Agent Technology in Agile Production and Product Support

Leo van Moergestel
HU Utrecht University of Applied Sciences
Utrecht University
Utrecht, the Netherlands
My books
Overview

- Part 1: Manufacturing overview
- Part 2: Manufacturing 2.0
- Part 3: Agent-based manufacturing
- Part 4: Agent-based product support
Overview Part 1

- Industrial revolutions
- Standard manufacturing
- Modern technologies
- Concepts and hot topics
Industrial revolutions

- Power driven systems (steam, waterpower)
- Electrical driven systems, production lines
- Automation with electronics and IT
- Cyber connected systems
Revolution 1

- Introduction of mechanical production facilities with the help of water and steam power
- The first power loom was designed in 1784 by Edmund Cartwright and first built in 1785.
Revolution 2

- Division of labor, mass production, production lines
- Use of electric power
- First assembly line Cincinnati slaughter houses (1870)
- Remember 'Modern Times' (Chaplin)
Assembly line
Revolution 3

• Automation by electronics, IT and advanced electro-mechanical systems like industrial robots

• First Programmable Logic Controller (PLC) Modicon 084
Revolution 4

- Cyber-physical systems
- Smart interconnected systems communicating, sharing information, negotiating and making decisions
How things are made

- Single product (unique, tailor made)
- Continuous production (chemical industry)
- Batch production (food, consumer products, industrial products)

- Both continuous and batch are considered industrial production
Automation pyramid

- Business Management
- Production Management
- Process Management
- Process Control
- Process
Control layers

Business Systems - Intranet Networks

Corporate Management
Finance
Research
Marketing
Sales

Quality, validation
Maintenance
MES
Scheduling
Management Information

Supervisory Network

Public
Operator Consoles

SCADA
Batch Control
Lab Info Syst

Control System Network

Storage Management

PLC's
Control Stations
Fieldbus
Field

Safety System
Field Instruments

Smoke, Gas
& Fire
detection
Field Instruments
Intermezzo PLC

- Programmable Logic Controller
  - LD (graphical, relay logic)
  - IL (Textual, low level commands like assembler)
  - ST (Textual, Pascal-like procedural language)
  - FBD (graphical, logic diagrams)
  - SFC (graphical, state machine, GRAFCET)
Intermezzo PLC
PLC programming 1(2)
PLC programming 2(2)

OR

a

2

x₁

3

x₂

4

5

6

d

e

b

AND

a

2

b

3

4

5

6

7

8

d

c

e

f

h

j

10

h,i
Intermezzo Fieldbus

![Diagram of a system with a tank, valve, level sensor, and control system connected via a fieldbus.]
SCADA

- Supervisory Control And Data Acquisition
- Operates at a lower level than the Manufacturing Execution System (MES)
- Several commercial solution providers
- Connection with production system generated data
- Control at operator level.
MES (11 tasks)

- Resource allocation
- Operations scheduling
- Dispatching production units
- Document control
- Data collection
- Quality management
- Labor management
- Process management
- Maintenance management
- Product tracking
- Performance analysis
Concepts and hot topics

- What are concepts and hot topics in modern manufacturing?
  - Lean manufacturing
  - Agile manufacturing
  - RMS
  - Personalising products
  - Short time to market
Lean Manufacturing

- TPS
- What is the product value for the consumer?
- Discover where this value is added during production
- Determine waste in the process, remove it and shorten the duration of lead time
- Apply pull-driven production
- Keep the waste away
Agile Manufacturing and RMS

- Definition: An agile manufacturing system is a system that is capable of operating profitably in a competitive environment of continually and unpredictably changing customer requirements.

- Definition: A reconfigurable manufacturing system is a manufacturing system that is designed for fast changes, both in hardware as well as software components, in order to quickly adjust production capacity and functionality in response to sudden changes in market or in changes in requirements.
Personalising 1(2)
Personalising 2(2)
Time-to-market

Research and Development (R&D)

New Product → Upscaling to Real Production Equipment → Test Batch → Production Batch

Adjust Parameters

Time to Market
Conclusion so far

- Standard manufacturing automation is mostly based on industrial production (batch processing and continuous processing).
- This kind of manufacturing will not disappear but other solutions might be useful.
- Why is there a need for other solutions?
  - Customers want personalised products
  - New technologies available
  - Short time-to-market needed
Manufacturing 2.0

Summary of presentation by Dr. Hsu-Pin (Ben) Wang, Georgia Tech

Overview Part 2

• Research and manufacturing
• New technologies
  – Materials
  – 3D printing
• Conclusion
Some problems

- Innovation chain is not producing results
- It takes too long before new discoveries and materials are introduced and accepted by the industry
- In the current innovation chain there is a gap between the academia and the industry. This so-called valley of death should be bridged by applied research and fast technology maturation.
New materials

- We focus on just one example: C60
Nanotubes

- Based on C60 nanotubes can be made
- Stronger than steel and amazing properties
Buckypaper

- Nanotubes can be used to make buckypaper
- This material will be used in cars, airplanes and many other devices to make them light while keeping them strong and less power consuming

*Figure 2. Scanning electron microscopy image of buckypaper (left); 400 foot roll of CNT (right). Source: Nanocomp.*
Additive manufacturing

• Additive manufacturing (also known as 3D printing) is one of the new revolutions in the production industry.

• Industrial 3D printers are still much more expensive than the 'toy' devices offered to the public, but they can produce amazing results.

• Plastic printing, ceramic printing, metal printing and printed electronics are possible.
New opportunities

- Mass customization
- Variable lot size down to one
- On demand manufacturing
- Tool-less manufacturing
- Expanded design space
Conclusion

● To make these opportunities possible, research has to be done.

● New manufacturing paradigms should be developed
Agile agent-based manufacturing

Leo van Moergestel
HU Utrecht University of Applied Sciences
Utrecht University
Utrecht, the Netherlands
Overview of part 3

- Agent-based manufacturing
- Production grid
- Product flow in the grid
- Grid adaption
- Results
Manufacturing Challenges Resumed

• Short time to market
• Customer specific products
• Small quantities

Grid production

• Based on a grid of versatile production platforms (called equiplets)
• Agile and scalable software infrastructure
Classic pipeline production

Fixed product path
Similar products
Huge batch size
Grid production 1(2)

Different product paths (product threads)
Different products (multi parallel production)
Small batches or single product manufacturing
Grid production 2(2)
Example of a product path

production steps

1 → 2 → 3 → 4

equiplet A

5 → 6 → 7

equiplet B

product thread

8

equiplet A

9 → 10 → 11

equiplet C
Product agent and equiplet agents

- Equiplet A
  - Equiplet agent A
    - Product agent
      - Product agent path

- Equiplet B
  - Equiplet agent B
    - Product flow

- Equiplet A

- Equiplet C
  - Equiplet agent C
Grid production

- equiplet A
- equiplet B
- equiplet C

- central system
- production grid monitor

switch
Equiplets with different frontends
Impression of grid manufacturing
Grid with distances
Grid versus Line versus Circle

![Graph showing the comparison of Grid, Line, and Circle structures based on the square root of N.](image)
How things are made

• Single product (unique, tailor made)
• Continuous production (chemical industrie)
• Batch production (food, consumer products, industrial products)

• Both continuous and batch are considered industrial production
ICT infrastructure solution

- Every product is (possibly) unique
- Every product has its production steps
- Distributed system

- A product agent represents the product and knows what (production steps) to do
- An Equiplet agent represents the equiplet and knows how to do (certain production steps)
Agents

- Autonomous systems
- “Living” in an environment
- Sensing, acting, reacting

Definition by Wooldridge and Jennings:

“An agent is a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives”
MultiAgents

- Interacting agents
- Roles, communication
- Cooperation, negotiating
Multiagent production 1(2)

Equiplet agents publish their production steps on a blackboard

Product agents choose the equiplets and make reservations for these equiplets

Product agents negotiate to find a solution in case of scheduling problems

Product agents collect production information to build a product log.
Multiagent production 2(2)

Equiplet agents have a frontend (thus a set of production steps)

Equiplet agents publish these production steps on a blackboard

Equiplet agents wait for product agents to arrive

Equiplet agents send production information to product agents when performing a production step
Problems to be solved

Path planning
Production scheduling
Product logging
Transport (materials and products)
Error recovery
Software architecture
Path planning

- Choose a path with a minimum of hops
- Avoid overloaded equiplets
- Avoid erroneous equiplets
Scheduling

• Based on Realtime OS scheduling (single resource)
  • SPF (shortest process first)
  • EDF (earliest deadline first)
  • LSF (least slack first)
• Multi-agent based issues (multiple resources)
  • Weak versus strong
  • Low overhead / Fast
  • High grid load
EDF scheduling approach
Example of a missed deadline

Missed deadline (b) for product P2
Solution using EDF

Feasible scheduling solution for both product P2 and P1 after rescheduling using EDF
Comparison of different scheduling types

![Graph showing comparison of different scheduling types](image)
Architecture

MAS

Product Agent

Planning Blackboard

Production Steps Blackboard

Equiplet Agent

Database

Equiplet Node

Pick & Place Node

Vision Node

ROS

Gripper

Motors

Camera

LINUX
Implementation

- Webbrowser
  - HTML5
  - Javascript

- Webserver
  - Tomcat

- Timeserver
  - Time process
  - BB-planning
  - BB-steps
  - BB-logfile

- Java application
  - Jade Product Agent
  - Jade Equiplet Agents

- Equiplet 1
- Equiplet 2
- Equiplet 3
...
Web interface
Result

450
...
15
Using this model in a hybrid environment

• What to do versus how to do

• This model can also be used in the situation of human workers instead of equiplets.

• A product agent represents the product and knows what (production steps) to do

• A worker agent represents the human worker and knows how to do (certain production steps)
Hybrid architecture
Implementation

**Web Interface**

User requirements and specifications

**MAS**

**Web Interface**

Assembly guidance system

Capability announcing system

**Client**

**Worker**
Conclusion

The concept has been implemented in an experimental setup.

Agent technology fits well to a distributed infrastructure.

Concept can be the basis of product agents in the life cycle of a product.

The product agent is a good candidate to represent the product in the Internet of Things.
Agent-based Product Support

Leo van Moergestel
Overview part 4

- Life cycle of a product
- Roles of the product agent in different phases
- Implementation in a demo system
- Recycling and repair
- Conclusion
Life cycle of a product

- Design
- Manufacturing
- Distribution
- Usage
- Recycling

Note: the product life cycle is a different concept
What to do with the product agent when the manufacturing is done?

- Embed the agent with its information in the product
- Or transfer the information to another embedded agent
- Keep the product agent alive in cyberspace
Benefits of embedded agents

- Depends on the phase in the life cycle
- All information about a specific product is available
- Basis for implementing the Internet of Things
Embedding a product agent

a) product agent

b) Beliefs
   product agent
Logistics / Transport

- Monitor handling during transport
- Monitor temperature, humidity etc.
- Localize the product
- Arrange transport
Use phase

• Monitor the usage
  – Advice the end-user
  – User manual

• Alert end-user

• Check subsystems

• It all depends on the type of product, what should be done
Recycling

Show the re-usable subsystems
Show the position of re-usable materials

Participate in a trading market for used subsystems
ADRIE

Autonomous Discovery Robot for Indoor Environments
Mapping an indoor environment
Layered Architecture

Global planning
Mapping

Local planning
Monitoring agent

Calculate position
Motor control
Monitoring Agent

Product Agent

- WiFi_monitor
- R_motor_monitor
- L_motor_monitor
- Battery_monitor

- health
- status
- alarm

- Web_server
- System_logger
- Alarm_Handler
Battery status
WiFi signal strength
## Depletion of elements

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<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Years available</th>
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<tbody>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>29</td>
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<tr>
<td>Indium</td>
<td>In</td>
<td>13</td>
</tr>
<tr>
<td>Antimony</td>
<td>Sh</td>
<td>30</td>
</tr>
<tr>
<td>Hafnium</td>
<td>Hf</td>
<td>10</td>
</tr>
<tr>
<td>Tantalium</td>
<td>Ta</td>
<td>116</td>
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Discovering materials

This is a list of materials that the robot uses. Click on a material to see in which components it is used.

- rubber
- aluminium
- gold
- polymer
- copper
- platinum
- rhodium
- lithium
- indium

Material used: gold
Agent-based recycling

Recycling can be much easier if a list of “ingredients” is available (probably with its usage)

Position of the “ingredients” is also important information

Both features can be provided by a product agent

<table>
<thead>
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<th>Supplement Facts</th>
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<tr>
<td>Serving Size 8.0 fl. oz. (240 ml)</td>
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<tr>
<td>Serving Per Container</td>
<td>3</td>
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<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
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<td>9%</td>
</tr>
<tr>
<td>Total Carb</td>
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<td>9%</td>
</tr>
<tr>
<td>Sugars</td>
<td>27g</td>
<td></td>
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<tr>
<td>Vitamin B2</td>
<td>1.7mg</td>
<td>100%</td>
</tr>
<tr>
<td>Vitamin B3</td>
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</tr>
<tr>
<td>Vitamin B6</td>
<td>2mg</td>
<td>100%</td>
</tr>
<tr>
<td>Vitamin B12</td>
<td>6mcg</td>
<td>100%</td>
</tr>
<tr>
<td>Sodium</td>
<td>180mg</td>
<td>8%</td>
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<tr>
<td>Taurine</td>
<td>1000mg</td>
<td></td>
</tr>
<tr>
<td>Panax Ginseng</td>
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<tr>
<td>Energy Blend</td>
<td>2500mg</td>
<td></td>
</tr>
<tr>
<td>L-Carnitine, Glucose, Caffeine, Guarana Inositol, Glucuronolactone, Maltodextrin</td>
<td></td>
<td></td>
</tr>
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</table>

Percent Daily Values are based on a 2000 calorie diet.
Agent-based repair
Agent-based repair (2)
Agent-based repair (3)

- Remote Product Agent
- Webs server
  - Tomcat
- Java application
  - Jade Product Agents
- Blackboard for donors and acceptors
Donor or acceptor?

Owner decides in the first place

Number of working subsystems

Expected lifetime of subparts
Conclusion

Agents can play an important role in all parts of the life cycle of a product

A product agent is a good basis for the Internet of Things (IoT)

An aspect of IoT can be recycling and repair support

A product agent acts like a guardian angel (except for the spiritual aspects)
Thank you!
Questions?