Rockwell Automation

Model Predictive Control
(MPC) for cement

Process optimization solution

Global cement production is expected to increase to **4.37 metric tons in 2020**

As of today, China now produces over half of the world's cement, and is adding capacity almost daily. The demand for cement is not constrained to only Asia: after the 2008 economic downturn in the United States, with a decrease to 71.5 million metric tons in 2009, consumption has gradually increased to an estimated 96.2 million metric tons in 2016 in the U.S.

Though cement is on the rise, competition has never been more challenging with the pressures of lower cost imports and lower levels of domestic production. This, coupled with plant disruptions for upgrades, closures, and fluctuating economic conditions, cement producers need to maintain profitability as margins narrow, and demand may be unpredictable.

At Rockwell Automation, we understand the requirements of the industry and how to meet the challenges of today, and tomorrow.

Source: https://www.statista.com/statistics/373845/global-cement-production-forecast/

The global cement market is expected to increase to 682.3 billion (USD) by 2025*, with a CAGR of 7.8% during the forecasted period. **Infrastructural development globally will drive demand to levels never before seen in the industry.**

This rise in global infrastructure investment is being led by countries such as China, India, and the U.S. As the infrastructure across these economies requires upgrade and modification, especially in the U.S., the demand for cement over the forecast period will be fueled by the need to match the growth of industry and the urbanization of once rural communities.

Demand for residential properties alone, driven by rising household income, will help invigorate the industry. Coupled with improving economic conditions in countries with emerging markets, the demand for retail and commercial construction is on the rise. With opportunity also comes challenges: ability to meet demand, increasing competition, rising energy costs and a market that may fluctuate rapidly.

*Source: Grand View Research, Inc., https://www.grandviewresearch.com/industry-analysis/cement-market

Manufacturing has changed dramatically in the past decade and rapid changes are certain to continue.

Producers are continually required to achieve more with less. Progressive producers meet these various challenges by leveraging technology to help reduce the costs and risks from operations. However, a common obstacle remains for many. Critical decision-making information often resides within plant floor and business systems that ineffectively communicate with each other.

Global competition and market volatility have intensified the need for improved decision-making solutions for manufacturers. In markets with high demand, the drive to extract additional capacity from existing assets is a top priority.

When demand is weak, the ability to determine optimal production to remain profitable becomes critical. The need to accurately understand the economic performance and available options from a facility has never been greater, nor has the cost of making wrong decisions ever been higher.

The Connected Enterprise

One way to meet the challenges facing cement producers is Smart Manufacturing. It is the gateway to a digital transformation from traditional systems that are now becoming more obsolete each year. Connected smart devices open new windows of visibility into processes. Data and analytics enable better and faster decision making. Seamless connectivity spurs new collaboration.

The Connected Enterprise™ makes all this possible. It converges plant-level and enterprise networks, and securely connects people, processes, and technologies. Across the world and in all areas of cement plants, we've been helping customers. We have been able to help them reduce their costs while improving their operations.

FT FactoryTalk
by **ROCKWELL AUTOMATION**

+

INTEGRATED CONTROL AND INFORMATION

○ **OPEN**

○ **SECURE**

○ **SCALABLE**

MPC solutions

- **INCREASE** production

- **ENHANCE** profitability

- **REDUCE** manufacturing costs

- **IMPROVE** product quality

- **REDUCE** environmental risk

Model Predictive Control

HELPING YOU EXCEED YOUR BUSINESS GOALS

Model Predictive Control (MPC) is a Predictive Analytics solution from Rockwell Automation. MPC helps manufacturers achieve precision in a dynamic market, reducing product variability, while increasing yield.

- Providing Predictive and Prescriptive solutions to Customers since 1991

- Commitment to Innovation

- Industry data scientists leveraging more than 160+ patents in the field of modeling, advanced control, analytics and optimization

Rockwell Automation is a leading global provider of industrial power, control and information solutions. In fact, we are the largest company in the world that is solely focused on industrial automation and information. It is our only business.

We serve a very wide range of industries from Automotive and Consumer Packaged Goods, to Mining and Oil & Gas. We have a long history of serving our customers. We are over 111 years old. We attribute our success over the years to our intense focus on:

- Technology innovation

- Deep domain expertise in all industry verticals that we serve, and

- A culture of integrity and corporate responsibility

Our passion for technology innovation is led by an unwavering focus on listening to our customers and providing practical solutions to their business challenges. This is what leads us to host the Automation Fair every year. We're here to share our vision, expertise, and the most contemporary products, software, services, and solutions for industrial automation, and we're here to learn from our customers on what is driving their business today and in the future.

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Rockwell Automation Model Predictive Control (MPC) Applications provide control and optimization of the process through patented, industry leading technology powered by our FactoryTalk Analytics platform and applications for cement producers.

WHY ROCKWELL AUTOMATION?

- Broad experience in Cement

- ValueFirst® focus for greater ROI

- Full MPC not partial with rules and fuzzy tech – Efficient, smarter, easier to maintain

- Involvement across industries improves best practice, drives product road map

- Diversity of applications drives design, customer focus drives design

- Advanced Analytics capabilities with our Innovation Suite platform

Providing the world's leading model-based predictive analytic software for Machine Learning **to improve our customers' profitability.**

Our solutions are focused on:

GRINDING

- Reduce energy cost up to 10%
- Increase throughput 10%
- Reducing sizing variability up to 50%
- Improve product grade quality

KILN

- Increase throughput up to 2%
- Decrease product variability up to 40%
- Reduce energy costs up to 2%
- Improve product grade
- Reduce emissions

SOFT SENSOR

- Soft Sensor predicts quality or process variable

MATERIAL BLENDING

- Reduce blend variability
- Reduce blend costs
- Improve raw material resource usage
- Improve downstream and end-user performance

UTILITIES

- Reduce energy costs
- Reduce emissions

ENVIRONMENTAL

- Improve environmental compliance
- Real-time Environmental Management
- Software CEM

Our Mission is to provide the World's leading model-based software to **improve our customers' profitability and sustainability.**

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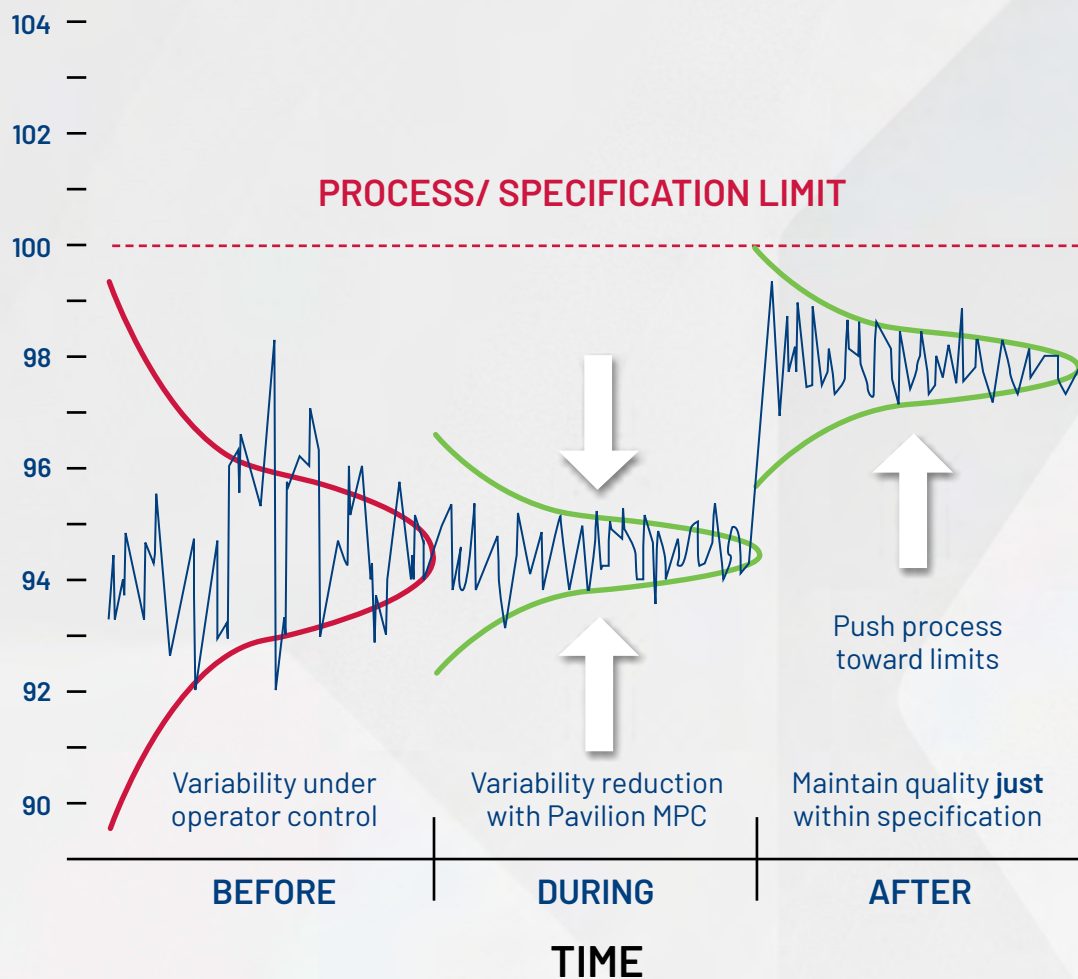
How MPC generates benefits

Model predictive control effectively reduces the variation of key product variables, optimization drives the average toward a more profitable operating point.

Maximum profitability is realized by operating a process as close to its constraints as possible while maintaining an appropriate margin of safety. The margin of safety is largely dependent upon the control system for the process.

Model Predictive Control Solutions are able to reduce process variability and enhance stability over and above what is currently possible with more traditional control schemes. This is accomplished through our multi-variable, nonlinear, model predictive control capabilities.

- **REDUCES** variability
- **ACHIEVES** "plant obedience"
- **MANAGES** the process within contraints
- **ACHIEVES UPLIFT –** operate closer to specifications and performance limits while maintaining safety margins

The facility: CVs, MVs, DVs

CONTROLLED VARIABLES (CVs)

Process variables that need to be maintained at a target or within a set range

MANIPULATED VARIABLES (MVs)

Process variables you can adjust that affect the CVs (typically PID set-points)

DISTURBANCE VARIABLES (DVs)

Measured process variables that affect the CVs that are not MVs

**MPC is the replacement of the driver with automated control that takes all variables into account for defined performance.**

CV
SPEED (MAXIMIZE)

CV
OIL PRESSURE

MV
ACCELERATOR

DV
WIND, ROAD, ROCKS
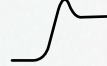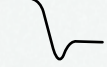
Controller matrix

Advanced Process Control (APC) software solutions deliver unparalleled modeling, prediction, control, and optimization capabilities in one unified solution.

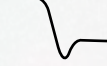Through superior data pre-processing, parameter formulation, modeling, and prediction techniques, APC provides extremely accurate representations of even the most complex processes. A multivariable predictive control solution is the only one in the market capable of synthesizing all available information — process knowledge, first-principle equations, or empirical models — into a comprehensive model of the production process.

Flexible and efficient, the control solution continuously drives the most out of your production assets to achieve your unique business objectives. Predictive analysis capability provides insight into key process parameters, reducing variability and eliminating the guesswork between infrequent lab sampling. Individual input output models are combined together in a matrix to give an overall picture of how the process behaves. This model matrix forms the heart of the MPC Controller.

Controller consists of a matrix of process model pairs that explain important interactions in the process...

Predict the values of the CVs by movement of all the MVs and DVs

+

Proactive control to achieve CV setpoints, prevent them from being violated, hence reducing variability

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PID	MPC
SINGLE VARIABLE IN & SINGLE VARIABLE OUT Set up a target and control process variable to the target. No awareness of how control changes impact other PID loops.	**MULTIVARIABLE IN & MULTIVARIABLE OUT** Control strategy based on a holistic comprehension of key process variables and their interdependencies.
FEEDBACK CONTROL The controller will take no action unless PV deviates from target	**PREDICTIVE CONTROL** Dynamic models developed through process step tests. Controller action based on current and future PV deviations from target.
INDIRECT CONTROL OF LAB MEASUREMENTS Control property variables through proxy (temperature, pressure, etc.)	**DIRECT CONTROL OF LAB MEASUREMENTS** Controller predictions of lab measurements used for control updated as available.
POOR ABILITY TO HANDLE PROCESS DELAYS During complex dynamic interactions	**EXPLICIT DYNAMIC MODELS** Full understanding of process dynamics and interactions
CONSTRAINTS Only internal awareness of loop's limits on set point and output	**CONSTRAINTS** Predict and monitor future values of constraints

EXPERT SYSTEMS	MPC
UTILIZES A MODEL OF OPERATOR REACTIONS	UTILIZES A MODEL OF PROCESS BEHAVIOR
RULE-BASED/FUZZY LOGIC CONTROL SOLVER	PREDICTIVE CONTROL SOLVER
INEFFICIENT (OPERATOR COMPREHENSION)	OPTIMAL (MATHEMATICAL SENSE)
HIGH MAINTENANCE REQUIRED	LOW MAINTENANCE

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Control structure before MPC

A PID loop system is limited to a single area of your entire process. This does not allow for proactive actions should any disruption in your system occur, such as unexpected changes in humidity, pump speeds, or feed variability.

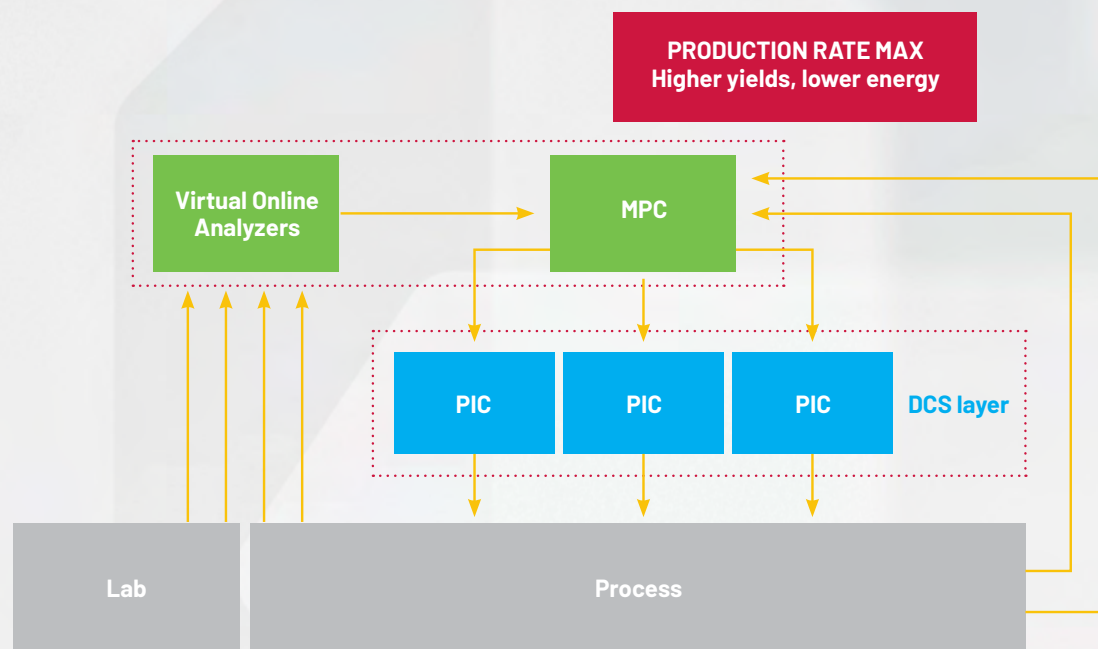Without a holistic view of any process, an operator will always be in reactive mode, and not in a predictive or prescriptive mindset.

Model Predictive Control sees the whole picture throughout the process and then is able to make adjustments prior to any slow-down or stoppage.

**??!!??!!
Step B, C, A, D?
Limits? How much?**

| PIC | PIC | PIC | **PLC/DCS** |

Lab

Process

BASIC REGULATORY CONTROL

MPC/optimization architecture overview

With MPC we can create virtual online analysers. These are inferential measurements that use easy to measure information in your process to provide continuous feedback of quality parameters that typically require lab sampling to measure.

These VOA's are typically used to provide feedback to our Pavilion8 MPC controller enabling continuous closed loop control of important quality parameters.

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Rockwell Automation Cement solutions

Rockwell Automation cement solutions improve production processes to facilitate quick response to market demands, continuous reduction of costs, consistent achievement of quality targets, and enhanced sustainability.

Our industry leading solutions address key areas of your plant including:

- **GRINDING & CRUSHING**
- **KILN OPTIMIZATION**
- **MATERIAL BLENDING**
- **PREDICTIVE QUALITY INDEX – SOFT SENSOR**

We help you achieve maximum performance through:

Operations & manufacturing intelligence

- Operations intelligence with IIoT analytics
- Production efficiency
- Capacity & product mix management
- Margin contribution & pptimization
- Materials management

Real-time compliance & sustainability

- Quality management
- Environmental management

INCREASE PRODUCTION

INCREASE THROUGHPUT

REDUCE VARIABILITY

REDUCE ENERGY

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MODEL PREDICTIVE CONTROL

Grinding and crushing

CUSTOMER CHALLENGES

Inconsistent product size and hardness

Inefficient energy usage

Disrupted production

SOLUTION

Model Predictive Control

- Manages grinding of mineral products to a size specification, while maximizing capacity which minimizes specific energy costs
- Increases throughput while maintaining safe operations within independent operating limits: mill loading, motor amps, cyclone pressures and sump tank level and density
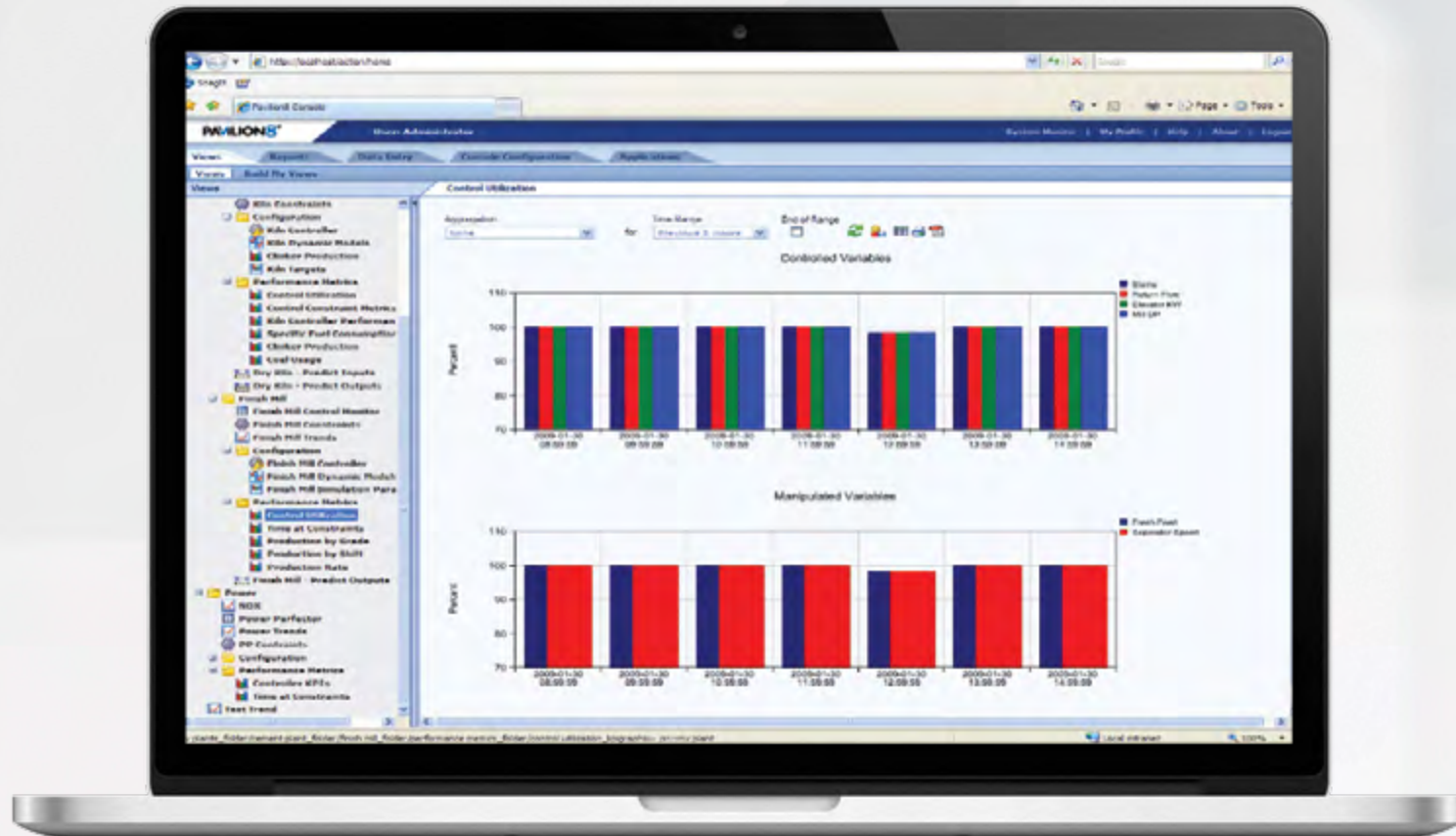- Responds to variable feed properties: hardness, particle size and grade

RESULTS

REDUCE energy cost per ton

INCREASE throughput

REDUCE sizing variability

IMPROVE downstream processing

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Grinding application screenshot

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Grinding application KPI screenshot

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MODEL PREDICTIVE CONTROL

Crushing or grinding application

MONITOR AND CONTROL

- Monitoring and controlling production can significantly reduce process variability, increase overall production rate and reduce energy cost per ton of product

- Real-time visibility of production and energy metrics compared to a baseline promotes a performance-driven culture

- Easily configured to meet individual and specific operational objectives. Application predicts and controls multiple process parameters in real-time

- Acts at a very high frequency for efficient and accurate calculation of controller setpoints

- Predicts internal process and quality parameters

- Control actions are updated continuously based on actual process values

- Incoming feed rate is increased and internal recirculation streams are keptin balance

- Circuit classification is controlled, taking throughput and sizing into account

- Constraints are taken into account to meet throughput, energy and product specification objectives

- Product sizing prediction (Predictive Quality Index – SoftSensor) used to improve feedback to the control application and boost overall production performance

IMPROVE EFFICIENCIES AND REDUCE COSTS

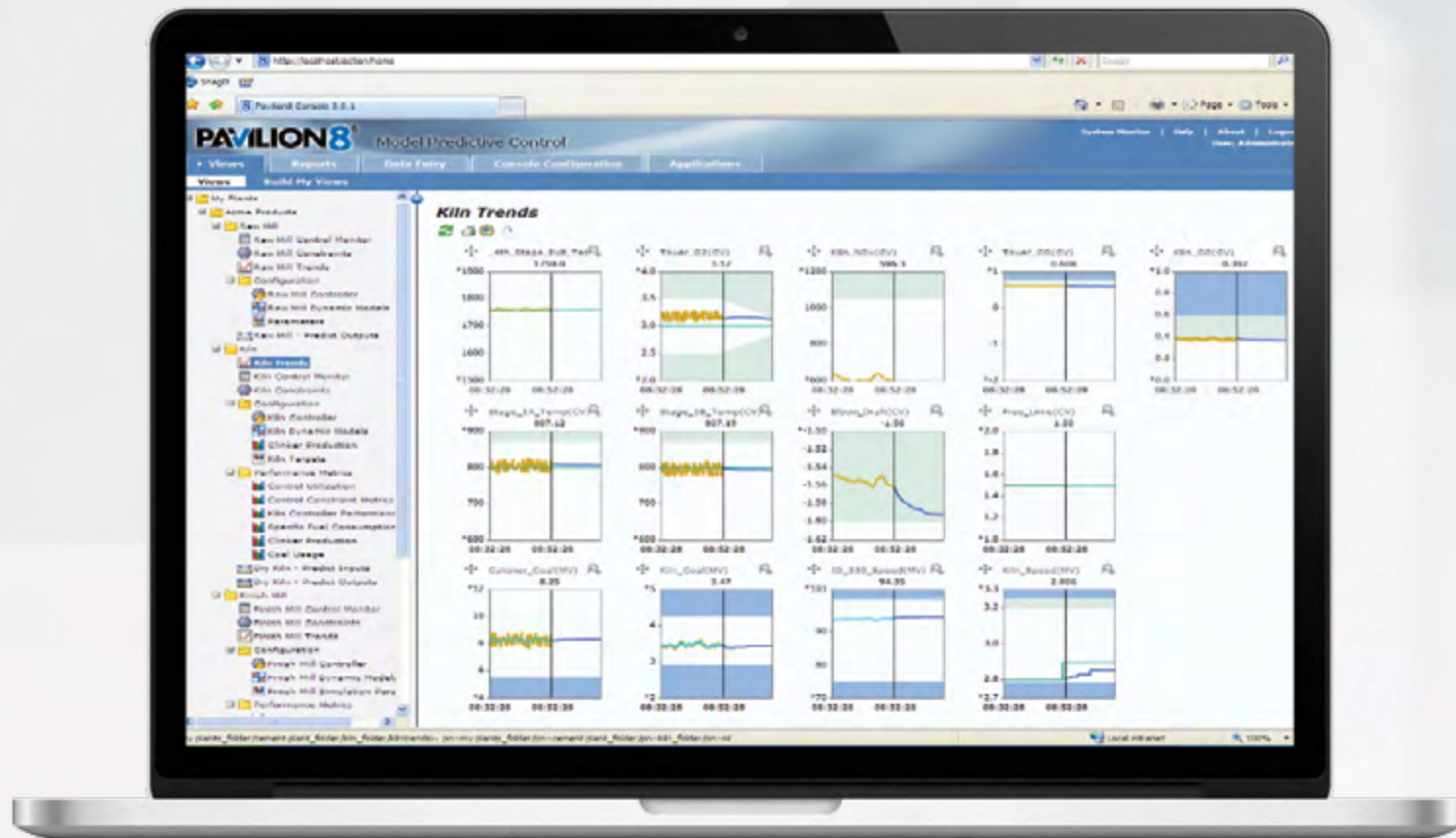# Crushing or grinding application

ENERGY USAGE

- Real-time performance management to promote consistent energy awareness, process evaluation and pro-active decision making

- Reducing energy usage lowers the direct energy cost component and delivers the added benefit of reducing greenhouse gas emissions from upstream power generation
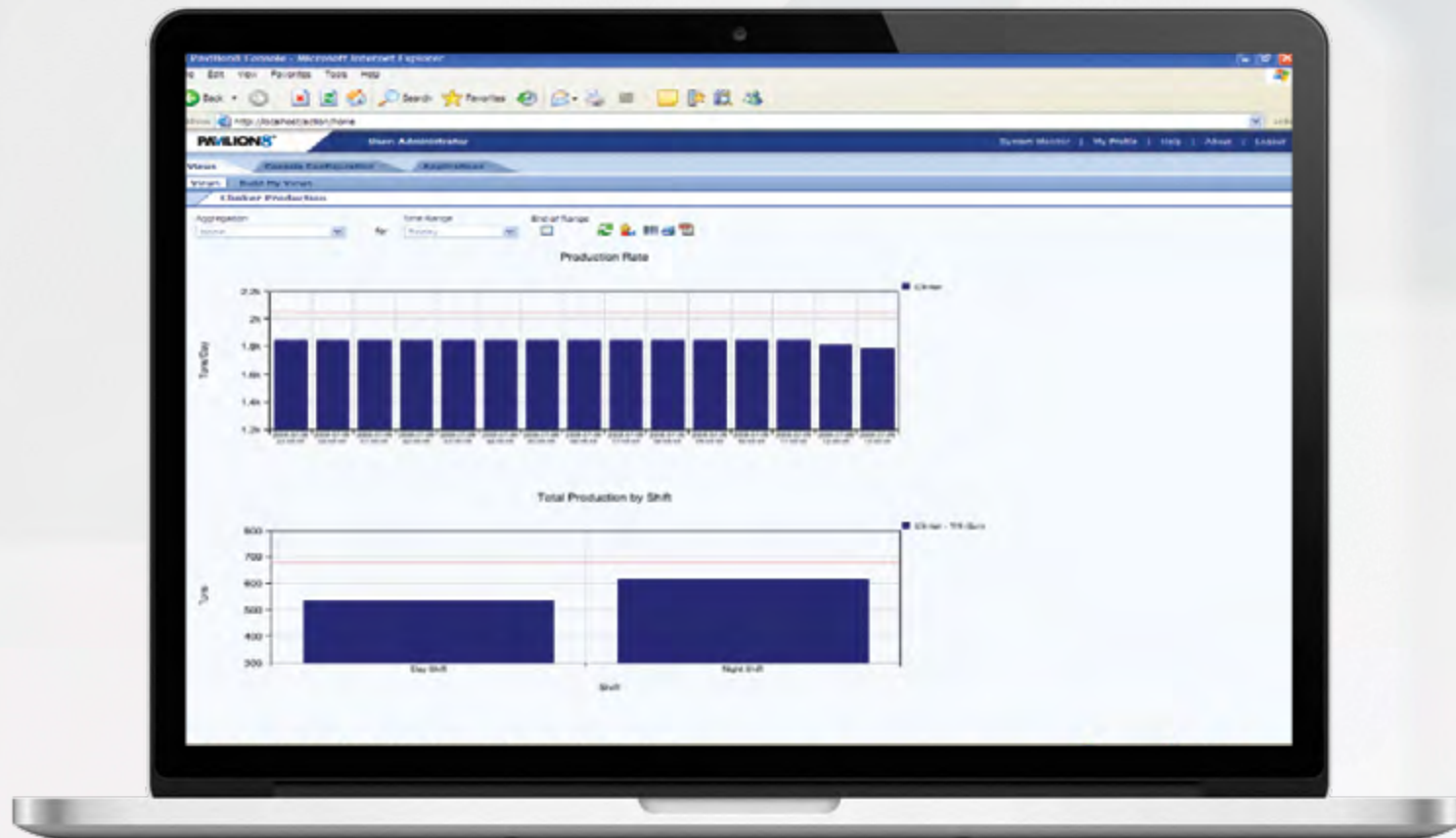
OPTIMIZATION

- Provides control performance by minimizing the disturbance effects from material variations and feed interruptions

- Real-time optimization is achieved by increasing throughput to plant constraints and reducing unit cost per ton
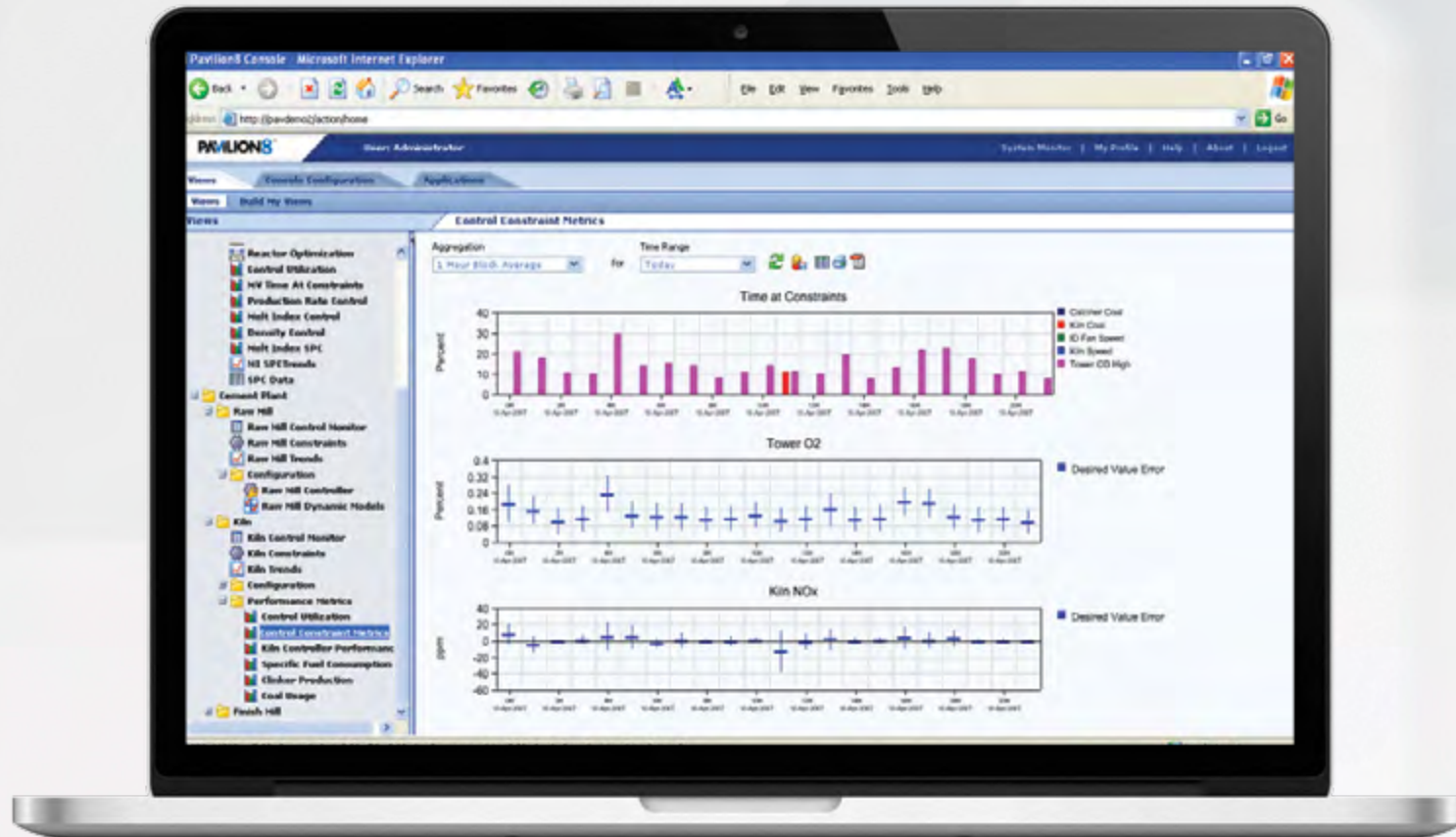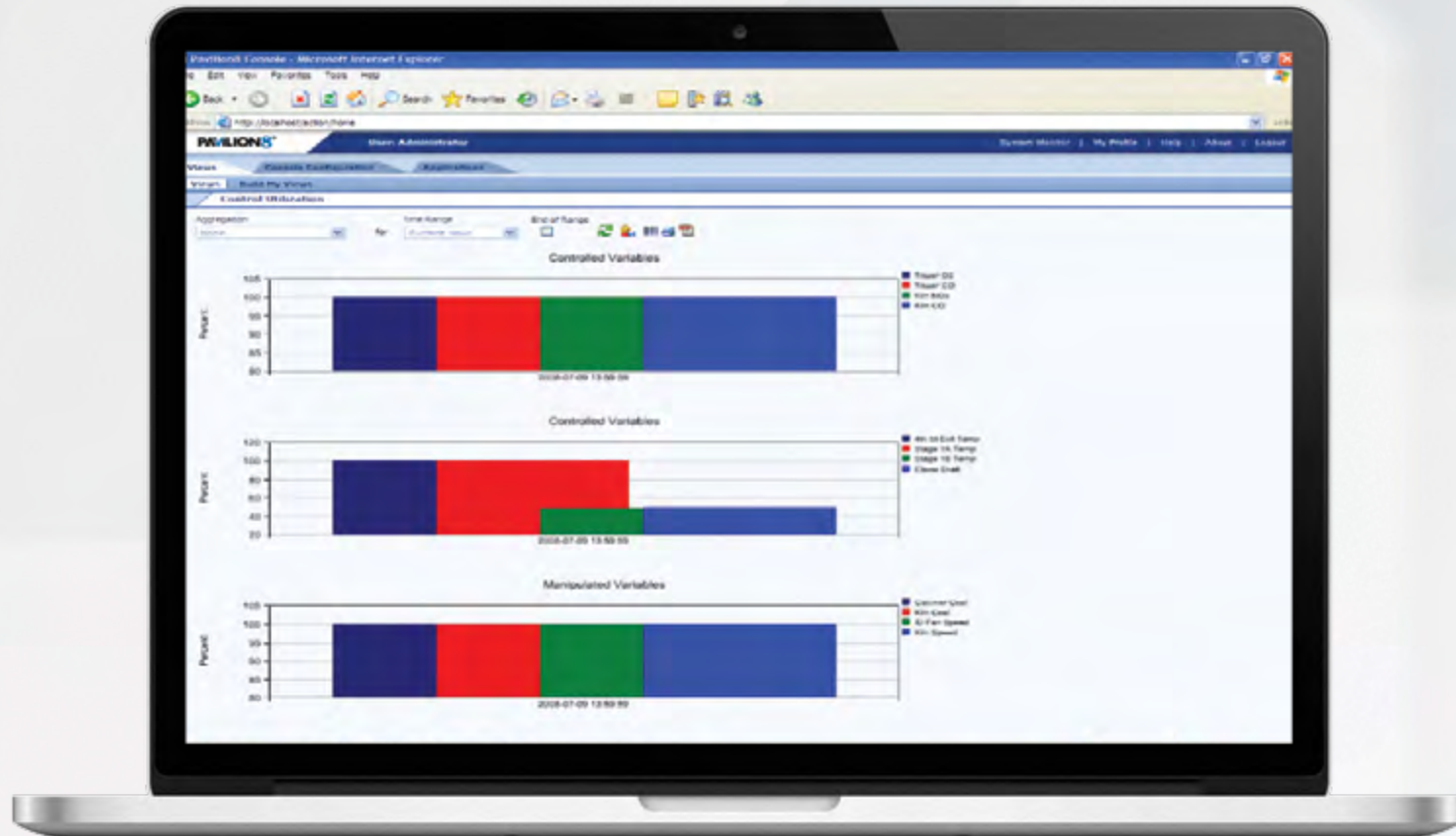
IMPROVE EFFICIENCIES AND REDUCE COSTS

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Kiln application screenshot

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Kiln production KPI screenshot

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Performance metrics screenshot

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Process variables screenshot

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MODEL PREDICTIVE CONTROL
Kiln optimization

CUSTOMER CHALLENGES

High energy costs due to interactions

Too much water in smelter feed

Unrealized production capacity

SOLUTION

Model Predictive Control

- Controls fuel, combustion air, fluidization air or rotary dryer speed to react to the amount of feed and feed quality by coordinating the set-points written to lower level control loops
- Responds to equipment and process constraints and product quality requirements

RESULTS

REDUCE energy costs

MAXIMIZE throughput

DECREASE product moisture variability

IMPROVE EFFICIENCIES AND REDUCE COSTS

Kiln control

MONITOR AND CONTROL

- Monitoring and controlling production can significantly reduce process variability, increase overall production rate and reduce material losses as well as energy costs per ton of final product

- Real-time visibility of production and energy metrics compared to a baseline promotes a performance-driven culture

- Easily configured to meet individual and specific operational objectives.

- Application predicts and controls multiple process parameters in real-time

- Acts at a very high frequency for efficient and accurate calculation of controller setpoints

- Constraints are taken into account to meet throughput, energy and product specification objectives

- Predicts internal process and quality parameters

- Control actions are updated continuously based on actual process values

- Incoming feed rate is increased and energy usage is reduced.

- Product quality and consistency is controlled, taking throughput and process condition into account

- Process stability is achieved through constraint variables to prevent overloading

- Product quality prediction (Predictive Quality Index – SoftSensor) used to improve feedback to the control application and boost overall production performance

Kiln energy

ENERGY USAGE

- Real-time performance management promotes consistent process evaluation and predictive decision support, reducing the time to corrective and predictive actions
- Reducing energy usage reduces direct energy cost components and greenhouse gas emissions

OPTIMIZATION

- Provides improved control performance by minimizing disturbance effects from process variations and assists in achieving real-time optimization
- Real-time optimization is achievedby increasing throughput to plant constraints and reducing unit costper ton

RESULTS

REDUCE energy cost per ton

INCREASE throughput up to 6%

REDUCE sizing variability up to 40%

IMPROVE downstream processing

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Kiln emissions

CUSTOMER CHALLENGES

Inconsistency inmaterial moisture

High energy use in production

Excessive emissions

SOLUTION

Model Predictive Control

- Control combustion atmosphere to optimize fuel economy and ID fan capacity utilization
- Monitor the kiln product quality
- Manage kiln constraints such as exit O2, CO, NOX stage temperatures, kiln drive amps, calciner heat input, fan speeds and pressure
- Responds to variable feed properties

RESULTS

○ **INCREASE** use of alternative fuels

○ **REDUCE** energy costs

○ **INCREASE** throughput up to 6%

○ **REDUCE** clinker free lime variability up to 40%

○ **REDUCE** emissions

○ **IMPROVE** environmental compliance

How does MPC work?

Understanding the relationships between variables and how they interact is key to modeling of a process. Once these variables are identified, control can be achieved, predictably. It's like having your best operator on the job every minute of every day of the year.

The application responds to equipment and desired process constraints and product quality requirements. This allows operators to run the plant at maximum capacity while maintaining quality standards and specifications. Model Predictive Control enables operations to increase production by utilizing existing equipment and systems to perform at their maximum potential through an advanced control strategy. This results in greater throughput at reduced energy costs per ton.

Benefits

- **INCREASE** production
- **IMPROVE** quality
- **REDUCE** sp. energy use
- **REDUCE** variability

SAMPLE KILN MATRIX

	COOLER UNDERGRATE PRESSURE (CV)	BURNING ZONE TEMP (AND FREE LIME) (CV)	BOTTOM STAGE EXIT TEMP (CV)	KILN CO (CCV)	KILN FEED/SPD RATIO (CCV)	TOWER EXIT O2 (CCV)	(CV)	KILN DRIVE AMPS (CCV)	3ARY CRUSHER LEVEL (CV)	3ARY CRUSHER CONSTRAINTS (CCV)	3ARY BELT 1 CONSTRAINTS (CCV)	3ARY BELT 2 CONSTRAINTS (CCV)
MV KILN SPEEDS	X	X	X	X	X	X						
MV ID FAN SPEEDS			X	X		X						
MV KILN FUEL(S)	X		X	X								
MV CALCINER FUEL(S)				X				X	X	X	X	X
MV FEED					X				X	X		X

Legend:
- ↕ Upper and lower constraint
- ▔↑ Upper constraint
- ↓▁ Lower constraint
- ⭕↑ Maximize
- → Target

Predictive Analytic Machine Learning

Predictive Analytic Machine Learning can be leveraged throughout a cement facility to provide additional oversight. Many Soft Sensors are in use to drive quality control within the previously described MPC applications where no online analyzer is available. Predictive Maintenance targets any equipment that rotates or has concerns on failure or high maintenance costs: mills or mill components, kiln drives, combustion air fans, conveyors, critical pumps or even trucks with connected sensors. Improve maintenance dispatch timing to improve the return for every maintenance dollar spent.

Anomaly Detection is very useful for any equipment section that periodically goes wrong and providing operators early insight into developing problems with kiln wall ring formation or gas flow blockages, ball mill losses, or equipment failure concerns where there is not an existing history of identified failures. With Anomaly Detection you can frequently gain advanced warning on detectable issues (measurement deviations) and resolve them to minimize periods of upset or poor performance.

If MPC is continuously driving good periods of plant performance to the highest levels, many of these predictive analytics are reducing time spent performing abnormally. Two collaborative drives to increase cement plant profitability.

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ValueFirst

THE WAY WE DO BUSINESS

ValueFirst is the Rockwell Automation unique customer engagement process that guarantees measurable value and lasting results. ValueFirst aligns every aspect of the Rockwell Automation people, process and product with customers' business needs to deliver and demonstrate the incremental and cumulative value of our solutions.

The ValueFirst methodology encompasses every step in our customer engagement process. From a simplified contracts process to a uniform set of performance metrics on every Model Predictive Control (MPC) and Environmental Compliance solution, we are is dedicated to delivering the highest possible value to customers, faster and better than alternative solutions.

ValueFirst® project methodology

Assess	Deliver	Audit	Sustain
• Propose & plan • Confirm business value • Set expectations • Determine benchmark metrics	• Design, develop, deploy • Data gathering & validation • Model development • Application deployment	• Commissioning • KPI configuration • Training • Performance validation	• Support • Knowledge transfer • Performance metrics • Ongoing support
VALUE-BASED PROPOSAL	**VALUE-BASED SOLUTION**	**MEASURE VALUE**	**ON-GOING VALUE**

Sustained value services

Support programs to help protect your investment

The Sustained Value Team is committed to keeping your investment at its optimal performance level, and our program of value-added services is designed to help deliver results to your bottom-line year after year. To achieve this goal, we off er proactive support to maximize your operations. This includes new software features and industry-specific applications, solutions and services to help customers increase production, reduce costs, improve quality and increase profitability.

Our Sustained Value Program provides you with the foundation to continue to leverage our industry leading solutions, ongoing insight into plant, application and solution performance and a proven path to achieve the greatest possible annual return on your investment in solutions from Rockwell Automation.

Key Benefits

- Proactive maintenance for optimal performance
- Improved application availability
- Refresher training for maintaining operator expertise
- Greater software availability through product enhancements, updates and quarterly application backups
- Enhanced visibility of application performance through quarterly status reports
- Disaster restoration of MPC application

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