Plant Control

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Agent-based modeling and simulation of an autonomic manufacturing execution system

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Why this topic?

- Personal Interest
  - My background: **ERP-Systems (SAP)**
  - **Integration** of multi-agent systems in classical production planning hierarchy
  - Interesting feature proposed: shared Gantt-Chart

- Overview over **all phases** in development of agent-based systems
  - planning, design, implementation, testing

- **Practical** simulation based on **real plant data**

- But: long paper with many details → focus on general idea
Real-world application
Production of paint

- Complex production structure
  - Equipments: 80+
  - Products: 100+

- Products differing by
  - Type: alkyd-, latex-, water-based
  - Family: same characteristics and colour, different container size
  - Packaging
  - Product size
  - Lot size
Overview: Planning and Control

PRODUCTION PLANNING SYSTEM (ERP)
- Order status
- Planned orders
- Detailed schedule

CONTROL EXECUTION SYSTEM (MES, CPM)

DATA ACQUISITION AND CONTROL SYSTEMS (SCADA, DCS, PLC)

Company Management
- Tactical decisions
- months
- weeks
- days
- Information scope

Production Management
- Operational decisions
- days
- hours
- minutes

Shop floor Control/Automation
- Automatic/manual decisions
- minutes
- seconds
- milliseconds
- Information detail

Software Logos:
- SAP
- Microsoft Dynamics NAV
- Odoo
Scientific basis: Referenced papers and ideas

- **PROSA**
  - **Completely distributed** architecture with Order-, Product-, Resource-, Staff-Agents

- **ADACOR**
  - **Centralized plan** from ERP-System; switch to distributed decision-making in case of disturbances

- **Cooperating MES** (Manufacturing Execution System)
  - Similar to ADACOR; shows that “following a priori defined scheduling is inefficient and sometimes almost impossible”
Proposed: @MES
Autonomic Manufacturing Execution System

ORDER- (OA) AND RESOURCE-AGENTS (RA)
AUTONOMOUS AND GOAL-ORIENTED
@MES
Inter-Agent **communication**

- Structured, direct
- Indirect via *shared Gantt-Chart*
  which is not provided by ERP PPS
Individual MAPE cycle per agent

- **Monitor**
  - Lookup Gantt-Chart updates
  - OA: watch current order process
  - RA: watch resource usage schedule

- **Analyse**
  - Generate list of alternative solutions; choose best processing route

- **Plan**
  - Book resources; update Gantt-Chart

- **Execute**
  - Complete resource usage-plan
Specify, design & implement
Agent-based systems
PROMETHEUS AND HERMES METHODOLOGY
Specify, design & implement **System Prometheus methodology**

Prometheus methodology

1st Step: System Specification

- Identify
  - Goals
  - Basic functionalities
  - Inputs (percepts)
  - Outputs (actions)
  using Use-Case Scenarios
Prometheus methodology

2nd Step: Architectural Design

- Which Agent types?
- Which interactions?
Prometheus methodology

3rd Step: Detailed Design

- Internals of each Agent
Specify, design & implement Messages Hermes methodology

- Incremental Waterfall
  - Derive from and give Feedback to earlier phase(s)

Hermes methodology

Interaction Goal Hierarchy Design

- Which interaction **Goals**?
- Which **Roles** are involved?

undirected line: sub-goal; directed line: dependency

Ask RAs for time slots; generate list of candidate solutions

Check resource availability

Monitor order execution

Disruptive event detected? Reschedule

Is order feasible?

Check resource availability

Monitor order execution

Ask RAs for time slots; generate list of candidate solutions
Hermes methodology
Action Map Design Phase

- Define **actions** and **action sequences**
- Evaluate validity and possible failures

Example: Monitor resource and reschedule interaction-goals
Hermes methodology
Message Design Phase

- Define communications between Agents

Example: Execute the individual tasks of an order

- Execute task @RA 1
- Execute task @RA 2
- Till order is finished
Hermes methodology

Verification Phase

- **Bottom-Up Design:** from “micro world” to **macro** behaviour
- “**Full of surprises**”
- Test **alternative** parameters/actions
  - Economic-oriented parameters: lead time reduction, increase machine utilization,…
  - Criteria for selecting process route
  - …
Simulation

USING NETLOGO
Simulation Description

- **Plant structure** according to [White]
- Processing **times** and in-depth **shop-floor** study in real plant
- Timeframe simulated: 10 months
- **Constraints**
  - Different **dispenser** speeds
  - Equipment **interconnections** between tanks and fill-out trains

Simulation Variety

- Order Agent **scheduling criteria:**
  - Earliest Finalization Time (EFT)
  - Shortest Total Processing Time (STPT)
  - Shortest Time Between Operations (STBO)
  - Largest Finalization Time (LFT)

- Order **Types:**
  - **High** arrival rates (e.g. type 1)
  - **Low** arrival rates (e.g. type 25)
Simulation Results (1)

- High variance in average processing time depending on Agent scheduling criteria

Shortest Total Processing Time (STPT)

Largest Finalization Time (LFT)
Simulation Results (2)

- Different Resource utilization

Example: Tanks

Earliest Finalization Time (EFT)  

Shortest Total Processing Time (STPT)
Simulation Results (3)
Reaction on breakdown

- Breakdown of fill-out train
  (→ Disruptive event)

Percentage difference in total processing time

![Bar chart showing percentage differences in total processing time for different criteria (EFT, STPT, LFT, STBO). The chart compares average frequent orders and average non-frequent orders.](chart_image)
Simulation Conclusions

- Variability **acceptable** (Max. processing time always \( \leq 3 \times \) average processing time)

  \( \rightarrow \) **robust and stable**, despite **total autonomy**

- Further improvements
  - Better **interaction with shop-floor** (sensors and actuators)
  - Individual and collective **learning** (dispatching in RAs and route selection in OAs)
Follow-Up papers

- **Referenced** in 14 papers
  Example:
  - Cyrille Pach, Thierry Berger, Thérèse Bonte, Damien Trentesaux, (Univ. Lille Nord, France)
    ORCA-FMS: a dynamic architecture for the optimized and reactive control of flexible manufacturing scheduling

- Follow-Up by the **original authors**:
  - Milagros Rolón, Ernesto Martínez,
    Agent learning in autonomic manufacturing execution systems for enterprise networking
    Computers & Industrial Engineering, Volume 63, Issue 4, December 2012, Pages 901–925
Agent-based modeling and simulation of an autonomic manufacturing execution system,
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