Challenges and potential of data-driven automation in complex manufacturing systems

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STMicroelectronics
We are creators and makers of technology

- One of the world’s largest semiconductor companies
- 2020 revenues of $10.2 B
- 46,000 employees of which 8,100 in R&D
- Over 80 Sales & marketing offices serving over 100,000 customers across the globe
- 11 Manufacturing sites
- Signatory of the United Nations Global Compact (UNGC), Member of the Responsible Business Alliance (RBA)
Welcome to Industry 4.0

- CROLLES 300mm fab
  - 24/7 – 365 days a year
- 100% of process starts on production tools done automatically
- 100% of transportation of material to tool done by Automated Material Handling System
- 95% of the dispatching decisions done without human intervention
- Advanced real-time Equipment and Process Control techniques fully deployed
So what? Job done?
A bit of context and history
Reentrant process flows

From 200 to 1400 Individual operations
Reentrant process flows

From 200 to 1400 Individual operations

Recipe Qualification

MES

Process Adjustments
From 200 to 1400 Individual operations

Recipe Qualification
Recipe selection
Recipe Validation
Recipe Setting
Recipe Adjustment

Manipulation

Equipement Automation

MES

(Tool, Recipe) qualification
Statistical Process Control

MES

SPC

Manipulation

Automatic Measurement Recipe Creation

Equipment Automation

Plot Scale

Upper Control Limit

Centerline

Lower Control Limit

Plotted Points

Point Labels
Statistical Process Control

Automatic Measurement Recipe Creation

Manipulation

Volume

Data Coll. Errors
Statistical Process Control

Automatic Measurement Recipe Creation
Automatic Tool Stoppage
Automatic Data Collection
Equipment Automation
Automatic Process Compensation

High Mix
Smaller Geometries

MES
Automatic Data Collection
Recipe Adjustment
Manipulation
Automatic Measurement
Recipe Creation

SPC
Automatic Tool Stoppage

R2R
Equipment Automation

SPC
Automatic Tool Stoppage

Fabrication Data Control

sensors integration
FDC

Recipe Adjustment
Automatic Measurement Recipe Creation
Automatic Data Collection
Automatic Tool Stoppage
Equipment Automation

Approved Quality Control
Industry expansion
On the road to Industry 4.0

- Fab Extension
- Inter-bay transportation
- Equipment Spread
- Logistics
- Paperless
- Manipulation
On the road to Industry 4.0

- Process Complexity
- Variety of product flows
- Logistics
- Lot Dispatching
- WIP Planning
- WIP Management
- Decision Support
300mm! On the road to Industry 4.0

Manipulation

AMHS

Logistics

<table>
<thead>
<tr>
<th>Width</th>
<th>416 mm (16.4&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>333 mm (13.1&quot;)</td>
</tr>
<tr>
<td>Height</td>
<td>335 mm (13.2&quot;)</td>
</tr>
<tr>
<td>Empty</td>
<td>4.2 kg (9.26 lb)</td>
</tr>
<tr>
<td>With wafers</td>
<td>7.3 kg (16.09 lb)</td>
</tr>
</tbody>
</table>
300mm!

On the road to Industry 4.0

Clean Room sqm cost

AMHS

Logistics

Manipulation
On the road to Industry 4.0

300mm!

- Manuplation
- AMHS
- Logistics
- Decision
  - Real Time Scheduling
  - Real Time Dispatching

Equipment complexity & heterogeneity
Full Automation didn’t come in one day

- A balance between challenges or threats linked to **business needs / context** and **opportunities** open by solutions to former difficulties
- A progressive understanding between pragmatists and visionaries

“A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty.”
- Winston Churchill
SC Manufacturing vs. Industrie/y 4.0
All countries 2004 till today
SEMI Standards

https://www.semi.org/en
Example

https://www.peergroup.com/expertise/resources/semi-standards/
From Industry 1.0 to Industry 4.0

**First Industrial Revolution**
- Based on the introduction of mechanical production equipment driven by water and steam power.
- First mechanical loom, 1784

**Second Industrial Revolution**
- Based on mass production achieved by division of labor concept and the use of electrical energy.
- First conveyor belt, Cincinnati slaughterhouse, 1870

**Third Industrial Revolution**
- Based on the use of electronics and IT to further automate production.
- First programmable logic controller (PLC), Modicon D64, 1969

**Fourth Industrial Revolution**
- Based on the use of cyber-physical systems.
- Degree of complexity
Happy?
• CROLLES 300mm fab is today operated in automatic mode
  • 24/7 – 365 Days a year
  • 100% of process starts on production tools done automatically
  • 100% of transportation of material to tool done by AMHS*.
  • 95% of the dispatching decisions done without human intervention

• Advanced real-time Equipment and Process Control techniques fully deployed.
YES!

- CROLLES 300mm fab is today operated in automatic mode
  - 24/7 – 365 Days a year
  - 100% of process starts on production tools done automatically
  - 100% of transportation of material to tool done by AMHS*.
  - 95% of the dispatching decisions done without human intervention
- Advanced real-time Equipment and Process Control techniques fully deployed.
A good engineer can analyze and understand almost everything.

Several specialists are required to come to the same result.

Depth of knowledge

- Physics
- and physical

Breadth of knowledge

- Still Physics
- But cyber-physical
Detection, diagnostic and prescription
Replacing the “human glue”

Operator
drives the machines and moves the products is physically present on the production floor uses his five senses to continuously analyze the situation

Indoor patrols, real-time detection of problems in the field and almost instant diagnosis

Technician
Technical field expert
Maintenance & Process diagnostic
Resolving issues on his perimeter

Workstation, Static personnel
Potentials of data-driven automation
A very complex system

- **Manual** configuration & maintenance
- Complexity & criticality require expert / trained resources
• System configuration:
  • Number of vehicles per zone
  • Default storage scenario by tool
  • Storage bins grouping and allocation

• Operational Research to optimize system configuration

• Digital Twin to simulate the system and validate proposed solution but…

• Manual configuration because of legacy UI

RPA could help there!
A very complex system

- **Manual** configuration & maintenance
- Complexity & criticality require **expert / trained resources**
- **Human** still controlling & supervising execution
- **Manual** adjustment to context when required
A set of techniques to prescribe what to do next and take action autonomously

A way from today’s automated systems toward real cyber-physical systems
Toward **real** cyber-physical systems

- Physical and software components are deeply intertwined
- Able to operate on different spatial and temporal scales
- Exhibit multiple and distinct behavioral modalities
- and *interact with each other in ways that change with context*
Application examples

- Adjustment of dispatching parameters and objective function to equipment and WIP situation
- Adjustment of automation parameters such as “delays” or “timeouts”
- Adjustment of local product priorities to general line and business conditions
Extension to the whole Supply Chain

- Develop “context sensitivity”, model awaited behavior
- Connect contexts and concepts along the value chain, model interactions
- From rule or scenario-based logic to objective or purpose driven approaches
Challenges
2 TB per day and per tool
Advanced process control and real-time adjustment

> 80% never really used
Consolidation and correlation across systems / silos

#1: Exploitable data
Semantic
• Connecting the various data silos
• Modelling key articulations and interactions
• Enabling “faster & smarter” AI

Analytics
• Leveraging state of the art statistical, mathematical and AI techniques
• Fueling powerful digital twins or decision support systems
• Putting AI everywhere as a “one size fits all” solution will come to a limit

• Cloud also has a cost, and it should be carefully balanced vs. expected gains

• Developing powerful models and ontologies will contribute reducing these costs

• Working on edge AI i.e., close to data source will also significantly help!
Prescriptive Maintenance

- Data from multiple sources
  Sensors, alarm management system, Automation, MES, CMMS, Production Planning, spare parts availability, etc.
- Planning and optimization techniques
- Traditional statistics and AI
- Human “contextual awareness”

⇒ Propose most suitable actions
• What’s not in the system can’t be known by the system
• Models used to drive the system must cover the full range of utilization
• Limits must be clearly identified (Explainable AI)
• Replacing manager’s “guts feeling” is often the most difficult thing

#3: There is no magic
Will for sure require:

- 24x7 Explain ability and maintainability
- Accurate control of risk to prevent human error
- and safety fence against Artificial Stupidity

Will anyway require a kind of letting go (on top of trust) from the whole management ladder
Data-driven automation in complex manufacturing systems
• Industrial automation is driven by business needs and constraints

• Data driven automation is needed to gain in flexibility, quality and speed

• “Brute AI” will not be sufficient nor sustainable

• Sophisticated, hybrid, multi-disciplinary approaches are required.
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