NTNU – Trondheim
Norwegian University of
Science and Technology

Operatorless Processing Plants

Status and challenges for autonomous control systems with focus on autonomous oil production.

Chriss Grimholt

7 December 2018

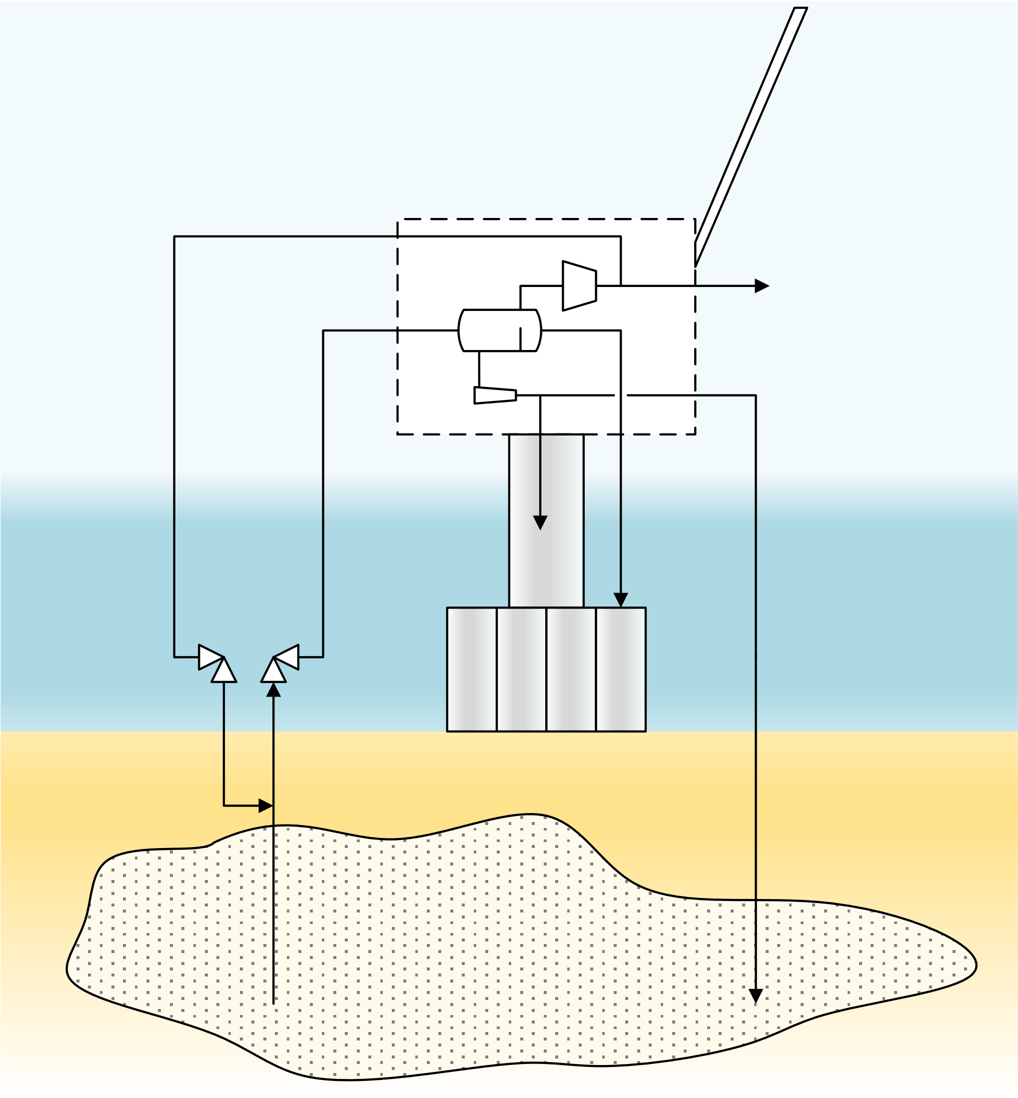
Plan

- Introduction
- History
- The Modern Operator
  - Field
  - Startup
  - Monitoring
  - Production
- Final Thoughts

Offshore Oil Production

Foto: ConocoPhillips

Offshore Oil Production



The Operator

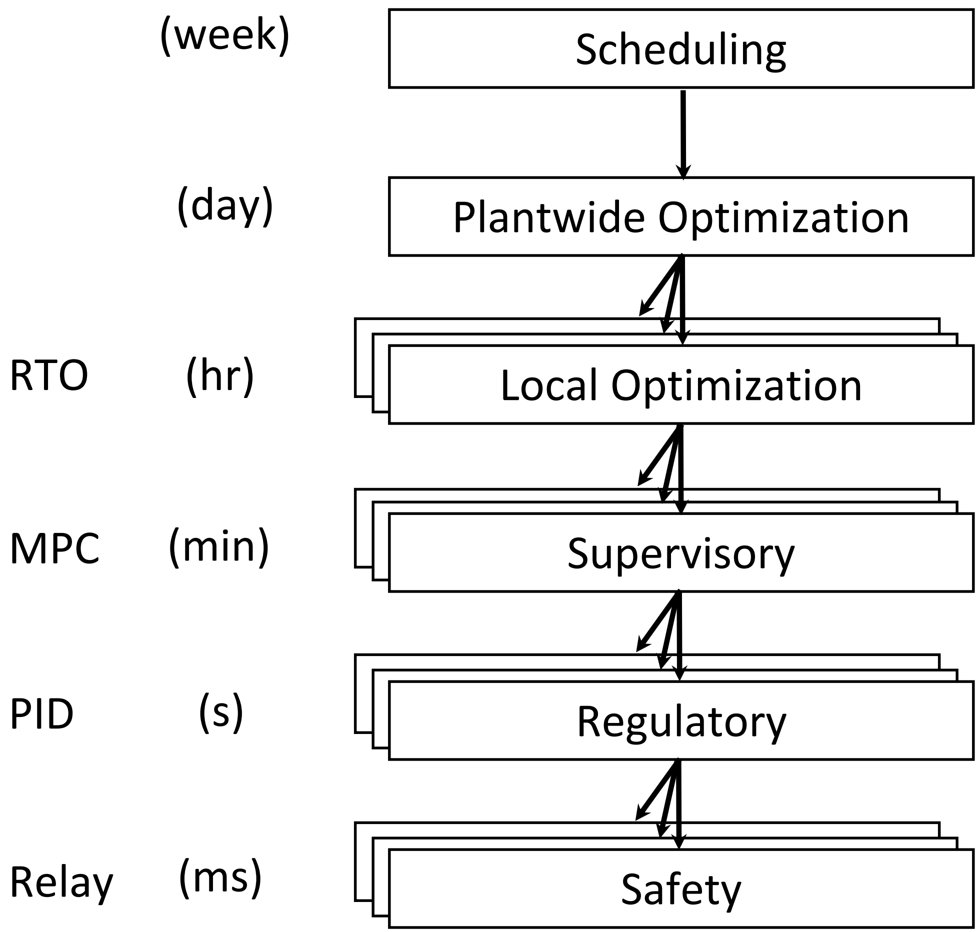
Probably the most famous operator in the world (though not very good)!

The Operator

The operator monitors the process and
does what is in his power to keep the plant running in a safe manner.

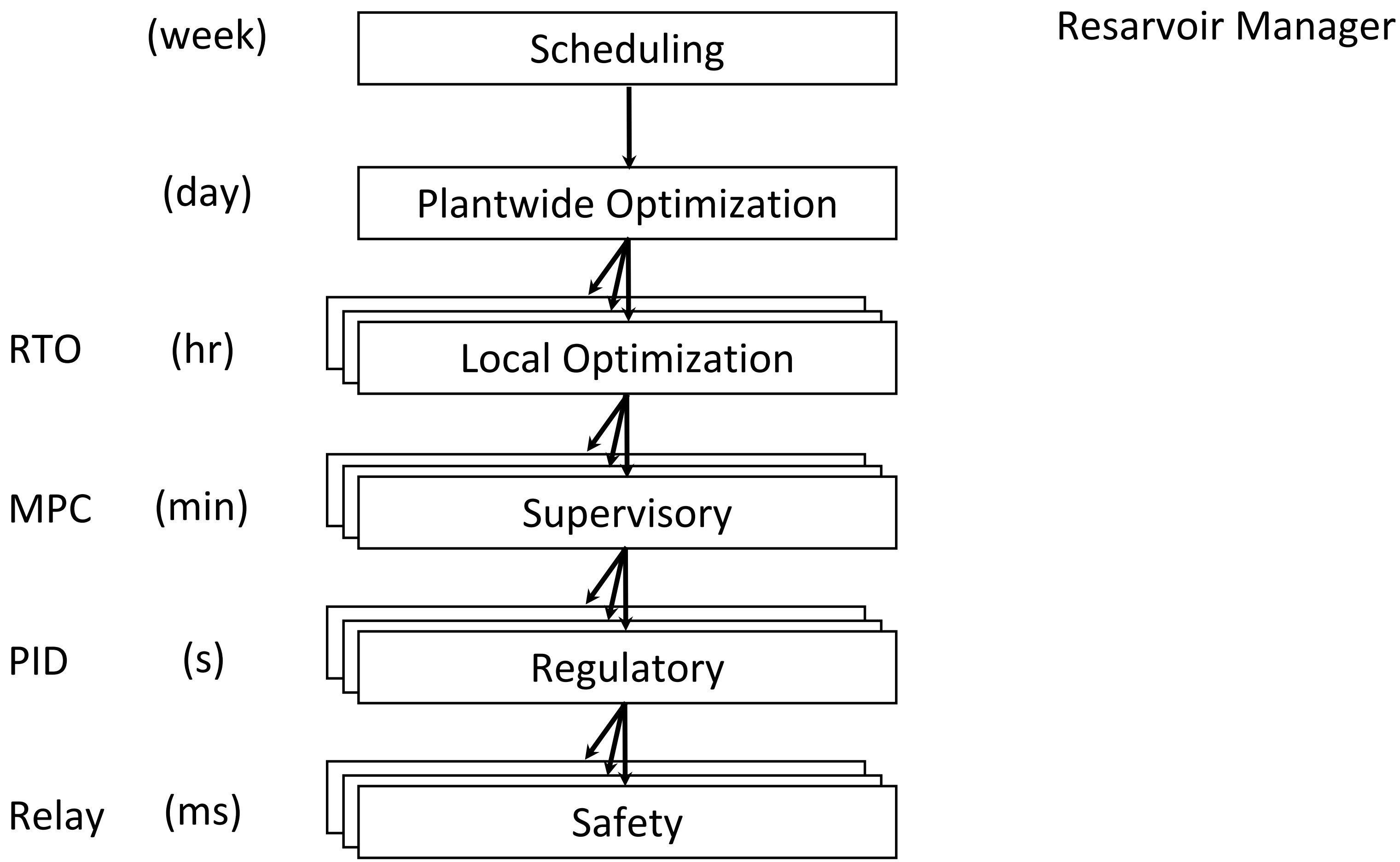
- Starts and stops the plant
- Detects and corrects for faults
- Tries to get the correct product quality
- …

Decision Hierarchy



Skogestad, Sigurd. (2000). Plantwide Control: The Search for the Self-Optimizing Control Structure. Journal of Process Control. 10. 487–507. 10.1016/S0959-1524(00)00023-8.

Decision Hierarchy



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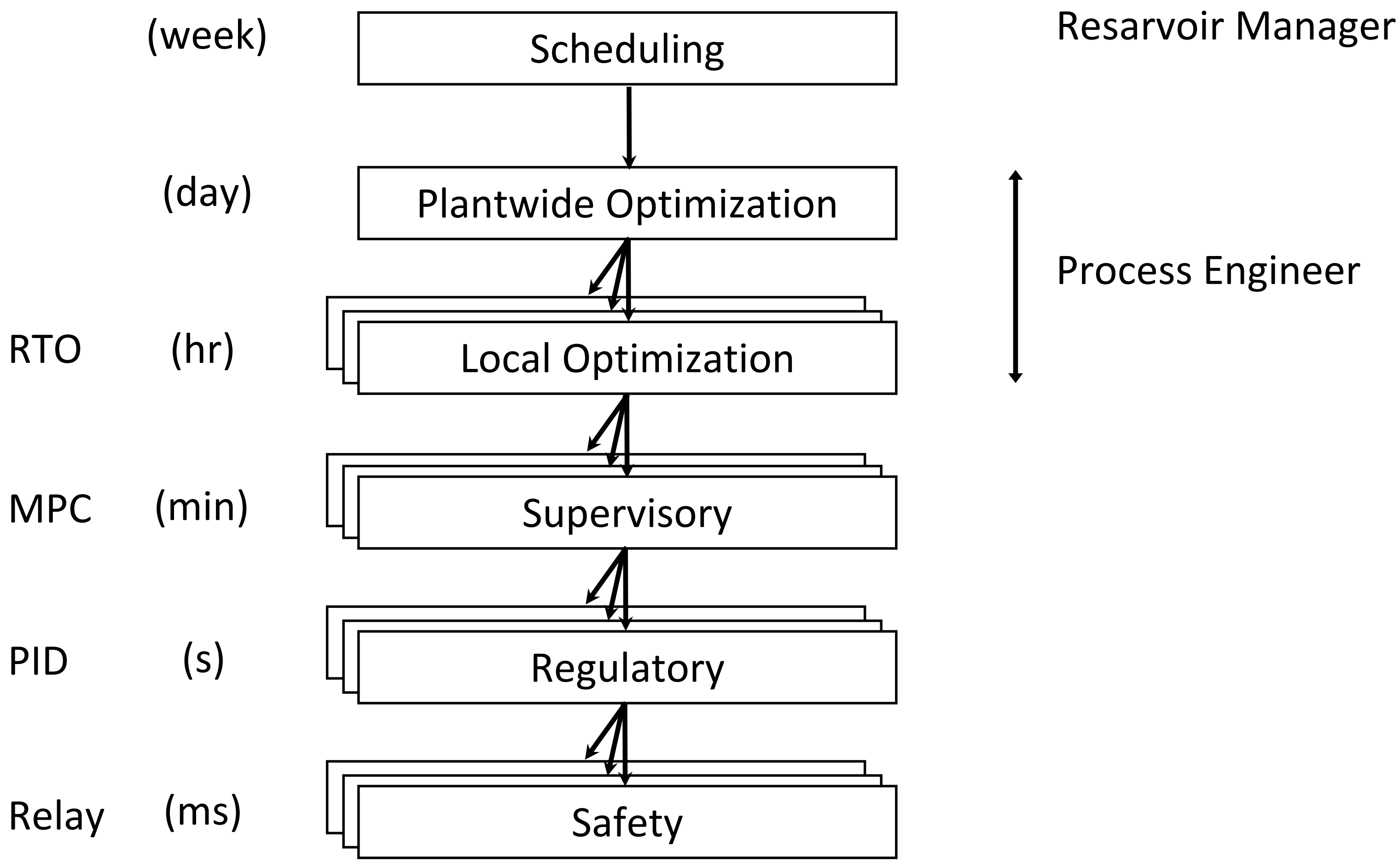

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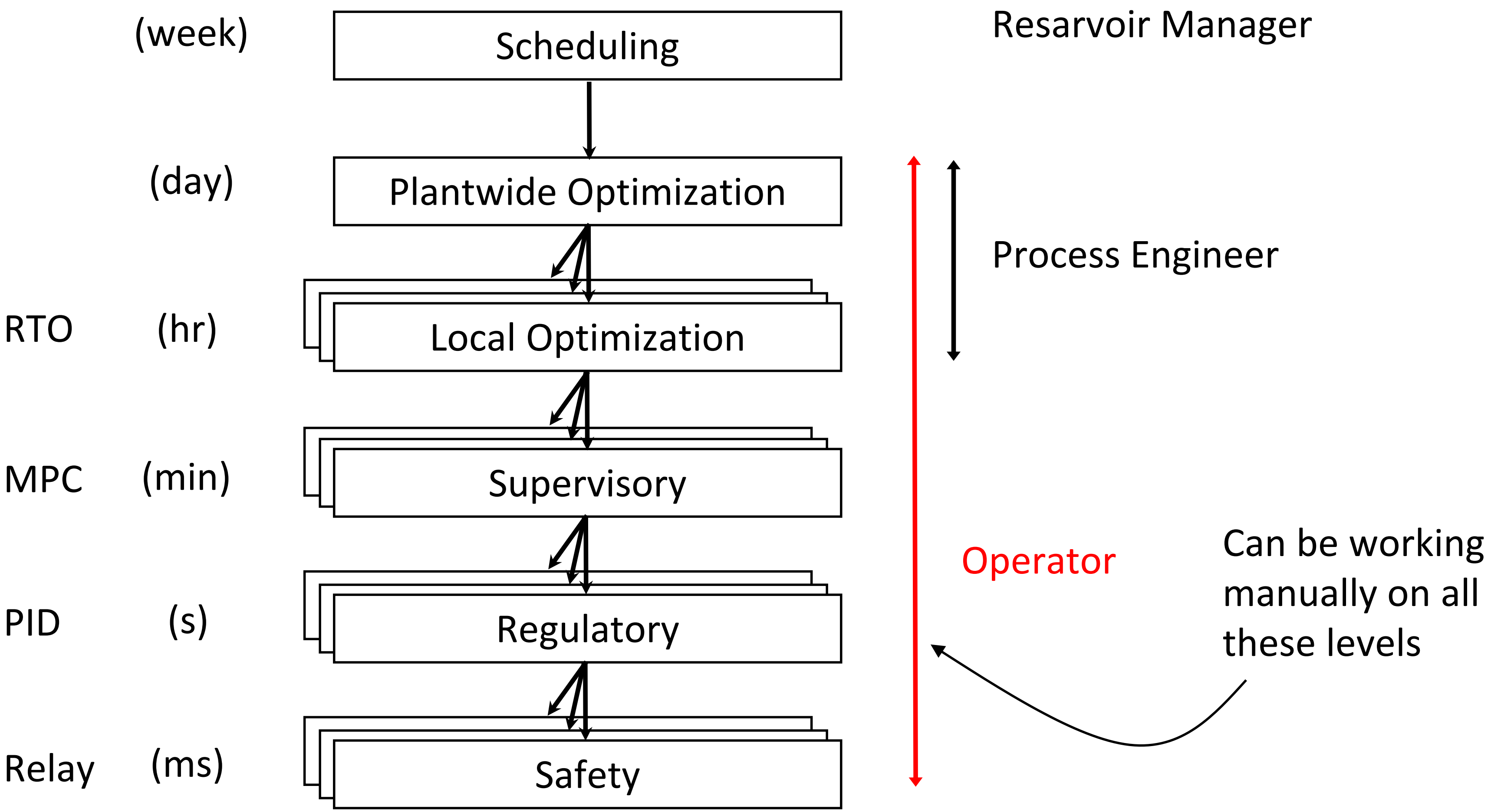


Skogestad, Sigurd. (2000). Plantwide Control: The Search for the Self-Optimizing Control Structure. Journal of Process Control. 10. 487–507. 10.1016/S0959-1524(00)00023-8.

Autonomous

"A system is autonomous if it can solve its task without external intervention"

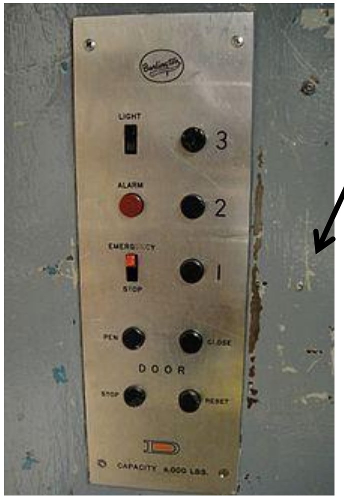
Wallén, Anders (2000). Tools for Autonomous Process Control. PhD Thesis, Department of Automatic Control, Lund Institute of Technology (LTH)

Autonomous

"A system is autonomous if it can solve its task without external intervention"

Elevator:

You give a command,
The elevator takes you there

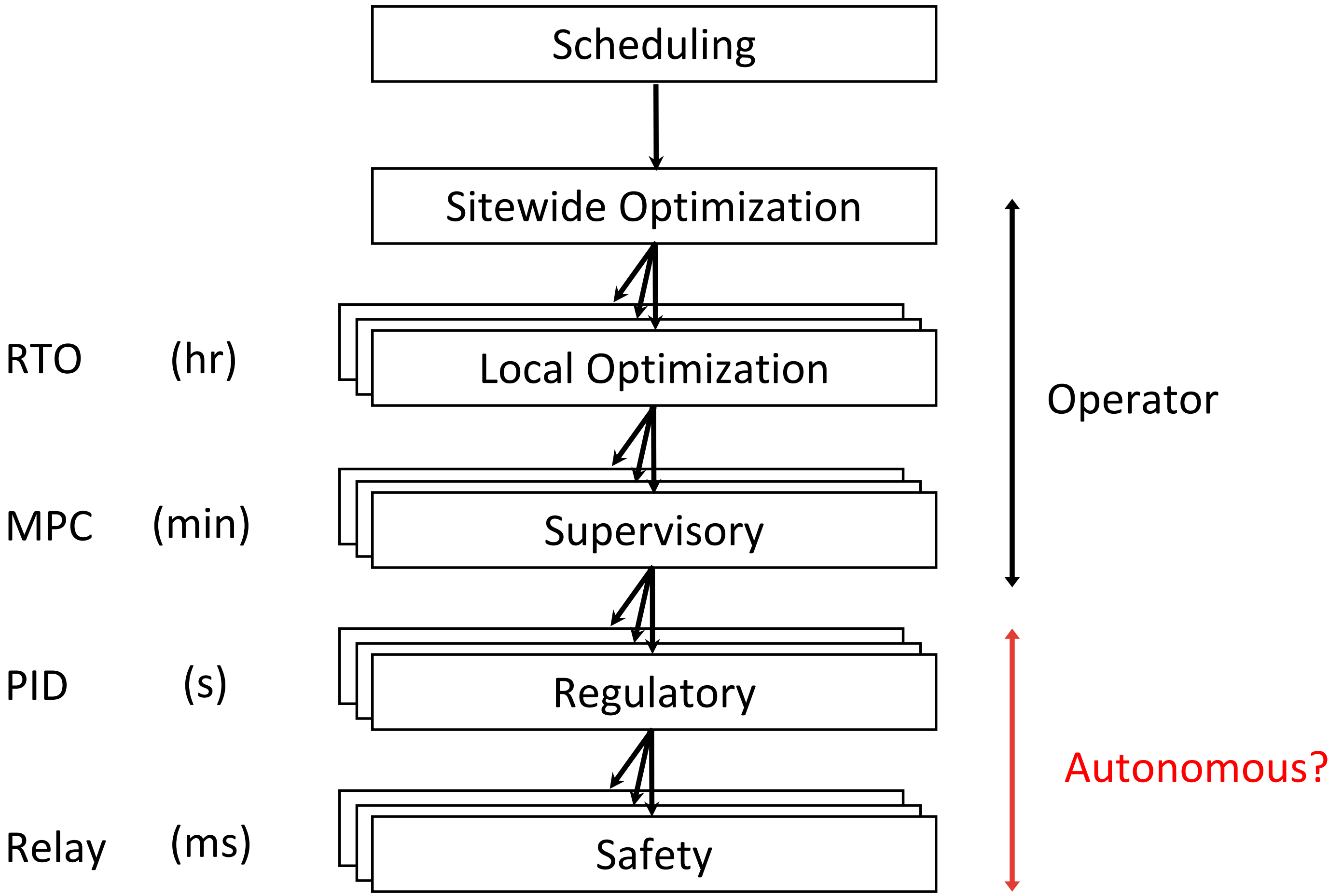


Can be said to be autonomous

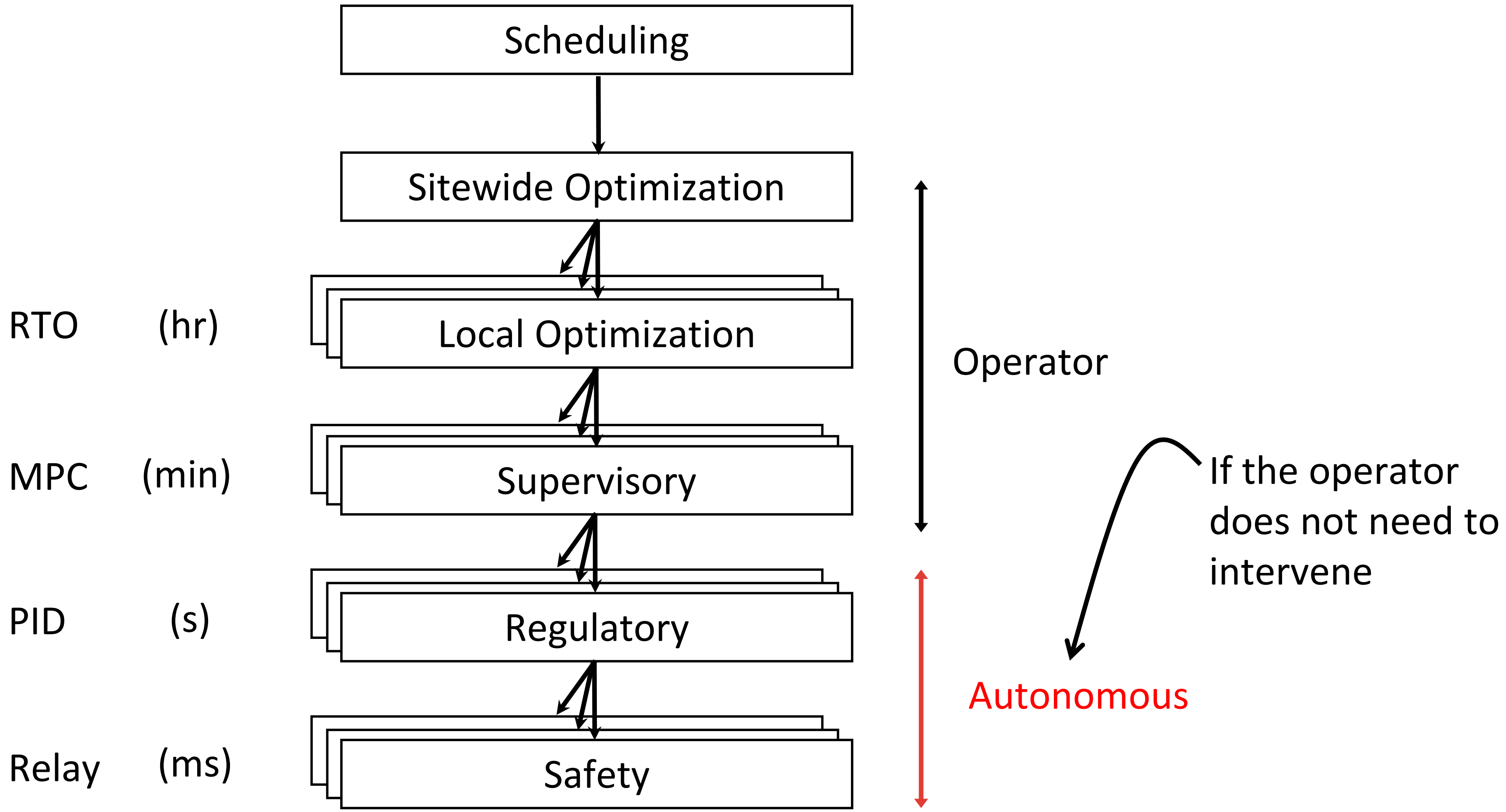
However, no system is autonomous under all circumstances.
E.g. Power loss, measurement loss, someone standing in the doorway.

Wallén, Anders (2000). Tools for Autonomous Process Control. PhD Thesis, Department of Automatic Control, Lund Institute of Technology (LTH)

Is it Autonomous?



Is it Autonomous?

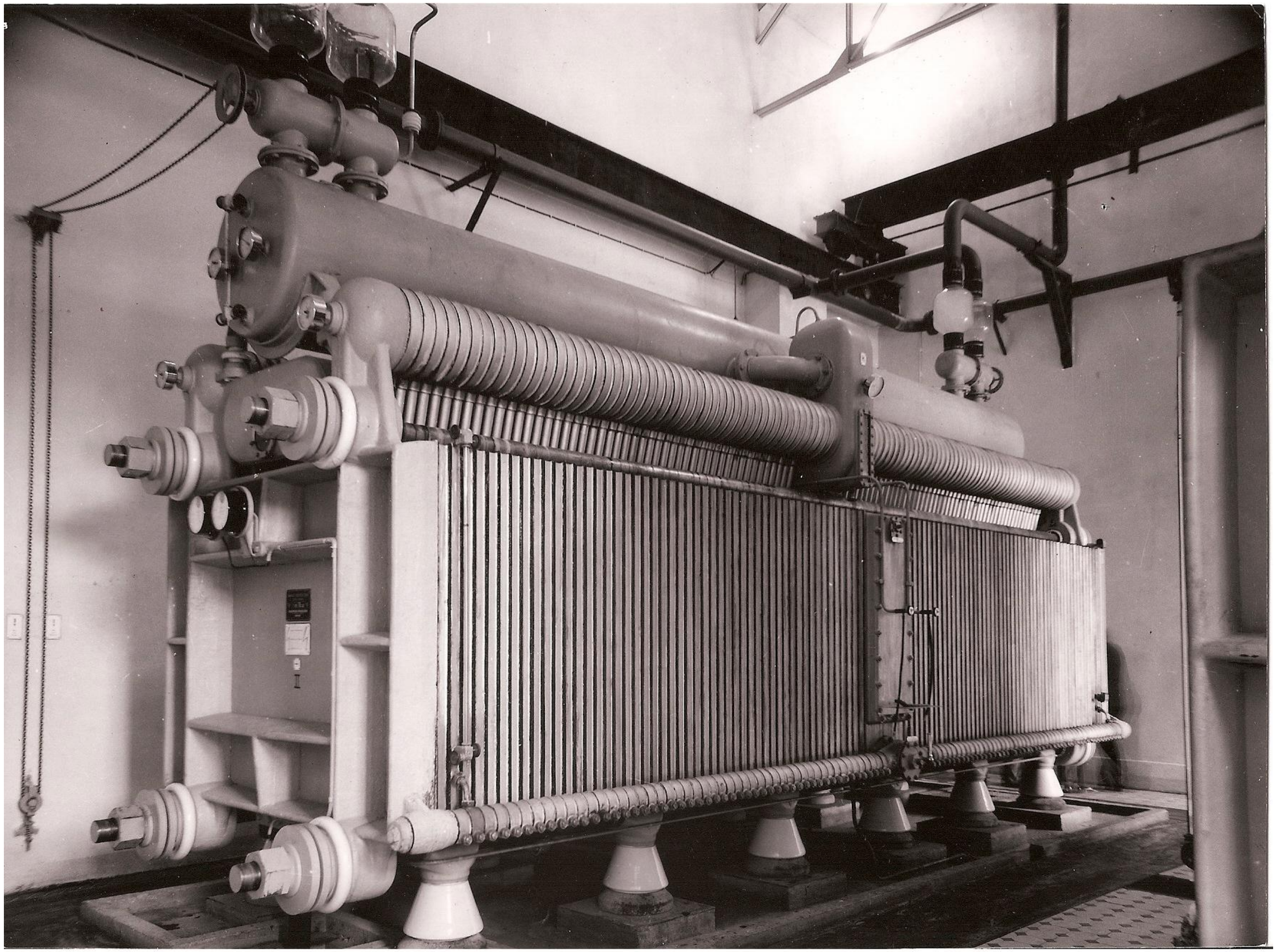


History of Jahre and Operators (simplified)

Tore Gjone Møller

1955 Kokerieri Gonvika

1930s

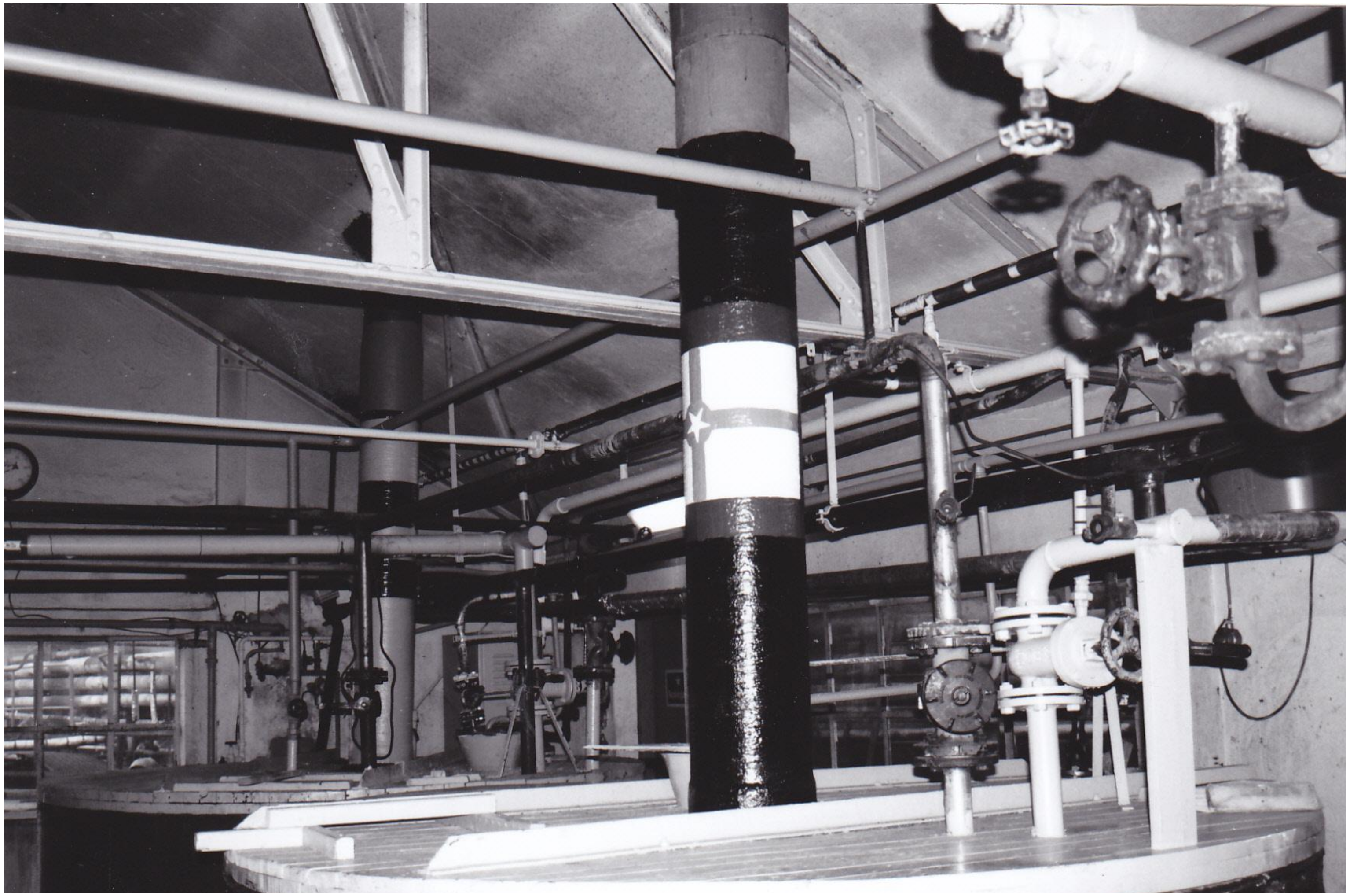


Tore Gjone Møller

1935 Elektrolysor 3 Bamag

1935 1950 1980 2000

1930s



Tore Gjone Møller

1935 1950 1980 2000

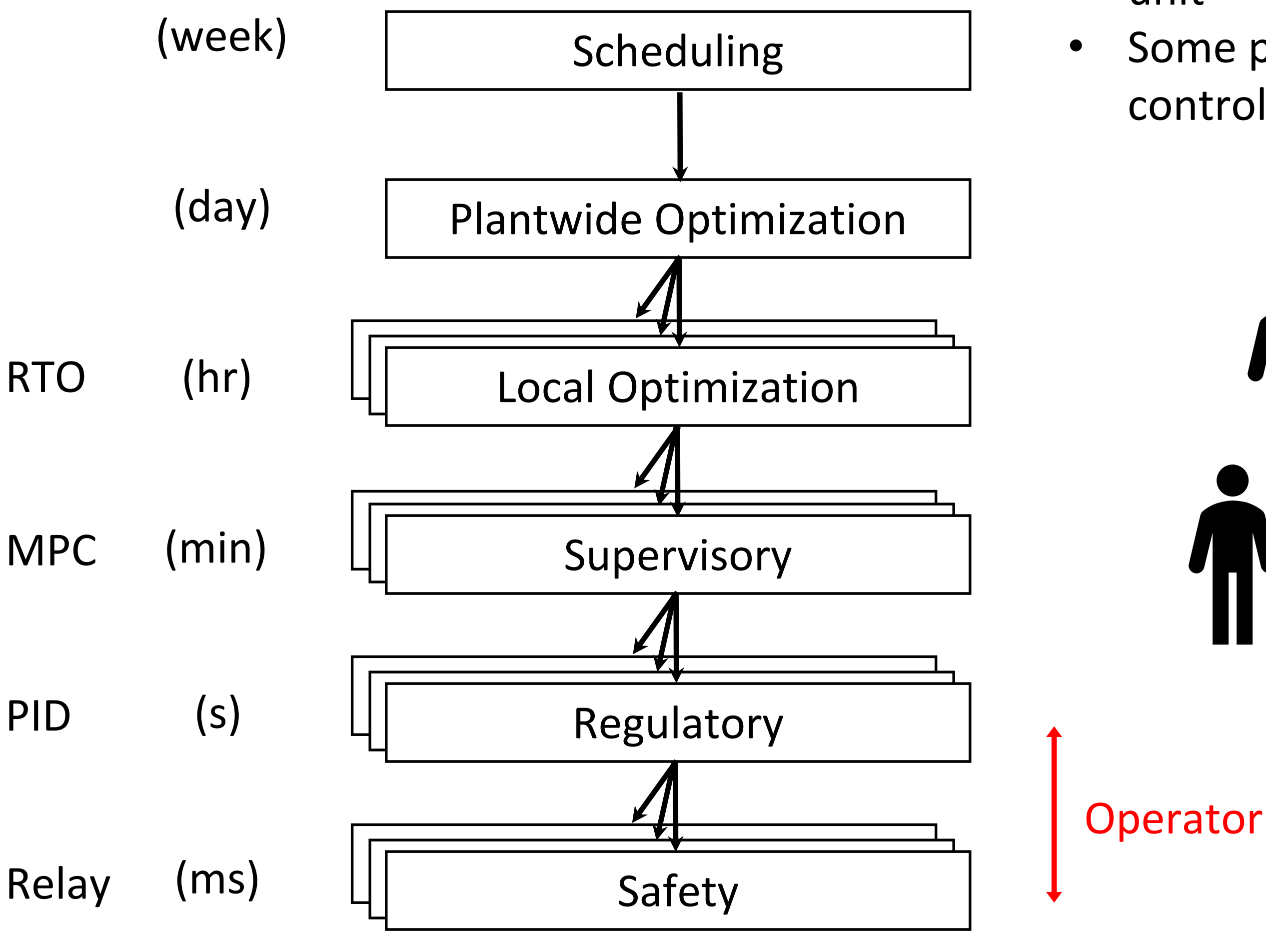
Example of Manual Control (not 1930s)

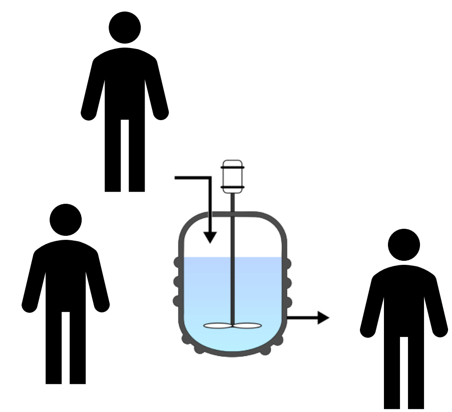
Oleon Scandinavia

1935 1950 1980 2000

Manual Control

- Mechanical measurements distributed in the prosessing unit
- Some primitive mechanical control





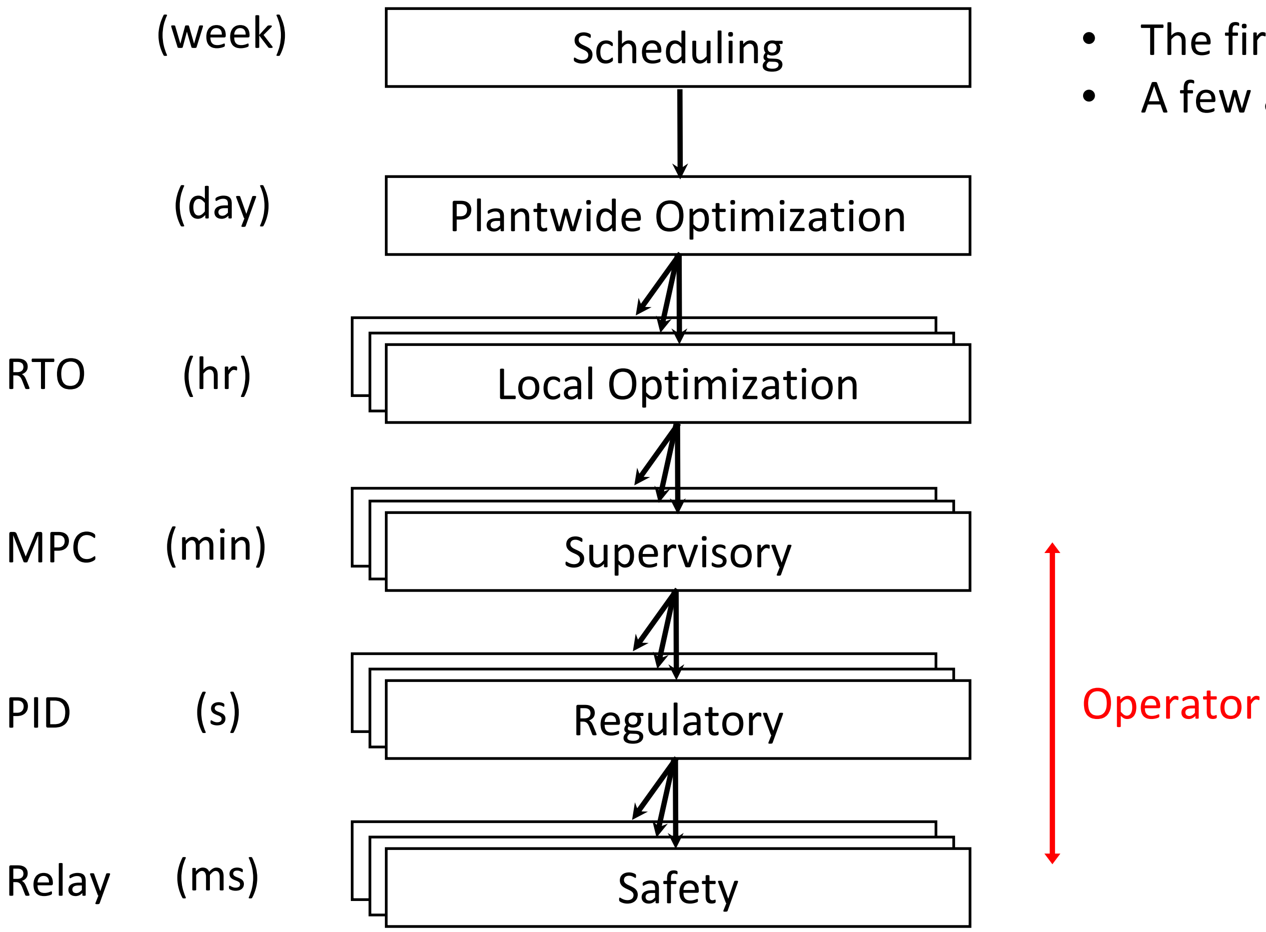
1950s

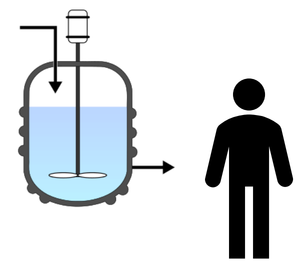
Tore Gjone Møller

1935 1950 1980 2000

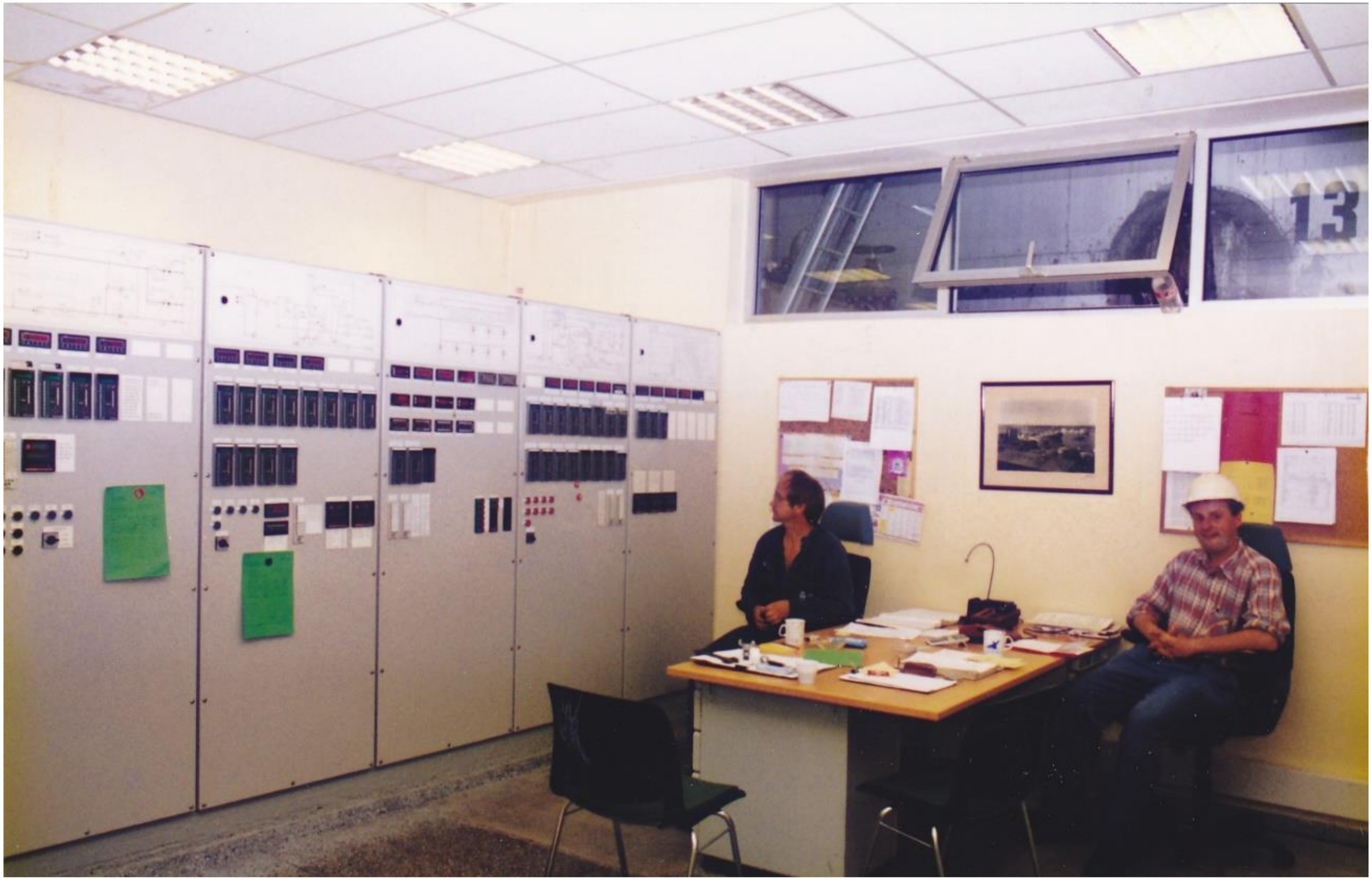
Pneumatic and control rooms

- The first control room
- A few alarms





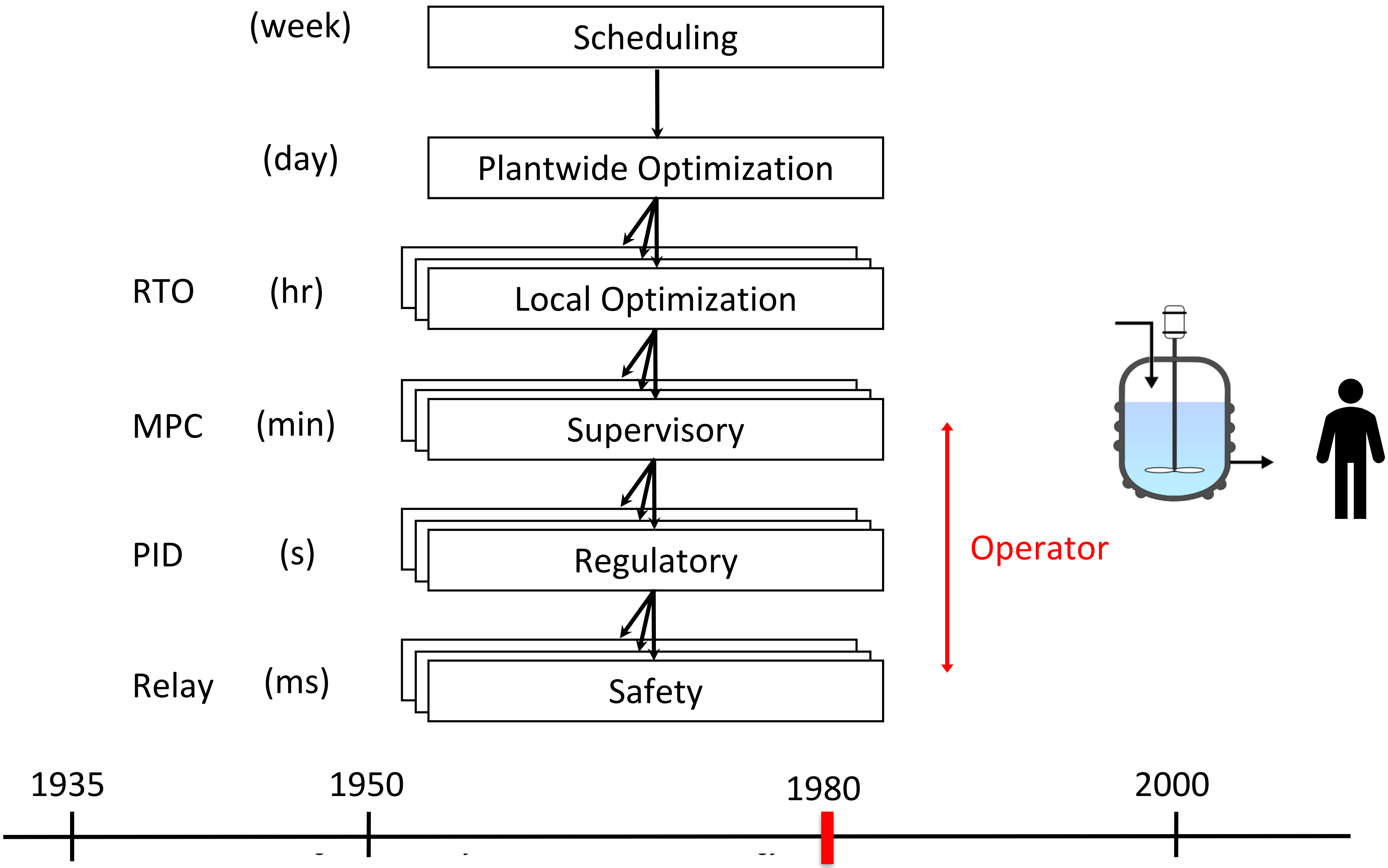
1980s



Tore Gjone Møller

1935 1950 1980 2000

Electric Control

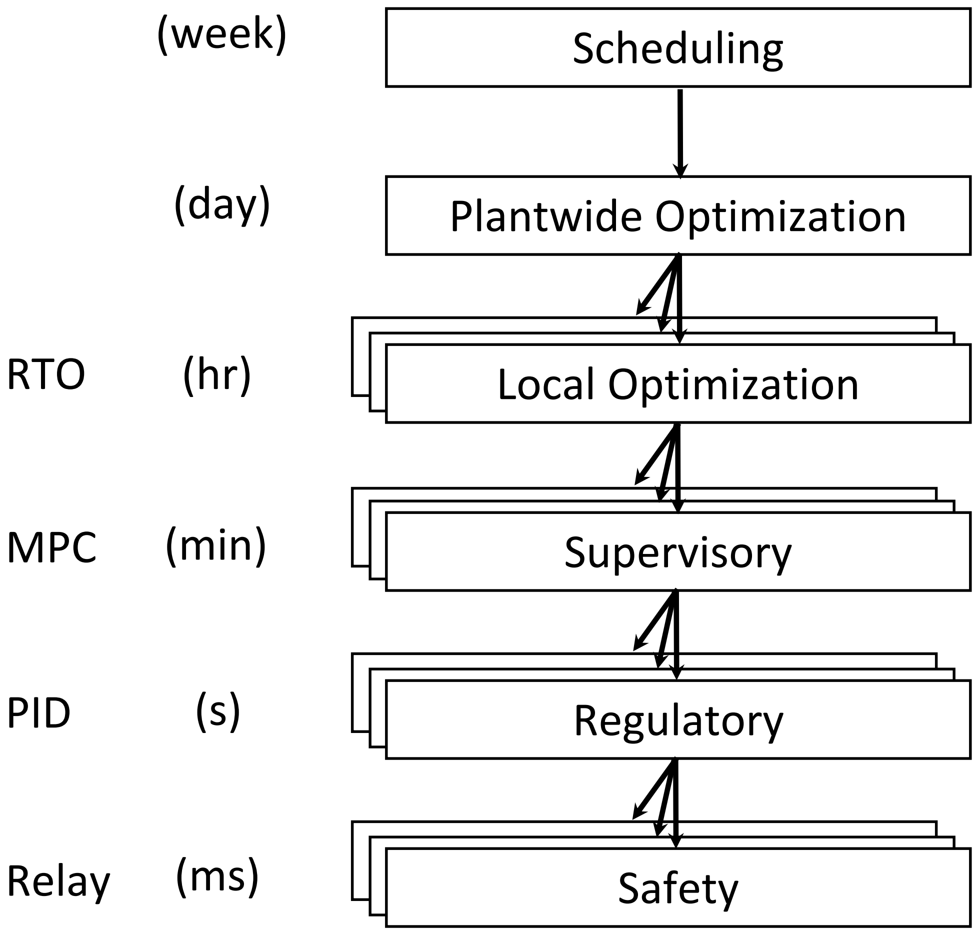


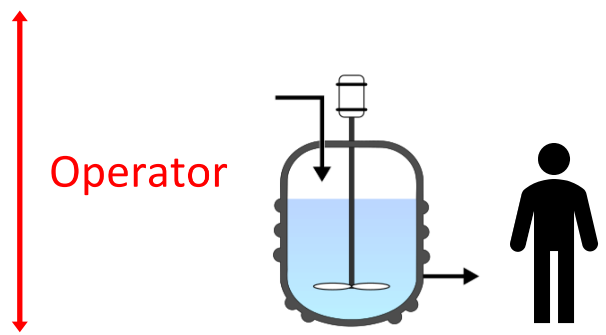
1990s

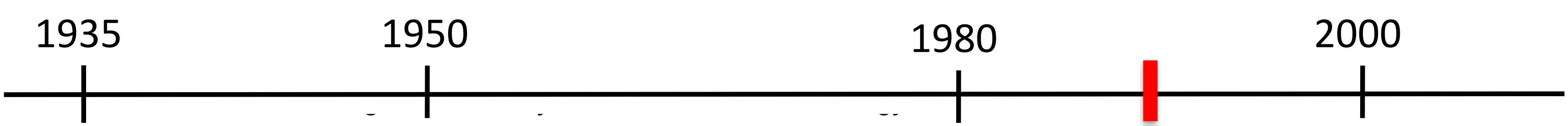
1935 1950 1980 2000

Distributed Control Systems

- Limited Process overview over on screen
- Much more flexible control!
- Alarms





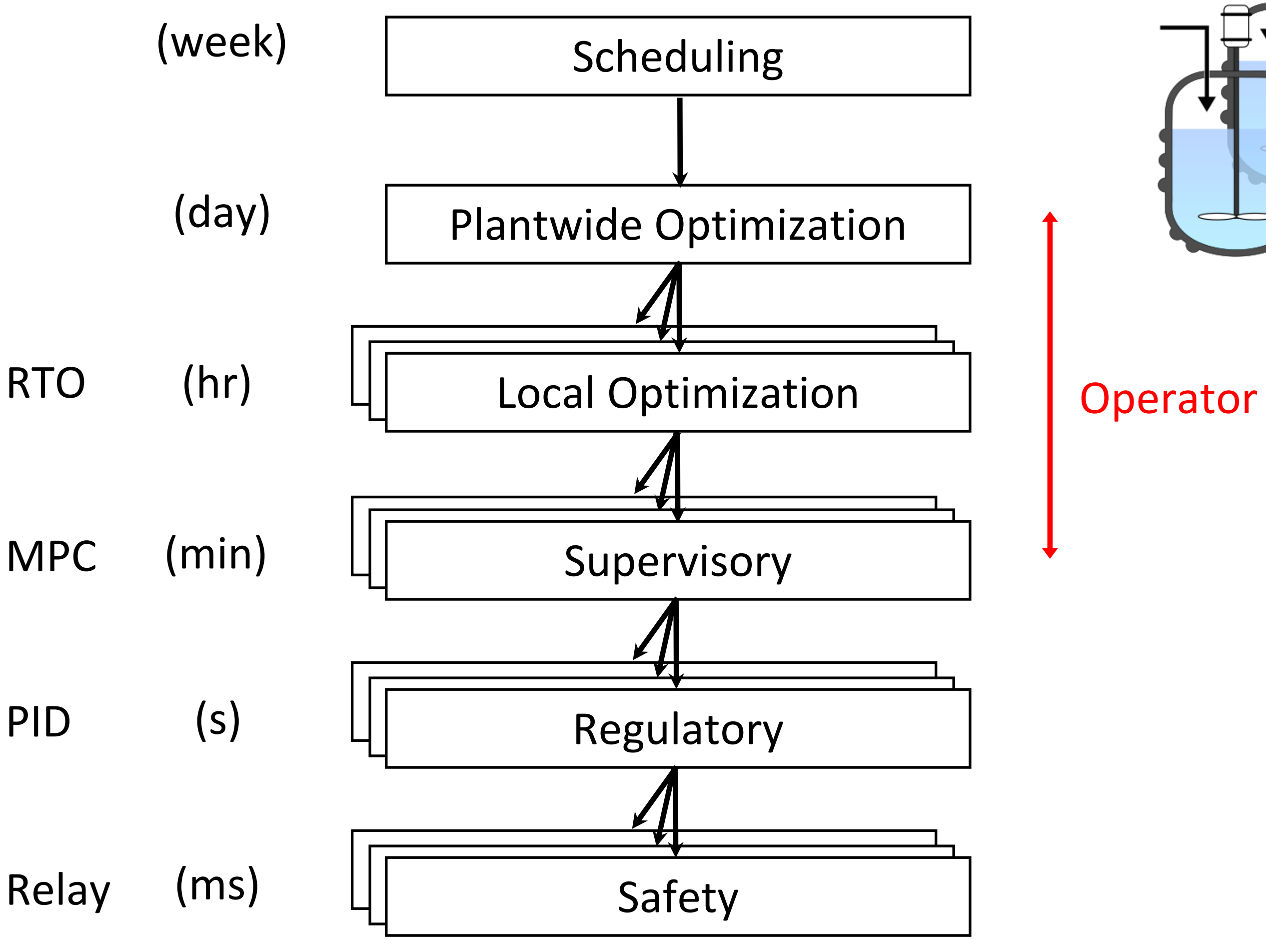


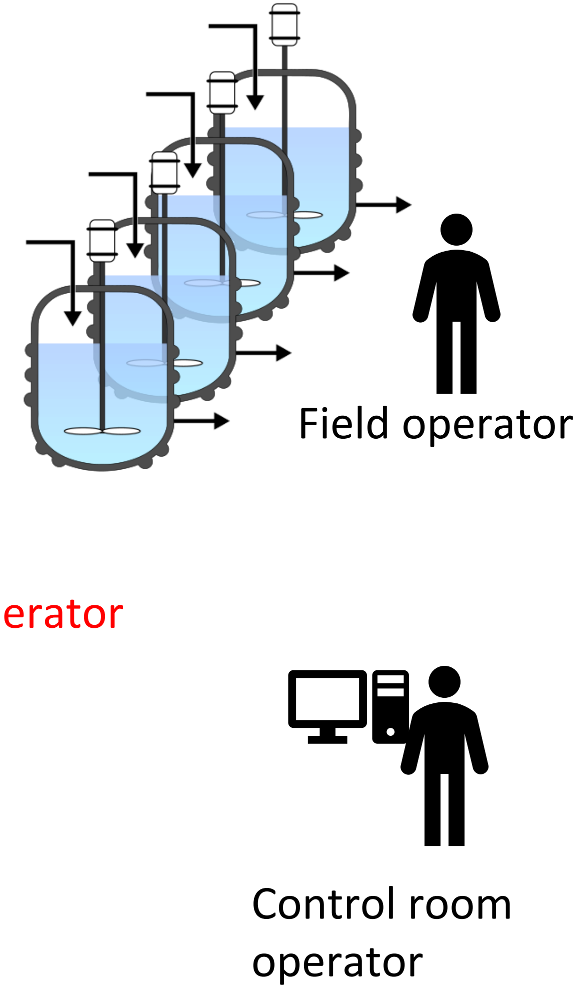
2000s

http://www.abb.com/cawp/seitp202/8583b3ebb6422b9ac1257eab001d38d9.aspx

1935 1950 1980 2000

Centralized Control Rooms





What Does the Modern Operator Do?

Field operations

- Operating manual valves
- Prepare for maintenance
- Sample taking/analyze quality
- Validating measurements
- Inspections rounds:
  visual, smells, vibration, sounds, temperature

Startup operations

- Startup and shutdown of plant
- Procedural operations like changing pumps, pigging, etc.

Monitoring operations

- Fault detection and correction
- Validating measurements
- Intervene when the plant is approaching some safety limit

Production operations

- Handling bottlenecks
- Backing off from constraints
- Controlling quality

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What do you think is the hardest to automate?

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Unmanned Offshore Oil Production

Oseberg H. Photographer: Erlend Hatteberg / CHC Helikopter Service / © Equinor

Equinor - Oseberg H

The first unmanned wellhead platform on the Norwegian continental shelf.

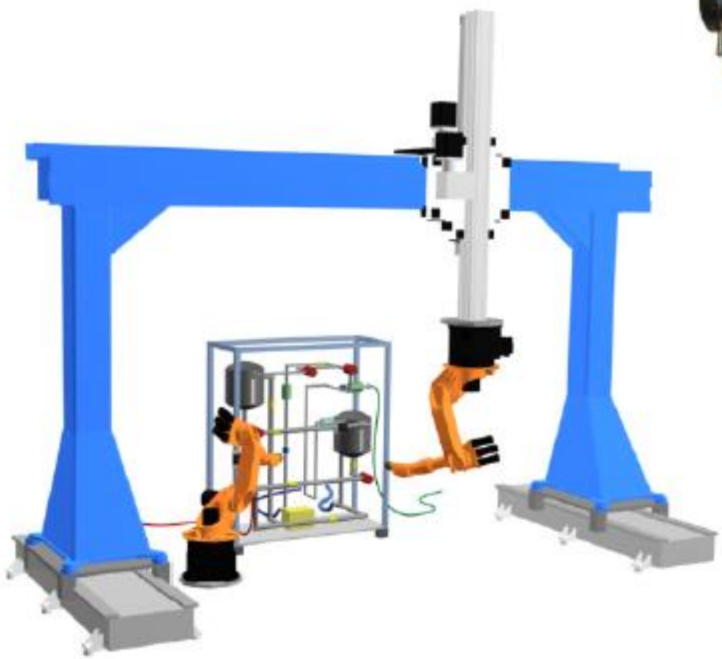
First production Oct 2018

Equinor - Peon (in planning)

The first unmanned production platform.

Outdoor Operator

Inspections rounds
- leaks
- smells
- vibration
- sounds
- temperature



R2D2

Erik Kyrkjebø, Pål Liljebäck, Aksel A. Transeth (2009). Robotic concept for remote inspection and maintenance on oil platforms. Proceedings of the ASME 2009 28th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2009-79702

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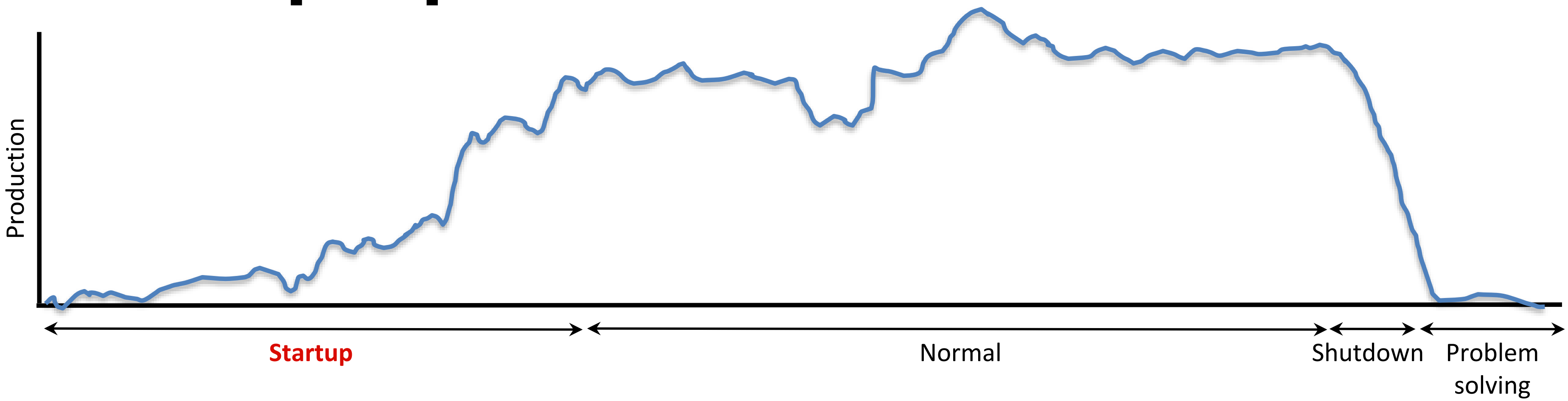
Startup Operations



Scheduling

Sitewide Optimization

Local Optimization

Supervisory

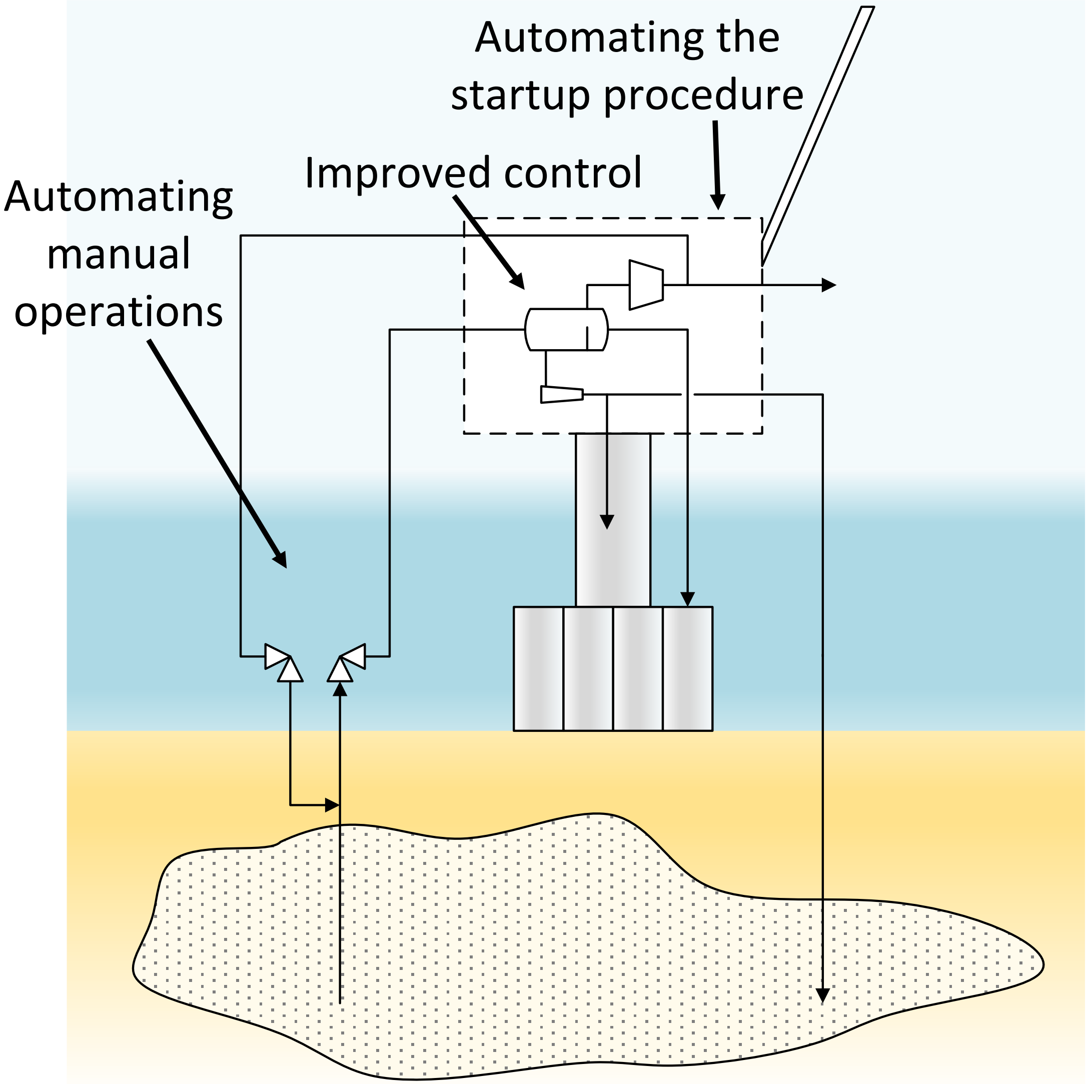
Regulatory

Safety

Operator

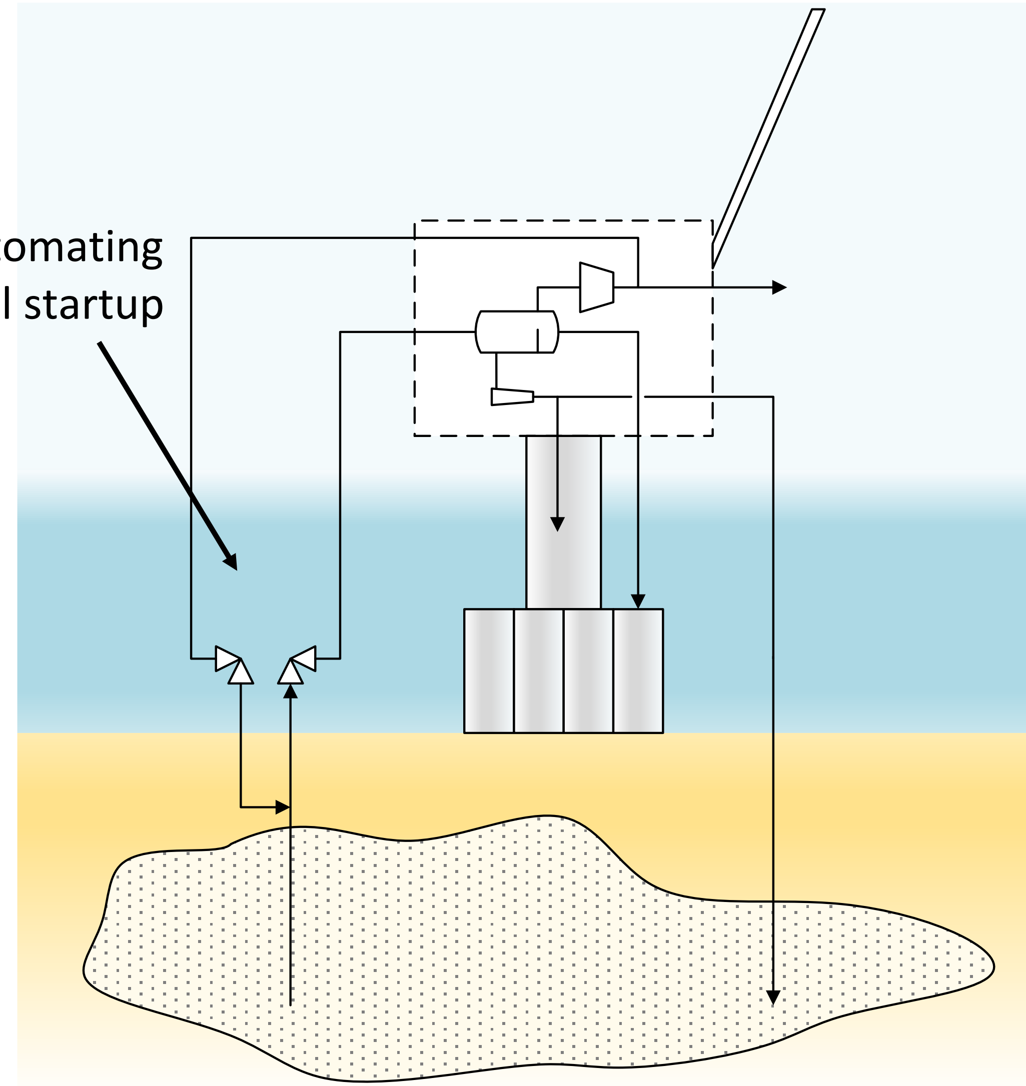
How can we push the operator up?

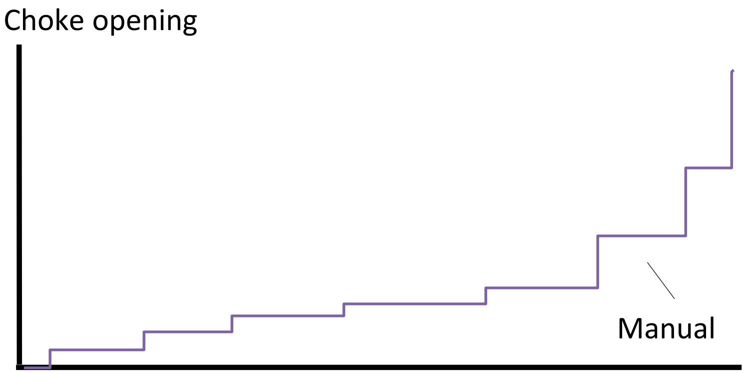
Three Main Challenges



Manuell well startup

Automating well startup

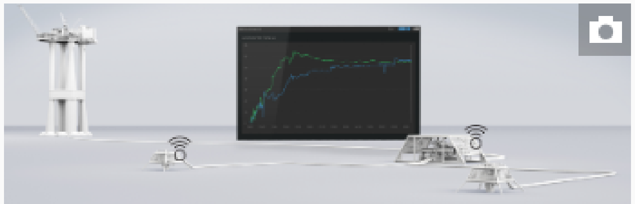




Example of well startup strategies

Automated Well Startup

ABB HOME → OFFERINGS → ABB OIL AND GAS → DIGITAL → SMART WELL GLOBAL SI



Autonomized Well Ramp-up

Wells are normally ramped up manually in a conservative way to protect the integrity of the well during periodic integrity testing and other planned/unplanned shutdowns. The result of this is a hidden production loss since the wells can be ramped up faster by using an autonomized approach still keeping the well integrity in a safe range.

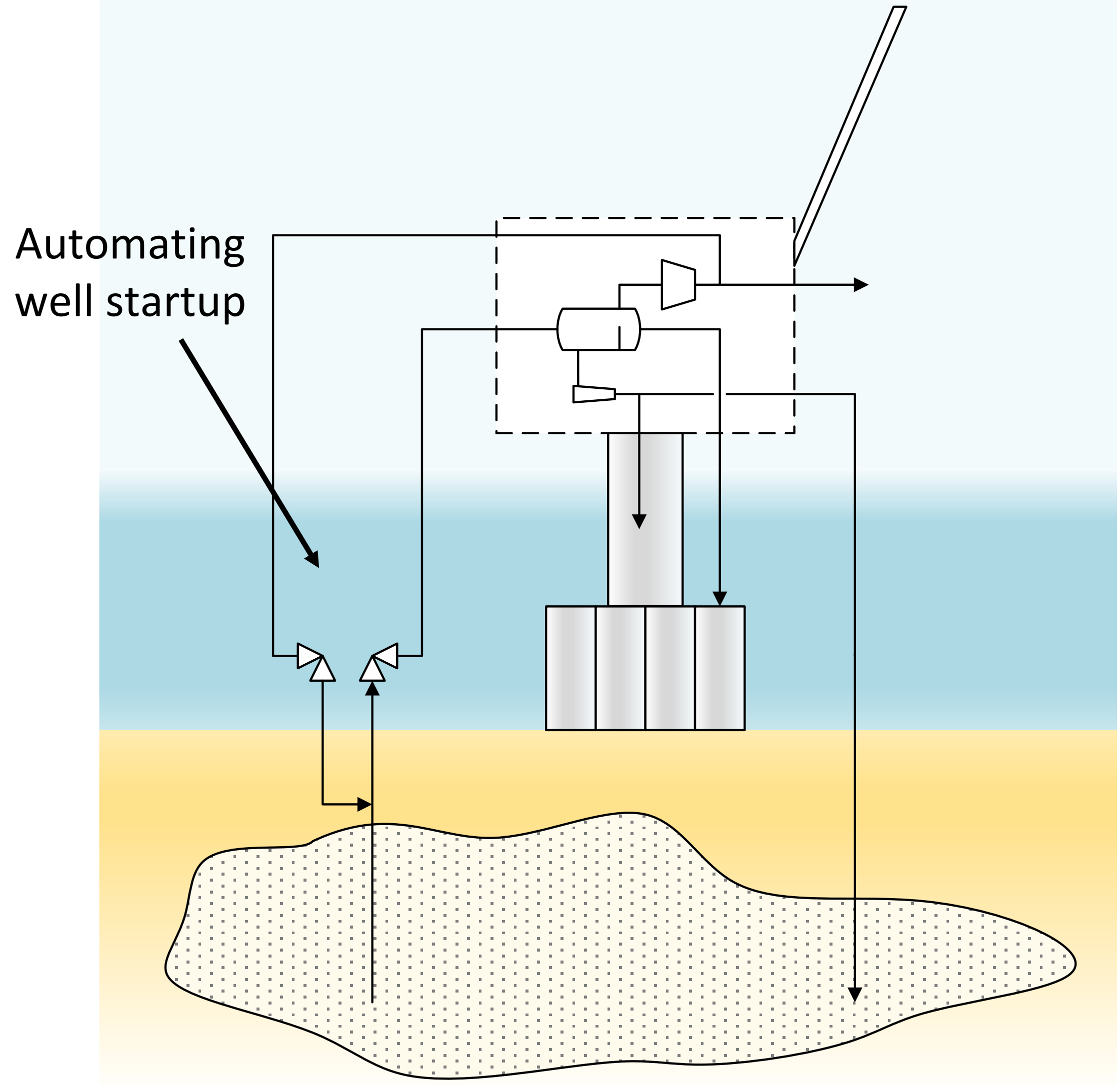
Our solutions

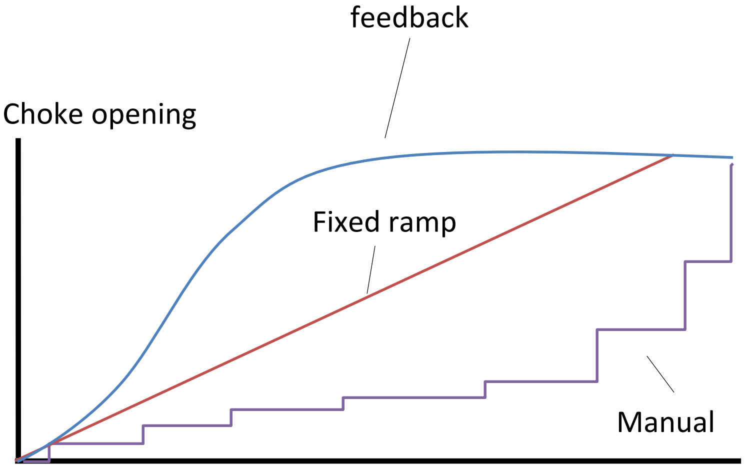
With Autonomized Well Ramp-up, operators are able to speed up the process and increase production. By monitoring and controlling critical variables in all the wells during ramp-up, and knowing what is happening in the well's process dynamics, the speed of the ramp-up is adjusted accordingly.

For example, there are 16 wells in production at Ormen Lange in the North Sea. Each well extends 2000 meters below the seabed and is surrounded by gravel and sand. Previously, it typically took 9 hours to ramp up a low pressure well and 15-20 hours for a high pressure well. The process was safe, but it did not take into account what was happening in the wells in real time. After installation of ABB's solution, the wells can now be opened much faster than before and with reduced risk to well integrity and safety. On average, it now takes only 2 hours to open low pressure wells and 6 hours to open high pressure wells.

https://new.abb.com/oil-and-gas/digital/smart-well

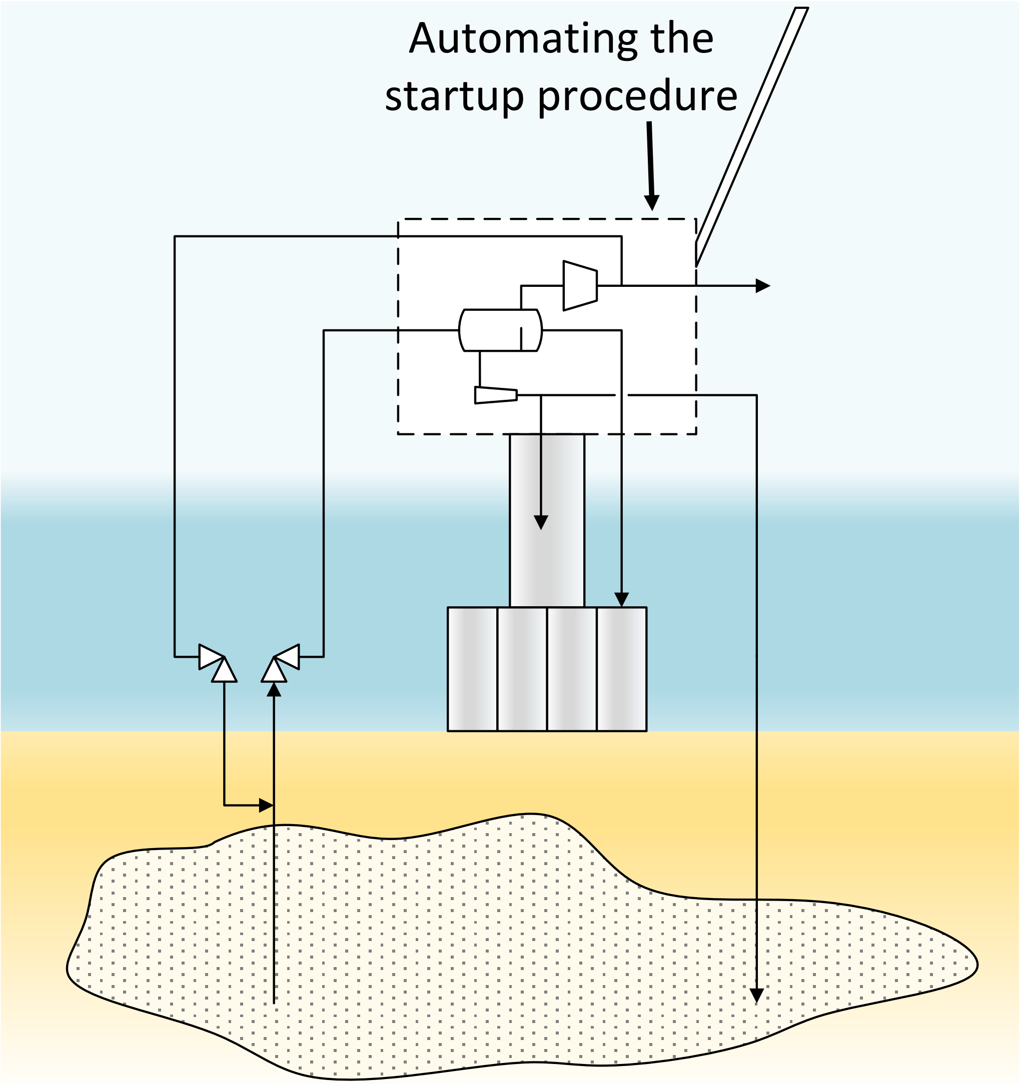
Automated Well Startup – just feedback





Example of well startup strategies

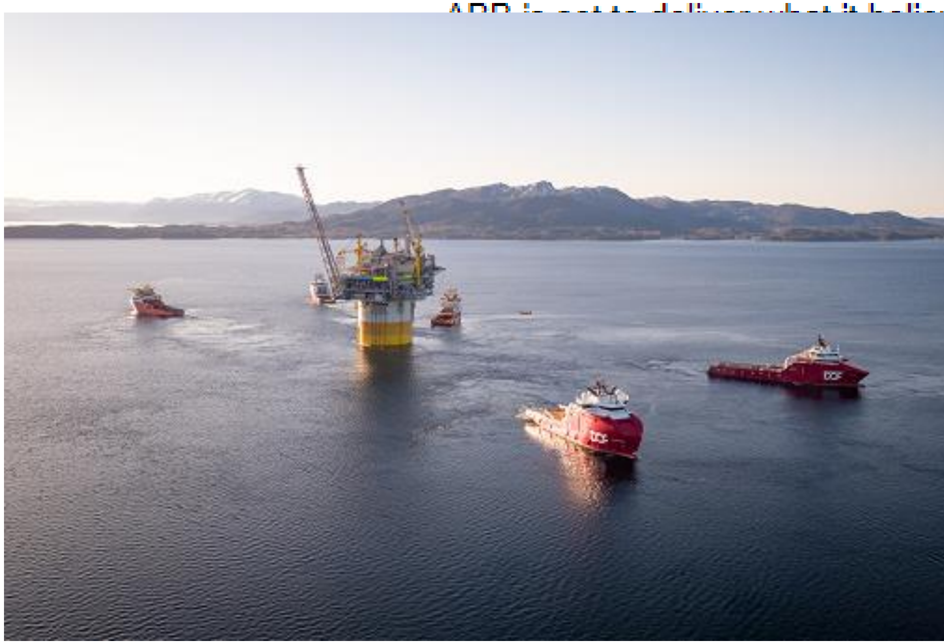
Manual Startup Procedure



Examples of automatic startup of plant

ABB to deliver fast upstream start-up for Aasta Hansteen's first gas production

August 27, 2018, Oslo, Norway – Ability™ technology estimated to save 40 days in commissioning phase by reducing manual interventions by 98 percent



…es to be the world's fastest start-up when Equinor's
…operating and produces its first gas later this year.

…ling a suite of innovative ABB Ability™ digital
… which is located in 1300 meters of water in the Vøring
…ilometers from land.
… to make the first gas start-up process as quick and
… needed to reduce a sequence of over 1000 manual
…e. The outcome is a series of buttons that are as simple

…-up steps, identified and defined obstacles that needed
…B Ability™ System 800xA simulator to do a virtual start-

Aasta Hansteen tow from Stord to the field, photo: Woldcam/Equinor

http://www.abb.com/cawp/seitp202/4160929811931378c12582f2003c782b.aspx

Examples of automatic startup of plant

YOKOGAWA

erators do not require any specialized engineering training to configure sequences.

The Challenges for Nippon Shokubai

In 2001 Nippon Shokubai built a new NVP (N-vinylpyrrolidone - a raw material used in pastes and photoresist coating) plant that used state-of-the-art technology. The prestigious Chemical Engineering Magazine subsequently conferred its Kirkpatrick Honor Award upon the company in recognition of this plant's safe and clean production of NVP using an innovative vapor phase continuous reaction processes and a new dehydration catalyst.

Nippon Shokubai faced a challenge in constructing an automatic start-up and shutdown system for production processes using this plant's DCS (Distributed Control System) as the new technology used in the plant produced frequent changes in operating conditions. As the DCS was not the best platform for controlling the plant through sequence programs, the company installed Exapilot so that start-up and shutdown sequences could be automated quickly, in spite of the demanding operating conditions.

Results

Exapilot succeeded in reducing operators' workloads dramatically at the time of plant start-up and shutdown. Before Exapilot was introduced, an operator had to constantly make manual adjustments to the DCS. Exapilot achieved a fully automatic system as follows:

1. A drastic reduction of DCS manipulations: from 4,350 times per month to 0 (zero)
2. DCS monitoring time reduction: from 138 man-hours per month to 1 man-hour per month
3. Lower power consumption and heat steam energy as the result of stabilized operations and minimized operation time
4. Elimination of problems caused by operator errors

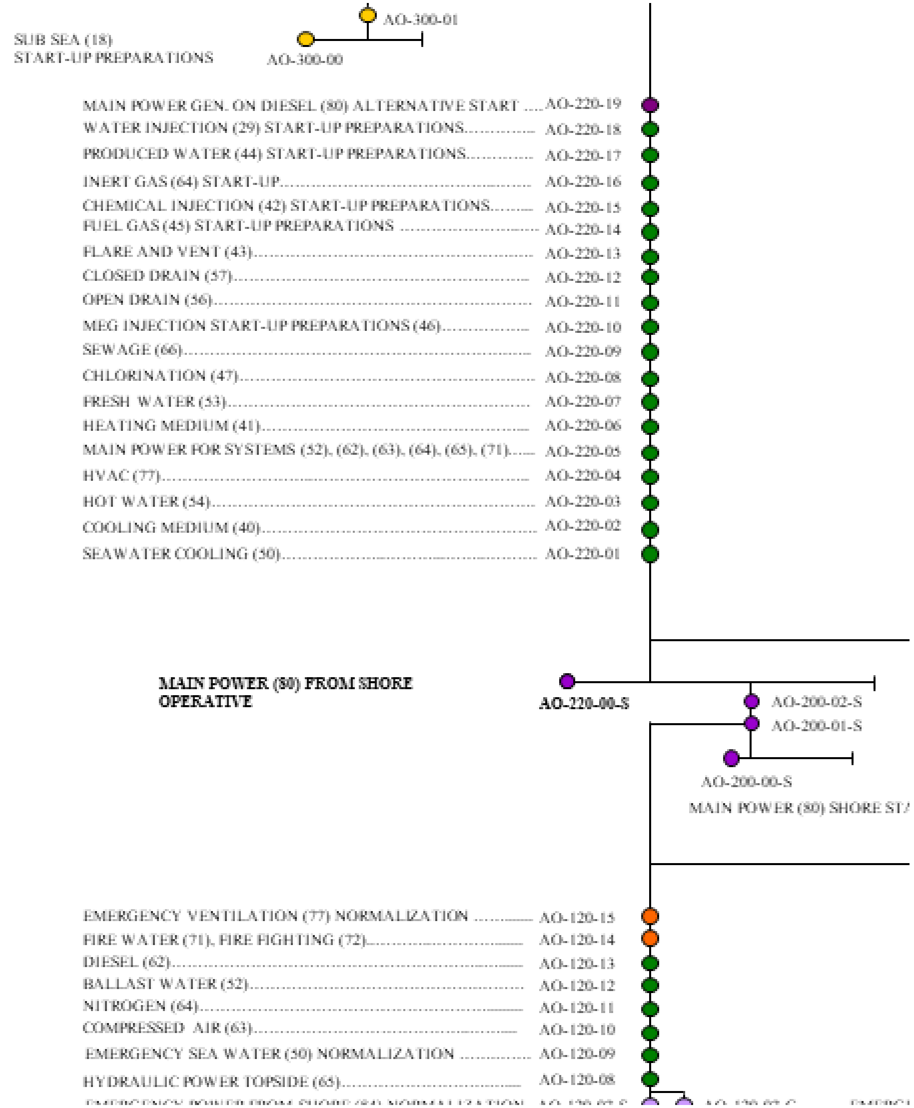
https://www.yokogawa.com/library/resources/references/drastic-reduction-in-operator-workloads-and-faster-plant-startup-and-shutdown-nippon-shokubai-co-ltd/

Automatic startup of plant

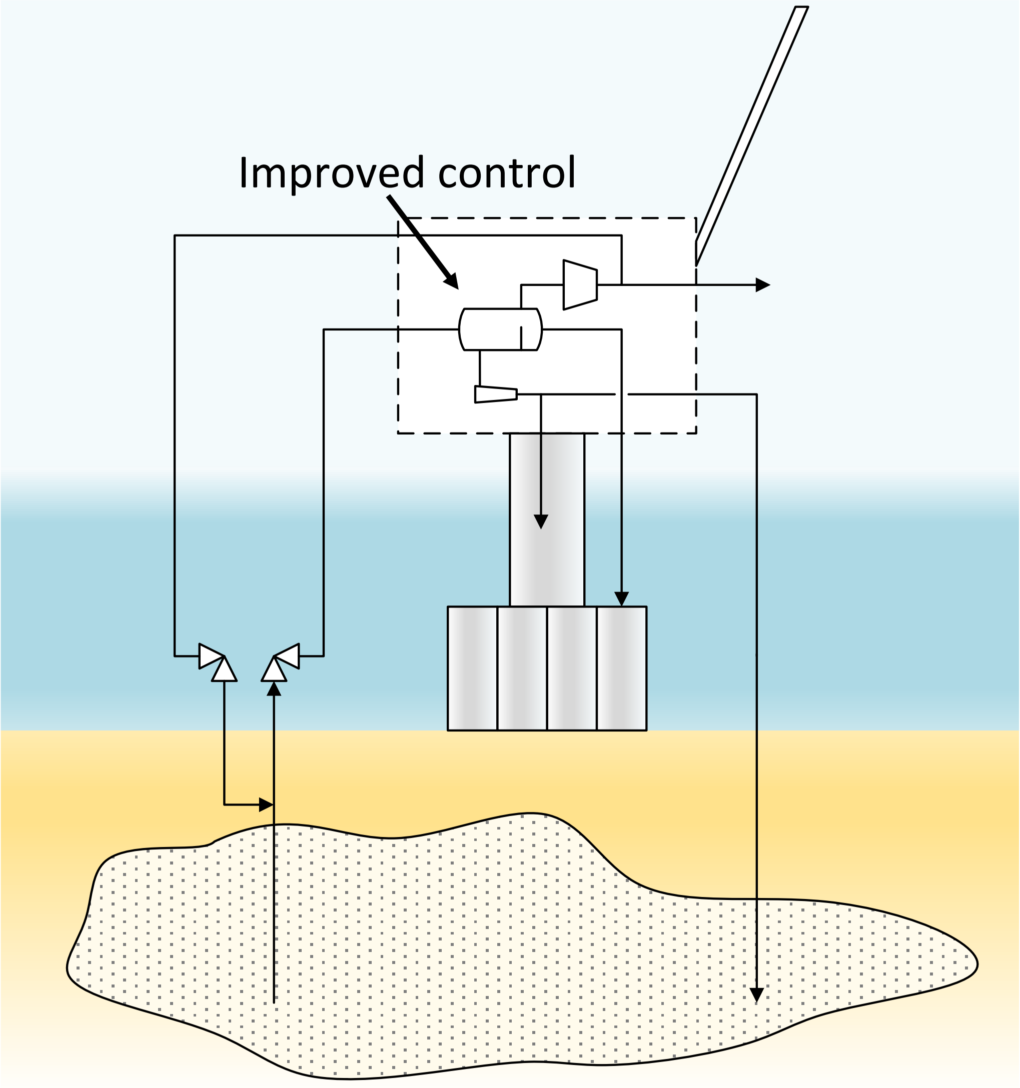
Procedure for startup/shutdown usually already exists.

Todays practice: Use experts knowledge and turning the procedures sequences.

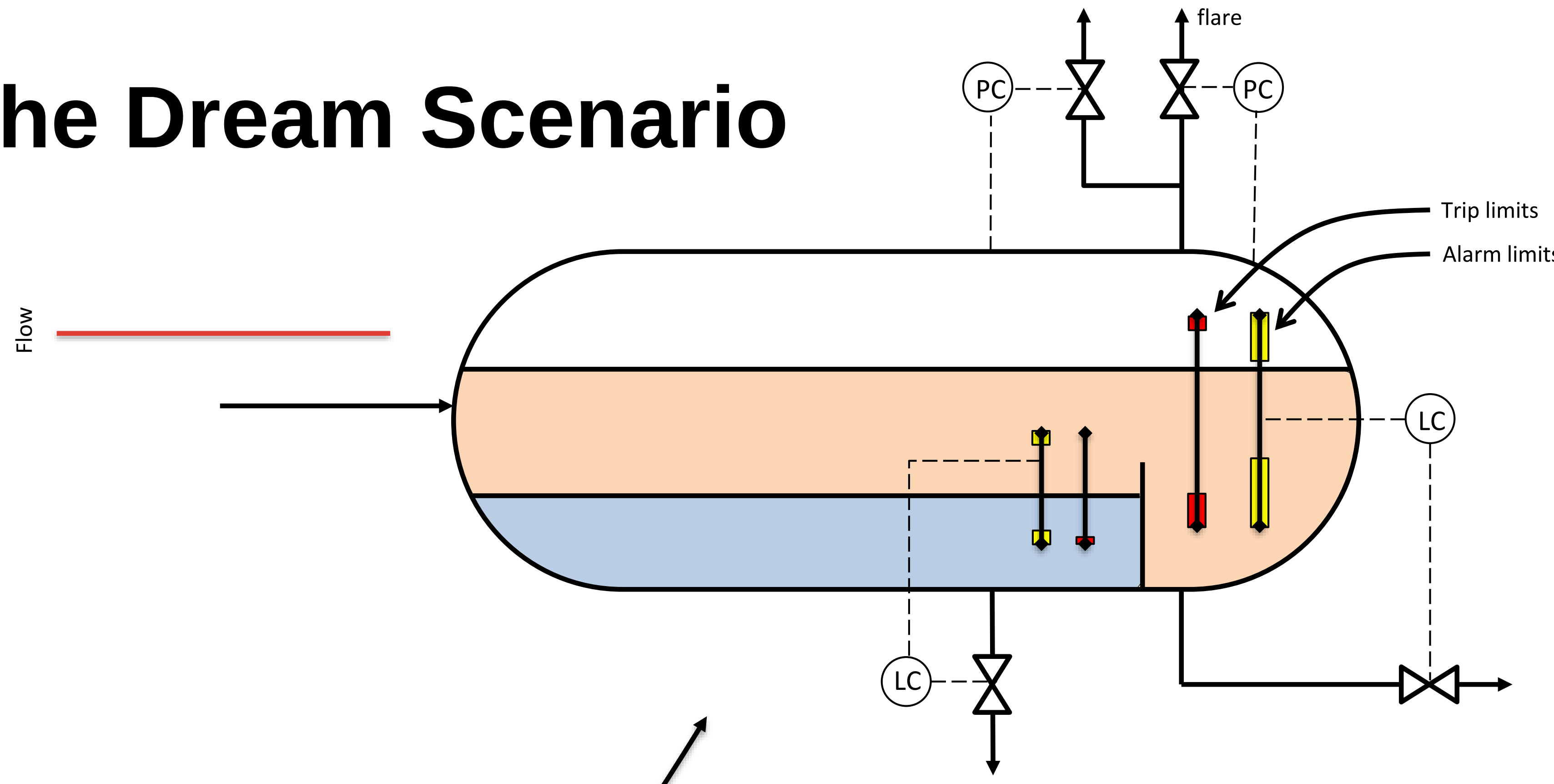
- Testing on simulator
- Tuning, tuning and tuning after commissioning



Improved Control

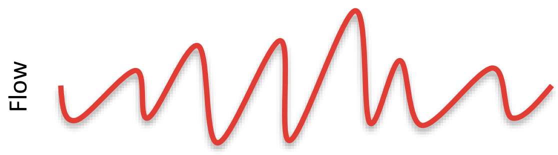


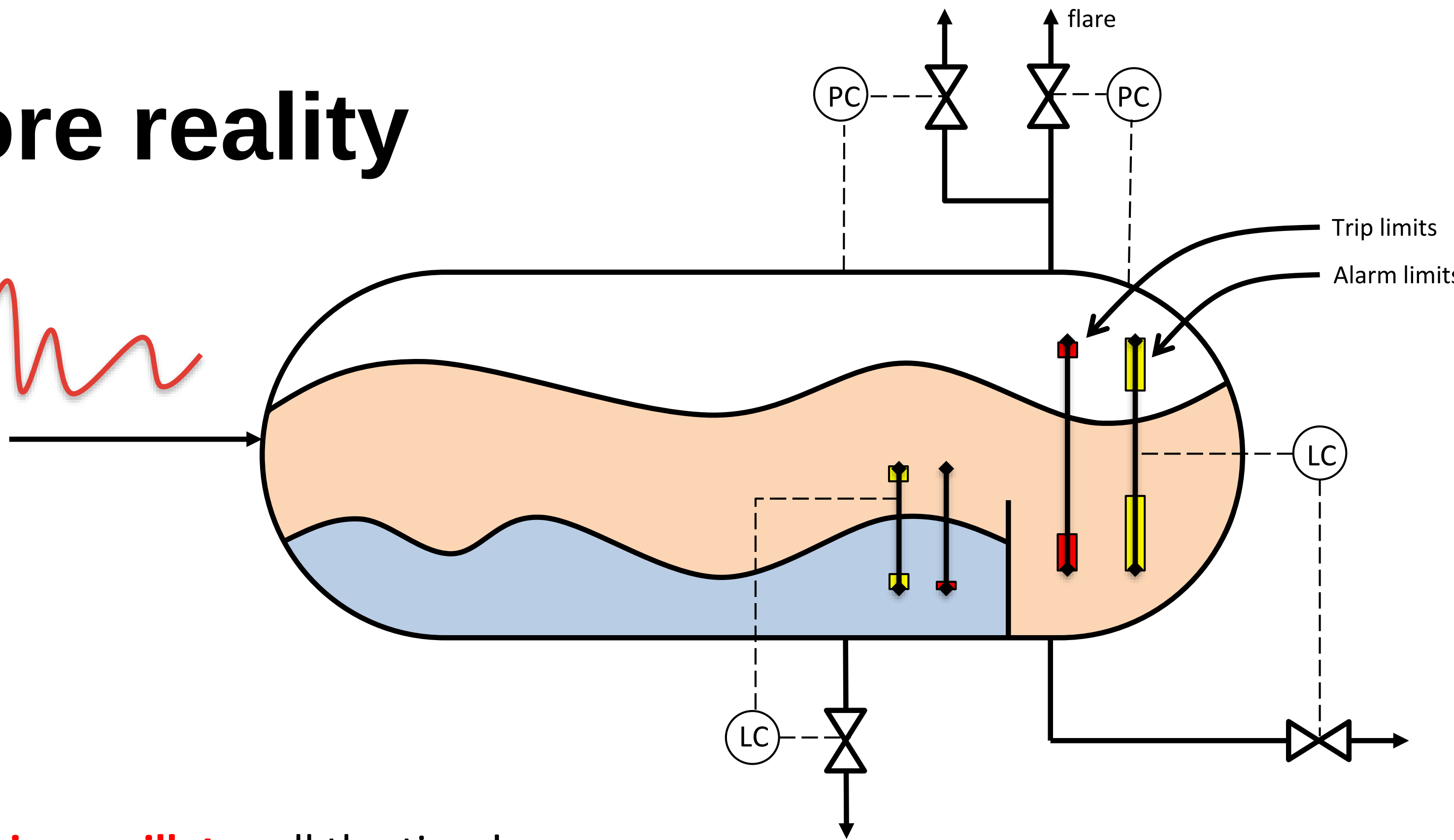
The Dream Scenario



A first stage separator
on an oil platform

Offshore reality





Offshore: **everything oscillates** all the time!

Controllers are tuned slow to dampen flow variations as much as possible for downstream units

Problem: you usually **need faster controllers during startup**

Improved Control

Improving controller performance for a wider range of situation

Manual tuning

Most issues can be solved with proper tuning

Adaptive tuning:
- Gain scheduling
- Heuristics, expert control system
- Fuzzy gain scheduling
- Self-tuning (direct, indirect)
- Auto-tuning

Improved control structure:
- Override controllers
- Correct ratio control

Advanced Controllers:
- MPC
- Higher order linear, Nonlinear
- Neural Net

Improved Control

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Manual tuning

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e.g. High level -> 2x gain

e.g. Startup -> 2x gain

e.g. fuzzy gain scheduling

	Small valve opening	*Large valve opening*
Low level	Normal	2x gain
High level	2x gain	Normal

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Common industrial solution

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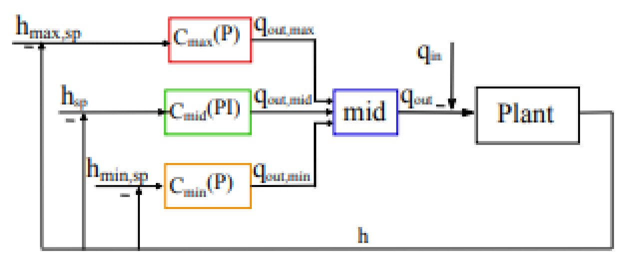

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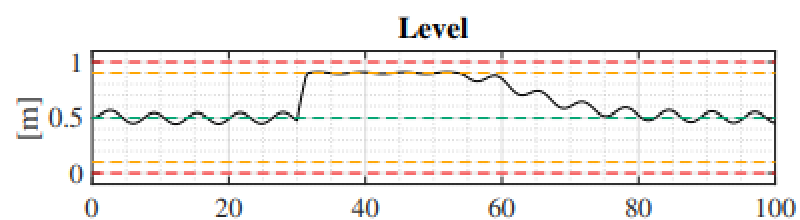

Adriana Reyes-Lúa, Christoph Josef Backi, Sigurd Skogestad (2018). Improved PI control for a surge tank satisfying level constraints. IFAC-PapersOnLine 51(4), 835-840

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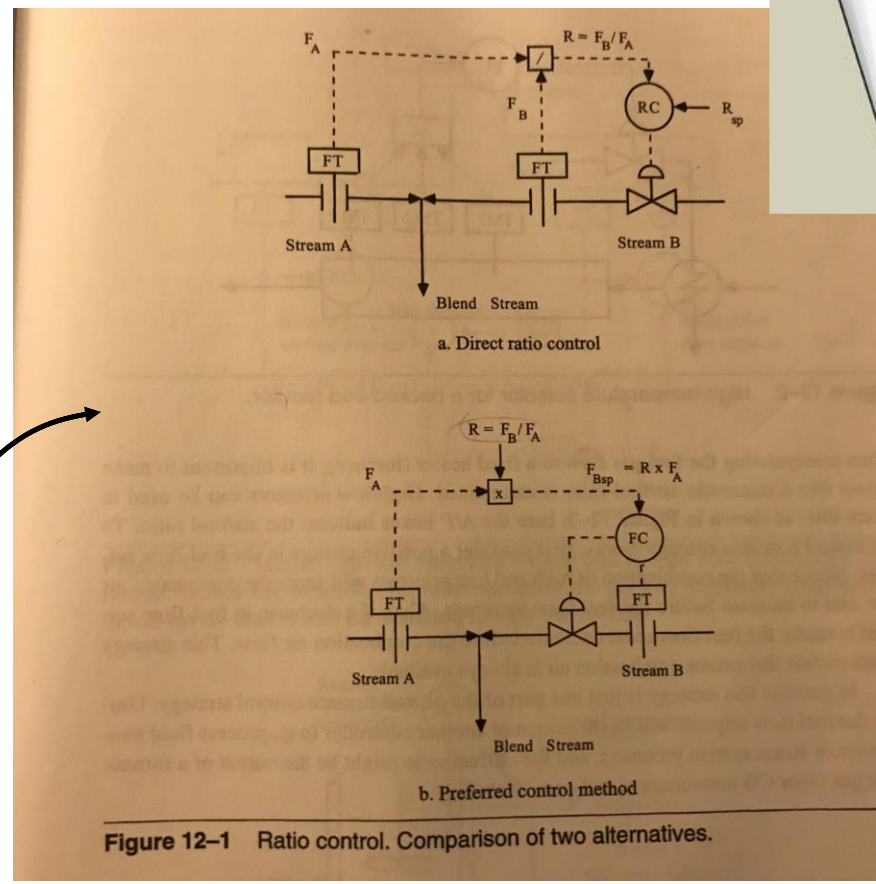

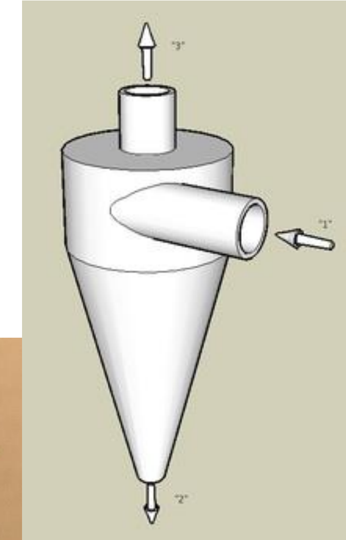

Bequette, B. W. (2003). *Process control: modeling, design, and simulation*. Prentice Hall Professional.

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Advanced Controllers:
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- Decouples
- Handles constraints on measurements
- Handles bottlenecks
- Possible with prioritization on soft-constraints

Probably no MPC offshore applications in Norway

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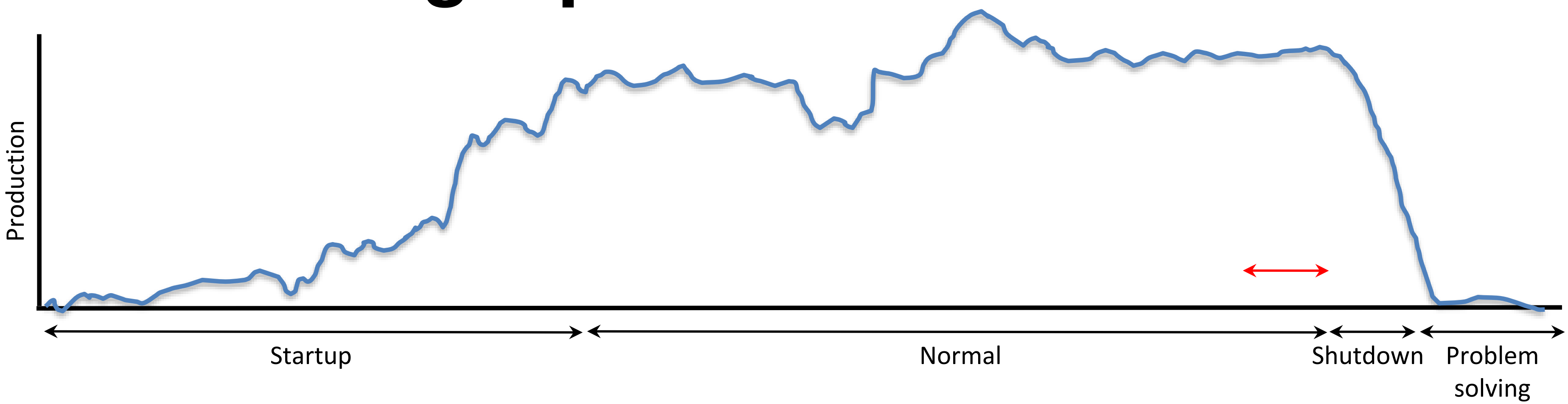
Monitoring Operations



Scheduling

Sitewide Optimization

Local Optimization

Supervisory

Regulatory

Safety

Operator

How can we push the operator up?

Fault Detection, Diagnosis and Mitigation

Can be worked around → Fault vs. Failure ← Irrecoverable

Scheduling

Sitewide Optimization

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Safety

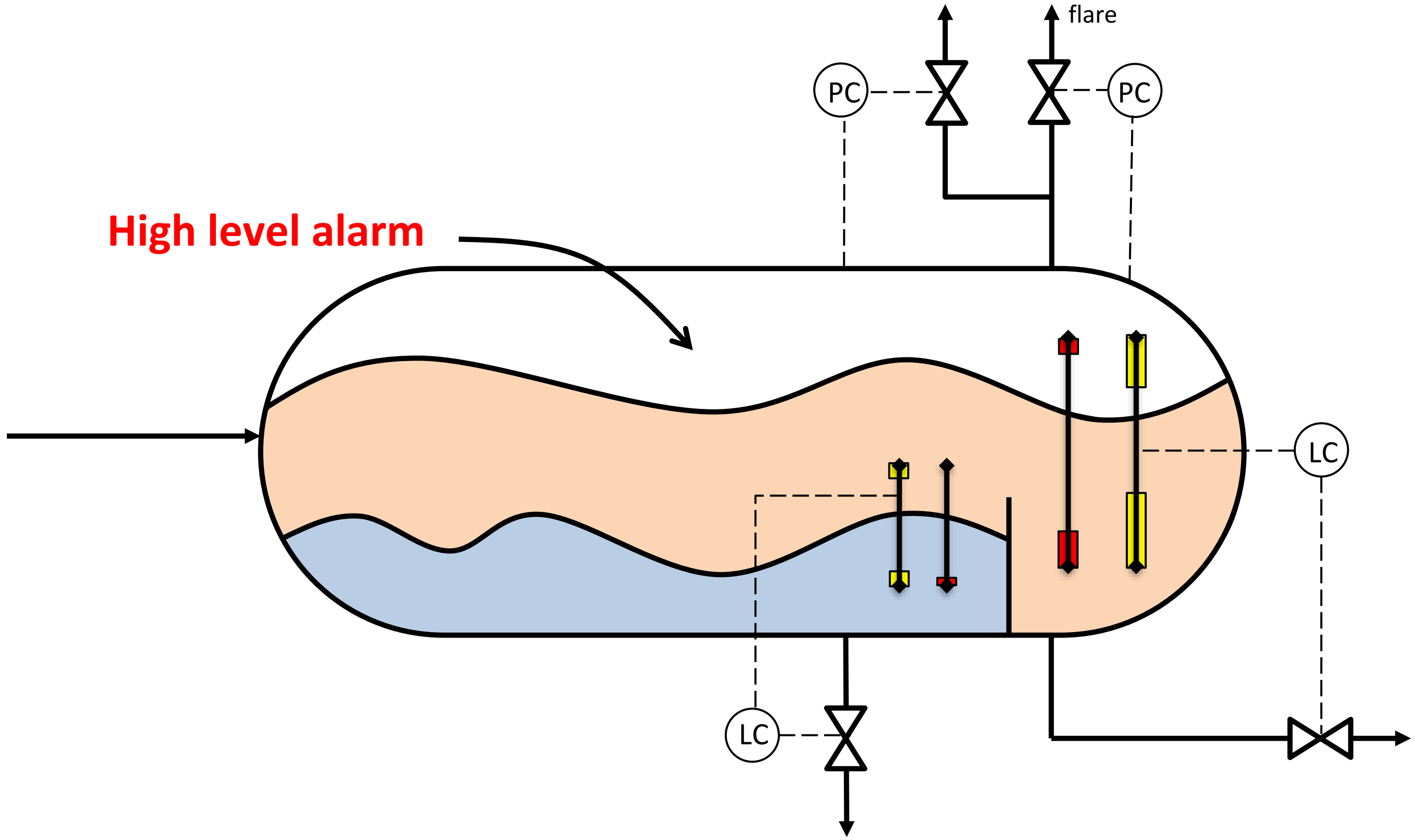
Alarms: The simplest fault detection method

Detects failure and shuts down the plant

e.g. rector temp > 200 °C -> Trip plant

Mogens Blanke, Michel Kinnaert, Jan Lunze, Marcel Staroswiecki (2018). Diagnosis and Fault-Tolerant Control. 2nd Edition. Springer. ISBN: 978-3-540-35652-3.

Manuel Operation



Why:

- Large disturbance?
- Is the level measurement correct?
- Is the valve working?

Probably not acceptable to shut down the platform because of a faulty sensor

Automated Solutions for Fault Detection, Diagnosis, and Mitigation

e.g. Principal Component Analysis (PCA)

Bakdi A, Kouadri A. An improved plant-wide fault detection scheme based on PCA and adaptive threshold for reliable process monitoring: Application on the new revised model of Tennessee Eastman process. Journal of Chemometrics. 2018;32:e2978. https://doi.org/10.1002/cem.2978

Detection:

- Analytical
- Data-Driven
- Knowledge Based
- Fuzzy Logic
- Pattern-Recognition

Eg, Alarm limit

Eg. Large deviation between the two oil level measurements

e.g. Deep Learning

Lv, Feiya & Wen, Chenglin & Bao, Zejing & Liu, Meiqin. (2016). Fault diagnosis based on deep learning. 2016 American Control Conference (ACC). 6851-6856. 10.1109/ACC.2016.7526751.

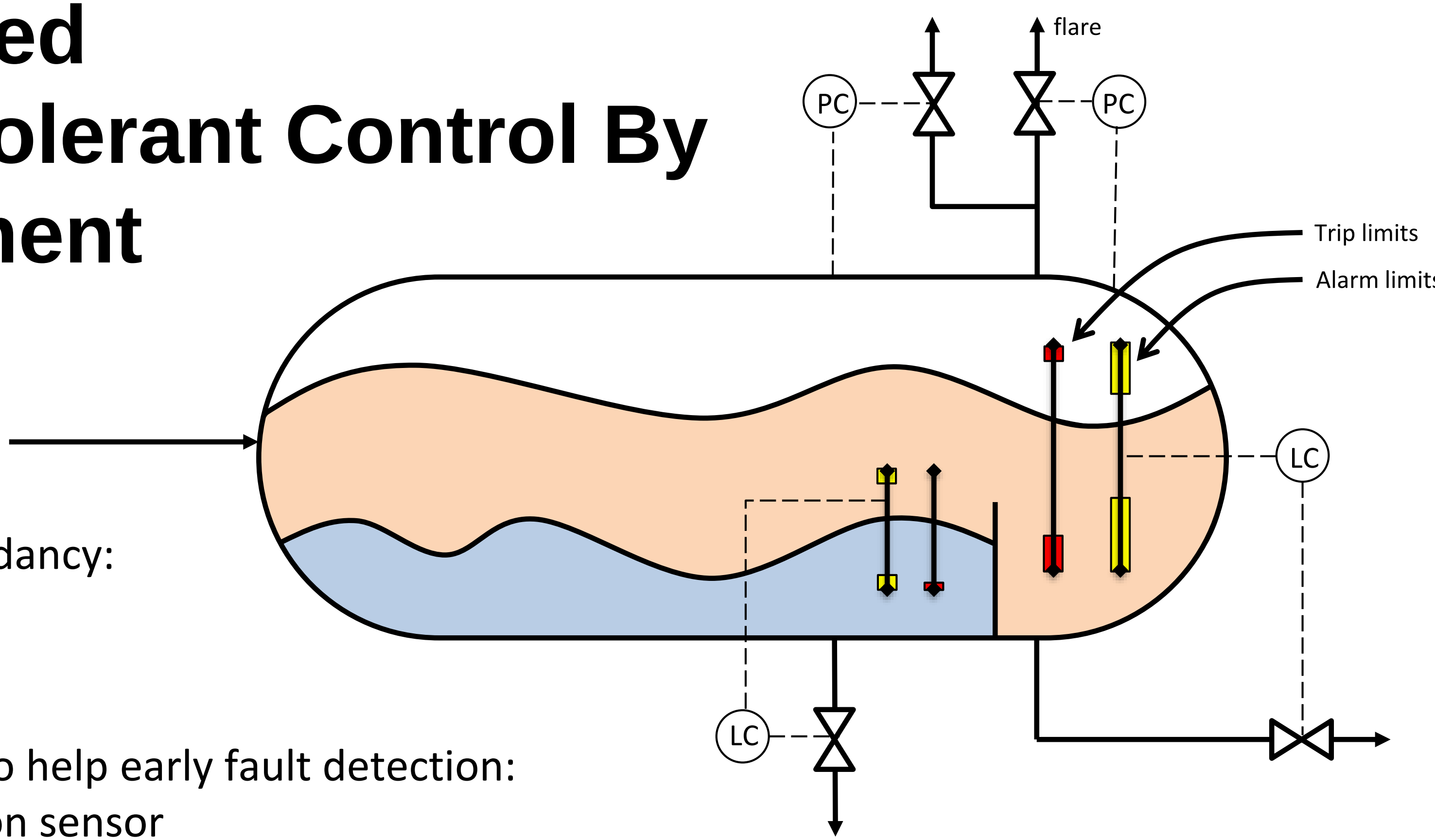
Diagnosis

Mitigation:

- Virtual/soft sensors
- Virtual actuators

Many solutions, but not widly adopted in industry...
Must be considered much more in operatorless future

Improved Fault Tolerant Control By Equipment



Physical Redundancy:
- Sensors
- Actuators

Extra sensors, to help early fault detection:
- Valve position sensor

Robust Equipment:
- Sensors: e.g. rather orifice than ultra-sonic
- Actuators: not sensitive to scaling

Two sensors, detect error but must shut down.
Tree sensors, can detect error and continue controlling

What Does the Modern Operator Do?

Field operations

- Operating manual valves
- Prepare for maintenance
- Sample taking/analyze quality
- Validating measurements
- Inspections rounds:
  visual, smells, vibration, sounds, temperature

Startup operations

- Startup and shutdown of plant
- Procedural operations like changing pumps, pigging, etc.

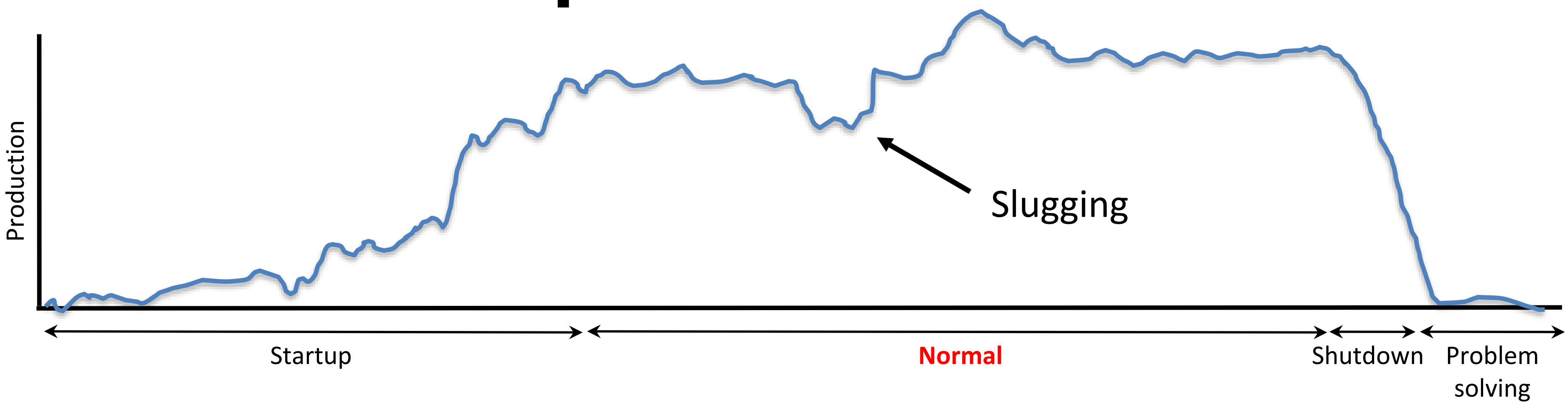
Monitoring operations

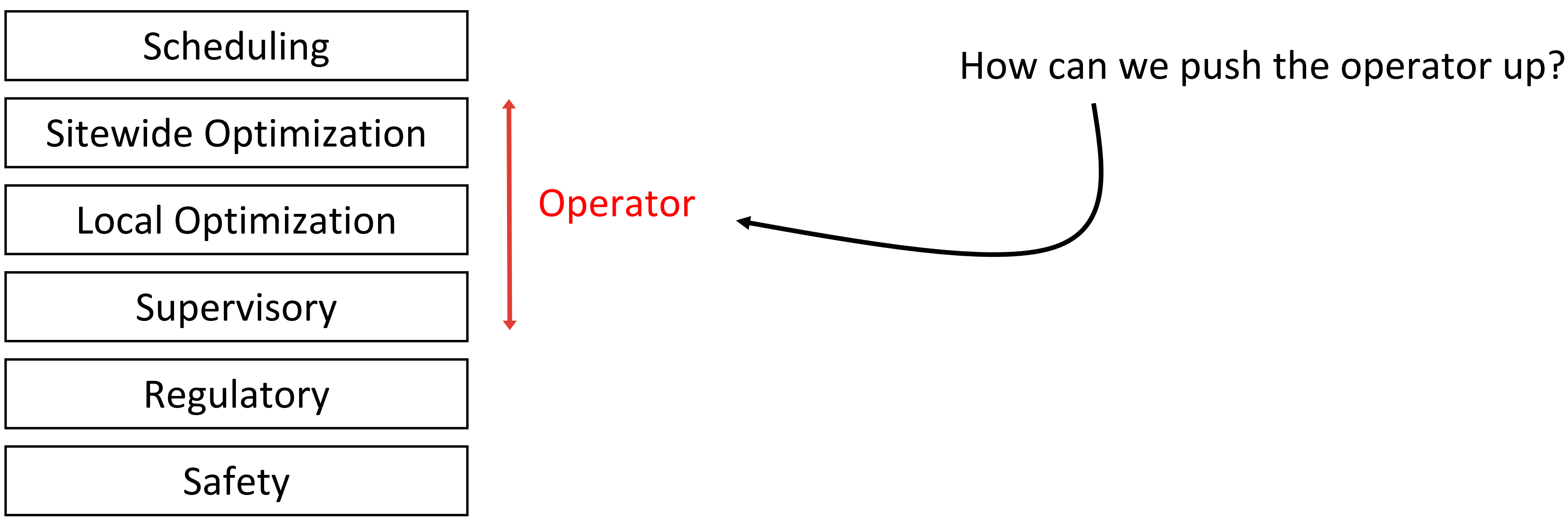
- Fault detection and correction
- Validating measurements
- Intervene when the plant is approaching some safety limit

Production operations

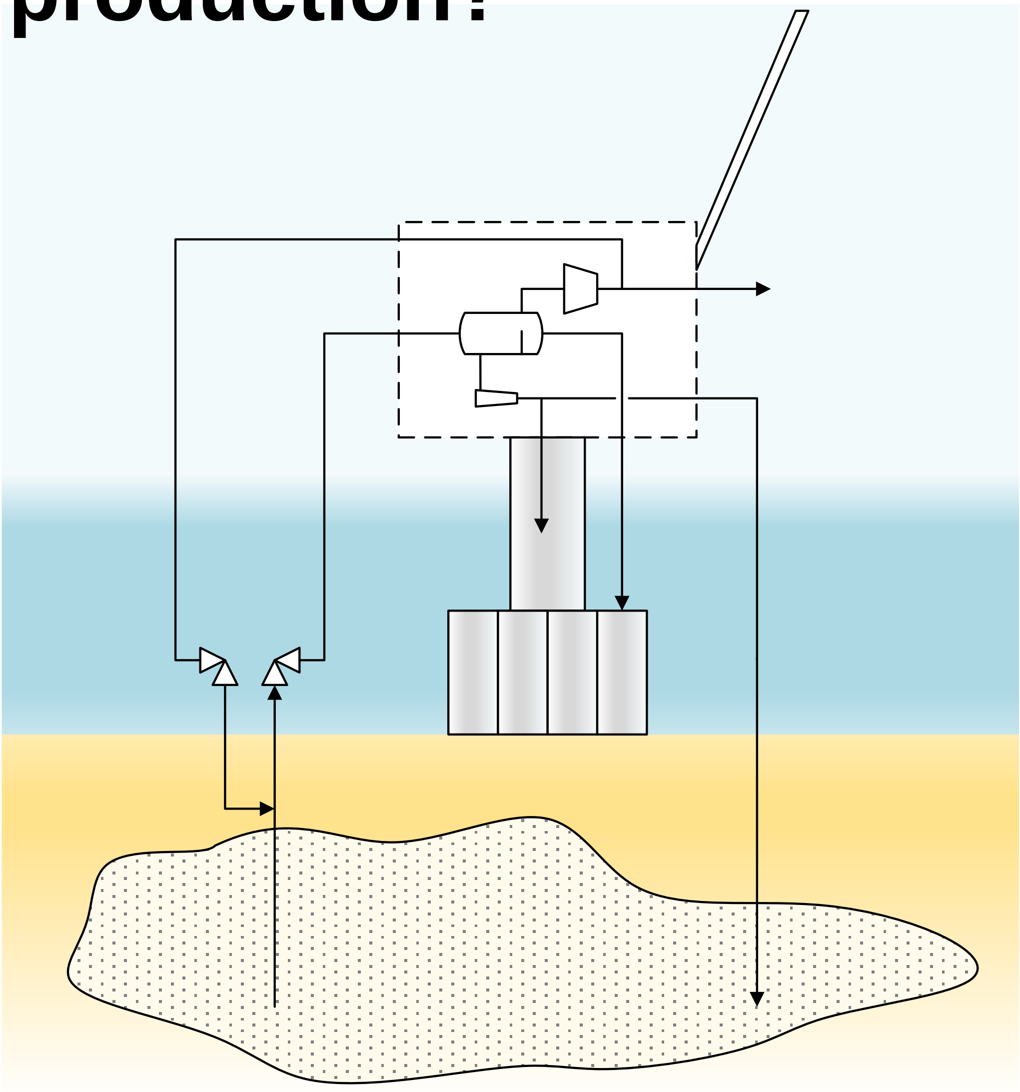
- Handling bottlenecks
- Backing off from constraints
- Controlling quality

Production operations





Why does the Operator reduce production?



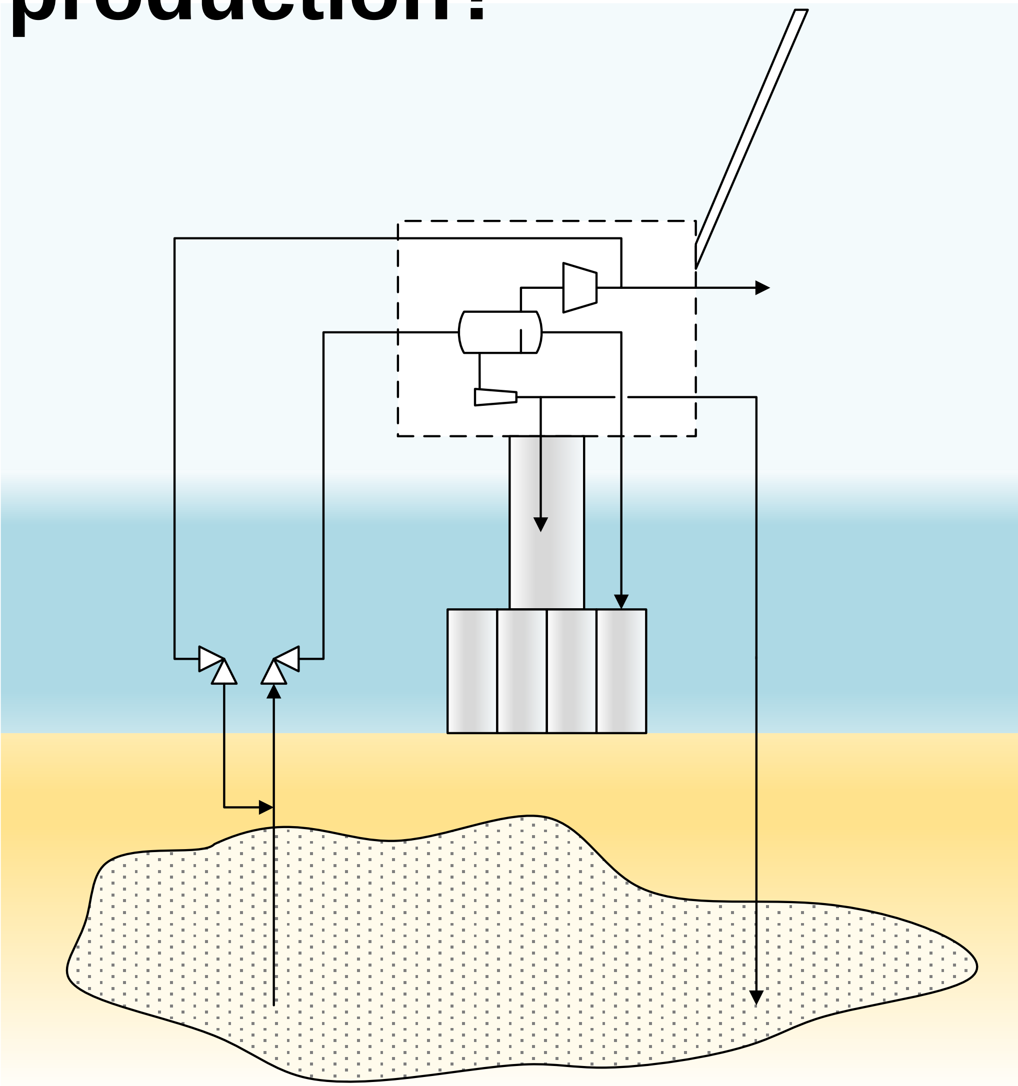
Production rates are given.

Each well has:

- Startup priority
- Target bottom hole pressure
- Target gas lift rate

Why does the operator choke back?

Why does the Operator reduce production?



Production rates are given.

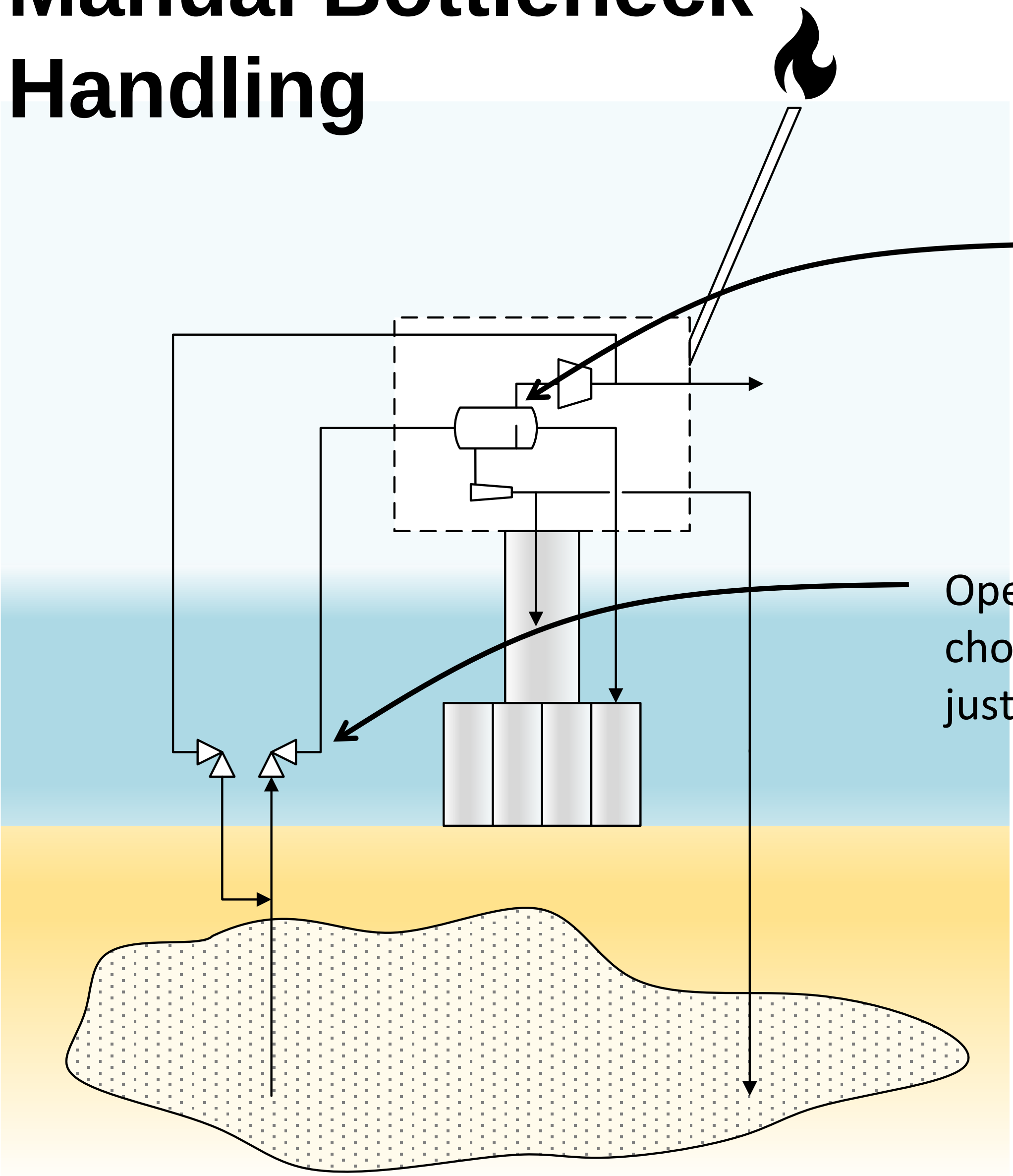
Each well has:

- Startup priority
- Target bottom hole pressure
- Target gas lift rate

Why does the operator choke back?

- Bottlenecks
- Back-off from constraints

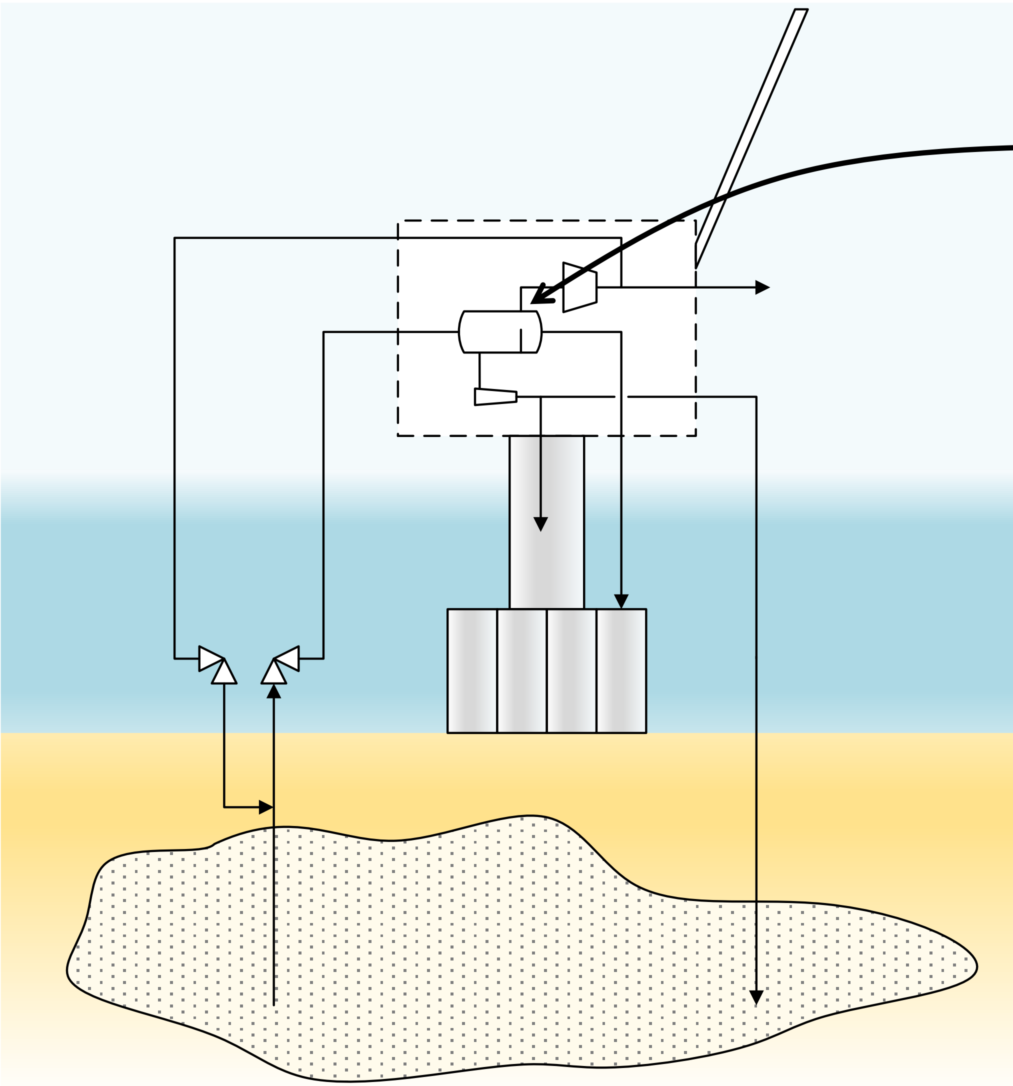
Manual Bottleneck Handling



e.g. Gas handling constrained

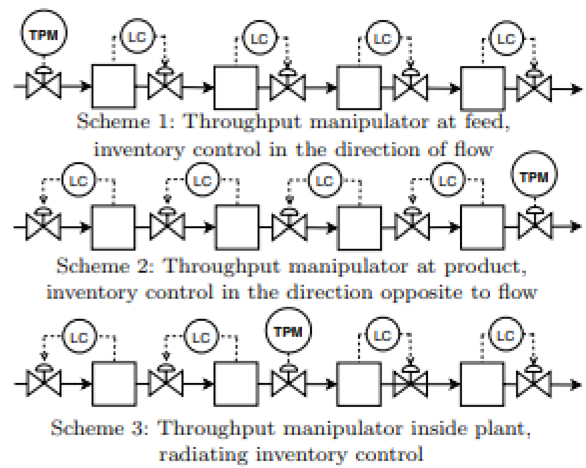
Operator manually chokes down wells to just avoid flaring

Automatic Bottleneck Handling



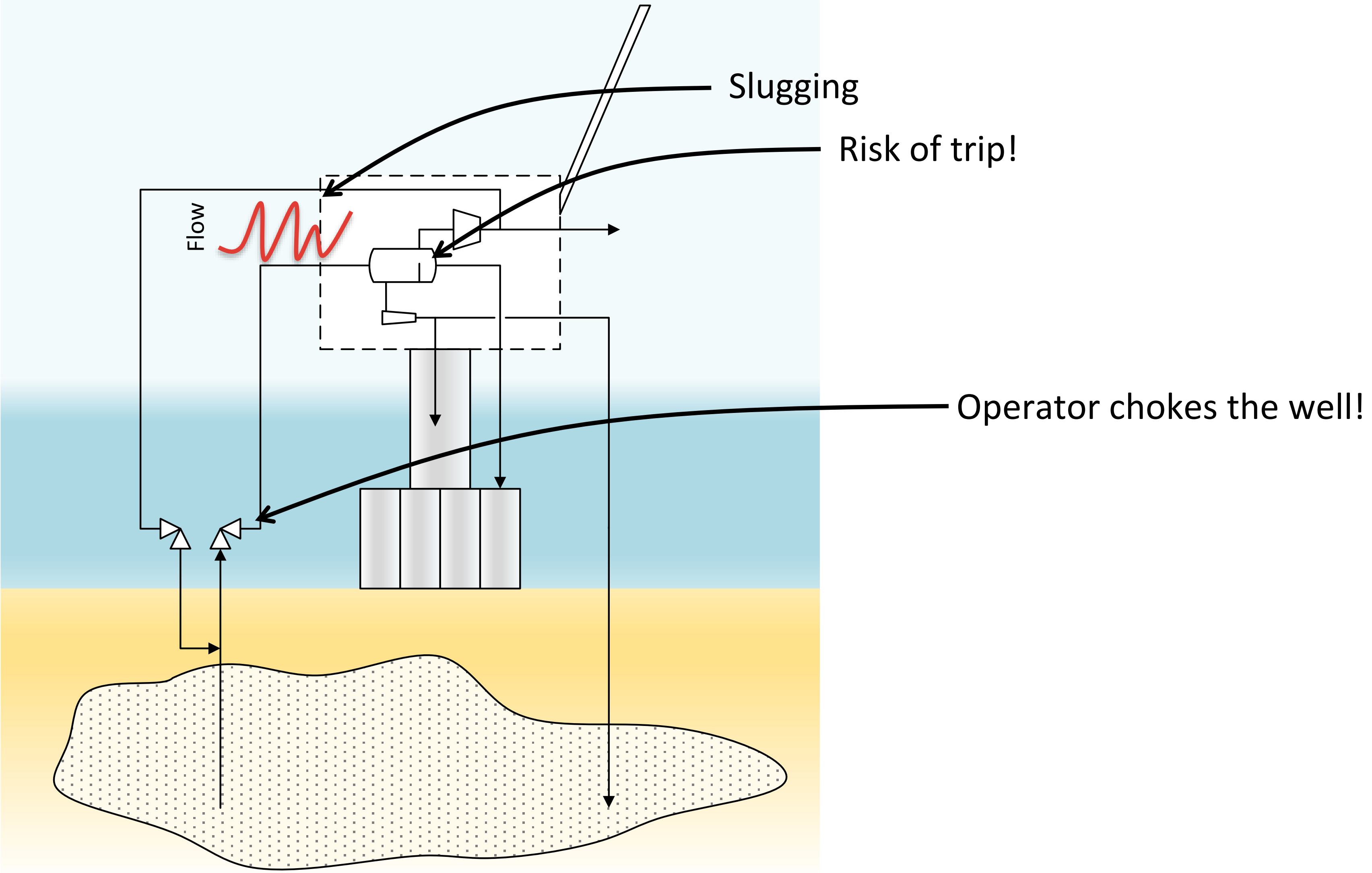
e.g. Gas handling constrained

Need to take into account constraints and how this affects the control structure

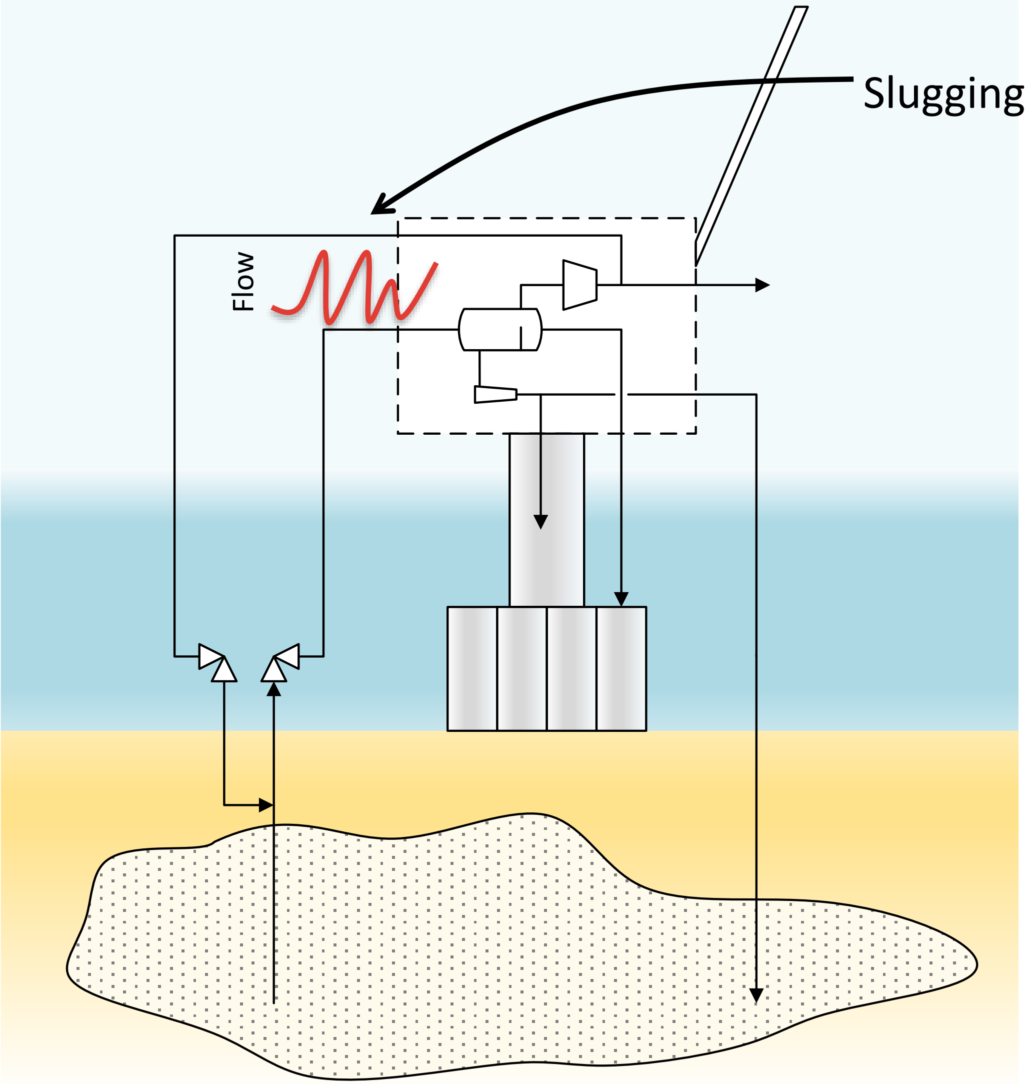


Elvira Marie B. Aske, Sigurd Skogestad, Stig Strand (2007). Throughput maximization by improved bottleneck control. IFAC Proceedings Volumes, 40(5), Pages 63-68

Back-off because of Slugging



Current Automatic Solutions to Slugging



Different apaches:

- Overload Avoidance
- Slug Mitigation
- Stabilization (wells, pipelines)

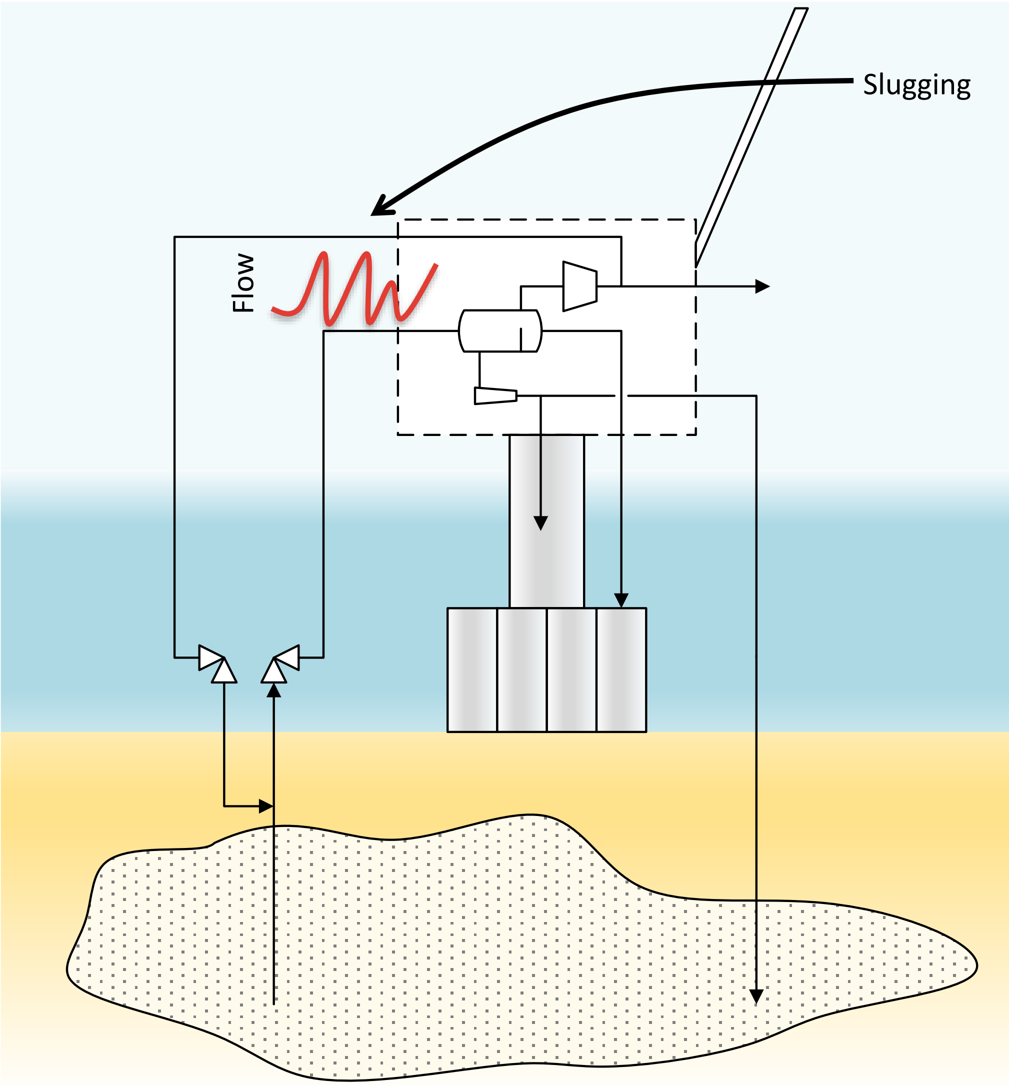
Ideally stabilize the slugs

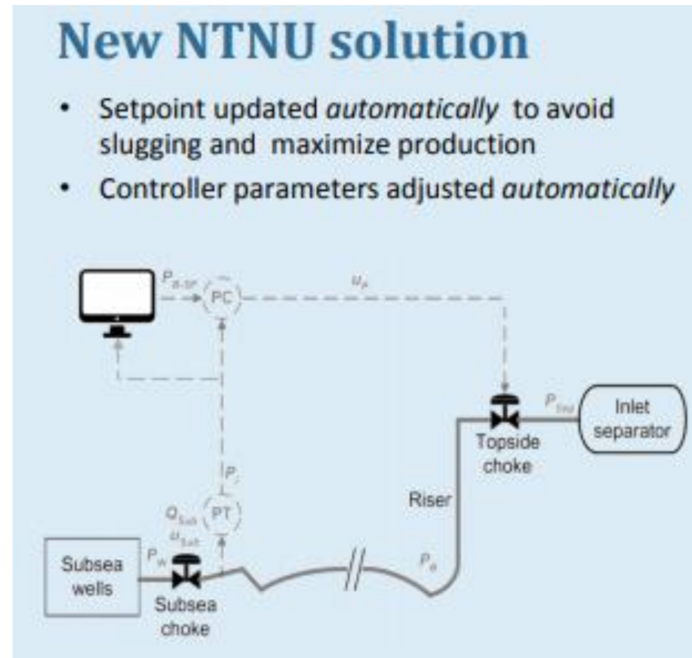
- Squeeze and shift in process
- Increased production from the wells

Stabilizing is difficult:

- Changing process dynamics
- Small sett of parameters that stabilize
- Often slow valve

Next Generation Slug-Controller?





Vinicius de Oliveira, Johannes Jäschke, Sigurd Skogestad (2015). An autonomous approach for driving systems towards their limit: an intelligent adaptive anti-slug control system for production maximization, IFAC-PapersOnLine, 48(6), Pages 104-111, ISSN 2405-8963

http://folk.ntnu.no/skoge/publications/2015/oliveira-antislug-patent/NTNU%20Anti-slug%20control_product%20sheet.pdf

Final Thoughts

- Operatorless plant, closer than we think?
- The push for unmanned production platforms will make operatorless more likely
  - Because of more focus on measurements, actuators, and redundancies.
  - Because process design will be simplified.
- Gradual transition, reducing the number of operator...
- First iterations does not need to be optimal, just better than what now.

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