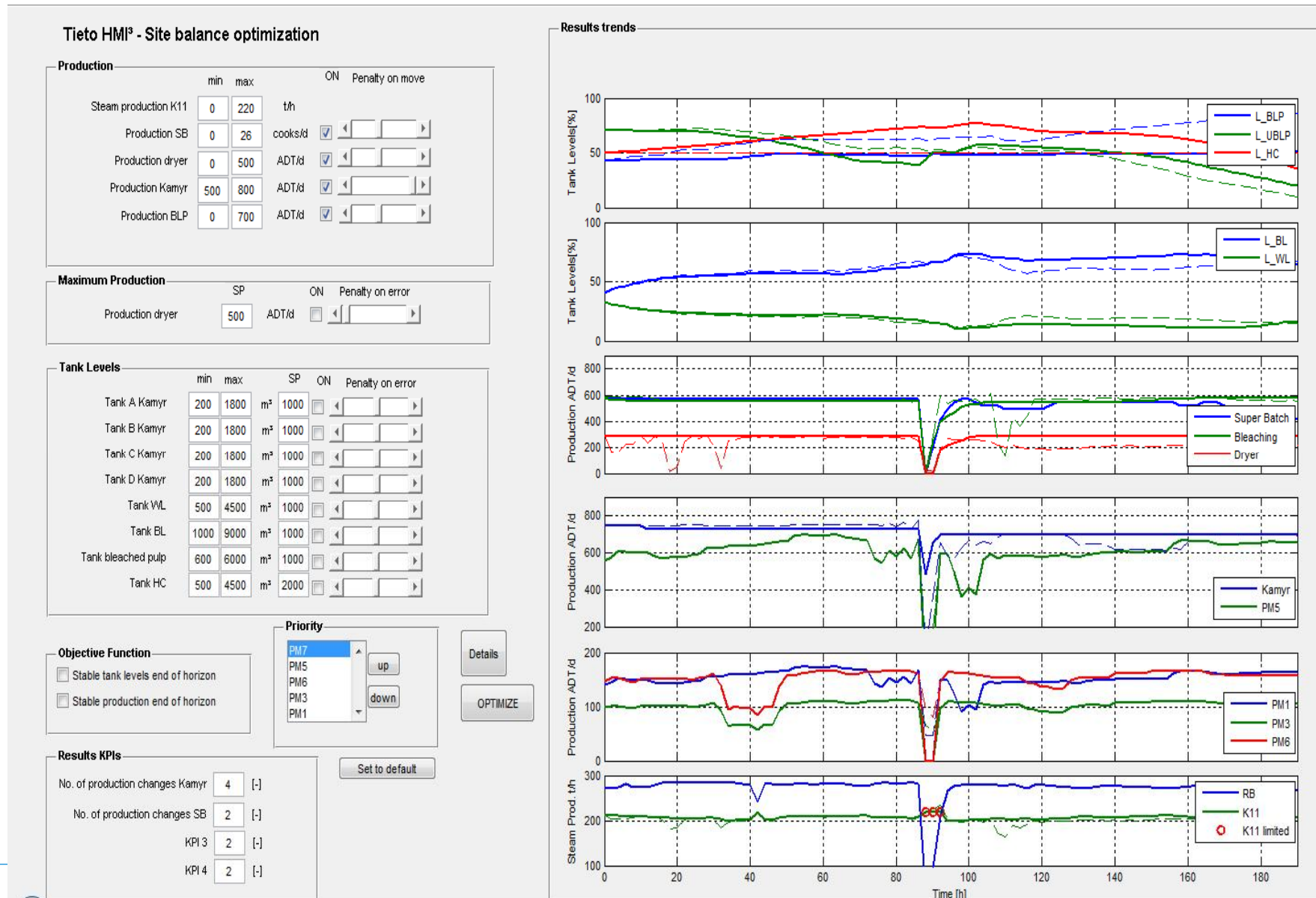
# Recovery Boiler Optimization

Process Variable	Engineering Unit	Value	Value	Value	Value	Value	Value	Value	Value
RB steam flow	mt/hr	290.00	290.00	290.00	290.00	289.00	289.00	289.00	289.00
Black liquor consumption	mt liquor/hr	106.60	106.88	107.17	107.46	106.23	106.52	106.80	107.09
Dry Solids per hour	mt/hr	71.34	71.53	71.72	71.91	71.09	71.28	71.47	71.66
Reduction degree	%	80.00	85.00	90.00	95.00	80.00	85.00	90.00	95.00

# Recovery Boiler Optimization



# Optimization of integrated Pulp & Paper Mill



# Paper Machine Optimization (Quality)

## Quality Parameters

Tensile Strength Index (MD, CD,  
Geometric mean)

Stretch Elongation (MD, CD)

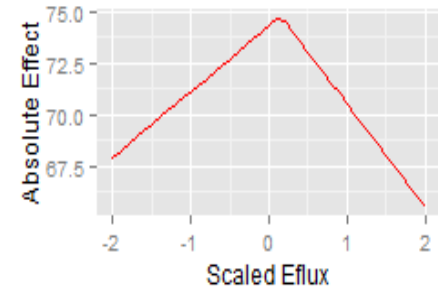
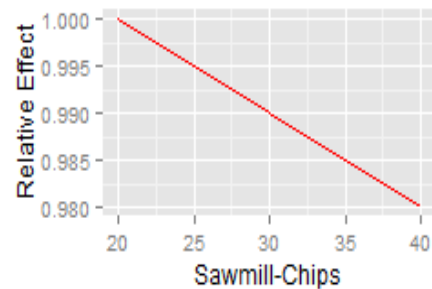
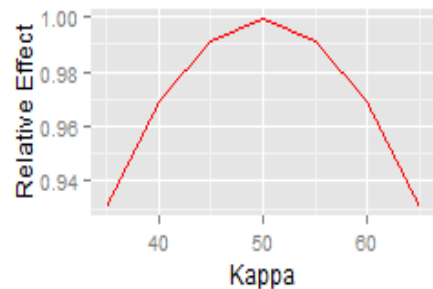
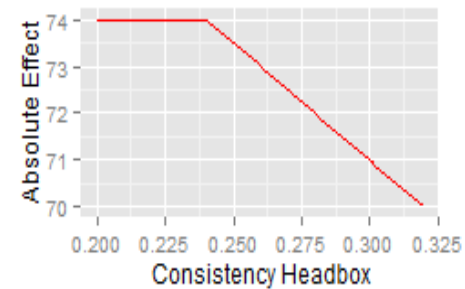
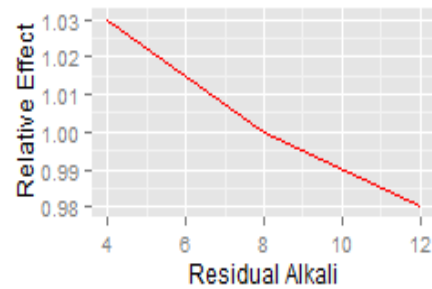
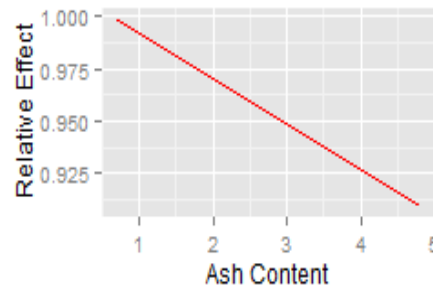
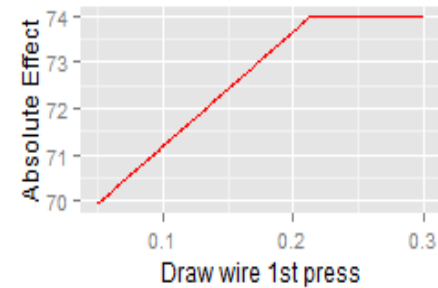
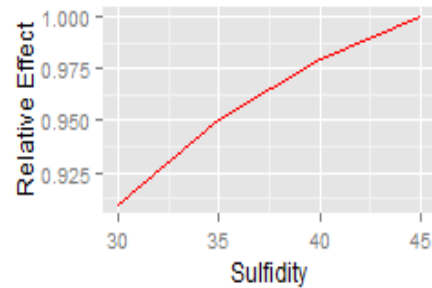
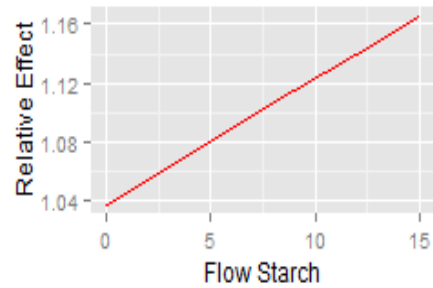
Burst Index

Porosity

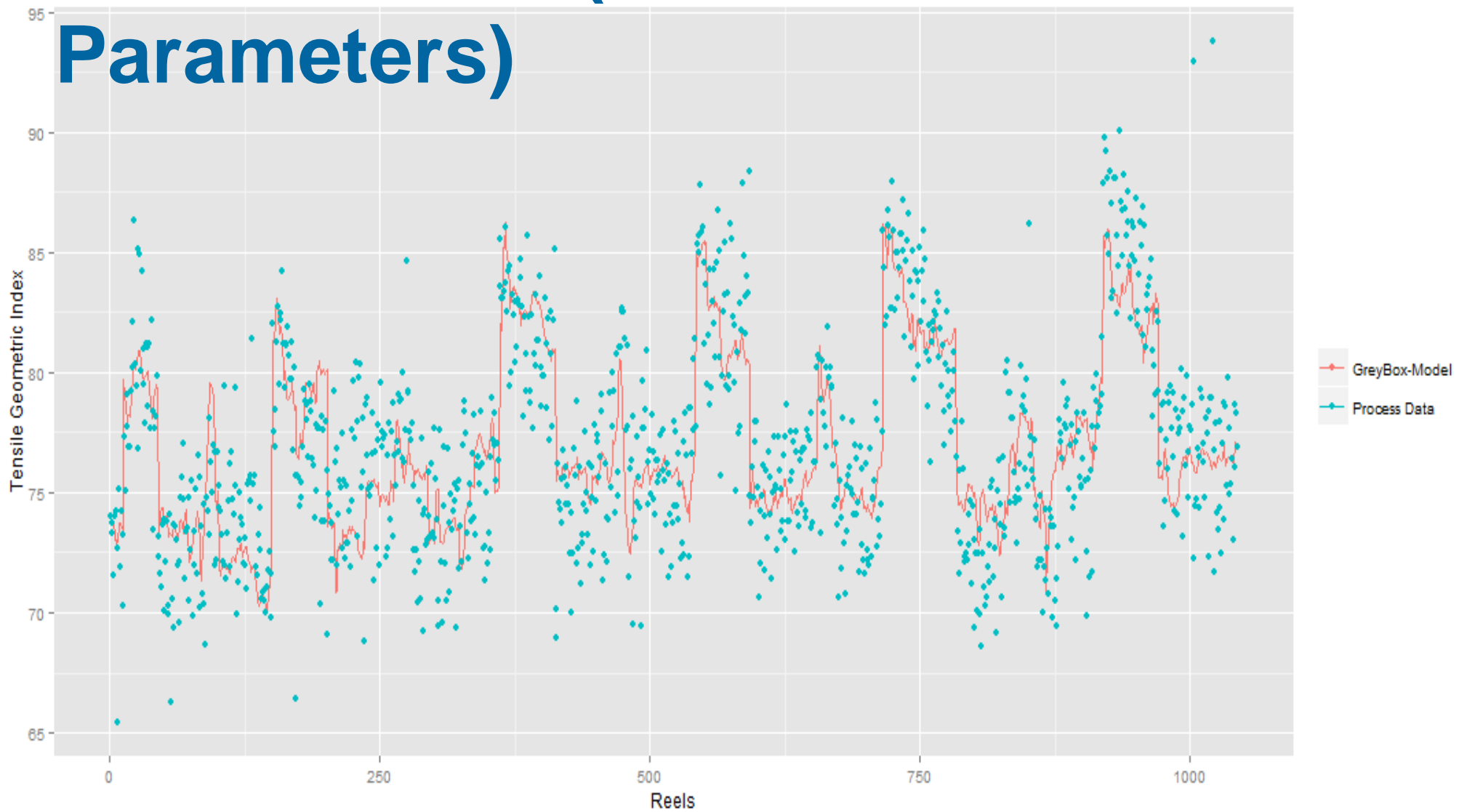
COBB

Others

# Tensile Index (Influence Par



# Tensile Index (Influence Parameters)

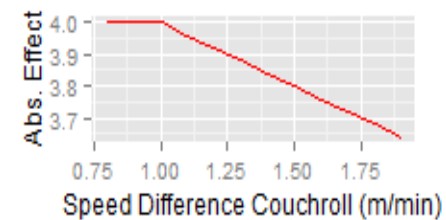
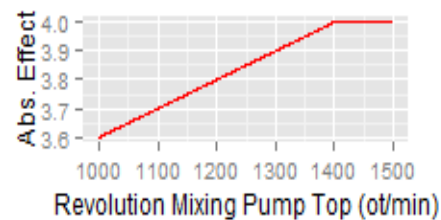
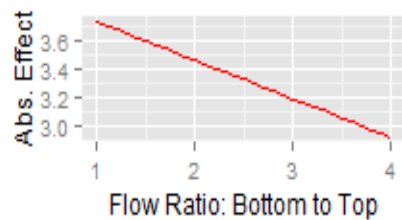
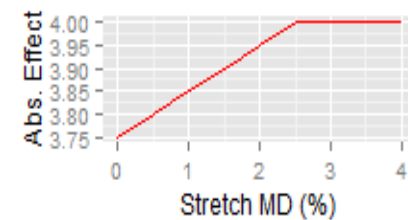
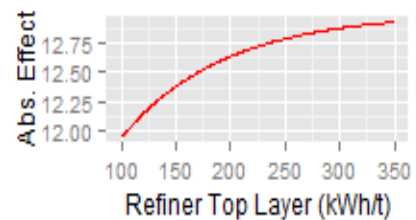
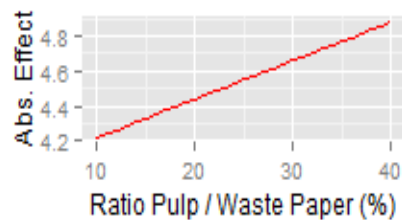
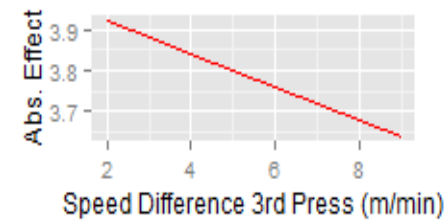
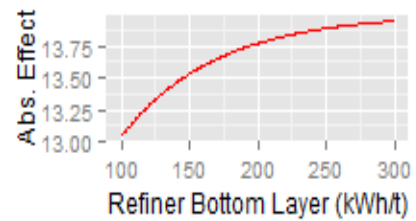
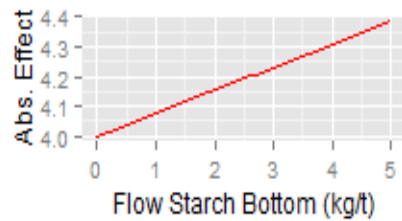
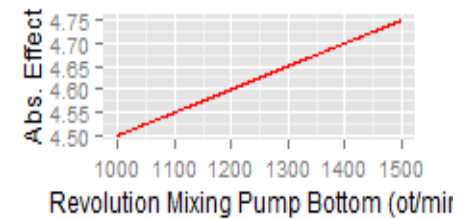
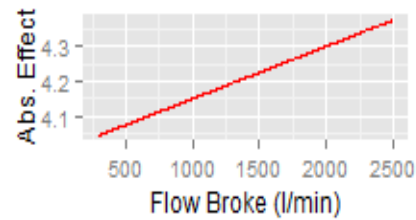
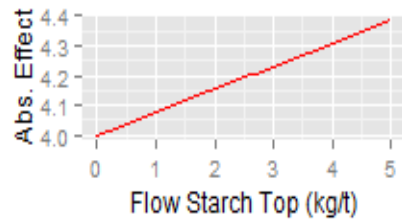


# Paper Machine Optimization (Burst Index)





# Influence Parameters



# HMI<sup>3</sup> task force Optimization

## Optimization Team @Tieto:

- Stefan Kohlegger (Evaporation, Bleaching, Drying)
- Stefan Grosswindhager (Paper Quality)
- Kathrin Zörweg (O<sub>2</sub>-Delignification, Causticizing)
- Andreas Roither-Voigt (Recovery Boiler, Digesters)
- John Köhler (Steam Networks, Boilers)

# Changing perspectives™

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