Data-Driven Production Optimization

B. Tubbs & Associates Consulting

CIM Conference

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Introductions – My Background

Bulk chemicals manufacturing

Management consulting

Oil and gas

Environmental management

Energy optimization

Independent consultant

ICI Chemicals & Polymers Ltd.

CELERANT CONSULTING
Operational strategy and implementation

HYDRO

Scottish Water
Trusted to serve Scotland

Spectra Energy

ICF INTERNATIONAL

SaskPower

HATCH

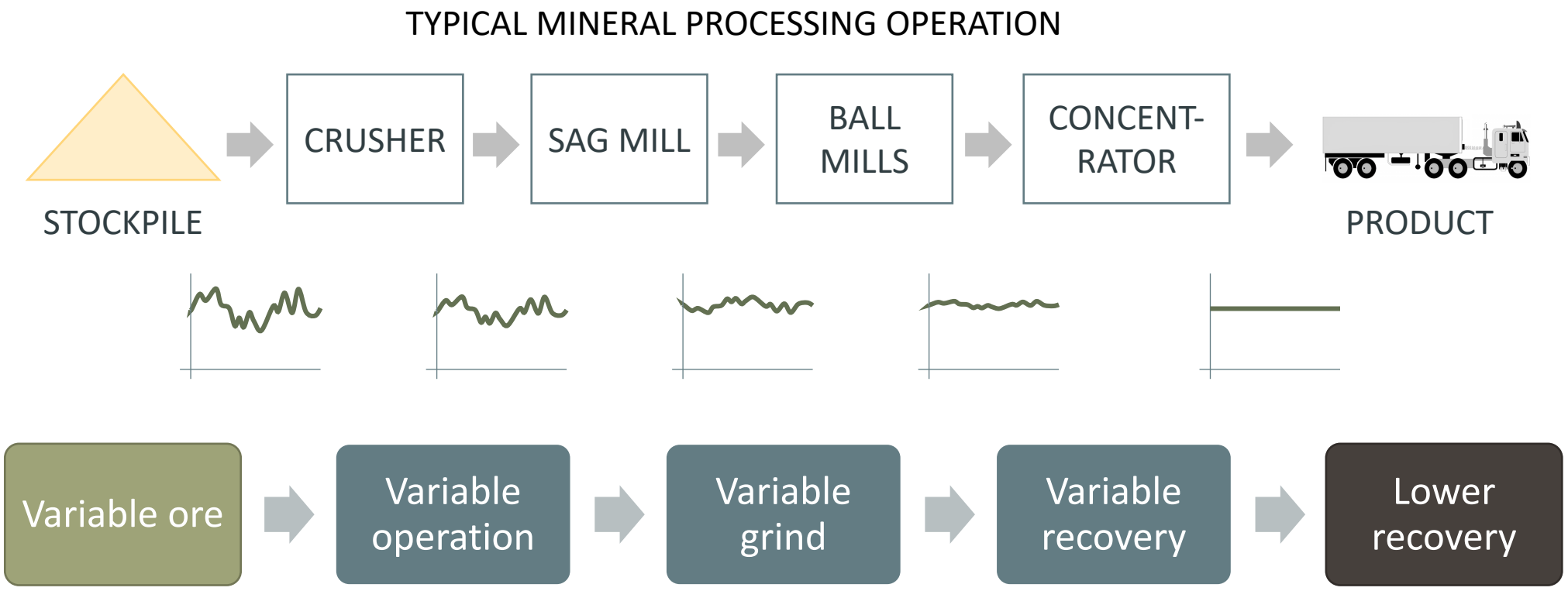
AREVA

Nutrien

Motivation

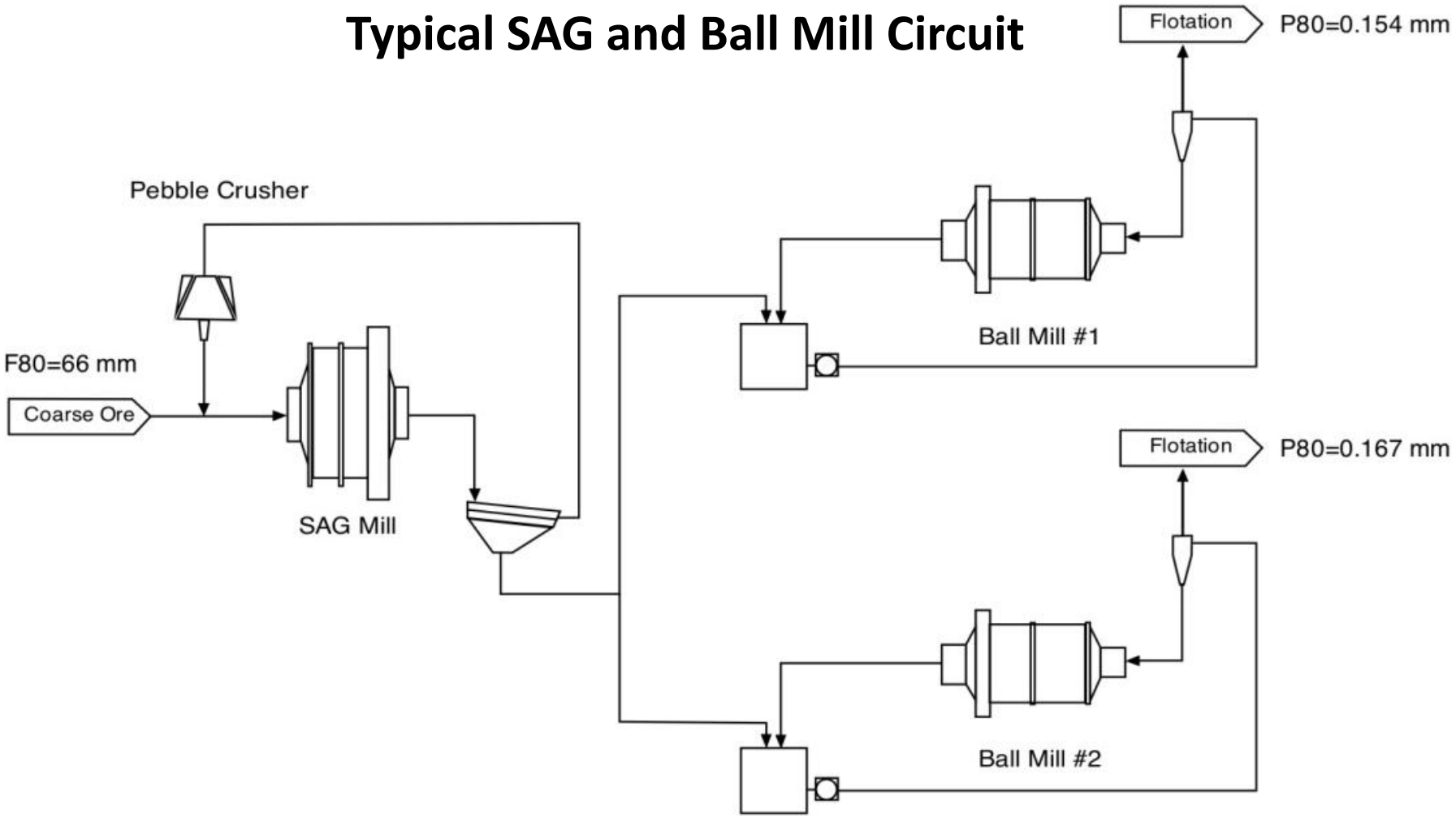
- How to optimize a mineral processing plant in real time given:
  - Partially-observable state
  - Unpredictable perturbations (changing ore properties)
  - Noisy, unreliable and lagging measurements
  - Non-linear, unstable dynamics
  - Non-stationary
- New developments in real-time process automation and dynamic optimization
- Are traditional operations management practices still relevant?
- What is the future role of the process operator?

Motivation

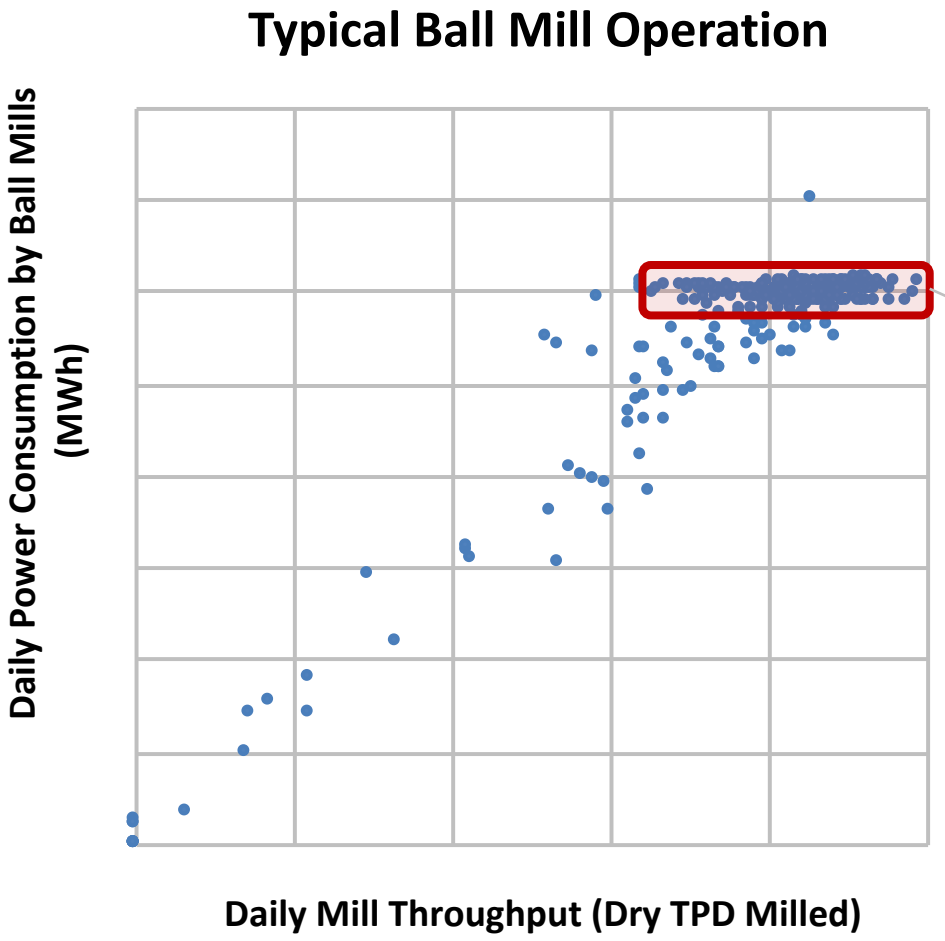


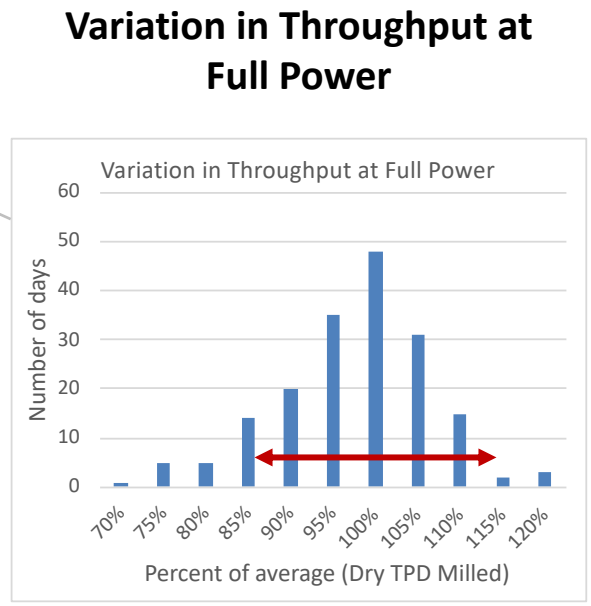
Powell et al (2009)

Motivation


Typical SAG and Ball Mill Circuit
Flotation
P80=0.154 mm
Pebble Crusher
F80=66 mm
Coarse Ore
SAG Mill
Ball Mill #1
Flotation
P80=0.167 mm
Ball Mill #2

Motivation





+/- 16% Variation In Daily Throughput

Motivation

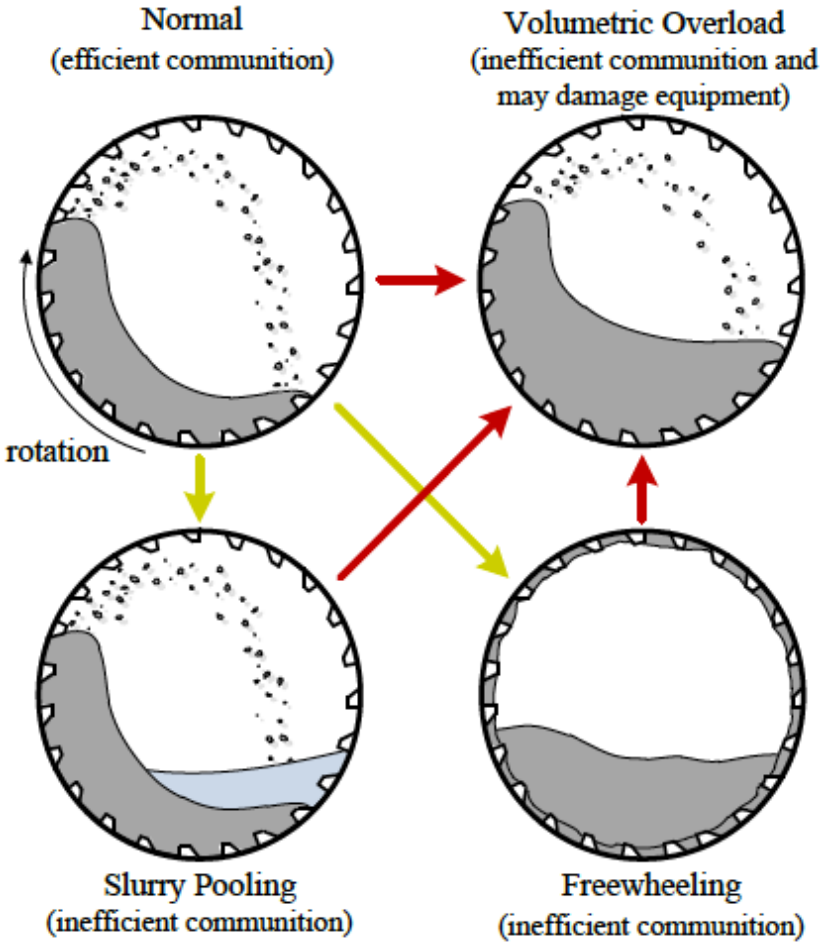
From the Literature

- A ROM ore milling circuit is a difficult process to control because of non-linearities, large time delays, unmeasured disturbances, process variables that are difficult to measure, and modelling uncertainties

(Le Roux et al 2016)

- The performance and robustness of the control system highly rely on a good understanding of the process dynamics

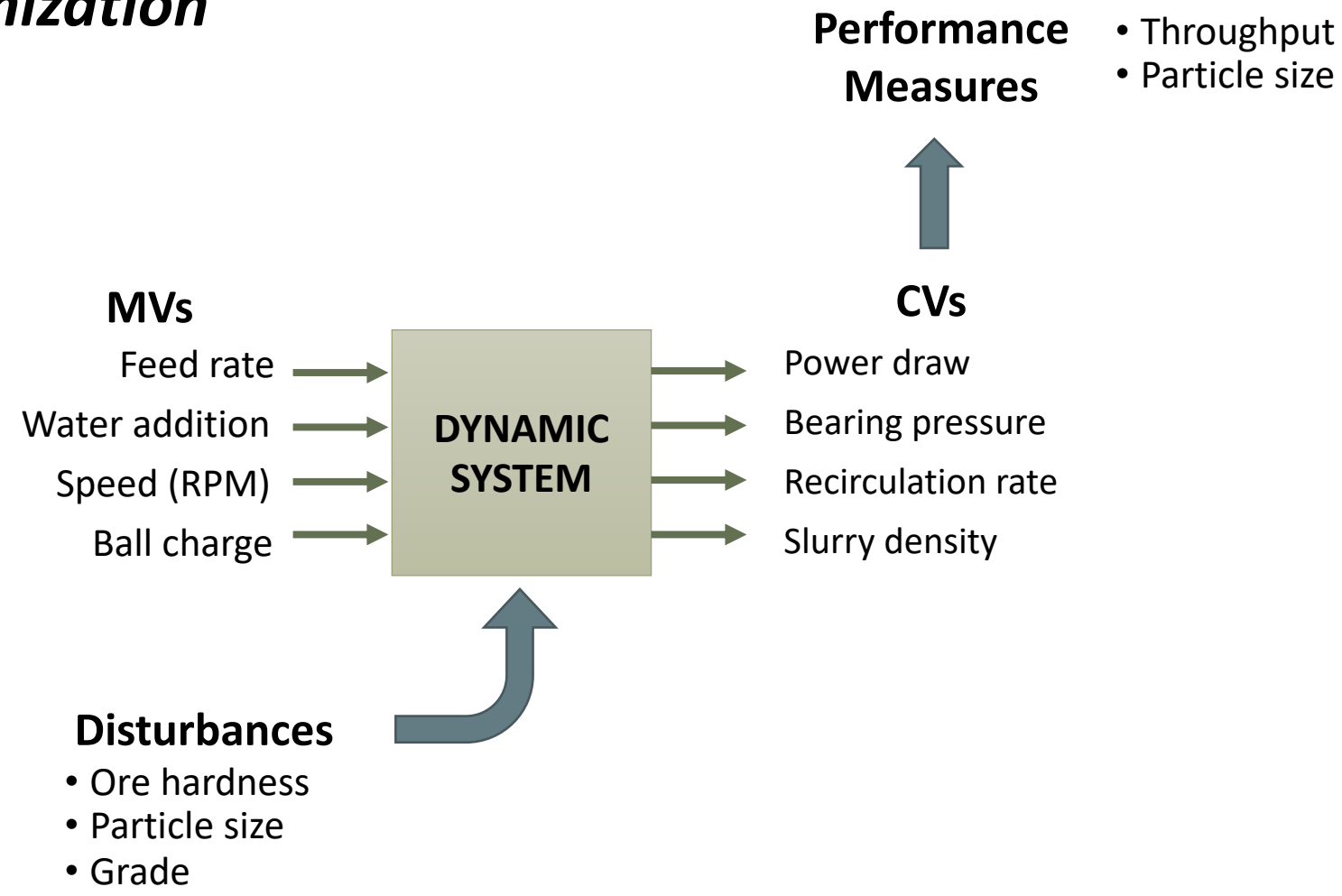
(Légaré et al 2016)



(McKlure and Gopaluni, 2015)

Motivation

Dynamic Optimization



What's New In Automation?

Physics-based Modeling

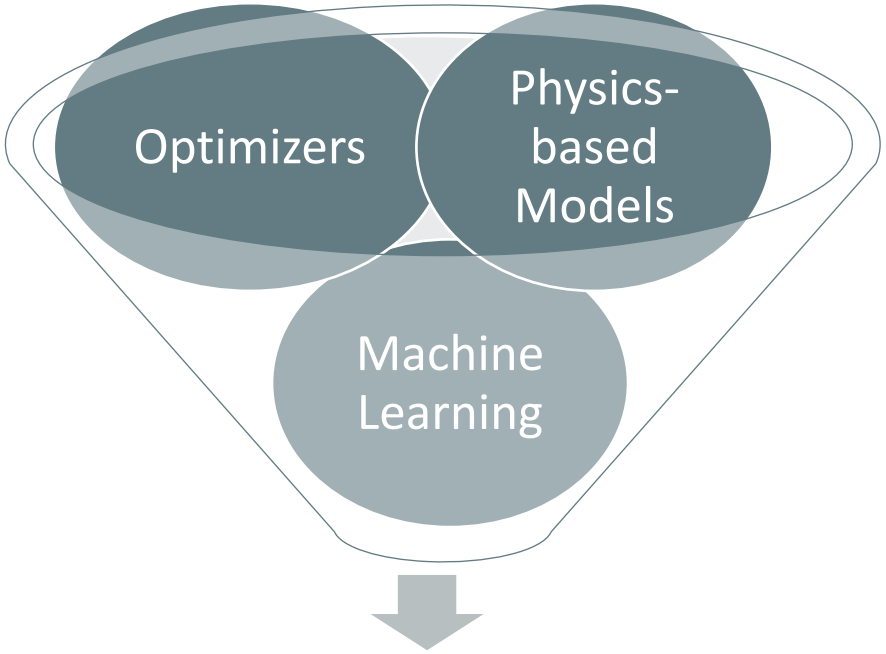
- Specialized process simulators
- Computationally intensive

Data-based Modeling

- Machine learning / AI
- Data intensive

Optimizers

- 2.5 billion times faster than 30 years ago
- Specialized computing hardware

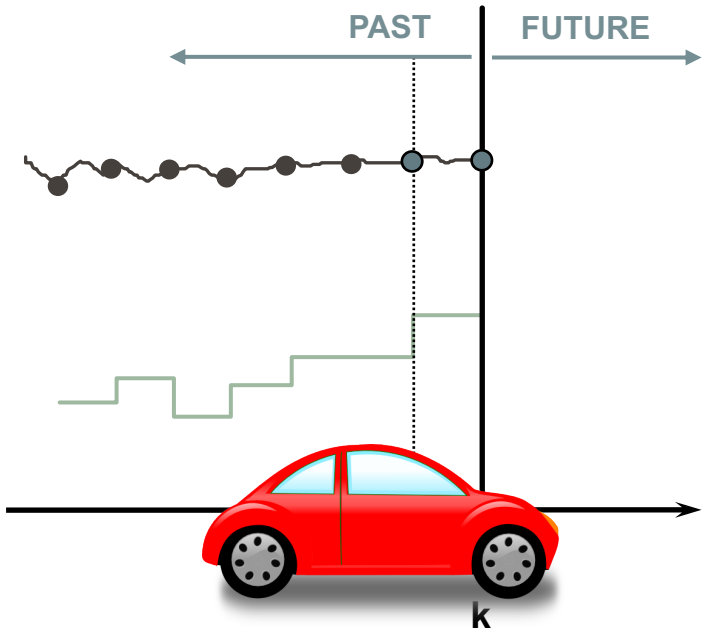


Decision Support and Automation

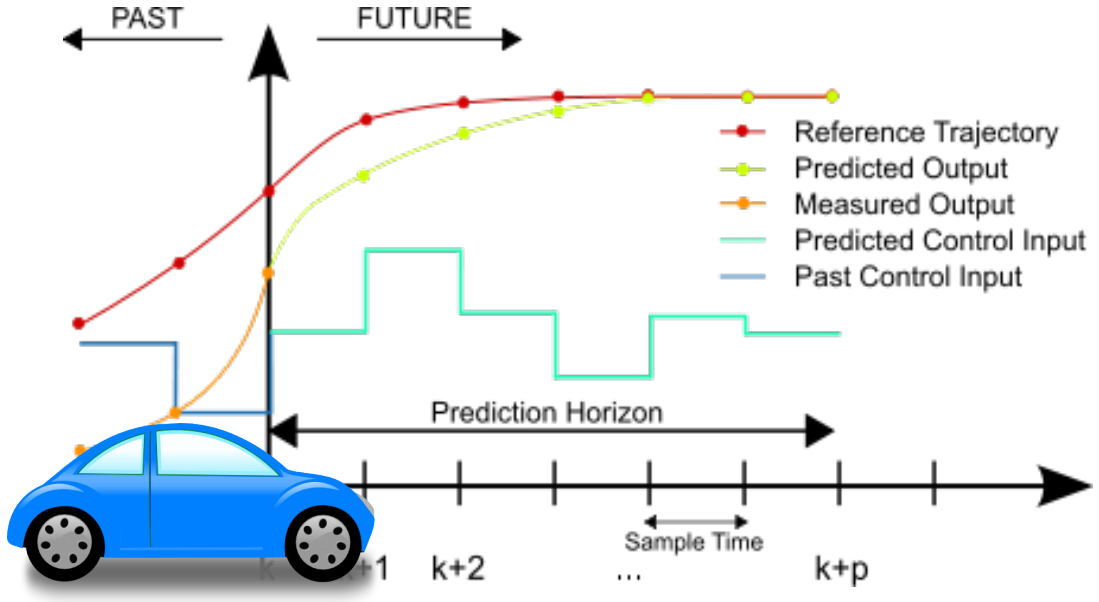
Source: John Hedengren, BYU (2018)

Advanced Process Control

Conventional Feedback Control



Model Predictive Control



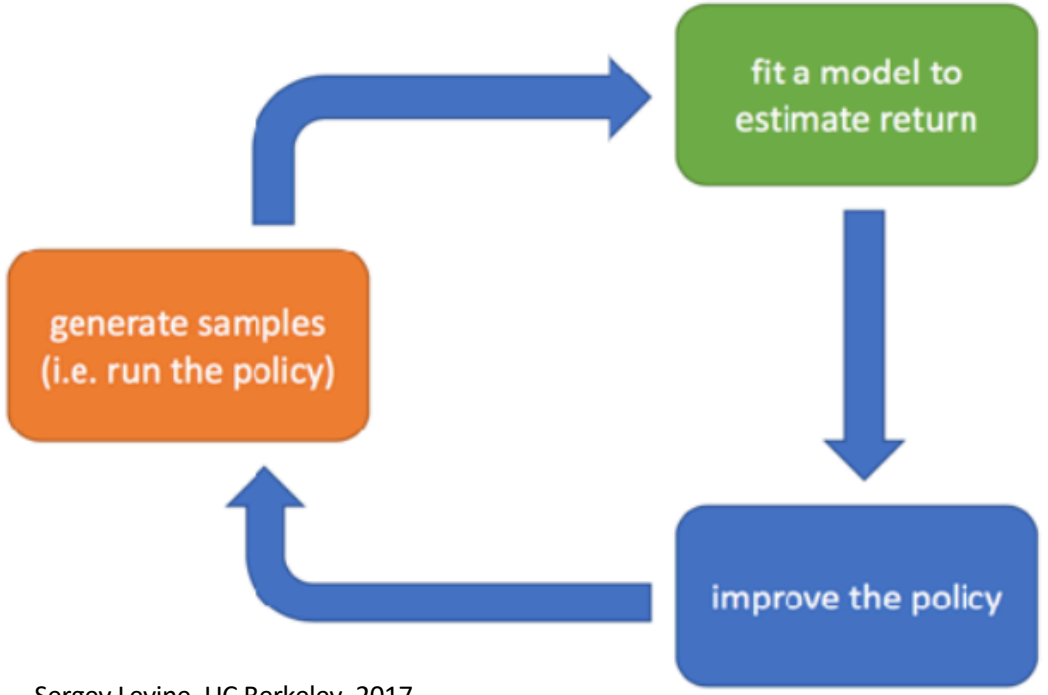
Source: John Hedengren, BYU (2018)

Model Predictive Control (MPC) Uses A Model Of The Process Dynamics To Determine The Optimum Control Strategy In Real Time

Data-Driven Approaches

Model-Based Reinforcement Learning

- Requires large amount of data
- 'Explores' the state-space
- 'Learns' the true dynamics
- Learns an optimal policy
- Not stable or provably robust



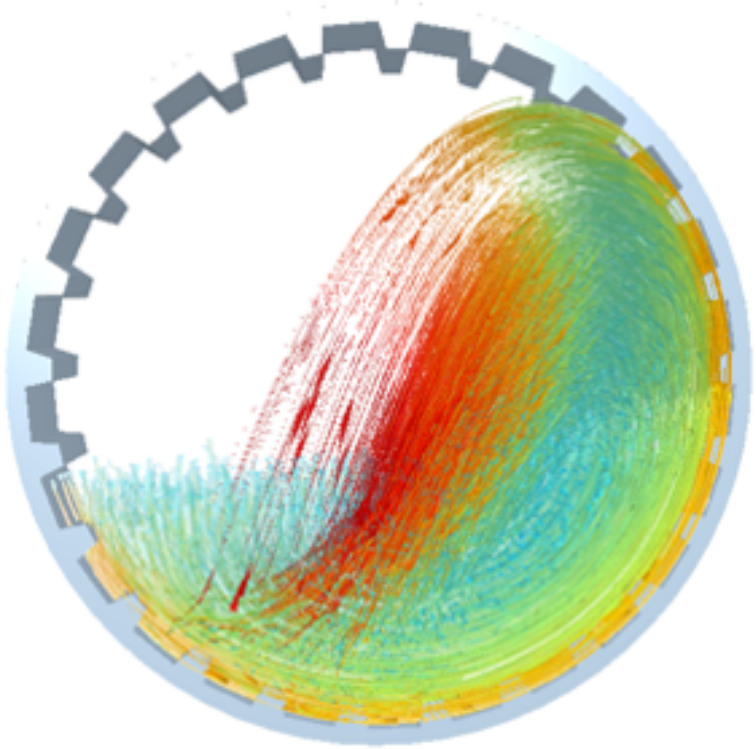
Sergey Levine, UC Berkeley, 2017.

Machine Learning Offers The Promise Of "Learning" An Optimal Control Strategy From Actual Operating Data

Process Simulation Models

Discrete Element Models (DEM)

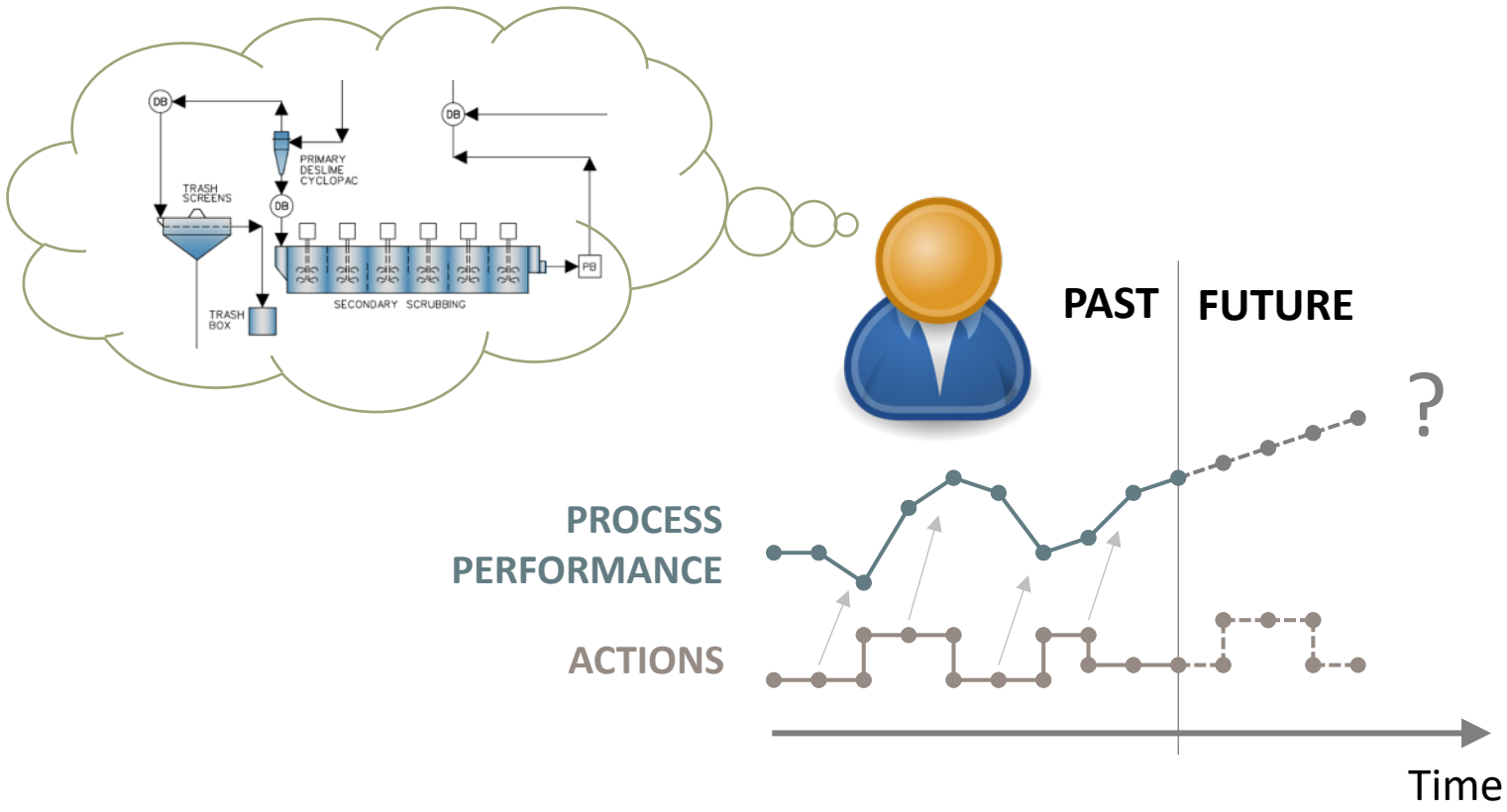
- High fidelity – simulate individual particles and breakage
- Requires high performance computing



EDEM Software, www.edemsimulation.com (2018)

High Fidelity, Physics-Based Models Such As DEM Have The Potential To Simulate The True Dynamics Of Real Process Equipment

Model Predictive Control



As Human's We Intuitively Use Mental Models Of The World To Predict The Future And To Decide On The Optimal Course Of Action

Human Capital

What roles do human operators excel at?

Human Strengths

- Pattern recognition
- Reasoning
- Problem-solving
- Anomaly detection
- Learning and adapting
- Multi-skilled

Automation Strengths

- Accurate
- Act fast
- Repeatable
- MIMO systems
- Dedicated
- Reliable (?)

We Still Need Human Operators Because Automation Systems Are Not (Yet) Capable Of Managing Complex Unpredictable Process Operations

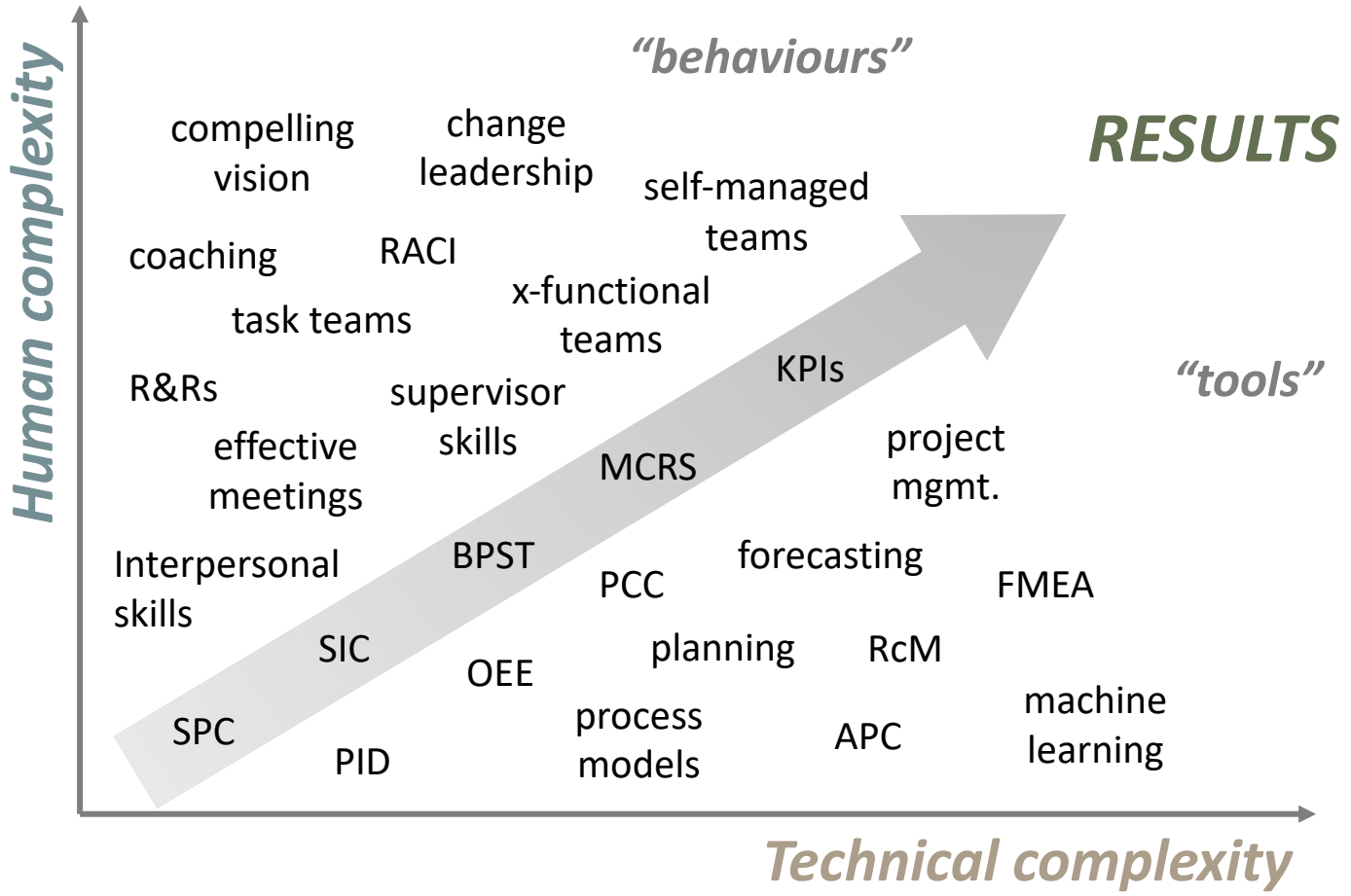
Process Operators – Best Practice

Short Interval Control

Time	Ore Type	MVs			CVs		Production Rate		Loss	Cause	Cumulative Production		Action Taken
		A	B	C	D	E	Plan	Actual			Plan	Actual	
08:00							100	101	-1		100	101	
09:00							100	98	2		200	199	
10:00							100	94	6	Ore properties	300	293	Increased speed
11:00							100	99	1		400	392	
12:00							100				500		
…													

The Discipline Of Short-Interval Control Leverages The Advanced Process Monitoring And Anomaly Detection Capabilities Of Human Operators

Technical And Human Dimensions



Complex Technical Solutions Could Deliver Safe, Sustainable Results When Combined With Human Strengths And Capabilities

Thank You

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