# T74:Fundamentals of Model Predictive Control

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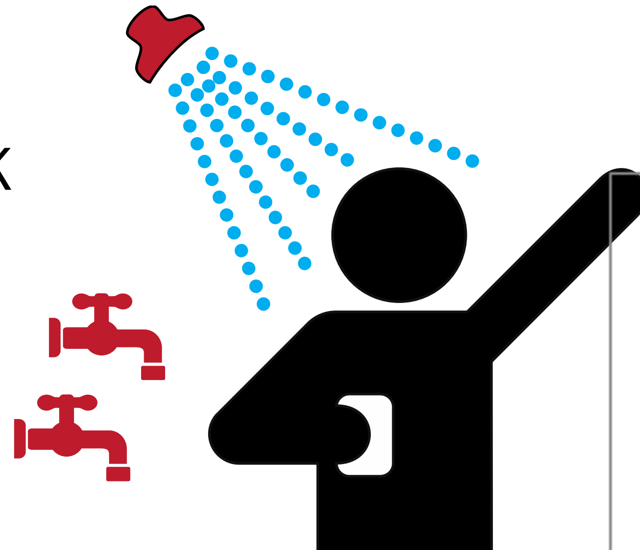
# The Fundamentals of MPC

- What is MPC
- Is my control problem a MPC problem? And how?
- What is the value of using MPC on my problem?

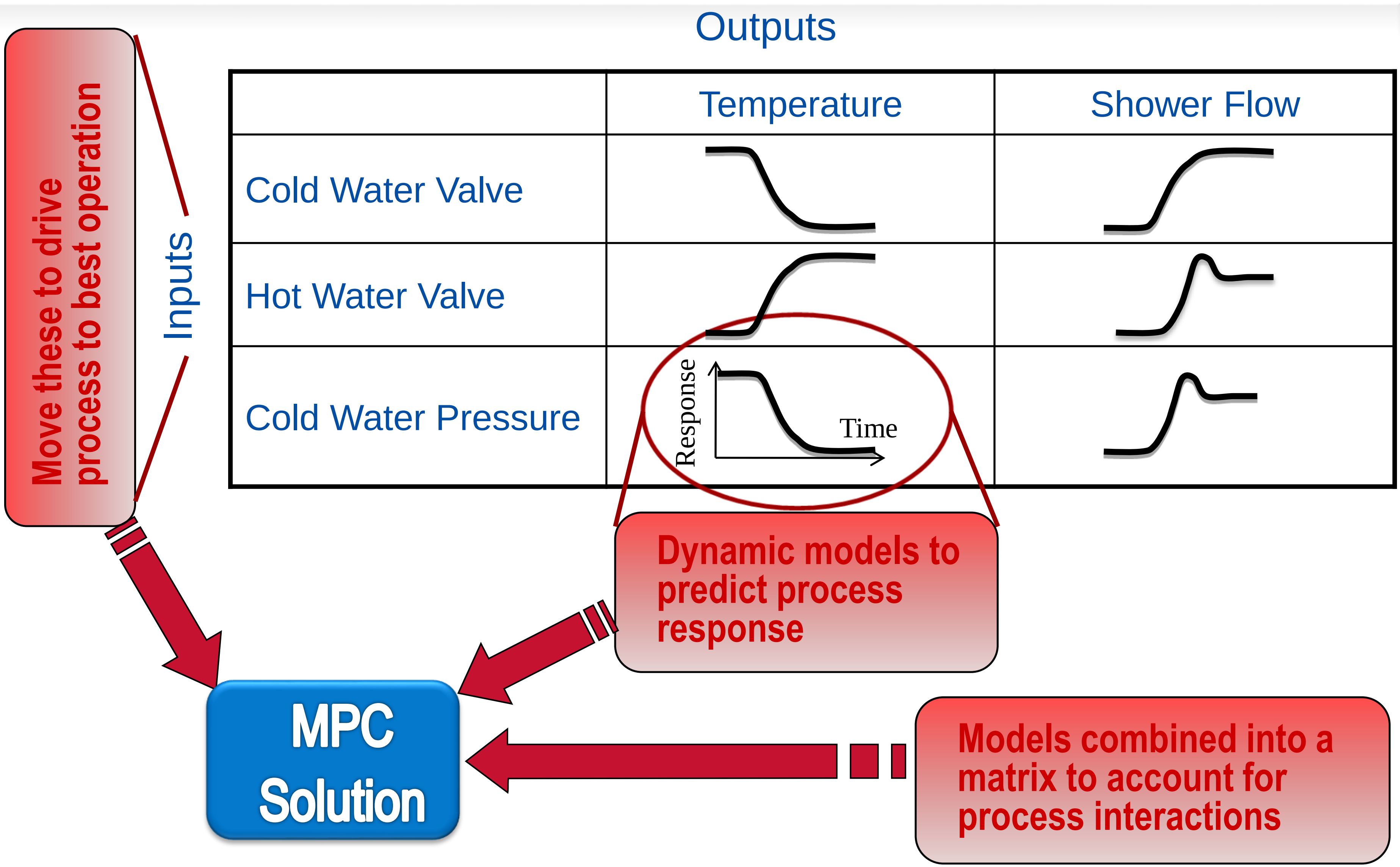
# A Simple MPC Problem

- Goals:
  - Get everything wet
  - Keep the temperature OK
- MV: Manipulated Variables
  - Hot water valve
  - Cold water valve
- Constraints:
  - Clean by 9:00
  - Don’t burn (T < 100° F)
  - Don’t freeze (T > 70° F)
- CV: Controlled Variables
  - Water temperature
  - Water flow



Handle Disturbances

# What is Model Predictive Control?



# Why Use- Model Predictive Control

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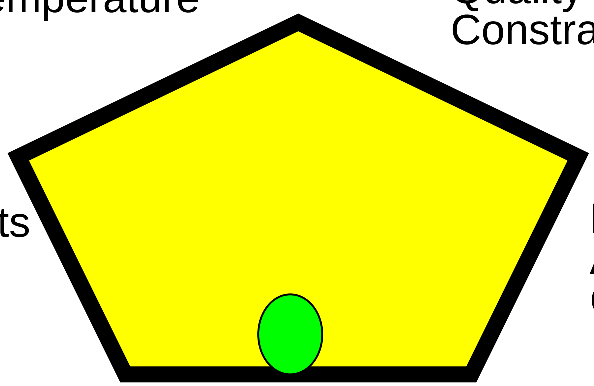
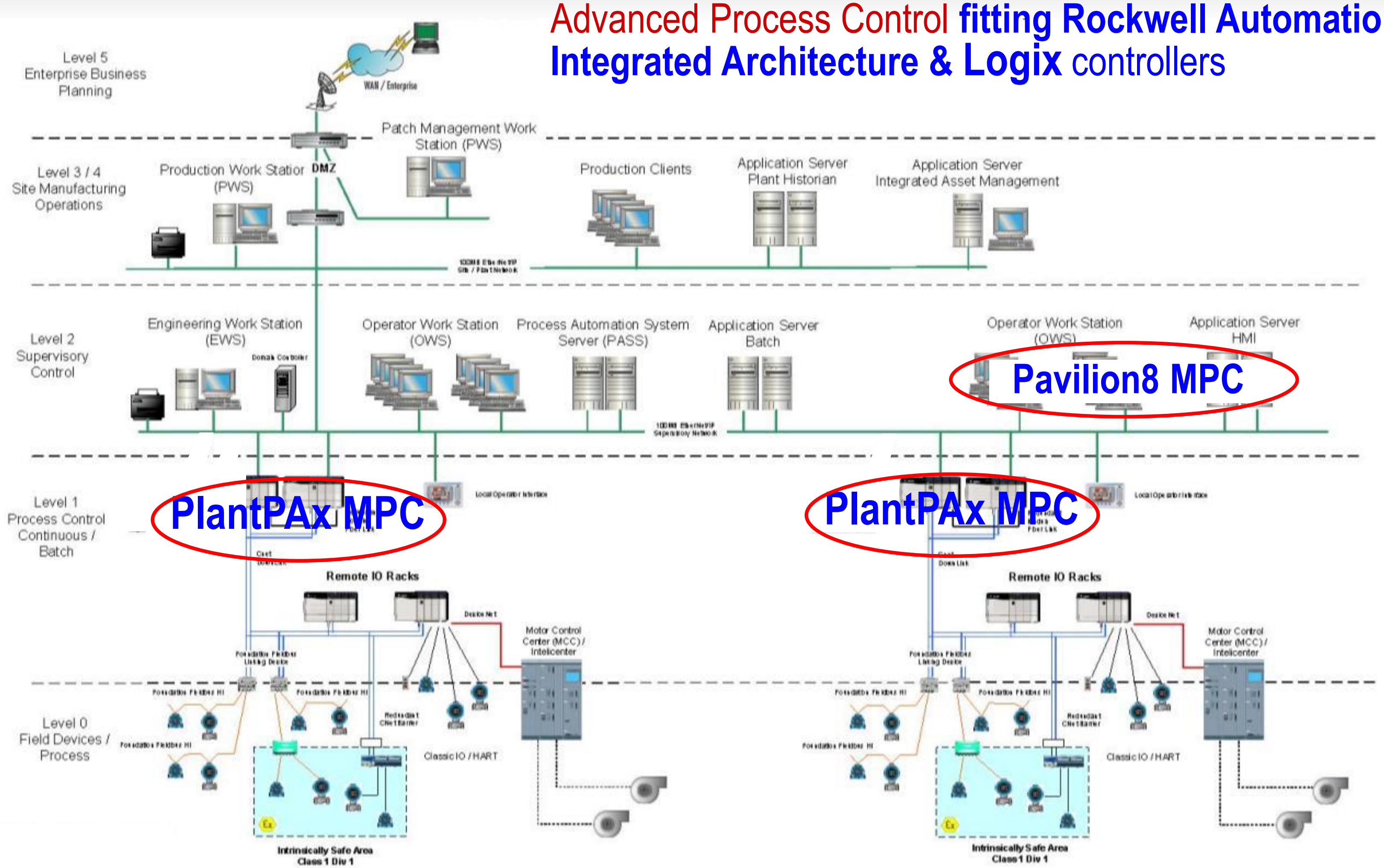
- Coordinate multiple interacting PIDs
- Directly reject influence of disturbances
- Handle slow or complex processing lags
- Actively enforce/push constraints

**MPC - Good for Multiple variables, long time constants, quality control**



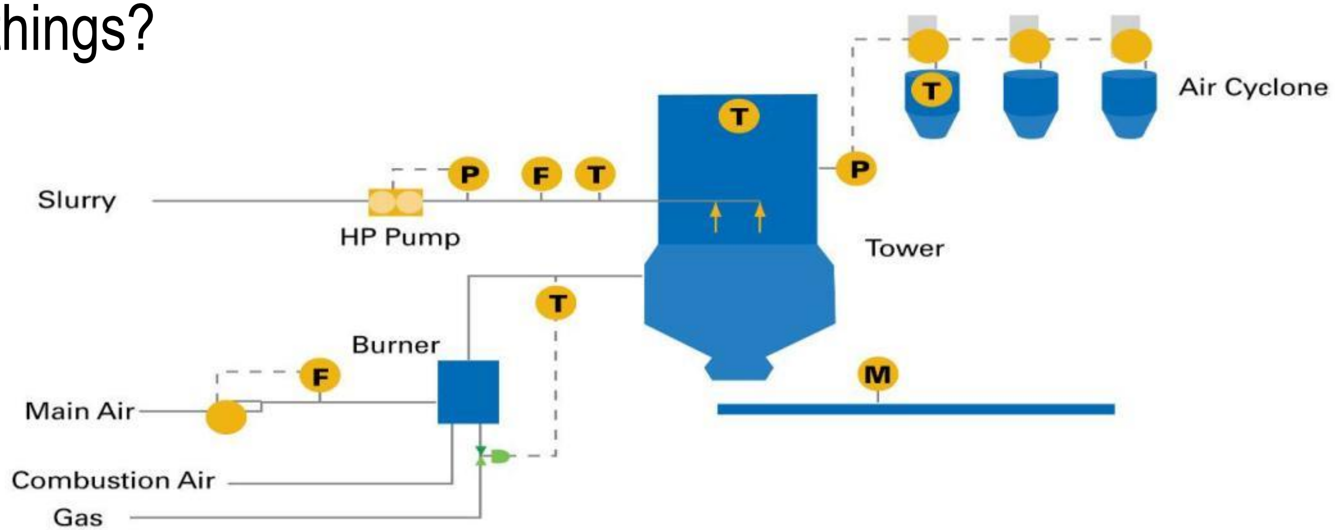
# Where does MPC fit in IA

Advanced Process Control **fitting Rockwell Automation Integrated Architecture & Logix** controllers



# Multivariable control issues

- What do you want to accomplish (better)?
- What do you have to adjust these objectives?
- Are there limits that must be observed?
- Are there qualities that cannot easily or reliably be measured online?
- Are there things outside your control that will shift things?

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# MPC Requirements/ Basics

- Material Balance is maintained: What comes in must balance what goes out. Level or Pressure control, discharge constraints (shower drain), balance of plant.
- Energy Balance is maintained: the heat that is added must balance with the heat that is removed. Temperature control, reactor duty balancing, (frequently) quality control.
- Quality targets are maintained: the product being produced must be sellable, dischargeable or rejected/recycled. This includes primary products, co-products, by-products and residuals sent to the drain/utility plant. Residence time, feedstock chemistry/ratios, temp/pressure control.
- Environmental and Safety constraints must be maintained.

# MPC Design Questions

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- What are your current operating challenges?
- Where do you see the most significant variability?
- What is your biggest source/cause of losses and inefficiency?
- How are you dealing with this today?
- Do you make off-spec/off-grade/discounted product?
- How do you manage your product quality today?
- How do you measure success and measure a good day from a bad operating day?
- Who here knows more about this problem than anyone else?
- What do you get calls on after hours from the plant?

Objectives/CV's

- What are your current processing limits?
- What keeps you from pushing up capacity today?
- What limits you from increasing yields?
- What prohibits you from using less fuel/steam/energy today?

Constraints

# MPC Design Questions: Step 2

- What controllers (PID/valves) provide key ways to affect my control objectives?
- What controllers (PID/valves) are operators moving today to improve/adjust quality, efficiency, respond to these constraints?
- What controllers (PID) run generally in automatic and do the right thing today (e.g. are most LIC left as PID loops and left out of MPC scope)?

**Controllers/MV's**

- What quality, constraint, economic objective parameters should I calculate or control closer to real-time to achieve benefits?

**Calculations/SoftSensors**

- Are there disturbances that you can measure and respond to faster than you can respond to a CV alone? What DV's are significant, modellable and dynamically useful? Which are only SoftSensor not MPC inputs?

**Disturbances/DV's**

- How will/can you build models (fundamental, testing, reports/studies)?
- What uncertainty/risks can you foresee? Options to overcome/mitigate?

# Applied PlantPAx MPC Coating Oven

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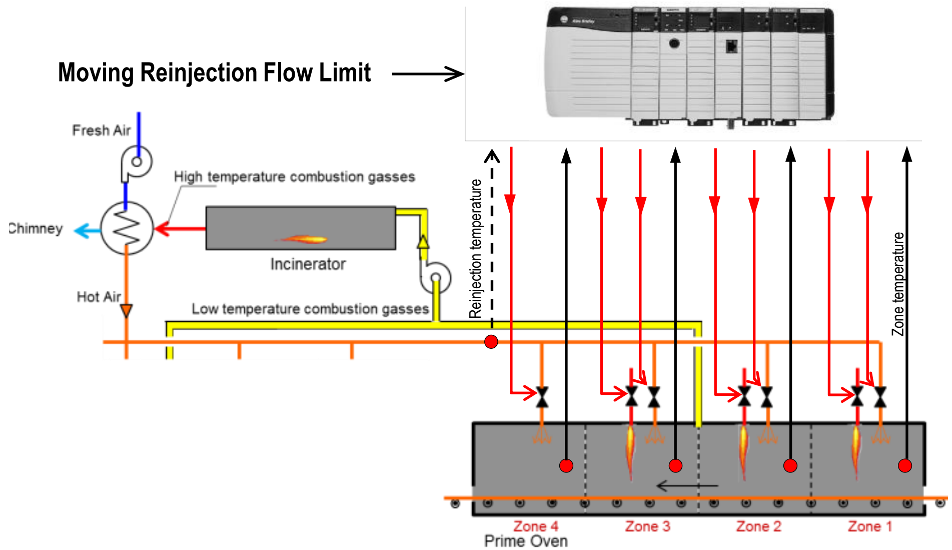
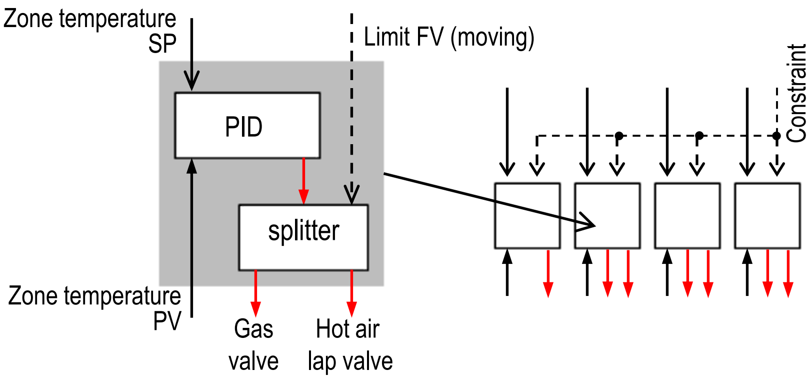
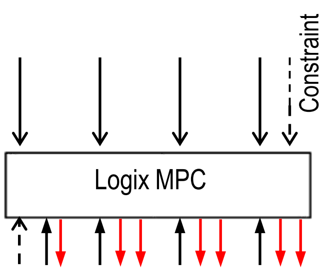
Organic Coating Oven




CV × MV × DV

4 × 7 × 2




**Quality** increased as variability decreased

**Energy** equal or less

**Wear-out** lowered

**Existing Control** **New Control**

# What's it worth?

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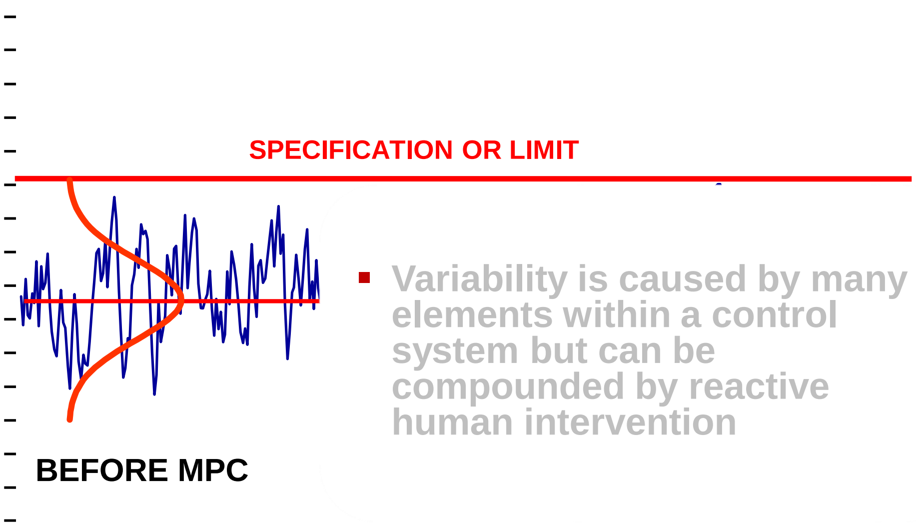
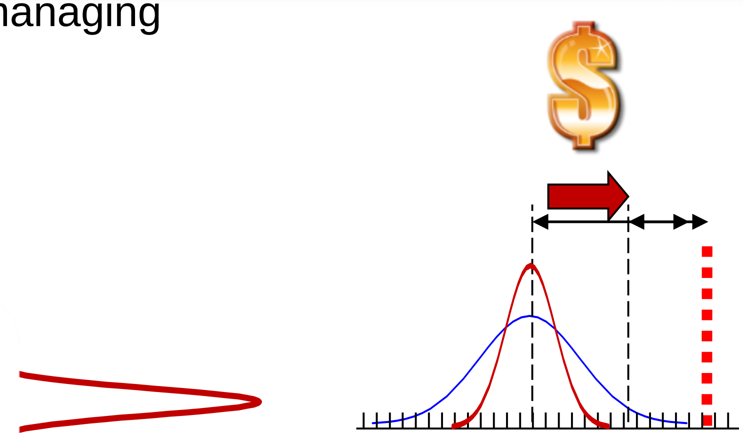
- Achieve Moisture Uplift closer to limits whilst managing process constraints and safety margins




- Variability is caused by many elements within a control system but can be compounded by reactive human intervention



- Reduction in Variability is typically up to – 60%

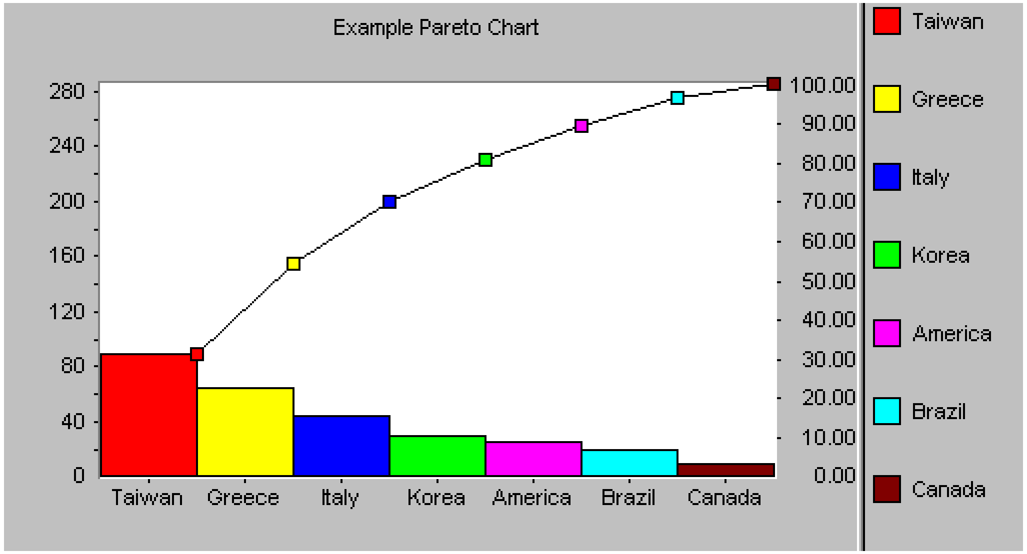
***The Business Value is Achieved by having confidence to "Raise the Bar"***

- Reduced Variability = "Plant Obedience"
- The MPC "intelligence" applied is based on real-time process data
- All significant parameters are considered in a Multivariable model.
- MPC systems predict changes caused by changing conditions
- Corrections to the process are applied before quality and process objectives are compromised.

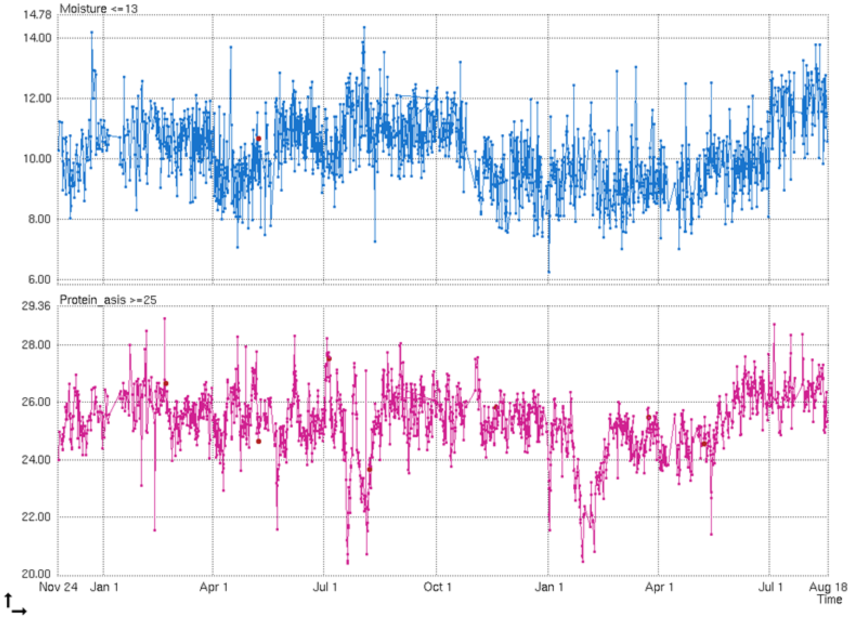
# MPC Audit Value Estimate

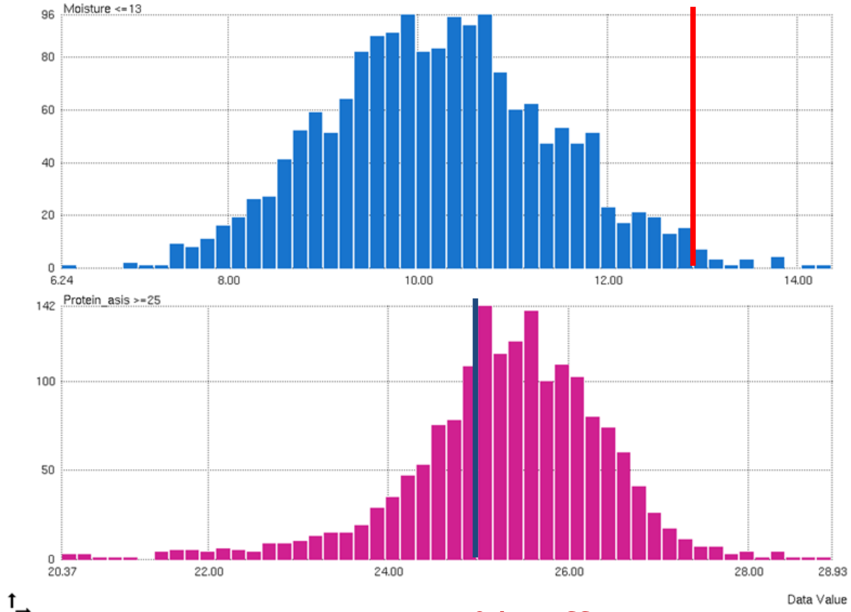
- Each benefit needs a baseline calculation:
  - Capacity (add constraints/limits)
  - Specific energy, energy/feed rate (look for key disturbances or shifts. If bi-, tri- or more modal data is apparent – segment by grade)
  - Quality on end product or end product/feed quality (yield/conversion)
  - % losses or % off-spec or % down-grade (ask for Pareto on causes)
- With grade-dependent operations – segment data per grade.

- Distance from constraint: average to limit * gain
- Reduce variation 35-65% σ
- Confirm statistics against standard project benefits!



# MPC Audit Concepts




Time-plots (with/w-o cut data)

Histogram, % off-spec

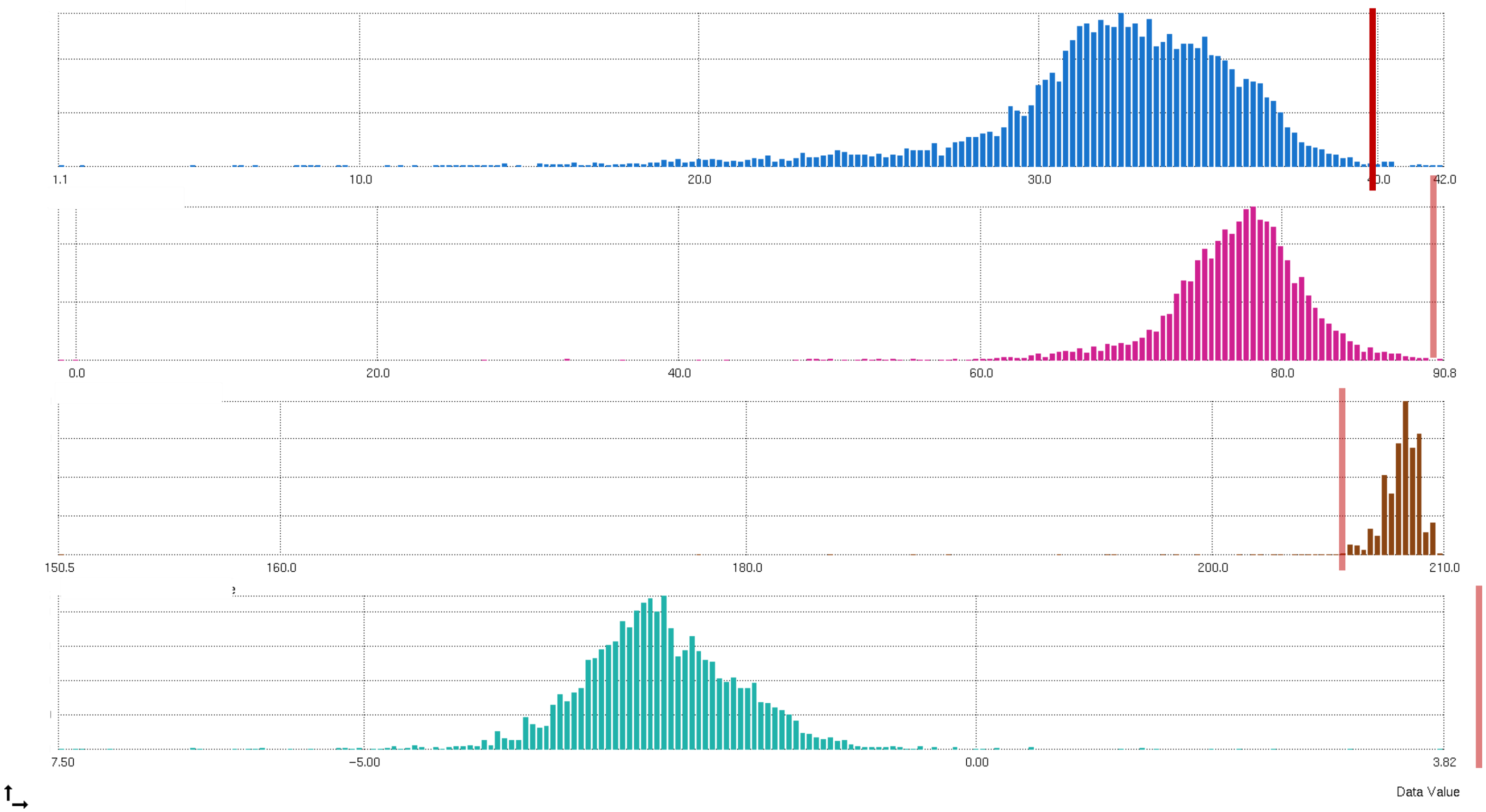
| | Average | Standard Deviation |
|---|---|---|
| Quality1 (as is) | 10.228 wt% | 1.194 wt% |
| Quality2 (as is) | 25.320 wt% | 1.108 wt% |

Statistics



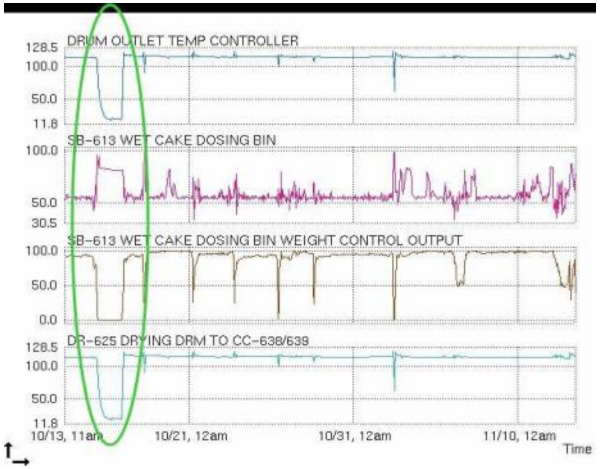
# Constraint Variables



# MPC Benefits Estimate: Finding a gain

**In decreasing reliability, increasing model uncertainty**

- Step data from manual/operator corrections. You need multiple independent steps, SISO (Controller dynamic ID). Watch for inverse gains (modeling control).
- Gain from past projects in same design and scale of equipment.
- Gain from operations study, model or knowledge.
- Gain from operator interview, (how much will this change if you move this 3 TPH (i.e. typical move size).
- Gain from ANN/historic/empirical model with limited number of key inputs and very limited input correlation (high R^2)
- Gain from clean (not noisy/broad) xy plot (high R^2).



# What is it worth?

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**Justification Calculations**

| | | |
|---|---|---|
| Budgeted Capcity | | TPY |
| Avg Feed Cost | | /Ton |
| Typical Yields | | |
| Avg. Product Price | | /Ton |
| Assumed Value of 0.01 | | |
| Density shift | | /0.01 shift/year |
| Steam Price | | /Ton |
| Steam/Feed | | T/T |
| Current % Off-Grade | | |
| Cost Boiler Retubing | | |
| Retubing/year | | |

All Dollars are R$

| | Variable Cost Margin Current |
|---|---|
| Product | |
| Steam | |
| Feed | |
| Estimated O2/consumables | |
| specific Electricity | |
| **Gross Margin/Product Ton** | /Ton Calc. Coke |

* assumption is that baseline quality remains consistent at project start
if quality shifts at project start an average of the last two months of data will be used to reset baseline

| **Capacity Increase (Feed)** | | | |
|---|---|---|---|
| Baseline Average | | TPH | Est Margin |
| Stdev | | TPH | |
| Minimum Tgt Shift | 0.00% | 0TPY | |
| High Tgt Shift | 5% | 7500TPY | |

| **Quality Target Shift (Density)** | | |
|---|---|---|
| Baseline Average * | | |
| Stdev | 0.009 | |
| Minimum Tgt Shift | 0.0050 | R$/yr |
| High Tgt Shift | 0.0100 | R$/yr |

| **Increase Steam Yield** | | |
|---|---|---|
| Baseline Average | | BFW/Green Coke TPH |
| Stdev | 0.13 | BFW/Green Coke TPH |
| Minimum | 2.0% | $178,831/yr |
| High | 5.0% | $447,078/yr |

| **Increased Boiler Tube life** | | | |
|---|---|---|---|
| **Failures in baseline year** | | Baseline Average | 1237.06 DegC |
| | | | Baseline % > |
| | | 41.48% | 1250 |
| Minimum | 25.0% | | |
| High | 50.0% | | |

| Benefits Categories | **Minimum** | **High** | 75% Minimum |
|---|---|---|---|
| Value From capacity increase | $ - | $ | |
| Value From QC shift | | | |
| Value from Steam Yield | | | |
| Value from Incr. Tube Life | | | |
| Expected Savings | $ 1,358,831 | $ 3,788,831 | $ 1,019,123 |

# Comments? Discussion

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Fundamentals of MPC

1. Actively enforce/push constraints
2. Directly reject influence of disturbances
3. Coordinate multiple interacting PIDs

A. Capacity
B. Yield/Quality
C. Energy

# Thank You! Questions?

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