



Asia Downstream Summit 2025

# **Not Just Complicated: Why Digital Twins Struggle with Real-World System Behavior**

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# The Phantom Traffic Jam



Stuck in traffic,  
expecting an accident...  
and there's nothing  
there?

# Patterns Across Industries

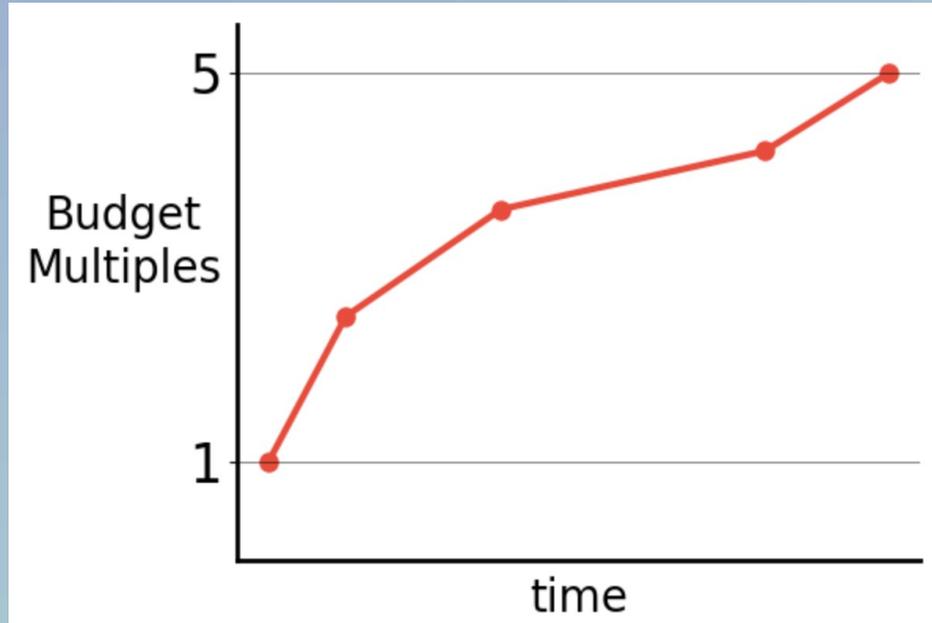
20+ years seeing mysterious behaviors experienced people couldn't fully explain

Automotive	Parts production line shows similar pattern as traffic jam
Steelmaking	Electric Arc Furnace behavior varied despite 'identical' setups – some variables were missing
Oil and gas	Alarm cascades created interdependencies that defied simplification

# The Cost of Failure

- Emergency Event at the Water Treatment Plant of the Utilities Area
- WTP failure triggers cascaded shutdown of the entire Base Plant complex for days!
- \$1M per hour in losses!

# When Requirements Miss Reality



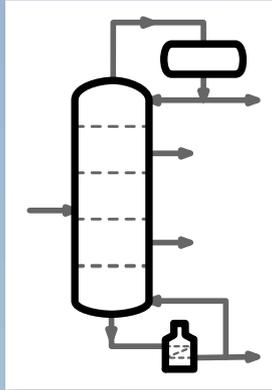
DCS system upgrade

- Why? ✓
- What? ✓
- How? ✗
- Who? ✗

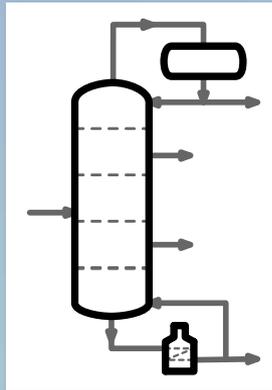
Seamless transition was required, but HOW to achieve it wasn't specified - scope exploded when reality hit.

# Something You're Familiar With

CDU 1



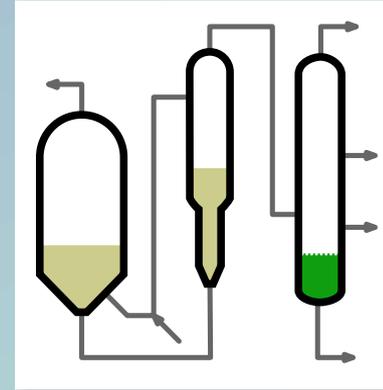
CDU 2



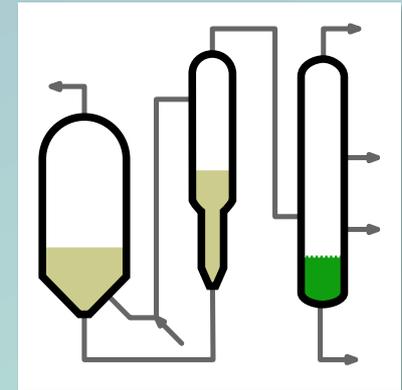
## Identical CDU pair

predictable behavior within tolerance

FCCU 1



FCCU 2



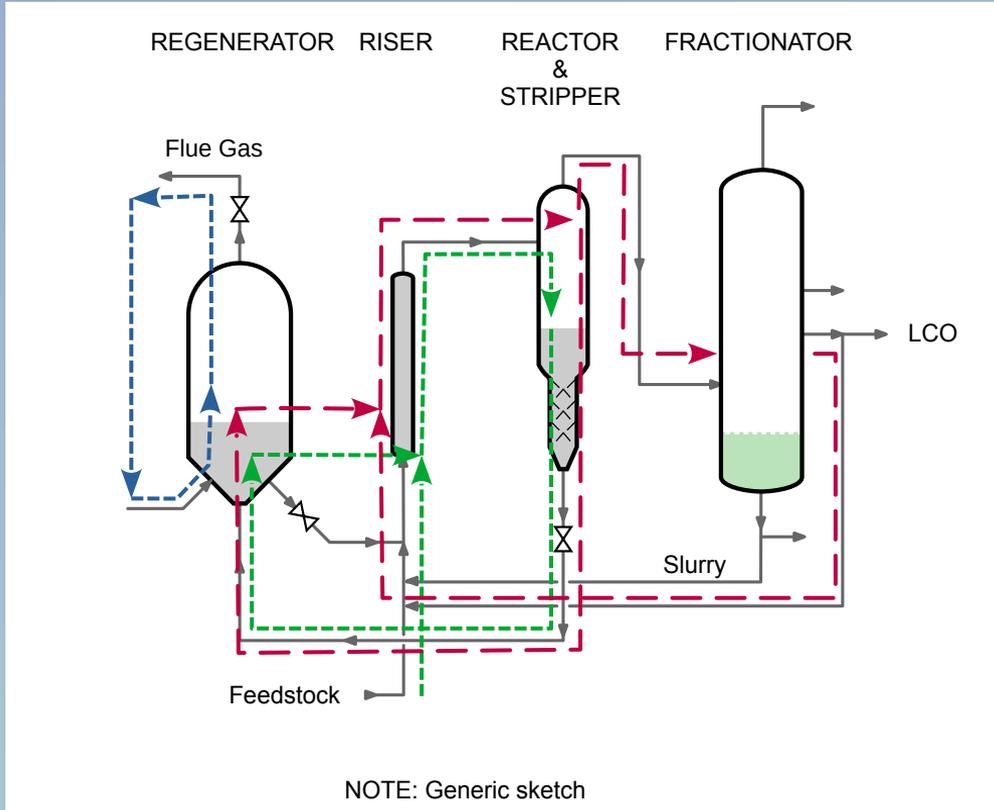
## Identical FCCU pair

unpredictable, sometimes wild deviations

Same design, same operators, same feedstock - why the difference?

# Inside the FCCU: How Interactions Create Unpredictability

## Case Scenario: Defluidization Event



### R1 – Coke/Heat/Severity (reinforcing): ----->

FEED Heaviness  $\uparrow \rightarrow$   
 COKE on CATALYST  $\uparrow \rightarrow$   
 REGENERATOR Temp.  $\uparrow \rightarrow$   
 CATALYST Heat to RISER  $\uparrow \rightarrow$   
 FEED Conversion  $\uparrow \rightarrow$   
 COKE on CATALYST  $\uparrow \rightarrow \dots$

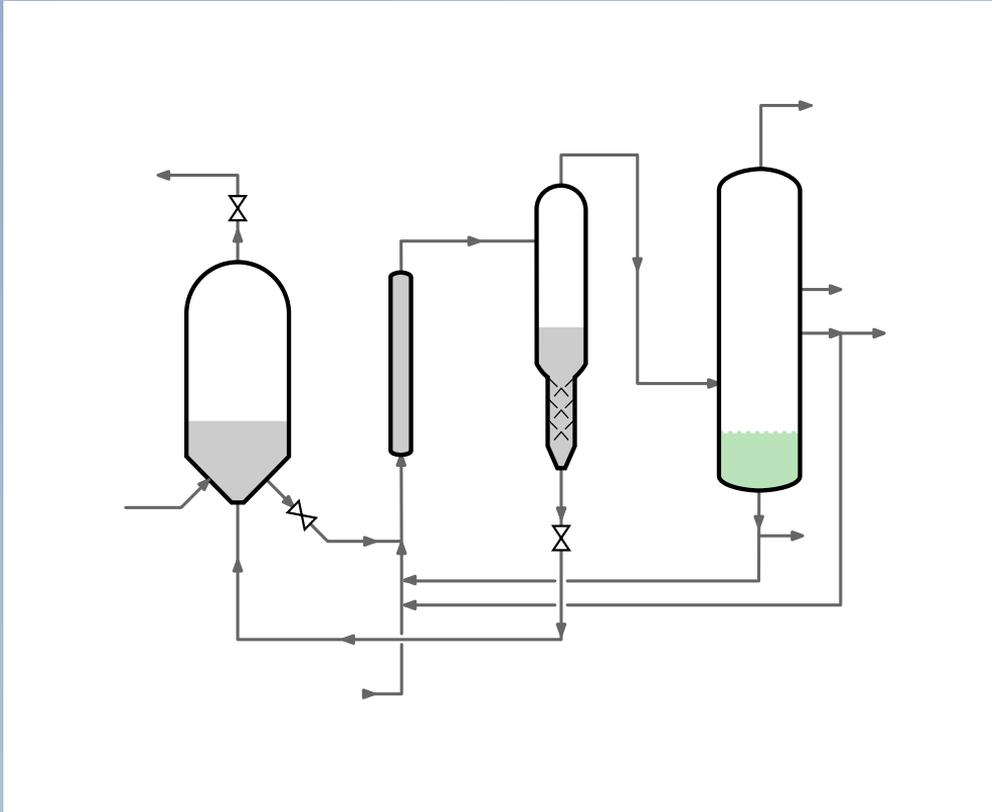
### R2 – Cut points & recycle (reinforcing): - - - >

Tighter FRACTIONATOR cuts  $\rightarrow$  LCO Recycle  $\uparrow \rightarrow$   
 Effective FEED heaviness/CCR  $\uparrow \rightarrow$  COKE  $\uparrow \rightarrow$  REGEN  
 T  $\uparrow \rightarrow$  RISER severity  $\uparrow \rightarrow$  Conversion  $\uparrow$

### B1: CO/Temperature Control Loop (stabilizing) - - - - - >

CO in FLUE GAS  $\uparrow \rightarrow$  Air Flow CONTROLLER  $\rightarrow$   
 REGENERATOR Temperature  $\uparrow \rightarrow$  CO Conversion ( $\downarrow$  CO)

# Behavior Emerges From Interactions



- Can we still explain defluidization without these interactions?
- Same components, but critical behavior vanishes
- Properties emerge from interactions between components, not components themselves
- Same components, different interactions = different behavior

# Complex Systems

- *Systems where behavior emerges from non-trivial interactions are called **Complex Systems***
- **Critical principle: "Complex systems cannot be understood by breaking them into parts"**
- This requires a different analytical approach: **holistic assessment of system interactions**, not component-by-component analysis
- In contrast, **complicated systems** (like CDU) have many parts with predictable, calculable interactions that can be understood through component-by-component analysis.

# A Familiar Complex System



- Can't treat headaches in isolation
- Must consider the whole organism
- Many industrial systems work the same way

# When Traditional Requirements Meet Complex Systems

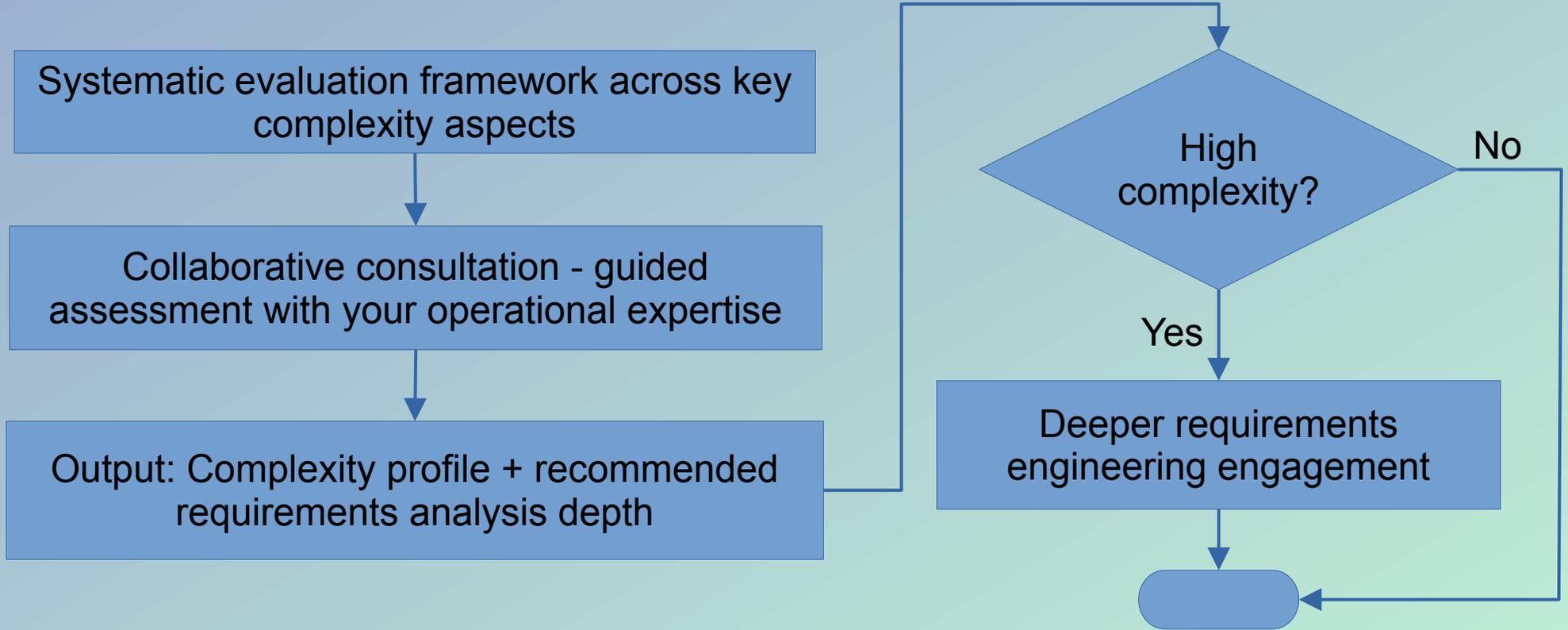
- Most large industrial projects underdeliver on expectations
- Not just digital twins - system upgrades, automation projects, infrastructure initiatives
- **Primary problem: Expectations not aligned with reality**
- System interactions creating emergent behaviors - often the least visible factor - is one key contributor

# What's Missing: Systematic Integration

Known in Silos	Missing
Nonlinear interactions	Systematic integration
Cascade failures	Upfront assessment
Multivariable coupling	Requirements engineering

- Complexity is not a Yes/No binary - systems show varying degrees of complexity across different aspects.
- Systematic assessment identifies which aspects drive the most risk.

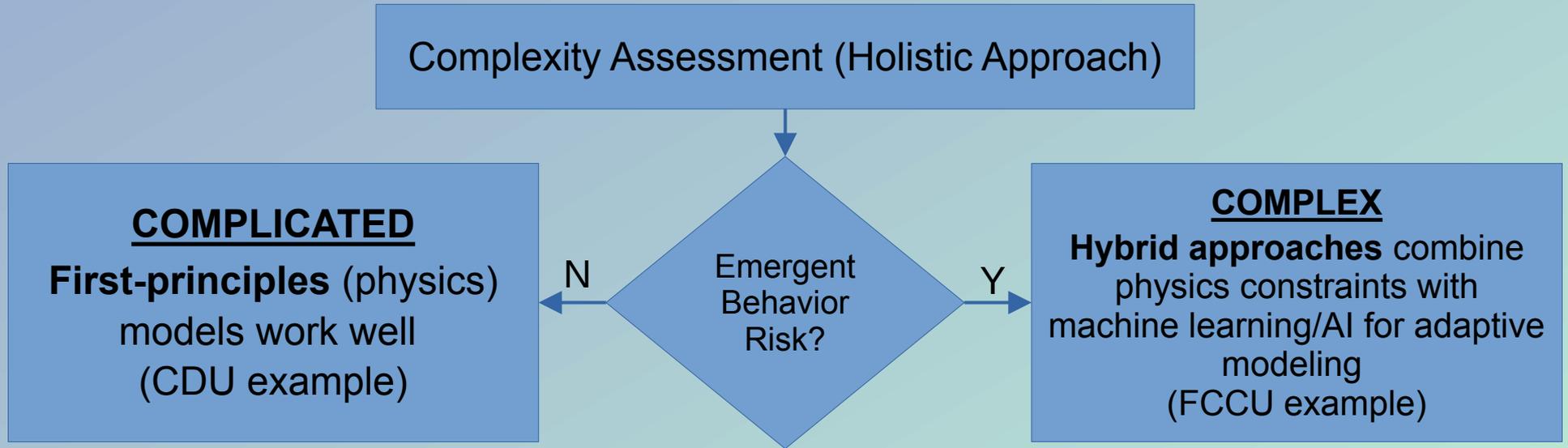
# Complexity Assessment - Collaborative Process



# Matching Expectations to System Behavior

For complicated systems (like CDU)	For complex systems (like FCCU)	NOT realistic for complex systems
<ul style="list-style-type: none"><li>• Accurate performance prediction</li><li>• Reliable optimization targets</li><li>• Precise control recommendations</li></ul>	<ul style="list-style-type: none"><li>• Pattern recognition (trending toward upset conditions)</li><li>• Early warning (approaching instability regions)</li><li>• Scenario analysis (likely consequences of changes)</li></ul>	<ul style="list-style-type: none"><li>• Exact prediction of emergent event timing</li><li>• Guaranteed prevention of surprises</li><li>• Replacement for operator expertise</li></ul>

# Matching Approach to System Complexity



Complexity assessment determines appropriate modeling strategy  
**BEFORE** project commitment

# Prevention vs. Discovery

- *"Better to spend weeks understanding what's actually achievable than months discovering what's impossible"*
- Systematic complexity assessment identifies the least visible risk factor
- Comprehensive requirements engineering prevents project redefinition and expensive surprises

# Where This Applies

## Common scenarios requiring holistic assessment:

- Digital twin initiatives - feasibility and scoping
- Major automation/DCS system transitions
- Process optimization projects with interaction risks
- Novel technology integration (hydrogen, CCUS, electrification)
- Multi-unit operational changes
- Brownfield expansion with existing system dependencies

## Assessment scope typically includes:

- Interaction mapping across system boundaries
- Emergence risk identification
- Appropriate modeling strategy recommendation
- Requirements engineering depth determination

# Key Takeaways

- Assess complexity BEFORE committing millions
- Match expectations to system reality
- Identify interaction risks early
- Choose modeling strategy based on assessment

# Visit us at Booth B8

## Let's discuss your specific project challenges:

- Complexity assessment for your systems
- Digital twin feasibility and scoping
- Major automation/DCS transitions
- Process optimization with interaction risks

**Live demonstration:  
How scale affects complexity levels**



## Resources and Contact Info:

<https://aprocesr.com/ADS2025>

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