Nominal is No Longer Adequate

Trends in Factory Automation

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ELYSIUM Parker Aerospace NORTHROP GRUMMAN BOEING

Who Am I?

- **Boeing Technical Fellow**
- **35+ Years Developing & Implementing Automation Systems**
  - **Metal & Composite Fabrication & Assembly**

- **1st Commercial Solid Modeling Based Numerical Control (NC) Programming System**
- **1st Commercial Generative NC Programming System**
- **Boeing's Composite Tape Laying NC Programming System**

Presentation Outline

- Abstract
- Background
- Industry 4.0
- Capability Improvements
- Edge Computing
- Responsibility Shift
- Shift Enablers
- Questions

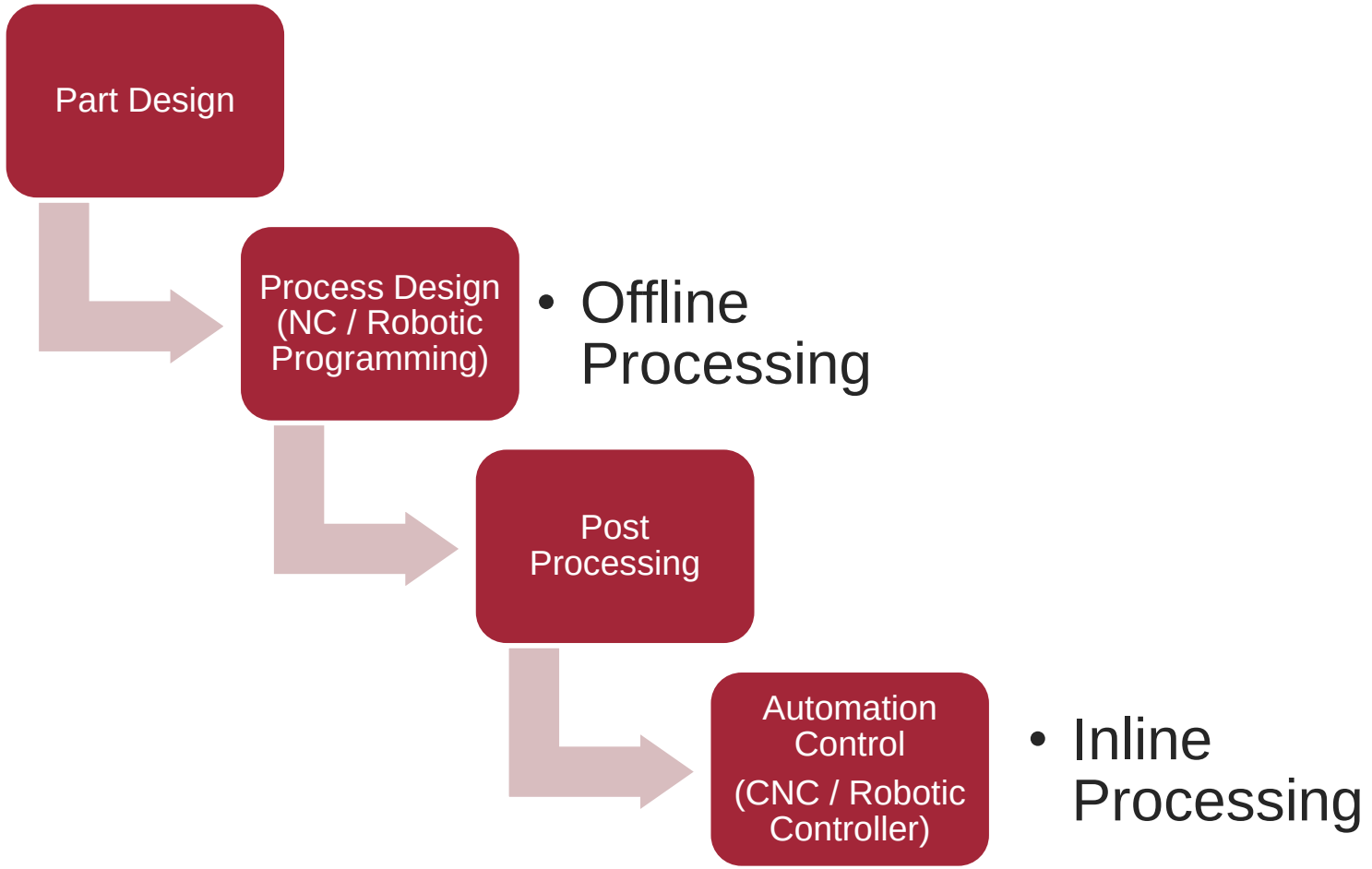
Abstract

- **Historically automation commands assumed nominal conditions yet machines today need to react to variation & anomalies**
- **Responsibility (decision logic) needs to shift from offline systems to onboard & inline systems**
- **Requires changes in both systems and data**
  - **A paradigm shift is needed in how machines are instructed to operate**
  - **The digital thread of information needs to be wider and richer**
- **Advances are required in both system design, modeling (of a digital twin) & simulation**
  - **Enables the onboard systems of these more capable machines to be improved & upgraded over time rather than locked down for fear of regression & costly associated mishaps**

Background – Automation Systems

- **Automation programming such as NC or Robotic Programming is typically performed prior to the shop order**
- **Offline Processing – performed before automation**
- **Inline Processing – performed during automation**

Process Flow



Offline Processing

- **Advantages**
  - **Does not impact time it takes to run automation**
  - **Can enable programming to be performed early**
  - **Is performed once & not repeated for each part instance**
  - **Typically has rich digital twin definitions to work with**
    - **part, fixture, machine, material, tools**
  - **Has lots of computing horsepower**

- **Disadvantages**
  - **Assumes nominal conditions with stock, WIP, fixtures, equipment**
  - **Limited ability to account for variability in the shop**

Inline Processing

- **Advantages**
  - **Can account for variability in the shop (for each part)**
  - **Processing is performed for each part instance**

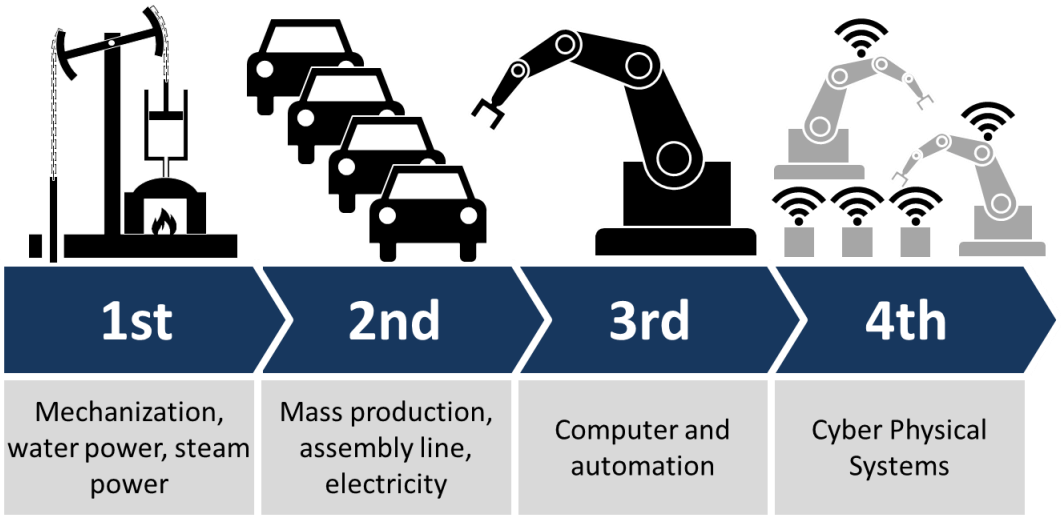
- **Disadvantages**
  - **Typically has limited information to work with**
    - **Low level machine instructions**
  - **Must be extremely repeatable**
    - **No person in the loop to mitigate**
  - **Risks associated with changing complex logic**

Trends

- **Dramatic improvements in computer processing performance and sensor technology is enabling advances at the Edge of the Automation System Architecture**
  - **Contextual awareness**
  - **Compute power for Inline Processing**

Industry 4.0

- https://en.wikipedia.org/wiki/Industry_4.0
  - **Cyber-physical systems**
  - **Internet of things**
  - **Cloud computing**
  - **Cognitive computing**



Rate of (Digital Capability) Improvements

- **Rate of change is accelerating exponentially**
- **The power of exponential growth, which in technological terms is synonymous with Moore's Law (number of transistors per square inch on integrated circuits doubles every year).**
- **Our human intuition can't cope with the constant doubling**

Rate of (Digital Capability) Improvements

- **2nd Half of the Board**
  - **As the legend goes, the inventor of chess introduced his game to the emperor of India, who was so pleased that he offered the inventor any reward he named.**
  - **Giving the impression of being humble, the inventor asked for a single grain of rice on the first square of the chessboard, two on the second, four on the third, and so on.**
  - **Soon after the piles of rice entered the second half of the chessboard, the emperor figured out what was going on, and as some versions of the story go, the inventor lost his head as a result.**

- **2^{64} = 18,446,744,073,709,551,616 grains of rice**
  (million -> billion -> trillion -> quadrillion -> quintillion)

What is the Edge?

- **Computing power at the End of the Network (at the machine / device) that can make decisions using data**
- **Machine controls (NC, Robotic, PLC) for reasoning and instruction**
- **Sensors for data collection**
  - **Probes**
  - **Vision, force, temperature, humidity, …**

What is at the Edge of Factory Automation?

- **NC / Robot Controller**
- **NC / Robot Controller with Sensors**
- **NC / Robot Controller with Digital Twin**
- **NC / Robot Controller with Digital Twin & Sensors**
- **Cell Controller**

What Comes with Industry 4.0?

Shift in Responsibility

- **As the system's Edge devices become more capable, they are able to take on more responsibility**

Extreme Case – Human Resource

- **Most sophisticated automated resource is a Human**
  - **Has sensory capability**
  - **Multiple end effectors**
  - **Extremely powerful reasoning ability**
  - **Extraordinary ability to deal with variation**
  - **Ability to comprehend (vision, audio, complex language)**
  - **Can work with other humans, tools, devices and equipment**
  - **Limited repeatability / limited durability**

Extreme Case – Human Resource (continued)

- **Most sophisticated automated resource is a Human**
  - **Ability to learn – how to do things**
  - **Can take on substantial responsibility**
    - **Can expect results by providing high level instructions and detailed information to draw upon**
  - **Can be told <u>What</u> to do and *knows* <u>How</u> to do it**

What Comes with Industry 4.0?

Shift in Responsibility

- **As automated equipment / devices take on more traits / ability of a Human, responsibilities will shift to the equipment**

Why is Shifting Responsibility to the Equipment a Good Thing?

- **Let's Look at Part & Automation Trends**

Trends with Machined Parts

- **Parts are more complicated**
- **Hard metals are more pervasive & challenging to machine**
- **Machining forgings result in variation due to stress relief with many cuts**
- **Tolerances are tighter & more challenging to achieve**

Trends with Assemblies

- **Assemblies being worked with automation are larger and more complicated**
- **Variation of assembly (condition)**
  - **Human error**
  - **Part shortages**
  - **Part variations**
  - **Process workarounds – to avoid scrap**
- **Variation of assembly results in variation of preassembled part locations**
  - **Pre-assembled parts aren't where you think they are**

Trends with Automation Cells

- **Desire to eliminate hard tooling**
  - **Results in variation of fixture & part location**
- **Desire to eliminate foundations**
  - **Results in variation of equipment location**
- **Desire for Humans to work alongside Robots**
  - **Results in variation due to human behavior**
- **Equipment / setup is getting more expensive**
  - **High consequences comes with risk of collisions**

Automation Trends Summary

- **Automation has to deal with more variation & complexity**

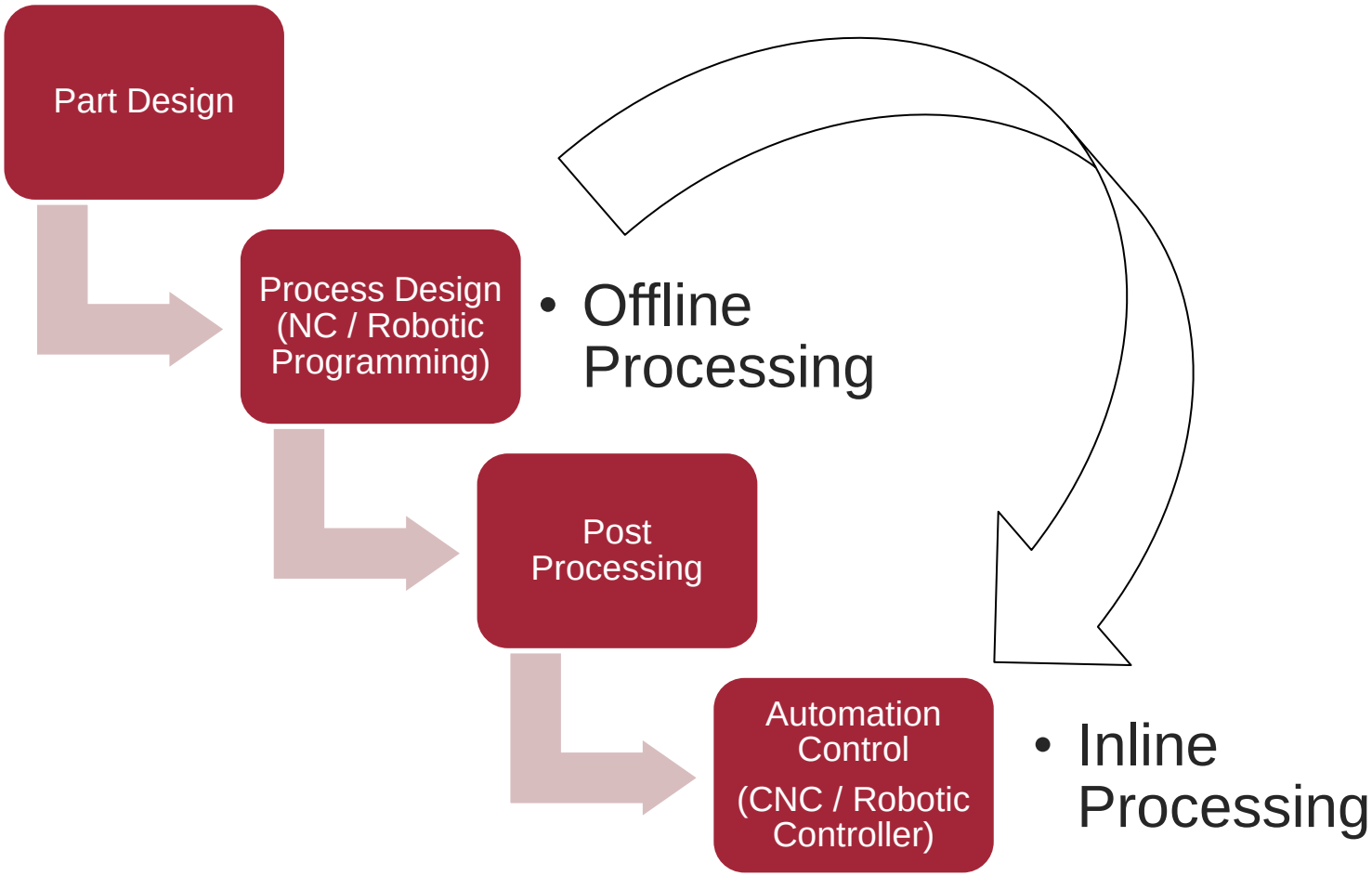
Why is Shifting Responsibility to the Equipment a Good Thing?

- **To deal with more variation & complexity**
  - **Offline Programming for nominal conditions has limited potential for dealing with variation**
  - **Ability of equipment / devices to deal with variation & complexity is / will be improving "exponentially"**

What Needs to Shift?

- **Responsibility will shift from Offline Programming / Processing to Inline Processing**
  - **Devices will know how to do things using Inline Processing**
    - **How to rough a pocket**
    - **How to insert a fastener**
    - **How to get from one location to the next (without collision)**
  - **Program instructions (created using Offline Processing / Programming Applications) will detail what to do**
    - **Rough a pocket (rather than goto, goto, goto)**

Responsibility Shift



This Shift Isn't New

- **Responsibility has shifted over time**
  - **Drill cycles**
  - **Adaptive control**

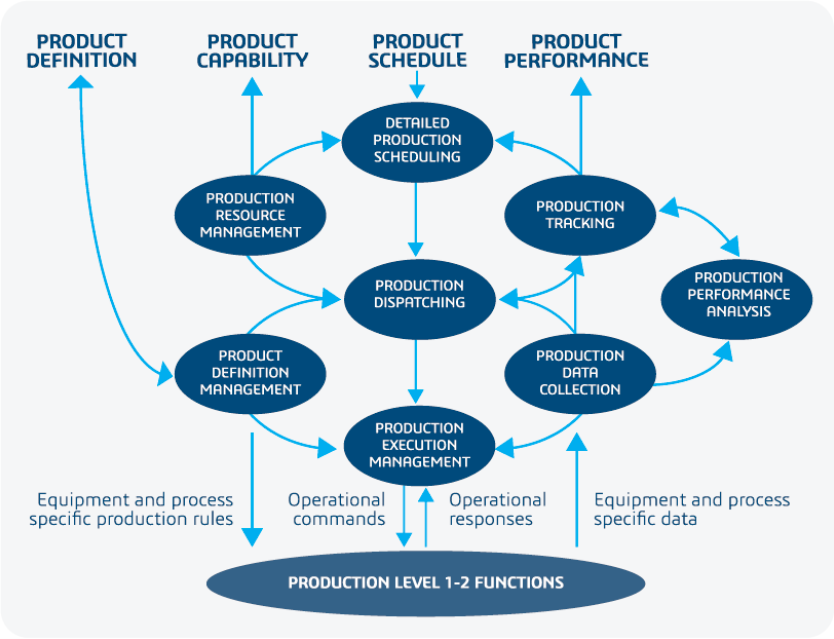
- **What is new is the ability of the equipment to do more and the rate at which It becomes more capable**

What Technical Advances are Needed to Shift Responsibility

- **Inline Processing will require additional context (Digital Twin)**
- **Inline Processing will require increasing compute power & sensory perception**
- **Inline Processing needs to be smarter**
  - **With algorithms from Offline Systems**
  - **Ability to act on sensory information**
  - **Using acquired knowledge (Deep Learning)**

What Else is Needed to Shift The Responsibility

- **Changes in data being exchanged across levels of the architecture (PLM / MOM / Controls)**



ANSI/ ISA-95.00.03 2013 Standard

What Else is Needed to Shift The Responsibility

- **Improved simulation that takes into account smarter device behavior**
  - **To develop Inline Processing**
  - **To enable the NC Programmer**
- **Increased IT / OT collaboration given the changes crossing both organizations**
- **Culture / attitude change**

Change Is Upon Us and Continues to Accelerate

- **Questions / Comments**