MODAPTO [101091996]: Modular Manufacturing and Distributed Control via Interoperable Digital Twins

3.1.2. Methods for reconfiguring production setups

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Methods for Reconfiguring Production Setups

Production reconfiguration is a key capability in modern manufacturing that enables organizations to adapt quickly to changing requirements by adjusting their manufacturing systems. The MODAPTO project addresses this challenge by developing frameworks and methodologies for flexible reconfiguration of industrial systems through production modules enhanced by distributed intelligence via interoperable Digital Twins.

Understanding Production Reconfiguration

Production reconfiguration refers to the ability to adjust manufacturing systems by rearranging, adding, or removing components to adapt to changing production requirements. In today's rapidly evolving manufacturing landscape, the ability to quickly reconfigure production setups is becoming increasingly critical for businesses to remain competitive and responsive to market demands.

In the MODAPTO framework, reconfiguration is supported by several key concepts:

1. **Production Modules**: Defined as "assets that carry out specific manufacturing tasks or processes and can be integrated or rearranged with other production modules to create a flexible, modular, and reconfigurable production environment." These can be physical assets (machines, robots) or logical assets (groups of machines, production lines).
2. **Production Schema**: Represents the hierarchy and precedence relationships between production modules. It can be in actual mode (currently used in production) or design mode (for experimentation with new configurations).
3. **Digital Twins**: Virtual representations of production modules that enable simulation, monitoring, and optimization of reconfiguration scenarios before physical implementation.

Parameters Defining Reconfigurable Production Processes

From the SEW pilot implementation in MODAPTO, several key parameters define reconfigurable production processes:

1. **Cell-Level Parameters**:
   - Number of production cells at each production step
   - Number of manually operated production assets per cell
   - Number of automated production assets per cell
   - Minimum-Maximum number of workers required per cell
   - Buffer capacity at cell entry and exit points
2. **Production Step Organization**:
   - Multiple production cells per step
   - Parallel processing capabilities
   - Buffer zones between steps
   - Flexible routing between cells

These parameters provide the foundation for reconfiguration capabilities, allowing manufacturing systems to adapt to changing requirements by adjusting cell configurations, worker assignments, routing options, and buffer capacities.

Workflow for Production Module & Schema Reconfiguration

The MODAPTO project defines a standardized workflow for reconfiguring production setups:

1. **Access Reconfiguration Environment**: The user accesses the Design & Reconfiguration Tool through the system interface
2. **Visualize Current Configuration**: The system displays the existing production modules and schemas
3. **Create/Edit Module Configuration**: The user creates new modules or modifies existing ones with specific attributes
4. **Save Module Configuration**: The updated configuration is stored in the system repository
5. **Create/Update Production Schema**: The user defines how modules are connected in the production flow
6. **Validate Reconfiguration**: The system verifies that the new configuration meets all constraints
7. **Deploy Reconfiguration**: The new configuration is implemented in the production environment

This workflow ensures a structured approach to reconfiguration that maintains system integrity while enabling flexibility.

Methods for Production Reconfiguration

Different methods for reconfiguring production setups have been developed and tested within the MODAPTO pilots:

1. **Modular Production Cell Reconfiguration**

This method involves:

- Defining standardized production cells with clear interfaces
- Enabling cells to be added, removed, or rearranged
- Maintaining standardized communication protocols between cells

Example from SEW Pilot: The SEW manufacturing system is structured with 8 production steps (6.1-6.8), each comprising one or more production cells. Each cell consists of one or more physical production assets that can be reconfigured as needed.

2. **Worker Assignment Reconfiguration**

This method focuses on:

- Flexible allocation of workers to production cells
- Adjusting worker assignments based on production demands
- Cross-training workers to handle multiple cell types

Example from SEW Pilot: The SEW system allows for dynamic worker allocation, with different cells requiring different numbers of workers (1-5). The system can be reconfigured by reassigning workers to different cells based on current production priorities.

3. **Production Routing Reconfiguration**

This method involves:

- Dynamic routing of products through alternative production paths
- Selection of optimal routes based on current system conditions
- Adaptation to equipment availability and bottlenecks

Example from SEW Pilot: Once work on a specific production cell is completed, products can be directed to any cell in the next production step, providing flexibility in routing.

4. **Buffer Capacity Reconfiguration**

This method focuses on:

- Adjusting buffer capacities between production stages
- Balancing work-in-progress inventory
- Managing production flow variability

Example from SEW Pilot: Buffer zones are established before and after production cells, with configurable capacities to accommodate different production scenarios.

Advanced Technologies Supporting Reconfiguration

The MODAPTO project has developed several technologies to support effective production reconfiguration:

1. **Digital Twin-Based Reconfiguration**

Digital Twins serve as virtual replicas of production modules, enabling:

- Simulation of different configurations before physical implementation
- Real-time monitoring of production module performance
- Analysis of reconfiguration impacts on overall system performance

The Digital Twin concept is central to MODAPTO, where “A MODAPTO Module is the combination of a production module with its Digital Twin (DT).” This integration enhances reconfiguration capabilities by providing a virtual environment for testing and validation.

2. **Co-Simulation for Reconfiguration Validation**

Co-simulation involves:

- Simulating multiple production modules simultaneously
- Evaluating interactions between reconfigured modules
- Predicting system behavior after reconfiguration

This approach enables comprehensive evaluation of reconfiguration scenarios, ensuring that changes to individual modules do not adversely affect the overall production system.

3. **Optimization Services for Reconfiguration**

These services provide:

- Suggestions for optimal production configurations
- Analysis of multiple parameters (orders, schedules, resources)
- Recommendations for optimal courses of action

From the SEW pilot: "The Optimization functionality supports multiple input parameters (e.g., orders and production schedules, quality specifications, shifts planning horizon, materials, carbon footprints, energy consumption) and produces suggestions for optimal courses of action."

Case Study: SEW's Transition to a Reconfigurable Manufacturing System

The SEW USOCOME pilot in the MODAPTO project provides a comprehensive case study of transitioning from a monolithic to a reconfigurable manufacturing system.

Initial State: Monolithic Production Line

- Sequential structure with multiple interdependent production steps
- Limited flexibility in responding to variability
- Manual production planning and scheduling
- Bottlenecks and disruptions due to unexpected events

Target State: Modular and Reconfigurable System

- Modular production cells that could be reconfigured as needed
- Enhanced flexibility in production routing
- Automated production scheduling and optimization
- Improved ability to handle unexpected events

Reconfiguration Implementation The reconfiguration was implemented through:

- Reorganization of production into 8 distinct steps (6.1-6.8)
- Creation of multiple production cells per step
- Introduction of buffer zones between steps
- Implementation of flexible routing between cells
- Addition of AGVs for material transport between cells

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Results and Benefits The implementation achieved significant improvements:

- Reduction in assembly flow lead time from 1.72 days to less than 8 hours (0.42 days)
- Increased productivity from 9 to 12 gearmotors per operator per shift
- Improved cell utilization rate to over 85% (reaching 89%)
- Enhanced flow rate stability (±9 gearmotors per hour)
- Increased production capacity from 500 to 800 gearmotors per day

Best Practices and Lessons Learned

Based on the MODAPTO pilots, several best practices for effective production reconfiguration have been identified:

1. **Design for Reconfigurability**
    - Define clear module interfaces from the beginning
    - Standardize communication protocols between modules
    - Design buffer zones to absorb variability between reconfigurable elements
2. **Data-Driven Reconfiguration**
    - Collect and analyze production data to identify reconfiguration opportunities
    - Use real-time monitoring to trigger reconfiguration when needed
    - Compare identical production cells to identify performance differences
3. **Simulation Before Implementation**
    - Use digital twins to simulate reconfiguration scenarios
    - Evaluate the impact of reconfiguration on key performance indicators
    - Validate reconfiguration plans before physical implementation
4. **Gradual Implementation**
    - Start with small-scale reconfiguration initiatives
    - Build experience and confidence before large-scale changes
    - Document and share lessons learned throughout the process
5. **Lessons Learned from Pilots** From the SEW pilot:
    - "The work of describing the current scheduling process in a scientific way was very long. It was and is still done manually, with people using methods acquired by a long experience."
    - "Working on this topic enabled the involved partners to describe precisely this process."
    - Different approaches to reconfiguration can be implemented, such as fixing the path between different cells in advance versus dynamic allocation when an order exits a cell.

By applying these methods and best practices, manufacturing organizations can develop effective reconfiguration capabilities that enable them to adapt quickly to changing requirements, improve operational efficiency, and maintain competitiveness in dynamic markets.

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