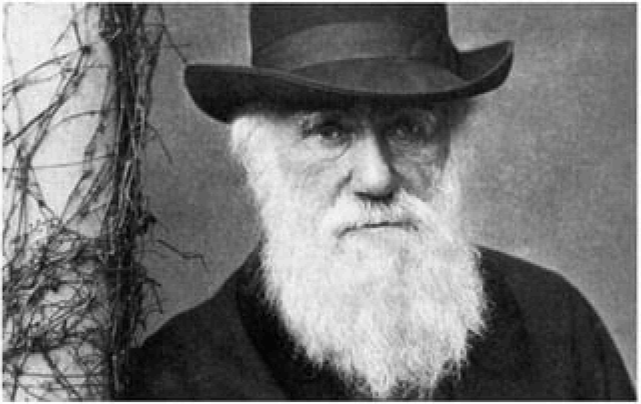
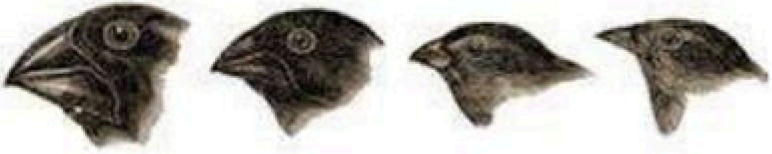
Applying MPC in Non-Refinery Settings

Agenda

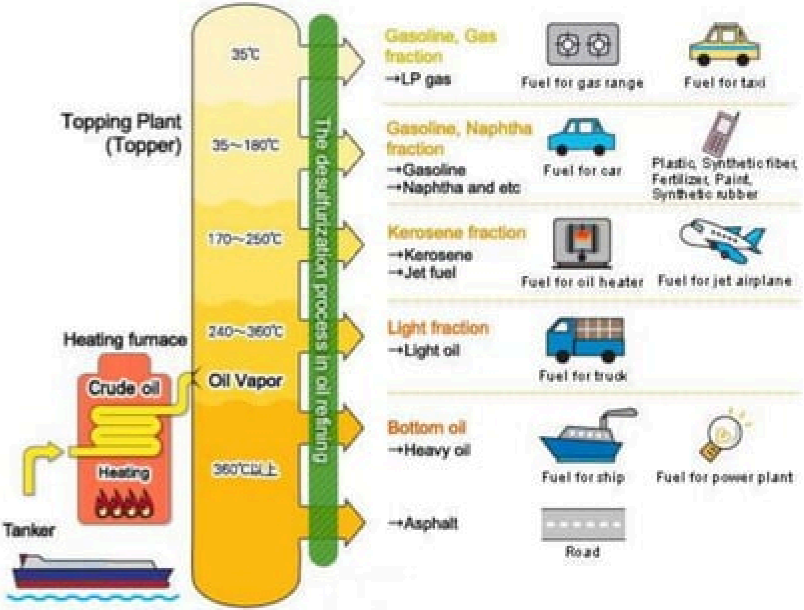
- Oil refining
  - MPC in oil refining
- MPC in other process industries

The Origin of Species

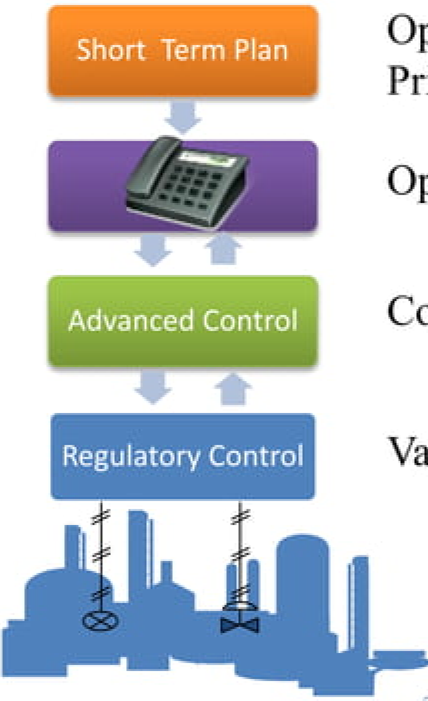




Petroleum refining



Optimization Hierarchy

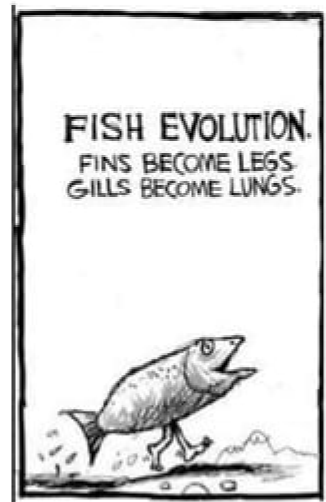


Operating Objectives, Component Prices, Constraints

Operating Targets

Controller Setpoints

Valve Positions



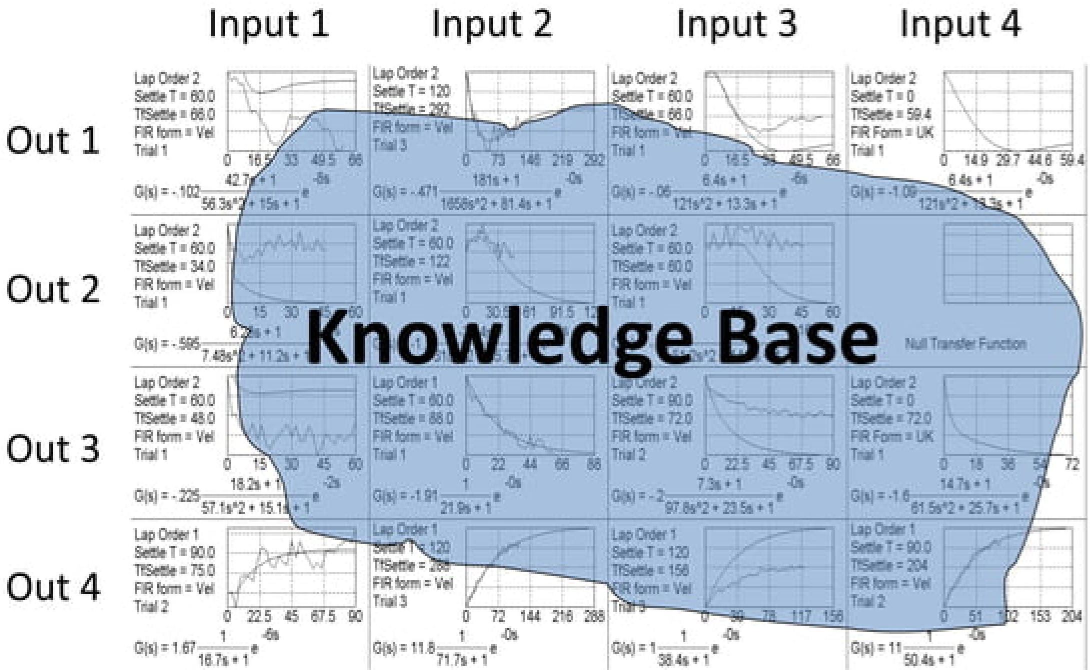
MPC History

- Oil refining started using linear programming in 1940's
- First adaption to nonlinear problems (SLP) published by Shell in 1950's
- Use of LP to solve control problems Exxon 1970's
- DMC (Shell) 1980's

Key features

- Definition of “good” control
- Time domain model
- Rules
- Control is online solution of optimization problem

MPC Model Matrix



MPC vs PI

- Discrete PI Control Law

$$\Delta CO = K(\frac{e(t)}{Ti} + (e(t) - e(t-1))$$

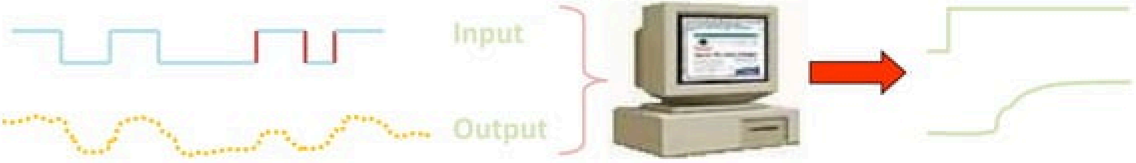
Control expressed solely in terms of current and past error

MPC Methodology

- Plants Tests
- Model Fitting
- Tuning
- Commissioning

Process models

- Process tests to identify the relationship
- Model identified for every input/output relationship
- Required for future prediction
- Models embedded directly in controller



Model: How does output change to a 1 unit change in input

Refinery testing

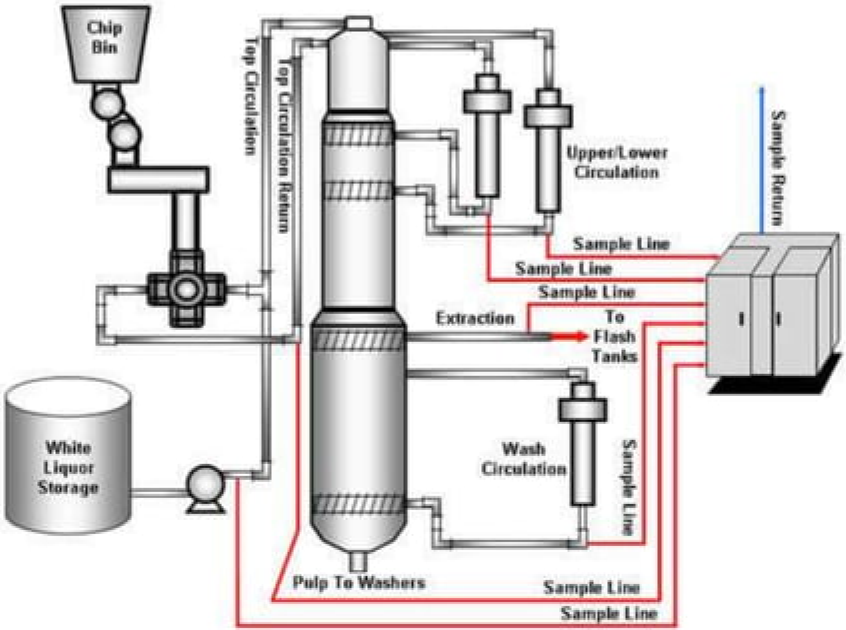
- We know the answer from first principles, simulation experience
- Stable feed stock, stable plant
- Common to test multiple inputs simultaneously

$$StdDev(gain) = \sqrt{\frac{n\sigma_{noise}^2}{tA^2}}$$

Testing in other industries

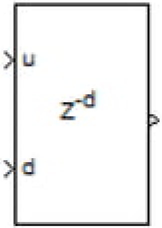
- Heterogeneous feeds
- Transportation delay
- Harsh environments
- Less instrumentation
- There is not a single “best” model that converges with longer testing
- Recognize when model is “good enough” to satisfy the objective

Chip Digester



Plug flow reactor with four hour transportation time delay

External Delay Handling



Two:

- Input signal to delay, u
- Delay length, d

U(t) → Delay → U(t-d) → Identification

Commercial time series analysis packages developed to meet the needs of oil refineries do not handle situations where the time delay varies during the plant tests

External delay stacks are required to preprocess the inputs

Equation transformation

Theory: Q$= \frac{V}{F} k e^{aT+b}$

Highly nonlinear

But: ln(Q) linear in T and ln(F)

Transforms of both controlled and manipulated variables often required

Performance

- Refining
  - Rules of thumb for variance reduction
    - 25-40% reduction
- Are these realistic elsewhere?

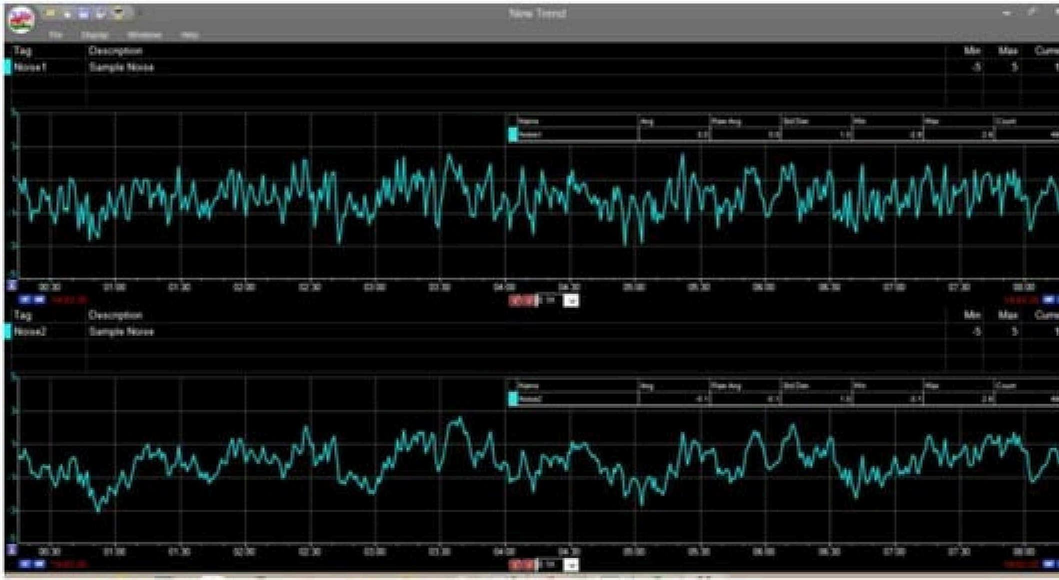
Regulatory Performance

- $Y(t) = G(s)u(t)+Noise(t)$

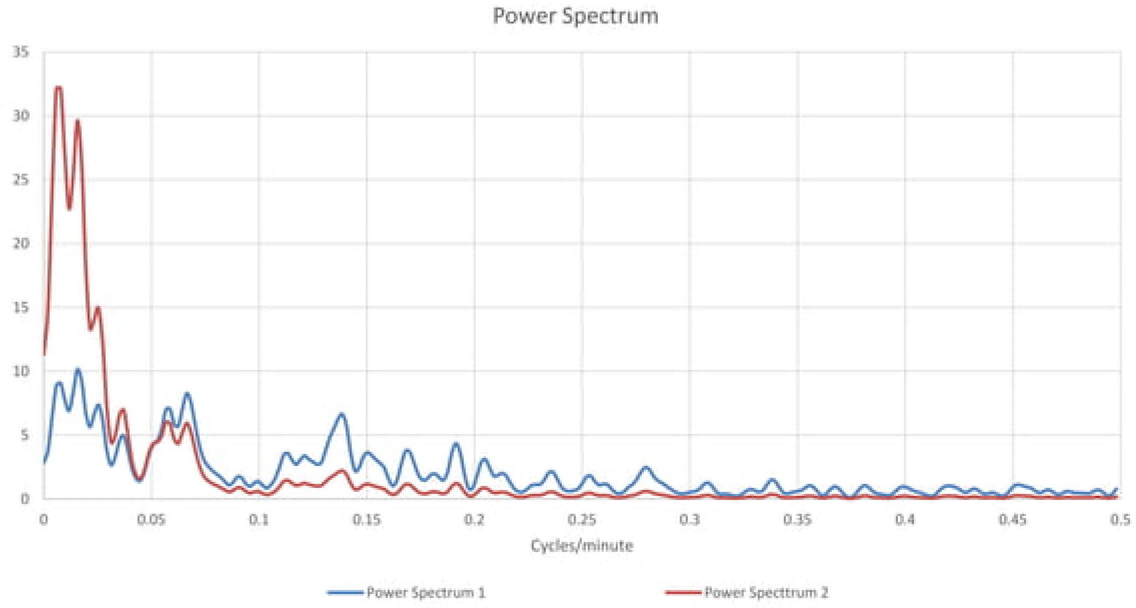
- Process model identification focuses on $G(s)$

- Variance reduction is by undoing or correcting for the $Noise(t)$

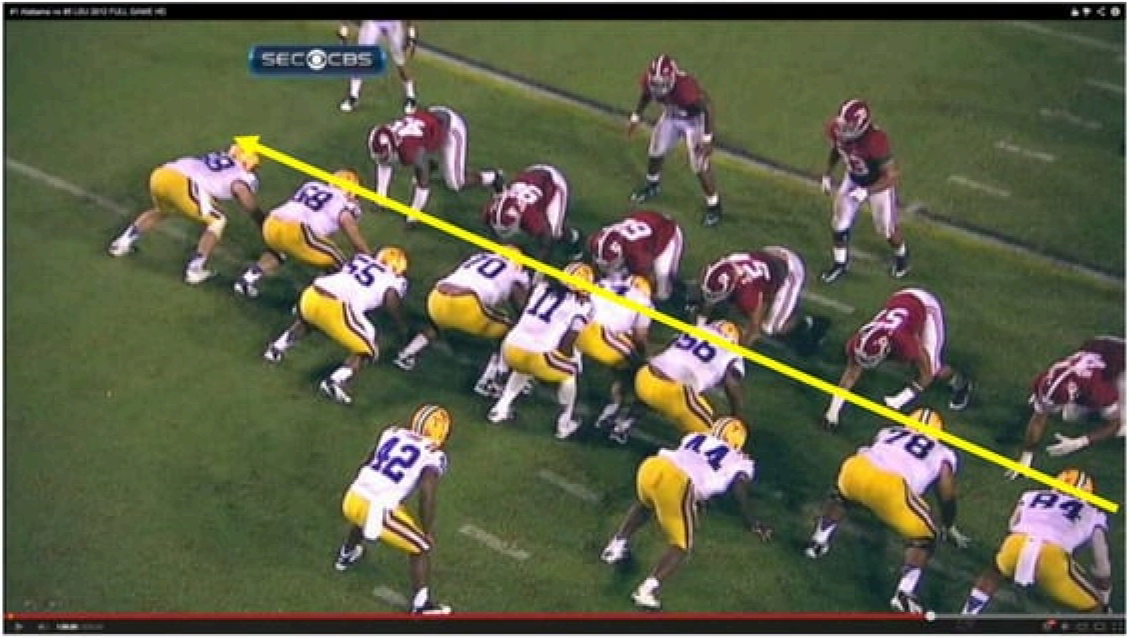
Two noise samples with identical variance



Variance decomposed by frequency



The noise vs control lineup



Poor control prospects

Catching the Noise

Control Performance

- Feedback at least as important as Predictive component

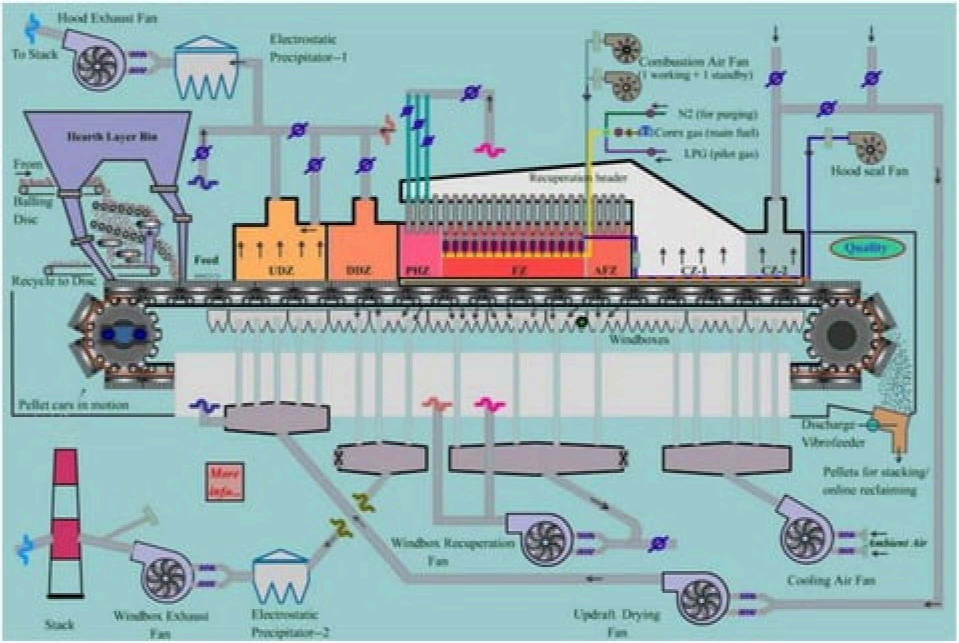
Robustness

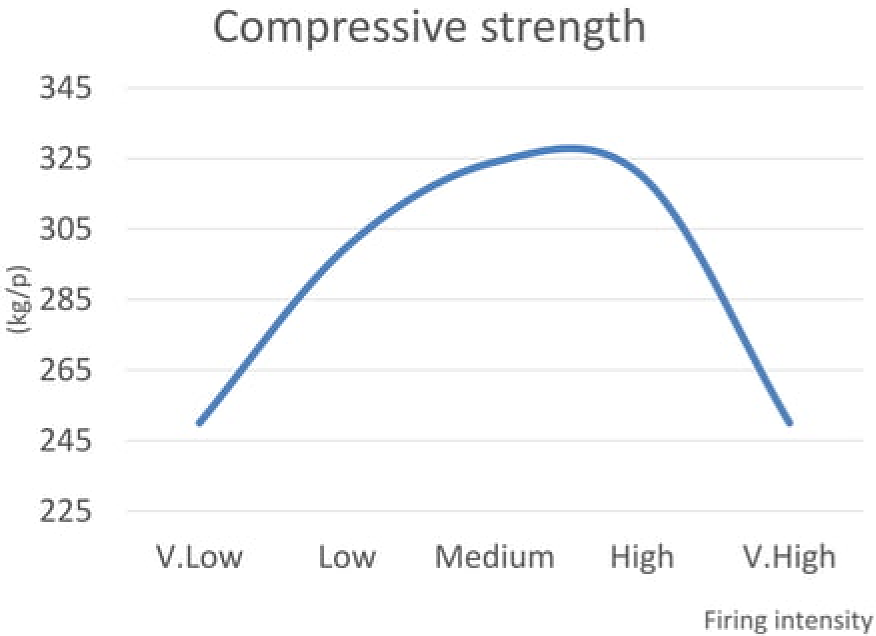
- Can’t control what you can’t measure
- Can’t control what you can’t model

Ore Crushing

Pellet preparation

Iron ore pellet induration




Compressive strength
345
325
305
285
265
245
225
(kg/p)
V.Low
Low
Medium
High
V.High
Firing intensity

Calculations to infer state

- Unusual Controlled/Constraints
  - Variance
  - Dominant cycle period
  - Continuous plant tests to detect gain reversals
  - Logistic regression

Logistic Regression

- Regression method to predict the likelihood of a binary outcome as f(x)

$$P = \frac{1}{1 + e^{-(a+bX)}}$$

- Similar to classical neuron
- Allows including constraints such as keep probability of upset event to less than z%

Bullet Proofing

- Instrument failures
- Trips
- Blockages
  - Safe Parking strategies essential

- Pure “MPC” of successful MPC project may be less than 40% of total engineering configuration

MPC contrast

- Refining
  - Stable systems with deep theoretical knowledge
- Other industries
  - Dynamic/variable/frustrating environments
  - MPC + “training wheels”

Conclusions

- The suitability of technology can't be considered in isolation from the environment that created it
- Refining MPC evolved to address specific situations and challenges
- Its fitness in other industries depends on careful adaptations