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Transforming Paper Mill Operations Through AI-Powered Digital Solutions

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Abstract: *The pulp and paper industry confronts mounting pressures from volatile energy costs, stringent environmental regulations, and intense market competition. To achieve operational excellence and competitive advantage, modern mills require a paradigm shift from traditional, reactive control systems to intelligent, autonomous decision-making platforms. This paper presents a comprehensive technical analysis of AI-powered digital solutions—Loop Performance Manager (AI enabler for monitoring and enhancing performance of PID loops), Expert Optimizer (Advanced Process control solution for Predictive process Control), and Plant Optimizer (Digital Twin for end to end Pulp and recovery Process)—that collectively enable digital transformation in paper mill operations, through detailed explanation of system architecture, implementation methodologies, and documented success stories, this paper demonstrates how these interconnected solutions deliver substantial improvements in process variability, throughput, product quality, and operational costs.*

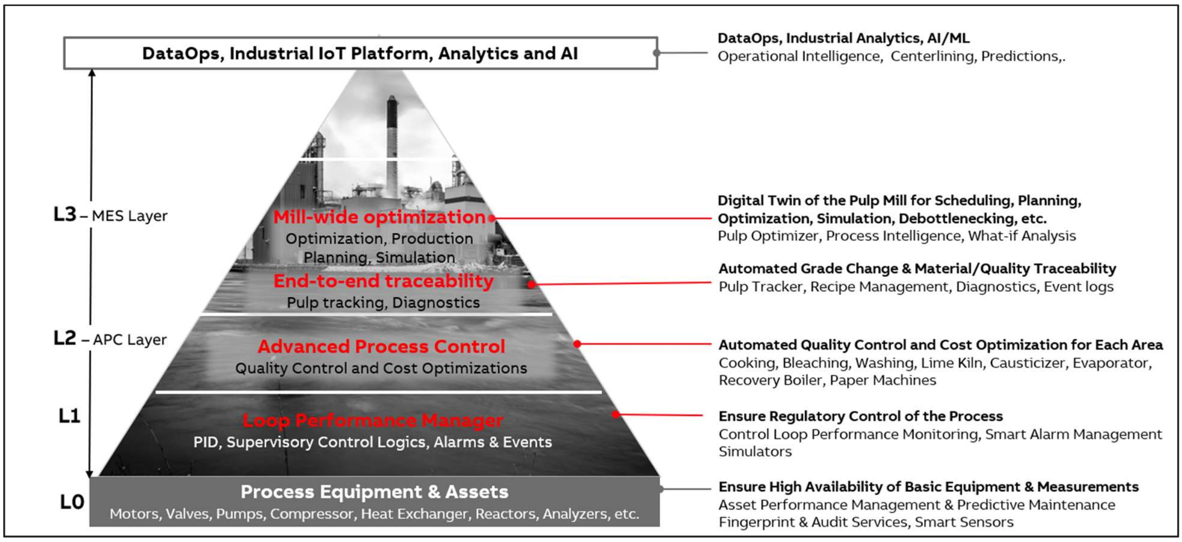
Keywords: *Artificial Intelligence, Digital Twin for Pulp Mill, Advanced process Control, Control loops performance moni-toring and tuning, Predictive Process Control.*

Introduction

In today's pulp and paper industry, especially for commodity products in a stable or declining market, it is difficult for producers to improve profitability by increasing output, since there is no guarantee that extra product would find a buyer. One avenue that can be explored to improve the profitability of pulp and paper industry is to reduce their process variability, which can lead to cost savings from reductions in energy usage, chemical usage, off-spec tonnage and even maintenance downtime. Process variability can have several causes, including raw material variation, sensor drift, control loop tuning, grade changes and human factors. In this current era of Digitalization and Artificial intelligence several technologically advanced tools are being co-created with collaborations between the manufacturers and the technology partners. The implementation of such advanced solutions for improving the performance of the sensors, valves, controllers and thereby optimizing the process and quality performance of the mills is the strategy being implemented by the pulp and paper mills globally.

Materials and methods

The process performance solutions being detailed in this paper deliver comprehensive coverage across the ISA95 pyramid for pulp mills and paper machines refer to figure 1. At L0 (Field Level), Loop Performance Manager continuously monitors sensor and actuator performance, ensuring data quality from instrumentation across pulping, bleaching, recovery processes and paper Machines. At L1 (Control Level), the solution optimizes distributed control system loops through AI-driven tuning and anomaly detection, maintaining stable base control across 20-30% of typically underperforming loops. At L2 (Supervision Level), Expert Optimizer and Plant Optimizer provide real-time process visibility and advanced analytics through SCADA integration, enabling operators to monitor multi-variable optimization and process trends. At L3 (Manufacturing Operations), Plant Optimizer, the Digital Twin for Pulp and recovery processes integrate with Manufacturing Execution Systems to translate optimized production targets into dynamic schedules, linking operational decisions with material flows, energy consumption, and profitability metrics—creating end-to-end visibility and autonomous decision-making across the entire mill value chain.



(Figure 1: Process optimization Digital solutions from ABB as per ISA95 stack)

1. Loop Performance Manager (LPM)

Loop Performance Manager (LPM) helps control engineers, instrument technicians and maintenance personnel maintain control loops for peak production performance. It connects academic technologies with industrial needs and operates through three modular applications. The control loop-auditing component monitors loop performance, while the tuning component improves it. Plant-wide Disturbance Analysis (PDA) analyzes multiple loops, detects common behaviors and identifies root causes. The solution connects to any DCS or PLC and integrates with enterprise data Historians. This enables performance monitoring and tuning of PID loops across the production process.

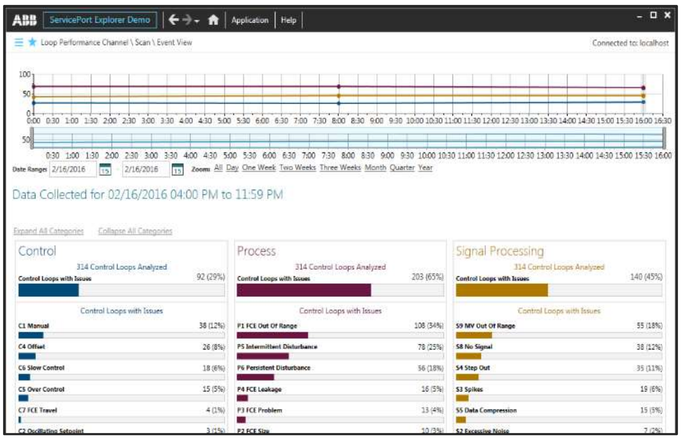
Three critical performance categories are monitored and analyzed to accelerate problem-solving.

Control: To keep the error at or near zero, the output of the controller is analysed to find the source of out-of-sync measurements, such as incorrect tuning parameters

Process: Confirms the valve or final control element (FCE) to the process is correct for that process type and is repeatable and predictable. Disturbances that could affect this relationship, such as process nature changes or FCE failure, are analyzed

Signal Processing: Ensures the measurement to the controller is as pure as possible by monitoring factors, such as outliers or calibration, that would create an implausible measurement

Through the built in AI models, LPM Identifies issues in PID loops automatically.



(Figure 2: Realtime Dashboard Performance Optimization for PID loops)

As shown in Figure 2, each KPI is displayed as a bar, 0 means no problem detected, 100 is a critical level of a problem, places them under categories. Loops are categorized into three different groups depending on type of detected problem, control, process and signal processing. Prioritizes in order of severity and criticality. The KPIs with the most critical problems are presented at the top in the pareto chart of each group for data driven decision making by the engineers.

Loop tuning

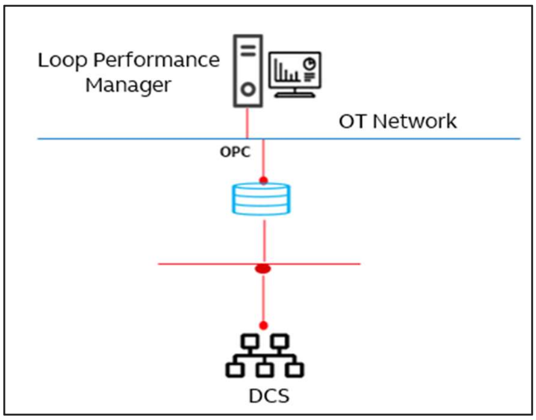
Performance Optimization for control loop tuning enhances the Performance Optimization for control loops service by giving process engineers the ability to create accurate models to predict events, so they can reduce or eliminate potentially disruptive process bump tests in control loop tuning.

Features:

- Link between Performance Optimization for control loops service and Control Tuning Workbench Tool
- Secure, remote diagnosis and proactive support from experts
- Historic loop data used to calculate potential issues
- Fully integrated with Advanced Services

Technical Architecture:

- Data Ingestion Module: Connects to distributed control systems (DCS) via OPC-UA or equivalent protocols as shown in figure 3, sampling control loop data at 1-10 Hz frequency
- Performance Analysis Engine: Calculates performance indices including oscillation metrics, deadband analysis, signal saturation detection, and loop robustness assessment



(Figure 3: LPM integration architecture)

- Machine Learning Module: Trains models on historical loop performance across industry benchmark databases, identifying loop configurations and tuning parameters that correlate with optimal performance
- Recommendation Engine: Generates ranked recommendations for loop tuning improvements, sensor calibration, or process modifications
- Integration Module: Executes approved modifications through OPC-UA write commands to DCS.

Loop Performance Manager Implementation

Baseline Measurement Period

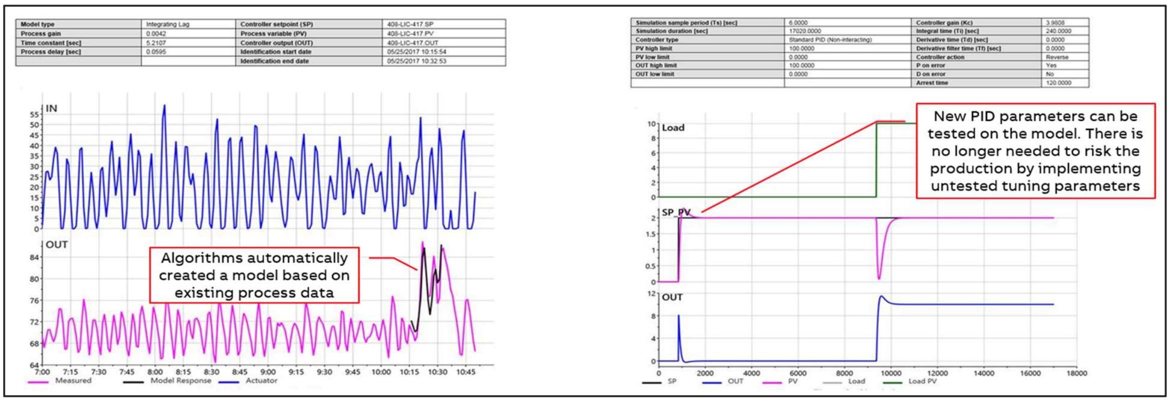
Deploy LPM in monitoring-only mode for 2-4 weeks to establish baseline performance metrics, identify problematic loops, and validate detection algorithms against known issues. This period builds stakeholder confidence and allows refinement of alert thresholds specific to each mill's characteristics.

Phased Loop Remediation

Rather than simultaneously retuning all loops, implement improvements in phases: (1) First phase addresses obvious failures (saturated valves, stuck integrators); (2) Second phase improves marginally performing loops with high impact on product quality or energy consumption by updating the loops with new tuning parameters tested and recommended by LPM, refer figure 4; (3) Third phase addresses remaining loops. This phased approach manages risk and demonstrates value incrementally.

Operator Training and Change Management

Control room operators require training in interpreting LPM diagnostics, understanding recommended changes, and executing modifications safely. Establish change governance requiring operator sign-off and documentation of all tuning changes. Recognize that operators often possess deep process knowledge and may identify practical constraints not apparent to optimization algorithms.

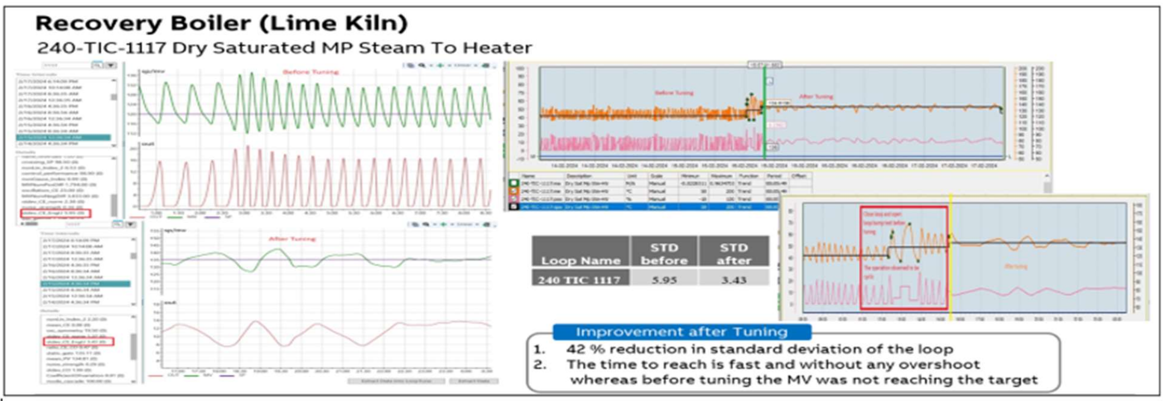


(Figure 4: Engineering user view for new tuning parameters identification and finalization)

Expected Results from LPM implementation:

Implementation of Loop Performance Manager has demonstrated up to 67% reduction in control loop oscillation and process variability across critical parameters, typical performance improvement in PID loops shall be as shown in figure 5. Tighter process control translates directly to:

- Reduced quality variability (up to 20% improvement documented)
- Fewer off-specification batches requiring remediation
- Improved consistency enabling premium product positioning
- Reduced equipment stress and extended asset life



(Figure 5: Loop Performance Manager implementation results)

LPM Success Story: Indian Paper Mill - Variability Reduction and Quality Improvement

Implementation Details:

- Scope: Tuning of 300 PID control loops across multiple units within an Indian paper plant
- Methodology: Optimized PID (Proportional-Integral-Derivative) control loops using ABB expertise
- Focus Areas: Process variability minimization and product quality enhancement in Pulp mills and paper machines

Benefits:

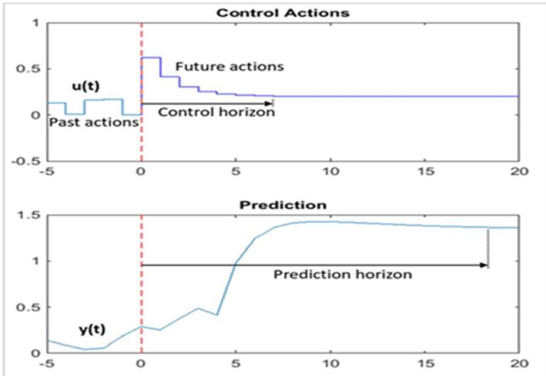
- Enhanced operational efficiency
- Minimized process variability
- Improved product quality across multiple production units
- Reduced manual tuning effort
- Greater operational control and consistency
- ROI – 6 Months

2. Expert Optimizer (EO)

Expert Optimizer has series of Advanced Process Control solutions series, for pulp mills and paper machines. Control is accomplished by applying a combination of predictive controls and pulp-tracking techniques to reduce variability. Pulp tracking is a concept that can track the performance of various key pulp properties through the process, such as moisture content in wood chips, pulp conductivity in brown stock washers, or chemical dosage in the first stage of bleaching. These process variables are tracked in space and time up to the location of interest. These transformed variables help build a soft sensor model that is then used in the appropriate APC module for online prediction of controlled variables. If off-spec pulp is produced for ten minutes at the digester, for example, the system can predict when this slug of pulp will reach the various bleaching stages and adjusts bleaching param-eters accordingly.

The APC platform consists of the following key features:

- Model and its adaptation: specify process model in transfer function form as shown in figure 6 and provides online adaptation
- Objective function: contains proper scaling's and weightings for making trade-off among CV's and MV's
- Constraints handling: includes a comprehensive set of constraints in predictive optimization
- Control mode provides proper interlock suspension and abort conditions considering control loop status
- Control tuning provides effective tuning parameters to achieve fast setpoint response and disturbance reduc-tion
- Economic optimization: allows end users to optimize economic objectives by setting proper CV's and MV's ranges and targets



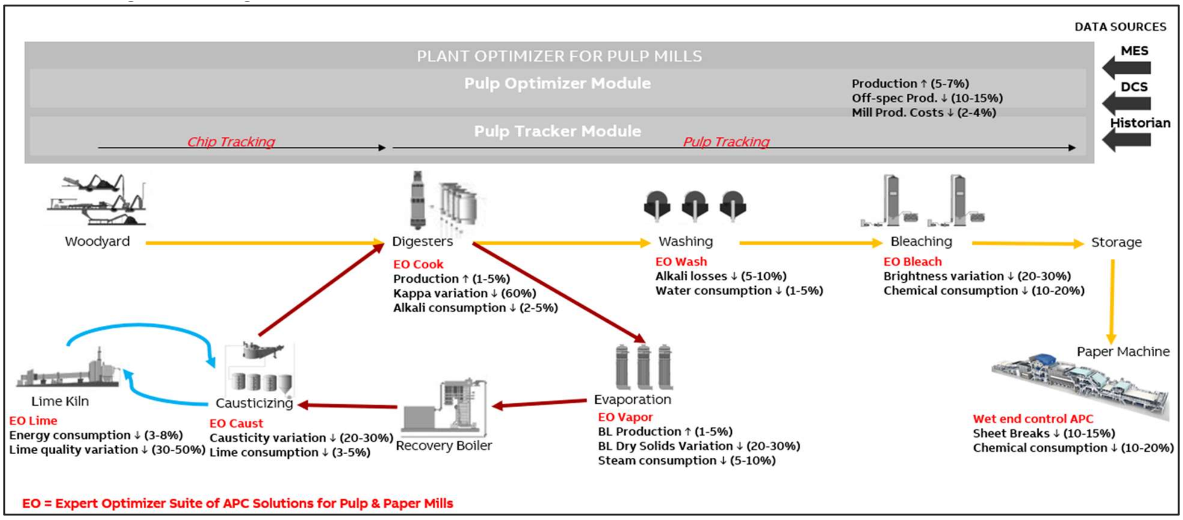
(Figure 6: Future control actions and corresponding predicted responses)

Expert Optimizer has multiple APC solutions suite catering to the needs of the complete pulp and paper manufacturing processes, as shown in figure 7.

APC solutions for fiber line: Cook/C for continuous Digesters, Washing, Bleaching

APC solutions for chemical recovery: Evaporator, Causticizer, Lime Kiln.

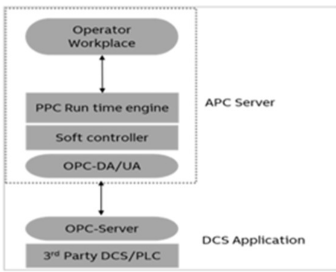
APC solutions for Paper Machines: Wet end Control APC, Refiners APC



(Figure 7: Expert Optimizer - APC solutions suite for Pulp mills and Paper Machines)

Expert Optimizer Architecture.

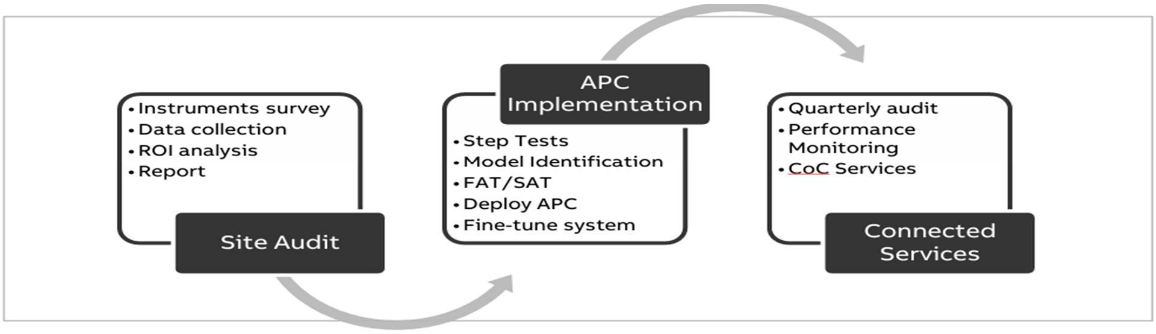
Predictive Process Control (PPC) is a Advanced Process Control (APC) platform within 800xA DCS environment. It is based on Model Predicative Control (MPC) technique that is applicable for various process industries. PPC has been applied to multiple pulp and paper processes such as lime kiln, bleaching, causticizing, paper machine wet end, etc. PPC can be applied as an integrated solution within ABB's 800xA DCS system or delivered as a standalone application with respect to a third-party DCS as illustrated in Figure 8. EO solutions form the fiber-line and chemical recovery process are based on MPC technology, a popular technique for advanced control.



(Figure 8: Standalone configuration for 3rd party DCS system)

Expert Optimizer Implementation

The successful implementation of APC solutions requires tight integration of the control strategies with the under-lying process control system. Before EO solutions can be applied to the control system, implementation process follows the proven three-phase delivery methodology - diagnose, implement, and sustain - to ensure optimal performance and ROI, as shown in figure 9.



(Figure 9 : APC Implementation and Delivery Methodology)

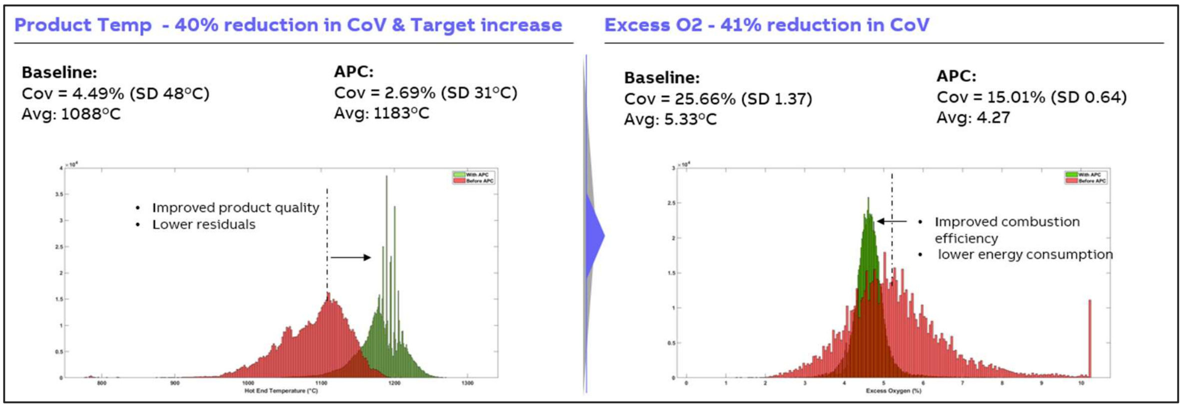
Diagnose: Fingerprint Service identifies, classifies and helps prioritize opportunities to improve the performance of your pulp production. Data from your process control systems is collected during scheduled and on-demand analyses and compared with best practices in the industry. This quickly pinpoints issues to ensure optimal performance of pulping or recovery process, improving reliability, availability and operational performance. The benchmark can be used as baseline performance to measure the impact of APC

Implement: Based on a thorough analysis, an implementation plan is developed by the control experts and the customer through a collaborative review. After the plan has been agreed upon, control experts will conduct tests to identify the process dynamics and build an MPC controller based on process model. Subsequently, this model will be deployed in the PPC platform. Phased implementation ensures that the process bottlenecks and instrumentation issues are identified and resolved before the APC implementation, ensuring process and equipment are ready to accept and implement optimized setpoints from MPC Controller.

Sustain and Continuous Improvement: All APC solutions leverage the Collaborative Operations service delivery model to provide 24/7 monitoring capabilities to sustain benefits and maintain control performance throughout changing mill / process conditions. Data collection and continuous or periodic monitoring helps to develop operational trends to allow early detection of abnormalities and provides continuous improvement action. Performance Monitoring Services: EO solutions also include a KPI module that calculates relevant control performance evaluation metrics for monitoring purposes. The performance KPIs should provide enough insight into the usage of the APC, process variability and chemical consumption metrics for tracking on monthly basis.

Expected benefits through Expert Optimizer

Optimized control and process parameters enhance quality performance by facilitating up to 50% reduction in quality parameters variations, refer to figure 10 below, reduce energy consumption (steam, electricity) and chem-ical consumption. Documented savings range from 2-8% depending on baseline performance and optimization scope. For energy-intensive mills, 4% energy consumption reduction translates to 200-500 ton CO_2 equivalent annual emissions reduction—supporting sustainability objectives and reducing regulatory compliance risk.



(Figure 10 : results from APC implementation in a pulp mill)

Expert optimizer Success Story: South Indian Paper Mill

A south Indian paper mill was facing a challenge, Lime kiln operators face issues with low thermal efficiency, high fuel consumption, process delays, build-up of rings and dust, overheating of refractory, poor quality of lime and increased emissions.

Expert Optimizer Lime Kiln was implemented in this mill with a multi-year site study assessed operational conditions with a tailored solution with quantifiable ROI, facilitated multivariable control and helped customer confidently achieve and exceed, their energy reduction targets for more sustainable mill operations.

Results achieved:

- Reduced fuel usage (Oil)
- Low excess oxygen
- Hot end temperature variation and excess O_2 variation reduction by 40%
- Higher efficiency point of operation with high utilization of APC
- ROI – 6 to 8 months

3. Plant Optimizer (PO)

Plant Optimizer for pulp mills connects production planning with real-time operations for end-to-end traceability, economic optimization and operational resilience. It helps production managers, engineers and operators align with production goals, respond quickly to issues and maintain consistent quality. The solution is a Digital Twin for the Pulp and Recovery processes, enables mills to operate closer to economic ideal conditions and supports future self-optimizing processes. Plant optimizer has two modules that can be used alone or together to improve collaboration.

Pulp Tracker

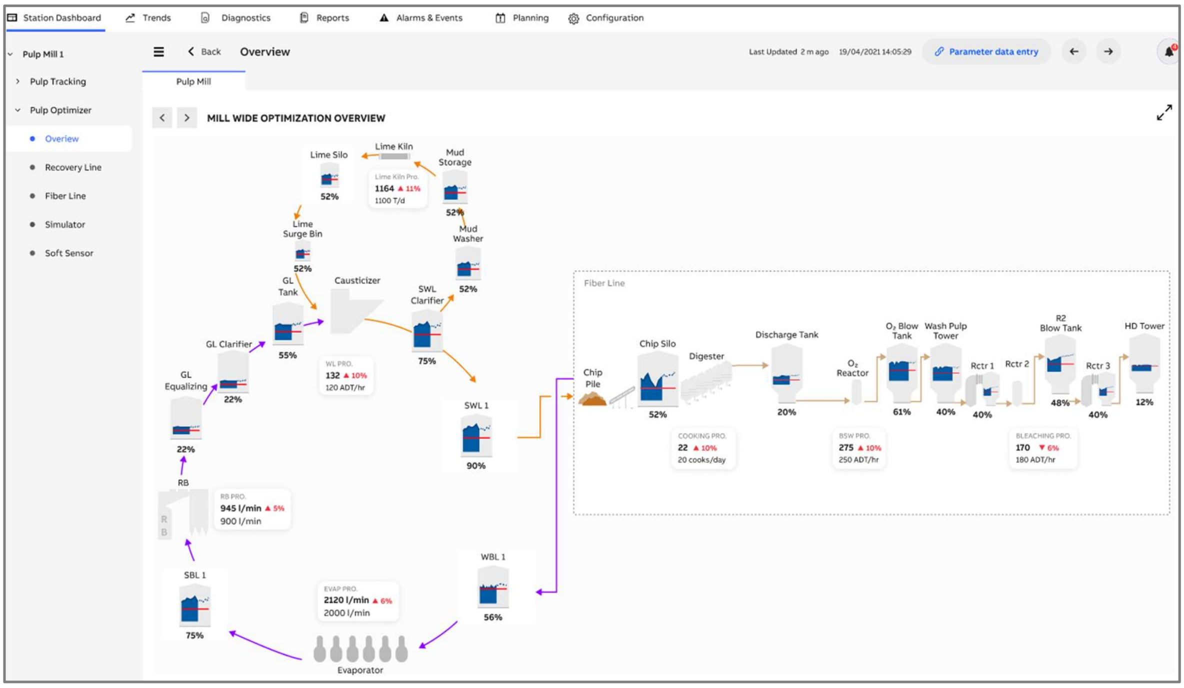
Reduce off-spec pulp through mill wide traceability

- Recipe management
- Diagnostics help
- Trends and role-based custom Report.

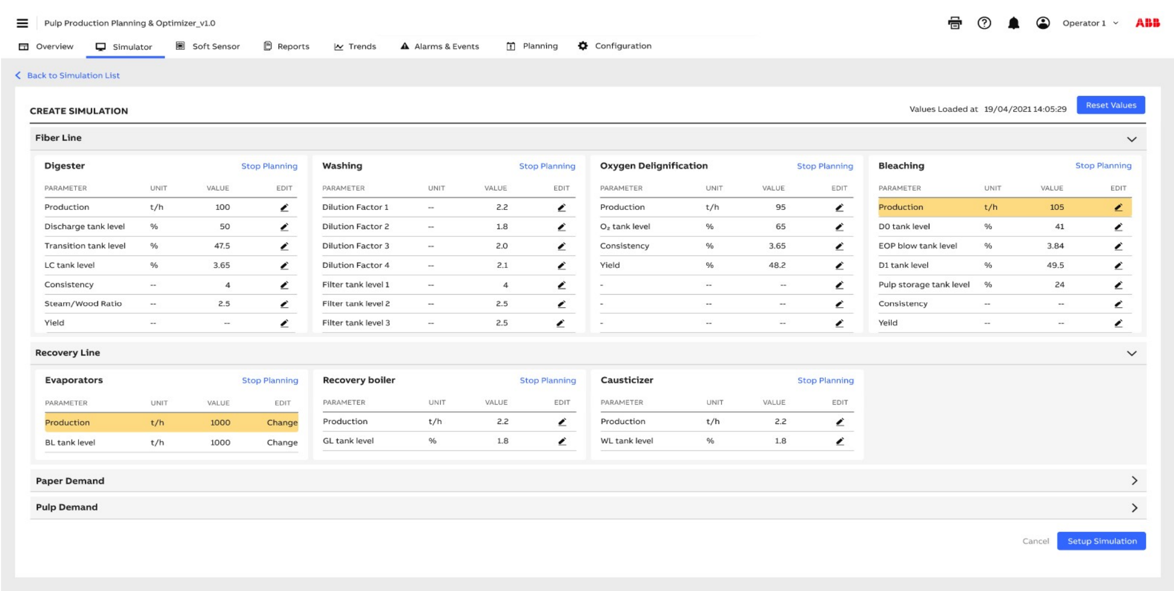
Pulp Optimizer:

Through various sub applications listed below Pulp optimizer enables pulp mills to Maximize throughput, lower inventories, and reduce production costs while being agile through economic optimization and operational resilience, figure 11 can be referred to for optimizer applications and figure 12 can be referred to for planning and what if simulations.

- Dynamic models
- On-Demand Optimizer
- Continuous Optimizer
- Soft Sensors
- Pulp production planning
- Stop planning
- Bottleneck analysis.
- What-if analysis



(Figure 11: Pulp and Recovery process overview dashboard –Plant optimizer)



(Figure 12: Production & Stop planning, Bottleneck Analysis Simulation view – Plant optimizer)

Plant Optimizer Implementation

Master Data Integration

Plant Optimizer requires accurate master data describing material flows, process parameters, equipment capabilities, and economic relationships. Critical inputs include: (1) Bill of materials defining pulping recipes and their yield impacts; (2) Process conversion factors linking inputs to outputs; (3) Cost structures for energy, chemicals, and materials; (4) Equipment capacity curves reflecting realistic throughput limits. Inaccurate master data pro-duces unreliable optimization.

Production Planning Integration

Establish formal integration between Plant Optimizer outputs and production planning processes. Define governance specifying how automated recommendations are reviewed, approved, and implemented. Implement feed-back loops so that actual results versus optimized targets inform future optimization.

Change Control and Governance

Establish formal change control processes ensuring that operational modifications recommended by automated systems receive appropriate review and approval. Document all changes, maintain audit trails, and establish pro-cedures for emergency override. Balance automation benefits against organizational governance requirements.

Plant optimizer expected benefits

Plant Optimizer delivers 1–3 percent production cost reduction by combining reduced variability, increased throughput, and lower resource consumption. Its economic optimization adjusts production targets dynamically to maximize revenue during high-price periods and boost cost efficiency when prices are low. Continuous optimization increases throughput by 3–5 percent and effective capacity by 4–6 percent, resulting in substantial revenue gains for mills with minimal capital investment. Scenario modeling helps mills find resilient production plans, supporting performance during supply chain disruptions or equipment maintenance.

Success Story Plant optimizer: North American Integrated Mill - Mill-Wide Optimization

A large integrated mill implemented all three solutions (Loop Performance Manager for foundational control, Expert Optimizer for bleaching processes, and Plant Optimizer for mill-wide optimization). Results documented over 18-month implementation:

- Production throughput increase: 4.8%
- Production cost reduction: 2.1%
- Energy consumption reduction: 5.3%
- Inventory reduction: 12% through improved production stability
- Off-spec material reduction: 9%
- Total annual benefit: 2.2% EBITDA improvement

Implementation required 18 months with:

- Months 1-4: foundational work (data quality, instrumentation audit, DCS compatibility);
- Months 5-10: Loop Performance Manager deployment across 600 loops;
- Months 11-16: Expert Optimizer development and deployment for three critical processes;
- Months 17-18: Plant Optimizer integration with MES. Key learnings emphasized importance of process engineer involvement in model development and phased transition to automation.

Conclusion

The pulp and paper companies can achieve the state of best optimized production to deliver highest quality products at the best possible production, the AI powered process performance solutions mentioned above can be put into implementation in a phased manner. Loop Performance Manager implementation helps addressing the performance issues with the sensors and control valves and redefined tuning parameters of the PID loops helps swift process and quality changeovers, Expert Optimizer the APC solutions can be implemented prioritizing the sub area within the mills which needs tighter process control and then the Plant Optimizer, Digital Twin for Pulp and Recovery processes to enable paper mills to progress from reactive control to fully autonomous operations, un-locking operational and economic value.

These solutions drive improvements in energy efficiency, environmental compliance, and workforce skills, supporting Sustainability Agenda of the Pulp and Paper companies. Documented results include up to 67 percent reduction in process variability, up to 5 percent higher production throughput, up to 8 percent energy consumption reduction, and 2 percent lower production costs. Successful adoption depends on high-quality data, instrumentation, process engineer involvement, and structured change management, leading to rapid ROI within one to two years. Mills using these digital solutions become technology leaders, continuously improving operations and workforce capabilities, and advancing toward Industry 4.0 excellence.