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PLANT-WIDE OPTIMIZATION USING PROCESS DIGITAL TWIN FOR PULP MILL

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Outline

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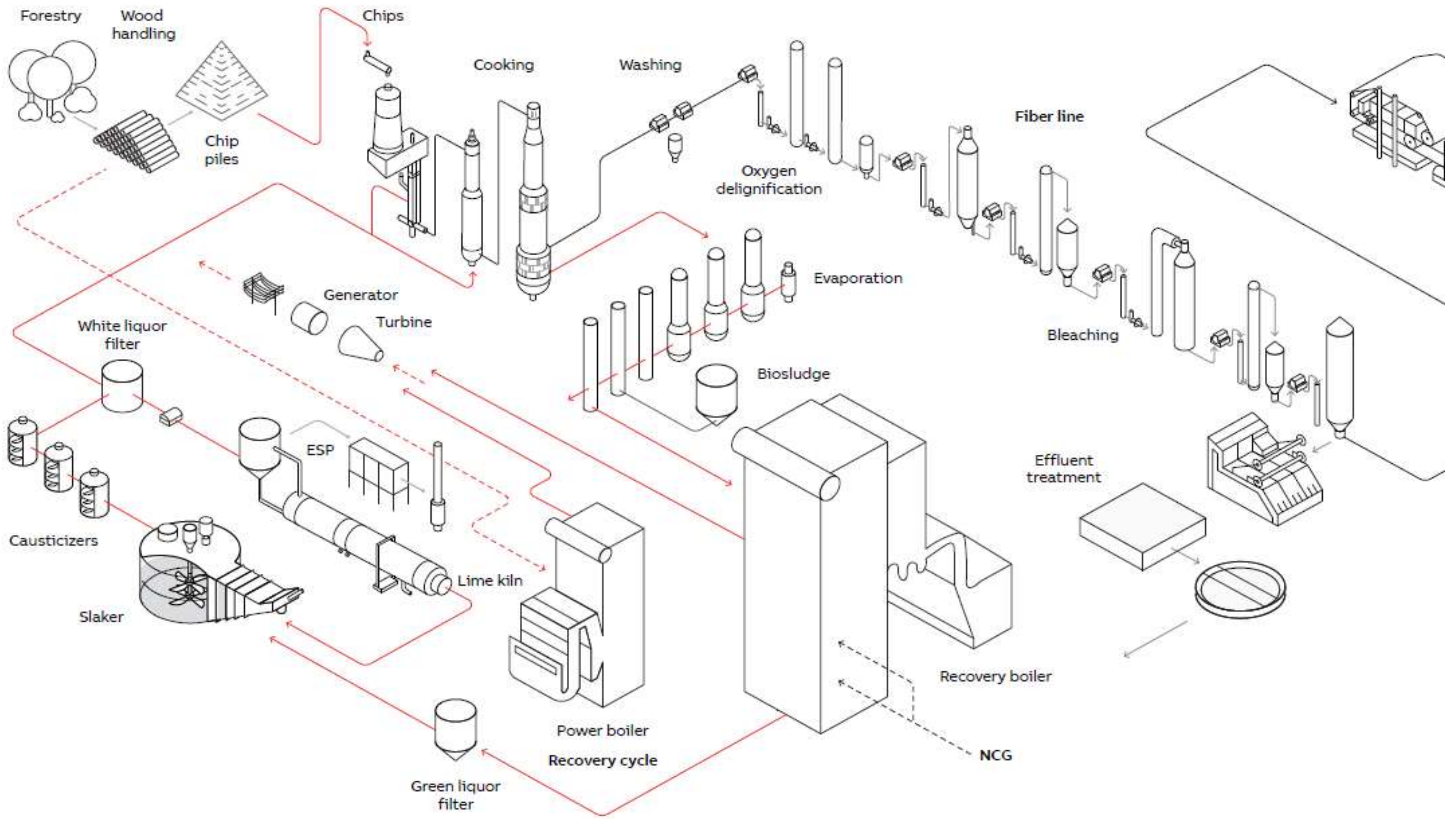
- Current State of Pulp Mill Operations
- Plant-wide Optimization
- Digital Twin Paradigm for pulp mills
- Process Models for Pulp Mill
- Optimization
- Results
- ABB Ability Plant Optimizer
- Conclusion
- Q&A

Introduction

- Process interactions and cross-section coupling
  - Hybrid processes (batch and continuous)
  - Differing dynamics in different sections
  - Frequent disturbances

- Optimizing individual processes independently is insufficient
  - Maximize mill throughput
  - Minimize overall chemical consumption



Complex network of operations in a pulp mill

Current State of Pulp Mill Operations

Challenges

Operator decisions based on experience

- Inconsistent across different operators/shifts

Unit/Area wise decisions

- Recovery team → max chemical recovery
- Bleach team → min bleach chemical consumption

Spreadsheet-based simple calculations

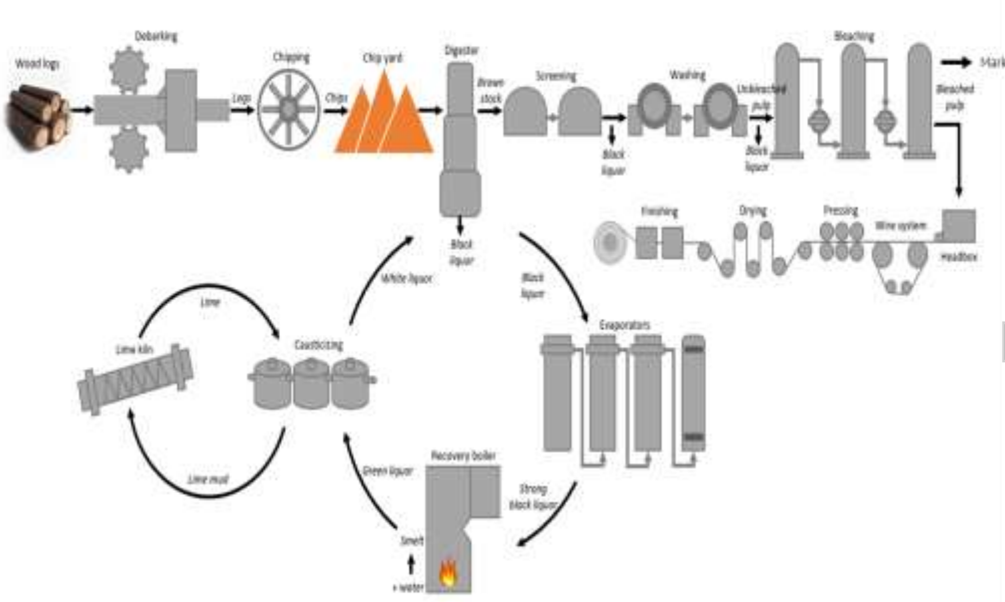
- Cannot handle real-time dynamic changes

No long-term forecasts/optimizations

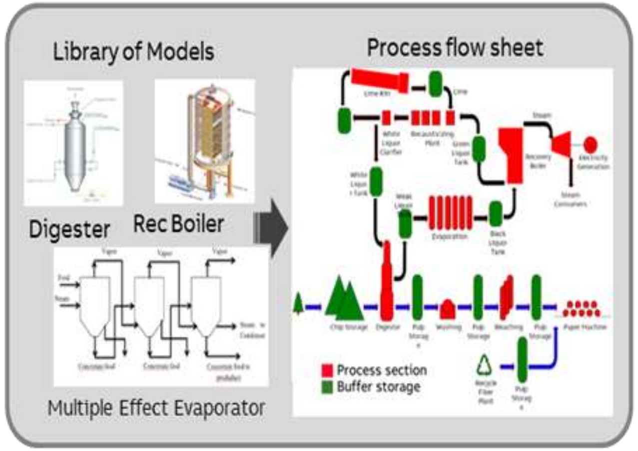
- Decisions are reactive, responding to immediate disturbances only

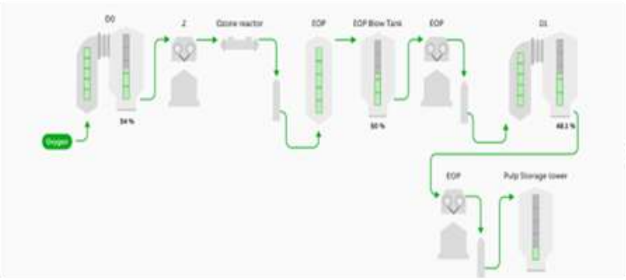
➢ **Need for a plant-wide optimizer coordinating all sections of a pulp mill**

Plant-wide Optimization

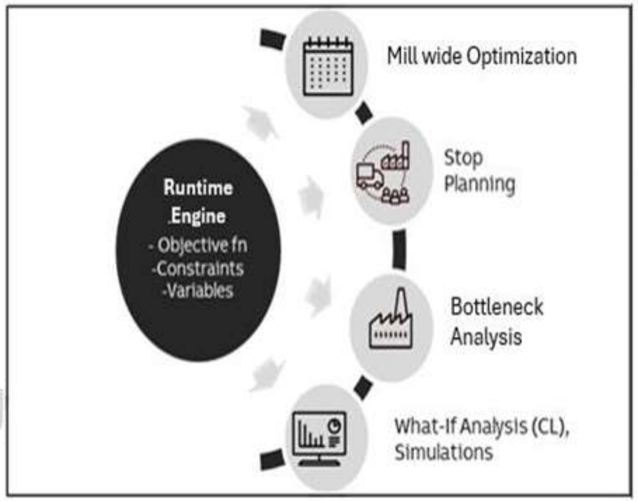


Virtual representation of pulp mill





Real-time plant-wide optimization



Step 1: Digital twin for the pulp mill using mathematical process models

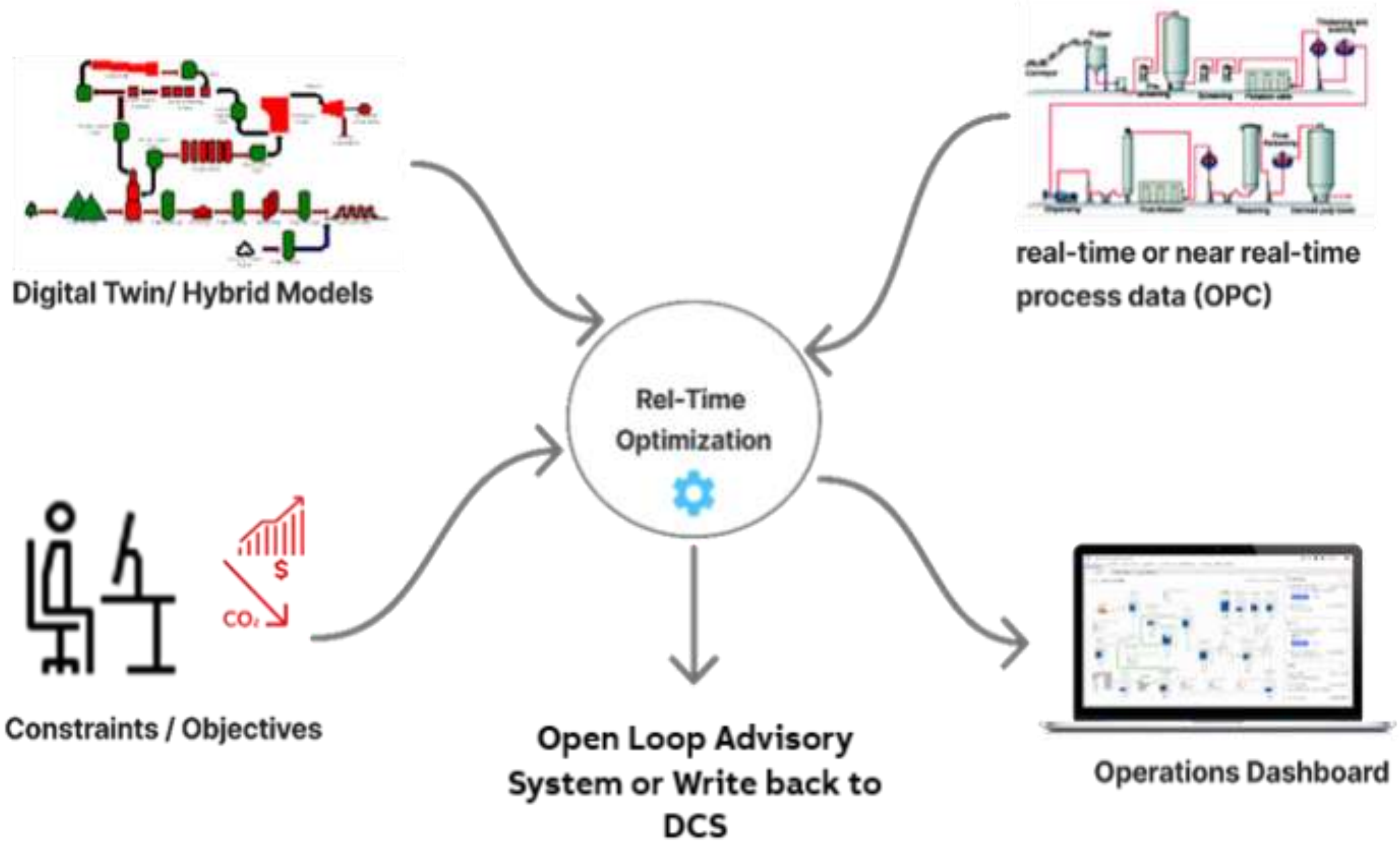
Step 2: Real-time plant-wide optimization utilizing the process models

Digital Twin for Pulp Mill

Definition and conceptual framework

Important Characteristics

- **Model Fidelity**
  - First principle mechanistic models
  - Steady State
  - Data driven empirical
- **Real-time data integration**
  - Historian, online quality
  - Lab
  - Data from MES
- **Connectivity**
  - Open loop
  - To APC/DCS

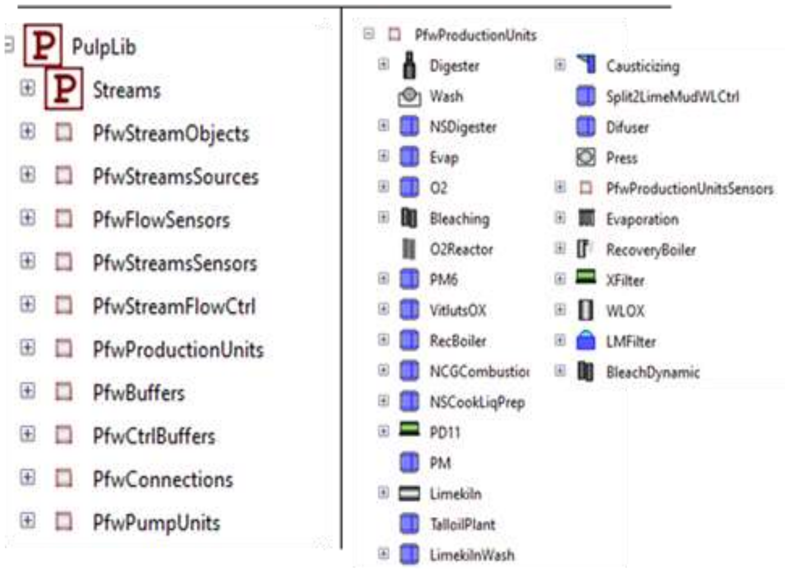


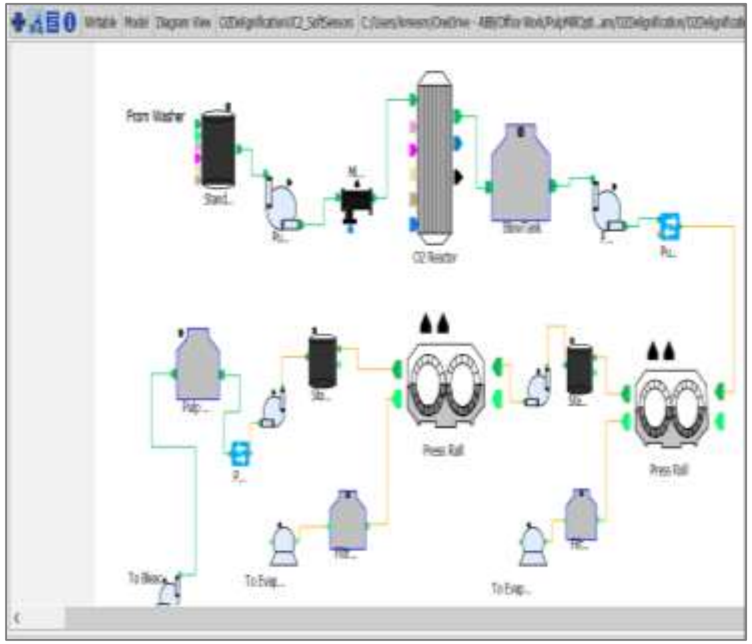
Process Models for Pulp Mill

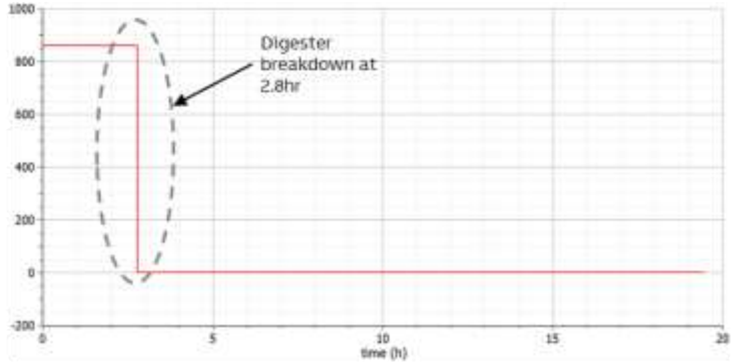
Comprehensive Library

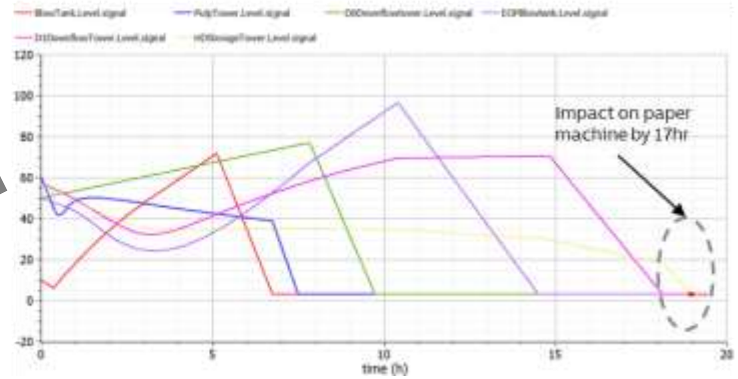
- ❑ First principles Models
- ❑ Library with Pre-defined Models
- ❑ What-if simulations can be created
- ❑ Can be used in real-time optimization

Pulp Library









Optimization

Example: Kraft Pulping Process

$$\underset{MV_{i=1,2,\ldots m}}{Min.} \quad J$$

$$\text{where } J = \sum_{t=0}^{T-1} \sum_{i=1}^{m} \left(u_{i,t+1} - u_{i,t}\right)^2$$

subjected to

model constraints

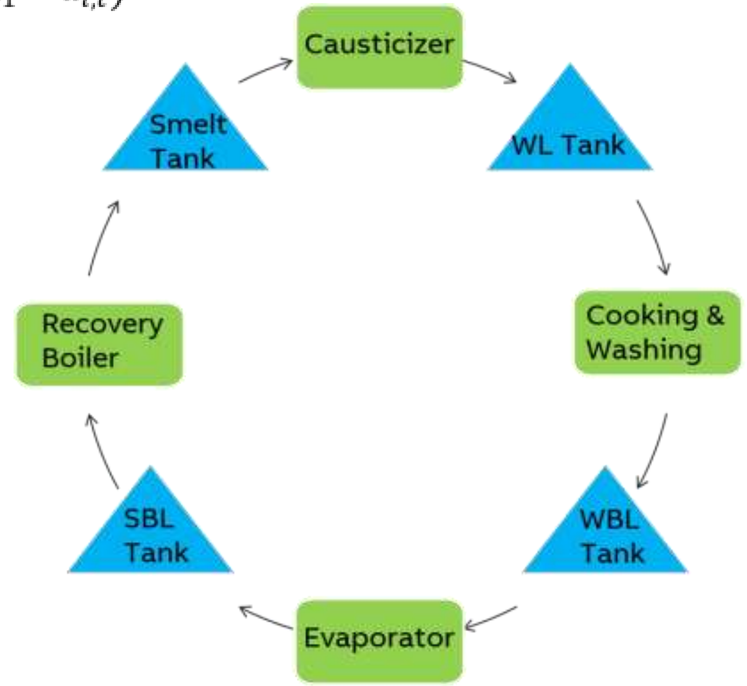
$$h_k(t, u, X, y) = 0;$$

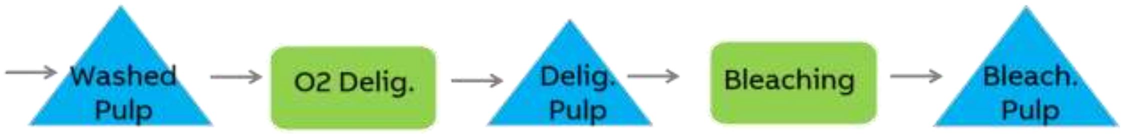
process capacity constraints

$LB \leq$ *cooking production rate* $\leq UB$
$LB \leq$ *O2 delign production rate* $\leq UB$
$LB \leq$ *bleaching production rate* $\leq UB$
$LB \leq$ *evaporator production rate* $\leq UB$
$LB \leq$ *recovery boiler production rate* $\leq UB$
$LB \leq$ *causticizer production rate* $\leq UB$

inventory constraints

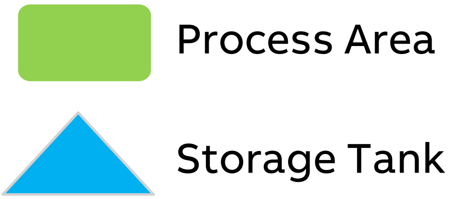
$LB \leq$ *bleached pulp tank level(%)* $\leq UB$
$LB \leq$ *delignified pulp tank level* $\leq UB$
$LB \leq$ *cooked pulp tank level* $\leq UB$
$LB \leq$ *weak black liquor tank level* $\leq UB$
$LB \leq$ *strong black liquor tank level* $\leq UB$
$LB \leq$ *smelt tank level* $\leq UB$
$LB \leq$ *white liquor tank level* $\leq UB$





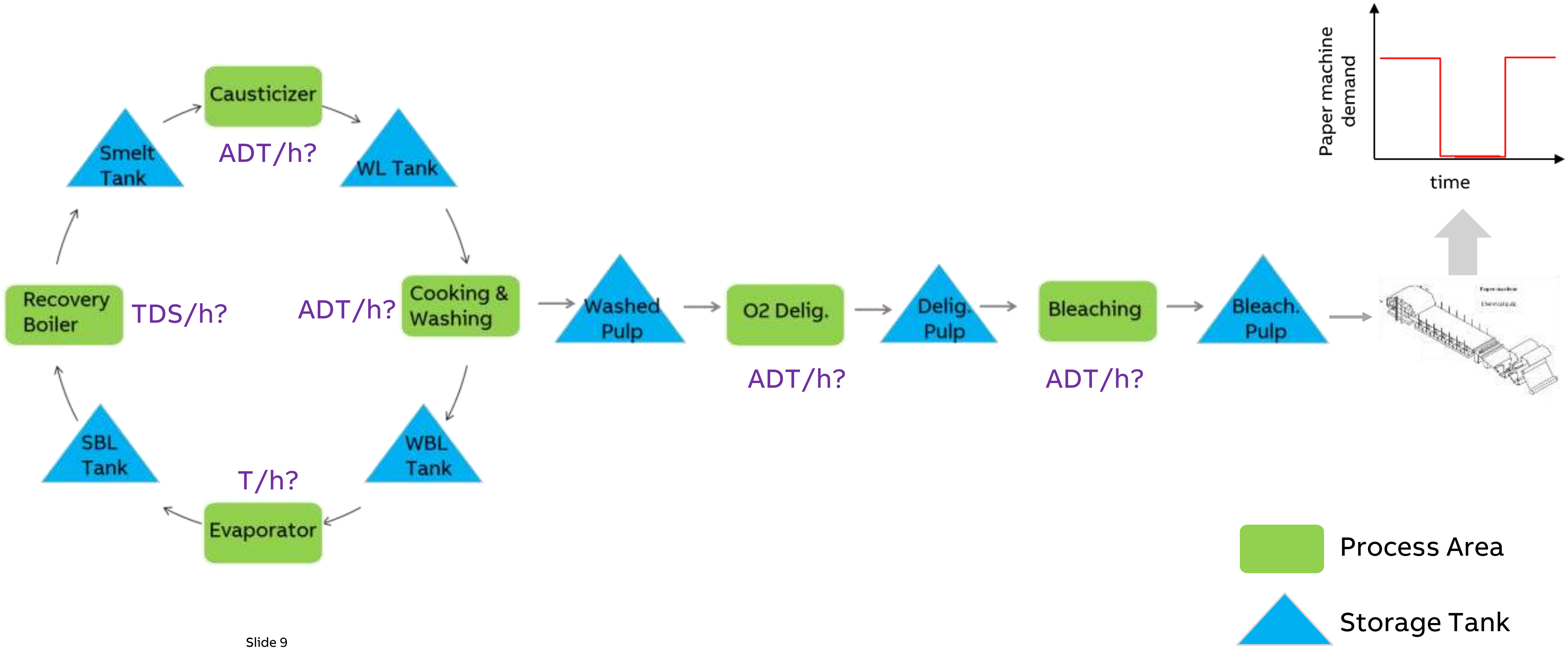
- Objective is to meet the variable demand from paper section while respecting process delays and constraints on inventories

Kraft Pulping Process with important inventory storages



Use Case - 1

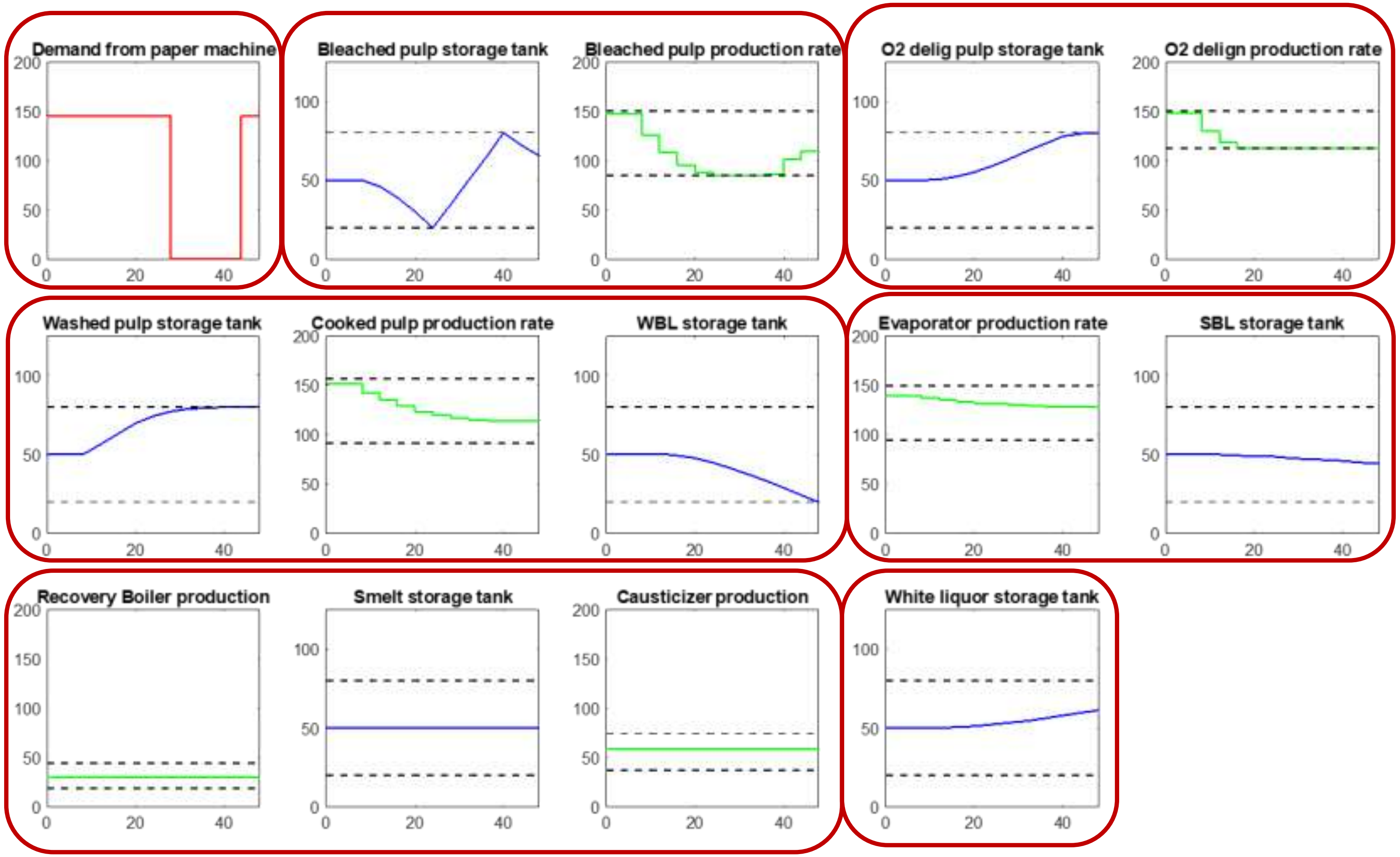
Variable Paper Machine Demand with Planned Maintenance



Use Case -1

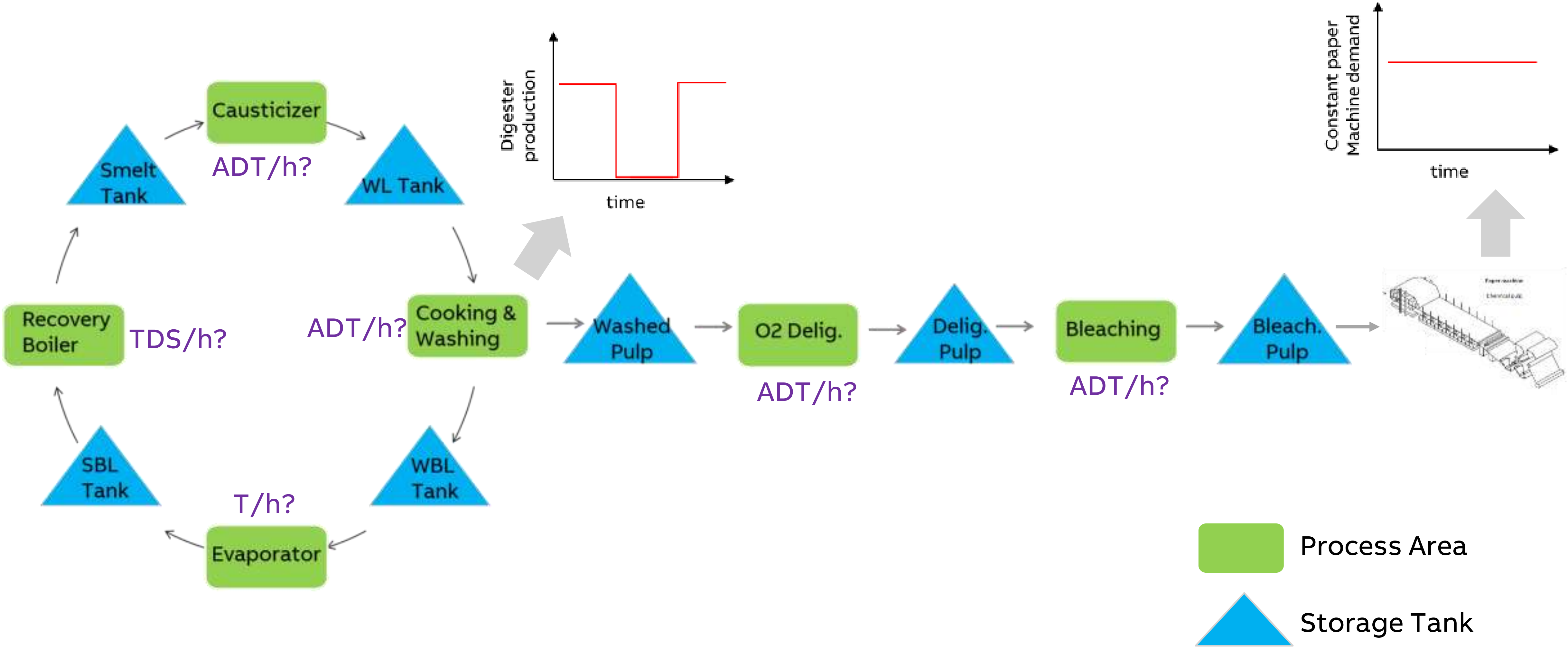
Variable Paper Machine Demand with Planned Maintenance

- Planned paper machine maintenance
- Proactive rate reductions
- All tank inventories maintained within limits (20-80%)
  - Bleached pulp storage approaches upper limit but never violated
- Proactive optimization
  - Anticipates demand change and acts in advance



Use Case - 2

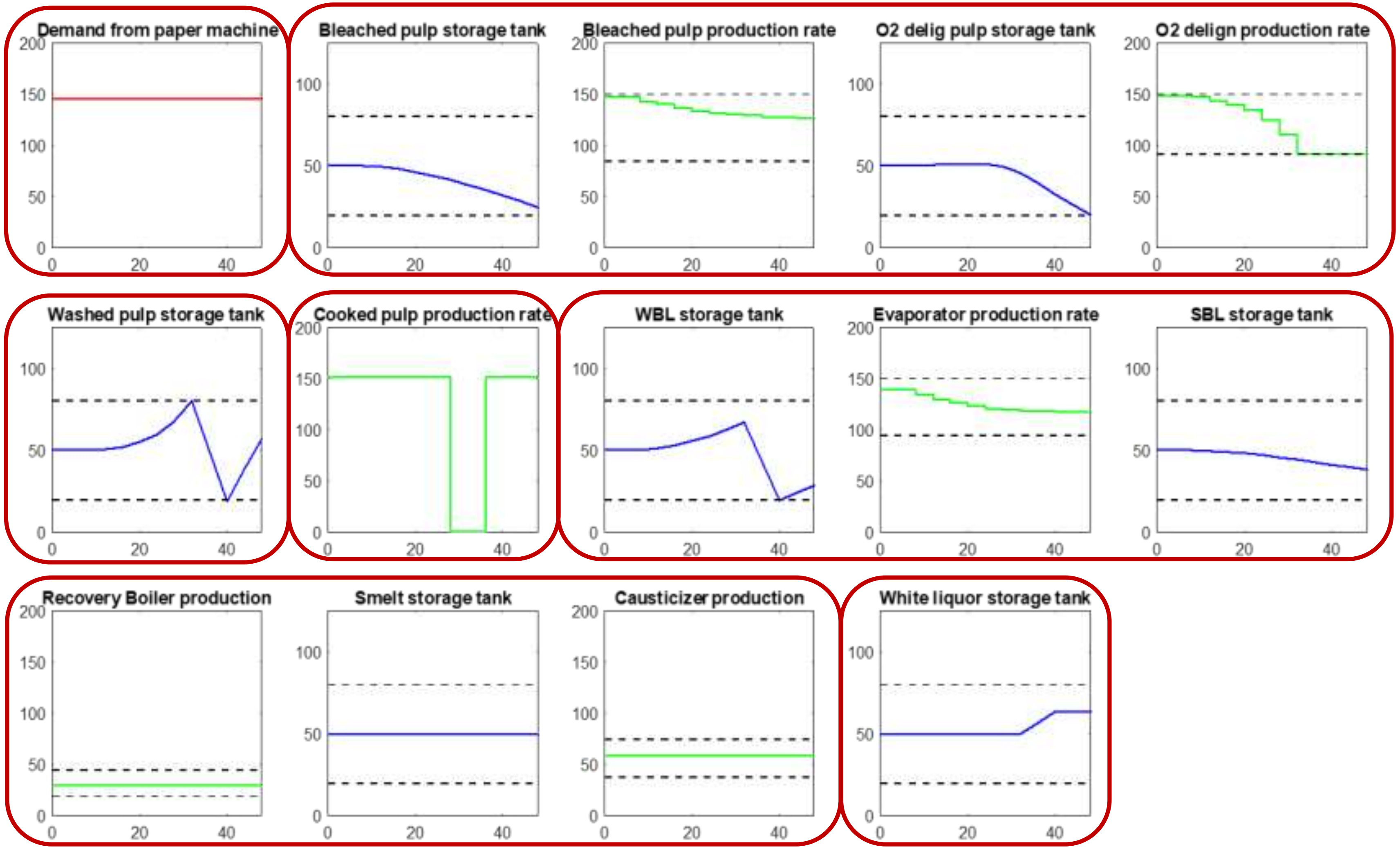
Planned Digester Maintenance with Constant Paper Machine Demand



Use Case - 2

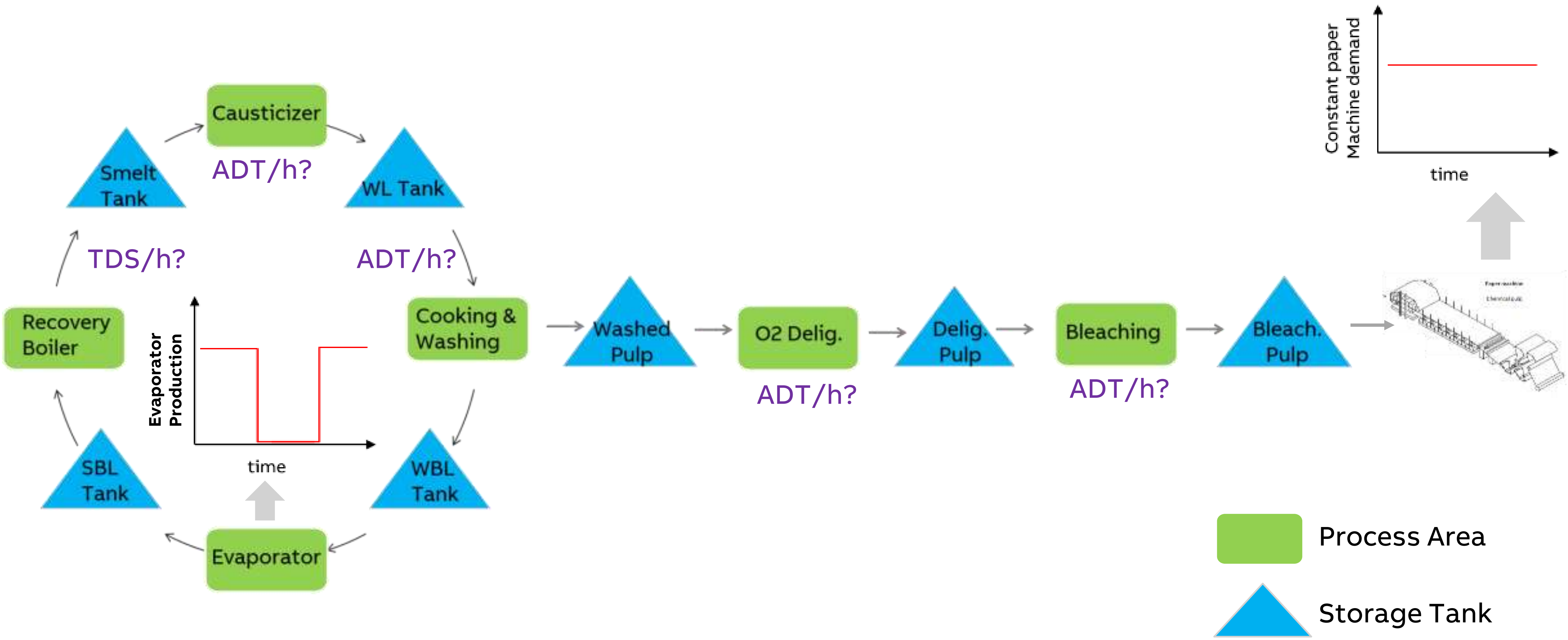
Planned Digester Maintenance with Constant Paper Machine Demand

- Digester outage with constant paper machine demand
- Proactive pre-positioning of washed pulp buffer
  - Optimizer fills washed pulp storage tank to upper limit
- All inventories remain within low and high limits with uninterrupted paper machine supply



Use Case - 3

Planned Evaporator Maintenance with Constant Paper Machine Demand



Use Case - 3

Planned Evaporator Maintenance with Constant Paper Machine Demand

- Evaporator outage with constant paper machine demand
- Proactively reducing cooking, O2 delignification and bleaching production rates
- Strong black liquor tank management
- All inventories remain within low and high limits with uninterrupted paper machine supply

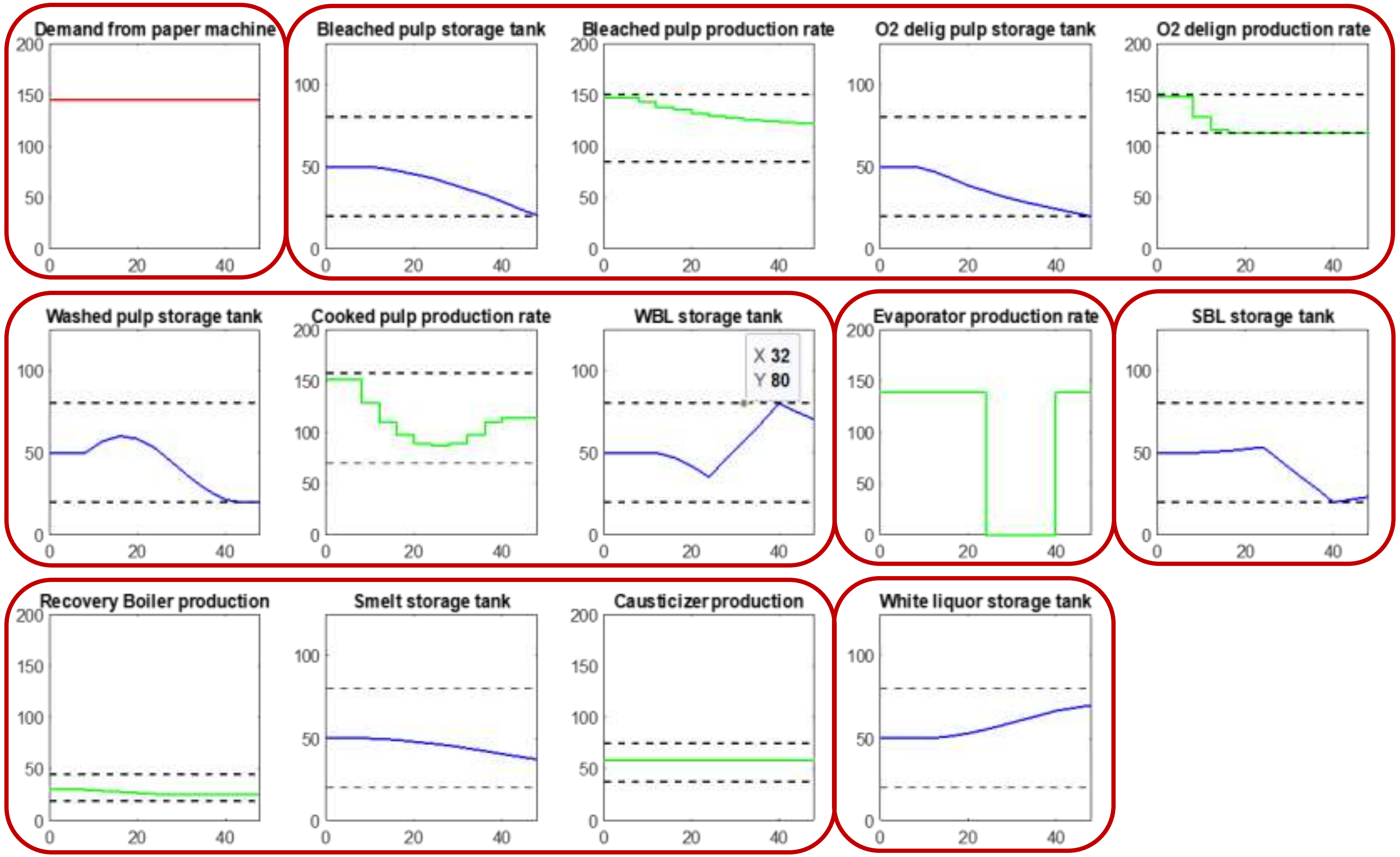


ABB Ability Plant Optimizer

One Mill. One Strategy

- Two-module architecture
- Pulp Tracker: Real-time traceability and KPI monitoring
- Pulp Optimizer: Economic optimization engine
  - Continuously computes optimal setpoints for production rates across all process areas
  - Respects quality limits and MES targets

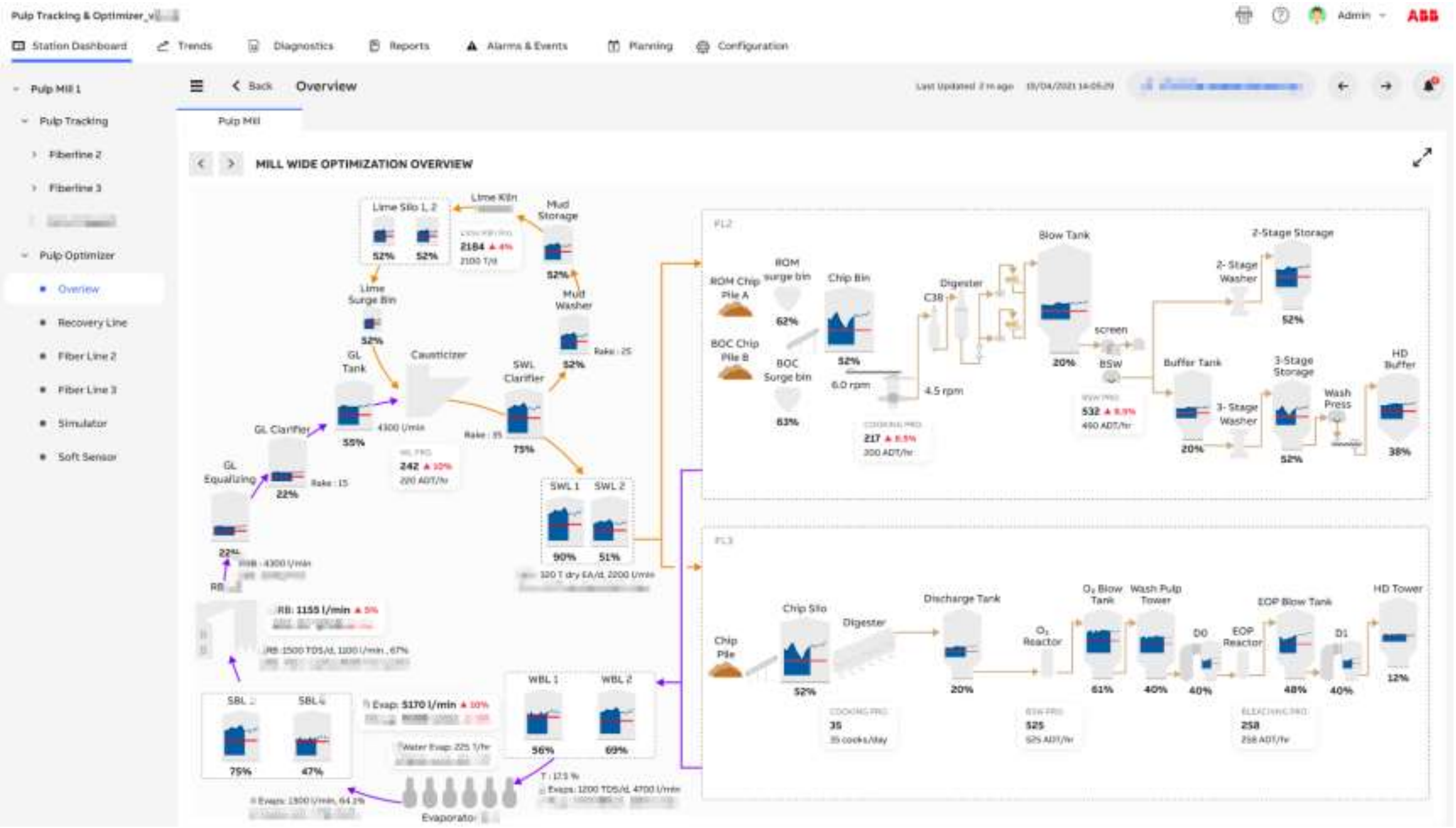


ABB Ability Plant Optimizer

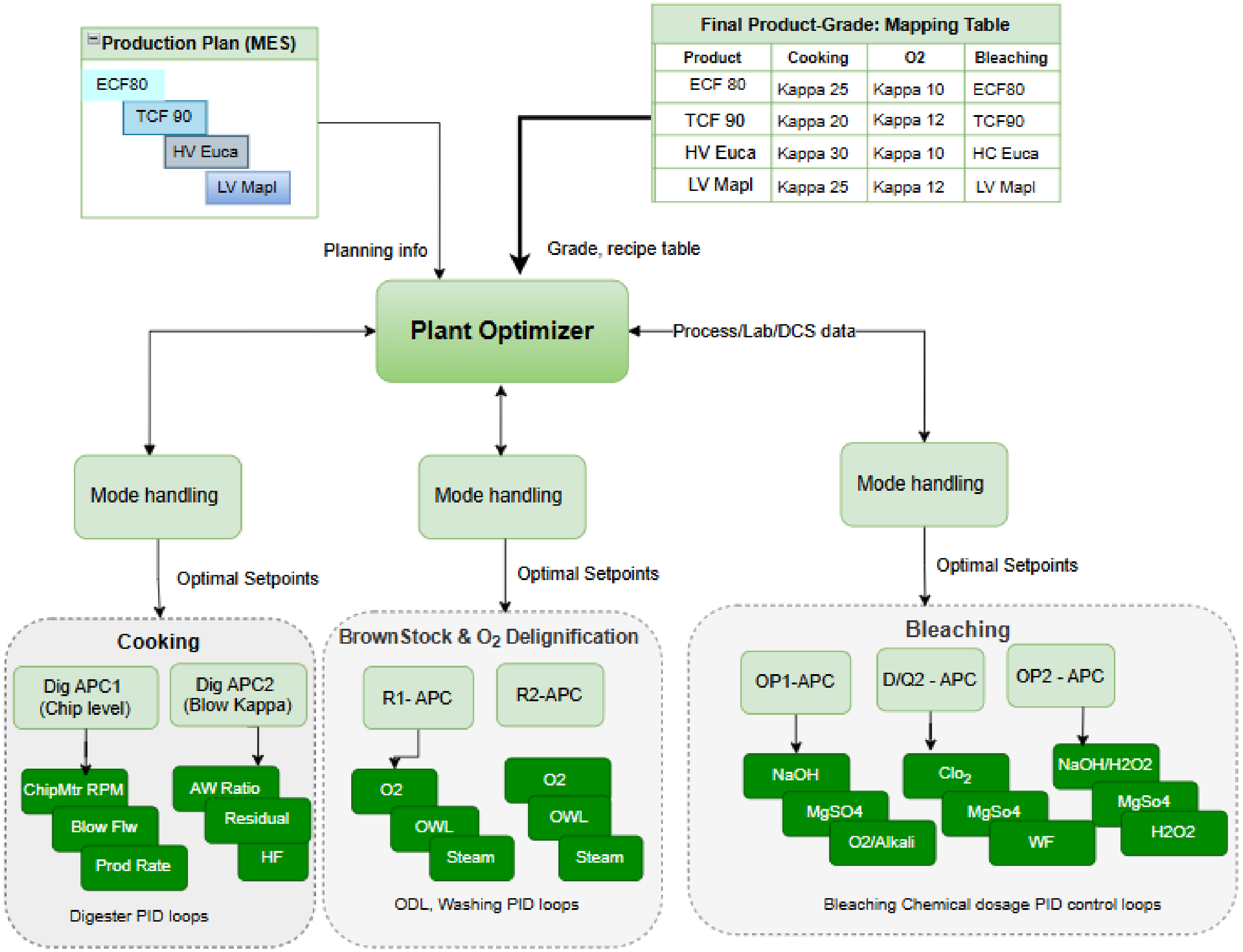
System Overview

Pulp Production Planning driven by MES System

Tracker and Optimizer

Modes of operation

- Manual
- Auto



Final Product-Grade: Mapping Table

Product	Cooking	O2	Bleaching
ECF 80	Kappa 25	Kappa 10	ECF80
TCF 90	Kappa 20	Kappa 12	TCF90
HV Euca	Kappa 30	Kappa 10	HC Euca
LV Mapl	Kappa 25	Kappa 12	LV Mapl

Conclusions

- **Root cause of performance gap: Structural coupling and process delays**
  - Plant-wide optimization closes the gap between manual coordination and theoretical mill potential

- **Digital twin enables proactive real-time plant-wide optimization**

- **Three use cases are verified using Kraft pulping process. Demonstrates capability to handle disturbances and improve productivity.**
  - Planned maintenance on paper machine, digester, and evaporator --- all successfully handled
  - All inventory constraints satisfied within low and high limits

- **Path Forward: Reactive → Proactive | Unit-level → System-level**