Software in Manufacturing
An Architectural Perspective

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Introductions

- Presenter - Brief Background
- Audience
  - Familiarity with Manufacturing Domain? Industry?
  - Familiarity with Manufacturing IT?
- Topic
  - Purpose
    - Understanding the Manufacturing Domain
    - Appreciate the diversity of software used in the Manufacturing Domain.
    - Understanding the architectural elements that makes such diverse software work together.
  - Takeaway
    - Understand software components (Names/Terminology/Jargon/TLA’s) used in manufacturing and their characteristics
    - Understand System Integration Issues across these components.
    - Understand some of the IT standards used in Manufacturing
    - Hopefully, get excited about working on Manufacturing IT, and decide an area that is to your liking!
Part 1:

Understanding the Manufacturing Domain
Classification

Manufacturing

Discrete  Batch  Continuous

(Process)
Mechanical Operations on Material
(Bend, Cut, Weld, Stamp)
Output measured as Parts per Time
(Engines per Day, Cars per Shift)
Predominantly Manual Process. Automation only when High accuracy AND High speed is required (High Speed Welding).
Difficult to Automate – High ‘Visual’ and ‘Tactile’ component
Discrete Manufacturing - Examples

How a Car Is Assembled

The assembly process is divided into several stages. The car parts are transported from a central storage area to the assembly line on a conveyor belt. The parts are then assembled into a complete car. The final product is then tested and inspected before being shipped to the customer.
Chemical Reactions on a ‘Batch’ of materials
Output measured as ‘Quantity’. (Liters, Gallons, Kgs, Tons)

Also called ‘Capacity’ of Plant
Imagine Cooking!
Combination of Manual and Automated Processes, SYNCHRONIZED with each other.
Batch Manufacturing - Examples

Food, Chemicals, Pharmaceuticals

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Chemical Reactions on a ‘Stream’ of Materials
Output measured as Quantity per Time (Million Gallons per Day, Million Tons per Annum)
Continuous Process - Characteristics

Almost 100% Automated.
No Manual Intervention.
High set-up time. Requires process to be ‘undisturbed’ for as long as possible.
Continuous Process - Examples

Oil Refining

Cement
... as expected, there is also None-of-the-above!

It is called Hybrid!
Manufacturing Imperatives

Minimize Cost
- Cost of Materials
  - Labor
  - Energy
- Cost of Operations
  - Waste/Rework
- Cost of Inventory
  - Raw Materials
  - Finished Goods

Maximize Sales
- Right Product (Design)
- Good Product (Quality)
- At the Right Time (Demand Fulfilment)
- In the Right Quantity (Inventory)
End of Part 1

(Understanding the Manufacturing Domain)
Part 2: Manufacturing IT
Manufacturing IT Areas

- Production
- Quality Control
- Supply Chain
- Logistics
- Design
- Business Intelligence
- Business Operations
Components of Production

0
Field Devices

1
Loop Control

2
Supervisory Control

3
Advanced Process Control

3
Production Control

4
Business Operations

Process Control

Field Instrumentation
Field Devices

Sensor
4-20 mA
0-5 V

Actuator
4-20 mA
0-5 V
## Software in Field Devices

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Embedded</td>
</tr>
<tr>
<td>App S/W Size (LOC)</td>
<td>n/a</td>
</tr>
<tr>
<td>Op. System</td>
<td>Embedded OS like VxWorks/QNX/Embedded Linux</td>
</tr>
<tr>
<td>Language</td>
<td>C/C++</td>
</tr>
<tr>
<td>Math Component</td>
<td>Linear /Non Linear Equations</td>
</tr>
<tr>
<td>Logic Component</td>
<td>Low</td>
</tr>
<tr>
<td>UI Component</td>
<td>Custom UI (LCD Readout)</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Micro Seconds</td>
</tr>
<tr>
<td>Things to Do</td>
<td>Develop Smart Field Devices</td>
</tr>
<tr>
<td>Background Required</td>
<td>Language, OS, Electronics</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>Sensor, Actuator, Valve, AC Drive, DC Drive</td>
</tr>
</tbody>
</table>
Loop Control

Set point → Process Variable → \( f(x) \) → Control Variable → Output Variable

Single Loop Control

Multi-Loop Control

DCS

PLC

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Supervisory Control

Supervisor

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## Software in Loop Control

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Application</td>
</tr>
<tr>
<td>App S/W Size (LOC)</td>
<td>Hundreds</td>
</tr>
<tr>
<td>Op. System</td>
<td>Proprietary</td>
</tr>
<tr>
<td>Language</td>
<td>Ladder Logic</td>
</tr>
<tr>
<td>Math Component</td>
<td>Low</td>
</tr>
<tr>
<td>Logic Component</td>
<td>Very High</td>
</tr>
<tr>
<td>UI Component</td>
<td>None</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>Background Required</td>
<td>Manufacturing Process, Instrumentation and Logic</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>PLC, DCS, Process Control</td>
</tr>
</tbody>
</table>
### Software in Supervisory Control

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Application</td>
</tr>
<tr>
<td>App S/W Size (LOC)</td>
<td>Hundreds</td>
</tr>
<tr>
<td>Op. System</td>
<td>Windows</td>
</tr>
<tr>
<td>Language</td>
<td>Ladder, VB</td>
</tr>
<tr>
<td>Math Component</td>
<td>Low</td>
</tr>
<tr>
<td>Logic Component</td>
<td>Very High</td>
</tr>
<tr>
<td>UI Component</td>
<td>Very High</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Seconds</td>
</tr>
<tr>
<td>Things to Do</td>
<td>Development of SCADA Products Creating Supervisory Control Systems based on SCADA products (Build Screens, Create Databases, Interfacing to Control Systems)</td>
</tr>
<tr>
<td>Background Required</td>
<td>UI Design, Logic, Manufacturing</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>SCADA, Supervisory Control</td>
</tr>
</tbody>
</table>
The Shower Problem

Flow $\propto$ Hot Valve $\times$ Cold Valve $\times$ Tank Level

Temp $\propto$ Boiler Power $\times$ Ambient Temp

Flow = F

Temp = T

# Software in APC

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Application</td>
</tr>
<tr>
<td>App S/W Size (LOC)</td>
<td>Thousands</td>
</tr>
<tr>
<td>Op. System</td>
<td>Window/Unix/Proprietary</td>
</tr>
<tr>
<td>Tools</td>
<td>Matlab</td>
</tr>
<tr>
<td>Language</td>
<td>C/C++ (Fortran)</td>
</tr>
<tr>
<td>Math Component</td>
<td>Extremely High</td>
</tr>
<tr>
<td>Logic Component</td>
<td>Low</td>
</tr>
<tr>
<td>UI Component</td>
<td>Moderate (Case basis)</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Seconds</td>
</tr>
<tr>
<td>Things to Do</td>
<td>• APC, Soft Sensor development Predictive Control Companies</td>
</tr>
<tr>
<td></td>
<td>• Process Modeling in Continuous Process/ Automotive/ Robotics/ Medical Diagnostics industries</td>
</tr>
<tr>
<td></td>
<td>• APC System Implementation</td>
</tr>
<tr>
<td>Background Required</td>
<td>Math, Control Theory, Software Development</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>Predictive Control, Advanced Process Control (APC), Multi-variable control</td>
</tr>
</tbody>
</table>
Production Control/MES

Composer

Orchestra

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Production Control/MES

Tune

Music

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Production Control/MES

Business Systems

Recipe

Plant Systems

Product

Machines  Operators  Automation Systems

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... and, an **MES** is...
... the **Conductor** of the Orchestra

Zubin Mehta conducting the New York Philharmonic Orchestra
An **MES** System understands a **Recipe and Plan** from the **Business System**
And Orchestrates its Execution on the Plant Floor

Plant Systems

Machines  Operators  Automation Systems
Using a Language...

... that THEY understand
### Software in MES

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<tbody>
<tr>
<td>Level</td>
<td>Application</td>
</tr>
<tr>
<td>App S/W Size (LOC)</td>
<td>Hundreds of Thousands</td>
</tr>
<tr>
<td>Op. System</td>
<td>Windows, Unix</td>
</tr>
<tr>
<td>Language</td>
<td>C++, C#, Java</td>
</tr>
<tr>
<td>Math Component</td>
<td>Low</td>
</tr>
<tr>
<td>Logic Component</td>
<td>High</td>
</tr>
<tr>
<td>UI Component</td>
<td>Very High</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Minutes</td>
</tr>
<tr>
<td>Things to Do</td>
<td>• Develop MES Products as a part of an MES Product Company</td>
</tr>
<tr>
<td></td>
<td>• Design and Develop MES Systems based on Products</td>
</tr>
<tr>
<td>Background Required</td>
<td>• Enterprise Software Development Experience</td>
</tr>
<tr>
<td></td>
<td>• Manufacturing Domain Knowledge + relevant Programming Language</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>MES, Manufacturing Execution</td>
</tr>
</tbody>
</table>
Enterprise Asset Management (EAM)

- Manufacturing Plants contain Machines, which need to be kept in running condition.
- Machines need to be maintained in order to be kept running.
- Type of Maintenance Techniques
  - Breakdown Maintenance
  - Scheduled Maintenance
  - Condition Monitoring and Maintenance
  - Predictive Maintenance based on Condition and Run History
## Software in Enterprise Asset Management

<table>
<thead>
<tr>
<th>Characteristic</th>
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<tbody>
<tr>
<td>Level</td>
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<td>Windows, Unix</td>
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<tr>
<td>Language</td>
<td>C++, C#, Java</td>
</tr>
<tr>
<td>Math Component</td>
<td>High</td>
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<td>Logic Component</td>
<td>High</td>
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<td>UI Component</td>
<td>Very High</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Days</td>
</tr>
<tr>
<td>Things to Do</td>
<td>• Develop EAM Products as a part of an EAM Product Company</td>
</tr>
<tr>
<td></td>
<td>• Design and Develop EAM Systems based on Products</td>
</tr>
<tr>
<td>Background Required</td>
<td>• Enterprise Software Development Experience</td>
</tr>
<tr>
<td></td>
<td>• Maintenance Domain Knowledge + relevant Programming Language</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>Asset Management, Plant Maintenance</td>
</tr>
</tbody>
</table>
Quality Control /Laboratory Measurements

Lab Instruments

- X-Ray Analyzers
- Spectrometers
- Agitators

Lab Systems

Laboratory Information Management Systems
## Software in Lab Instruments

<table>
<thead>
<tr>
<th>Characteristic</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Embedded</td>
</tr>
<tr>
<td>App S/W Size (LOC)</td>
<td>Hundreds (Scripts)</td>
</tr>
<tr>
<td>Op. System</td>
<td>Windows</td>
</tr>
<tr>
<td>Language</td>
<td>C++, C#, Java</td>
</tr>
<tr>
<td>Math Component</td>
<td>High</td>
</tr>
<tr>
<td>Logic Component</td>
<td>High</td>
</tr>
<tr>
<td>UI Component</td>
<td>Very High</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Days</td>
</tr>
</tbody>
</table>

**Things to Do**

- Develop Lab Instruments as a part of Instrument Manufacturers
- Write software for Integrating Lab Instruments with Enterprise Systems.

**Background Required**

- Software Development
- Laboratory Testing Domain

**Search Phrases**

Laboratory instruments, Analyzers
## Software in Lab Systems

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<td>App S/W Size (LOC)</td>
<td>Thousands</td>
</tr>
<tr>
<td>Op. System</td>
<td>Windows</td>
</tr>
<tr>
<td>Language</td>
<td>C++, C#, Java</td>
</tr>
<tr>
<td>Math Component</td>
<td>High (with high Statistical Analysis Component)</td>
</tr>
<tr>
<td>Logic Component</td>
<td>High</td>
</tr>
<tr>
<td>UI Component</td>
<td>Very High</td>
</tr>
<tr>
<td>Cycle times</td>
<td>Days</td>
</tr>
<tr>
<td>Things to Do</td>
<td>• Develop Lab Systems as a part of Product Manufacturers&lt;br&gt;• Write software for Integrating Lab Systems with Enterprise Systems.</td>
</tr>
<tr>
<td>Background Required</td>
<td>• Software Development&lt;br&gt;• Laboratory Testing Domain</td>
</tr>
<tr>
<td>Search Phrases</td>
<td>LIMS</td>
</tr>
</tbody>
</table>
Product Engineering
Enterprise Resource Planning (ERP)
Putting it all together

ERP
- CRM
- SRM
- MRP

LIMS
- Production Planning

EAM
- Production Control (MES)

PLM/PDM
- Plant Design
- Product Design

Process Control
- Advanced Control (APC)
- Supervisory Control (SCADA)

Lab Instruments
- Loop Control (PLC/DCS)

Field (Sensors, Actuators, Weigh Scales)

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.. and Making it work! The role of Standards.

OPC UA

ERP

CRM

SRM

Production Planning

ISA95/B2MML

LIMS

Production Control (MES)

EAM

PLM/PDM

Plant Design

OPC

Process Control

Advanced Control (APC)

Supervisory Control (SCADA)

Custom

Device Driver API’s

4-20mA/0-5V/FieldBus/Profibus

Lab Instruments

Loop Control (PLC/DCS)

Field (Sensors, Actuators, Weigh Scales)

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Making it work.. The role of standards

Outsourcing/ Fabless Company

RosettaNet

Vendor

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Fieldbus

- Type 1 Foundation Fieldbus H1
- Type 2 ControlNet
- Type 3 PROFIBUS
- Type 4 P-Net
- Type 5 FOUNDATION Fieldbus HSE (High Speed Ethernet)
- Type 6 SwiftNet (a protocol developed for Boeing, since withdrawn)
- Type 7 WorldFIP
- Type 8 Interbus

**PROFIBUS**

**Protocol Information**

- **Type of Network**: Device Bus, Process Control
- **Physical Media**: Twisted pair, fiber
- **Network Topology**: Bus
- **Device Addressing**: DIP Switch or hardware/software
- **Governing Body**: PROFIBUS&PROFINET
- **Website**: www.profibus.com

**Foundation Fieldbus H1**

**Protocol Information**

- **Type of Network**: Process Control
- **Physical Media**: Twisted Pair, fiber
- **Network Topology**: Star, Bus
- **Maximum Devices**: 32 nodes/segment
- **Maximum Distance**: 9500 meters with 4 repeaters (depending on minimum signal strength and power to reach the field devices)
- **Device Addressing**: Automatic when connected to segment
- **Governing Body**: Fieldbus Foundation
- **Website**: www.fieldbus.org
www.opcfoundation.org

http://www.commsvr.com/UAModelDesigner/Index.aspx
ISA-95 3.0 Detail

Product definition
- Production capability
  - Production schedule
    - Detailed production scheduling
      - Production resource management
        - Production definition management
          - Production execution management
            - Equipment and process specific production rules
              - Operational commands
                - Operational responses
                  - Equipment and process specific data
                    - Production level 1-2 functions
Cross Pollination
Best Practices

■ Things Manufacturing can take from Software
  □ Enterprise IT concepts and Standards (XML, SOAP)
  □ Configuration Management concepts

■ Things Software can take from Manufacturing
  □ Formalism of documentation - Specification, Design
    ❖ Importance
    ❖ Notation
  □ Distributed Manufacturing
  □ Measurement
    ❖ Importance
    ❖ Mechanism
  □ Modesty!
Thank you for your attention!

<End of Presentation>