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

MODAPTO

3.1.1. Designing production steps, cells, and modules

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Designing production steps, cells, and modules is a fundamental aspect of creating flexible, reconfigurable manufacturing systems. The MODAPTO project provides a comprehensive framework for this design process, emphasizing hierarchical structure, standardized interfaces, and digital twin integration.

Hierarchical Structure of Production Systems

Modern modular manufacturing systems typically follow a three-level hierarchical structure:

1. **Stage Level (Level 1)**: The highest level of organization, representing complete production workflows from input to output. Each stage encompasses a major production phase, such as pre-assembly, assembly, quality control, or finishing. Stages are sequentially structured with dependencies between them, forming the overall production process.
2. **Cell Level (Level 2)**: Each production stage contains one or more production cells. Cells perform specific functions within their respective stage and can operate in parallel to increase throughput and flexibility. A semi-finished product can be directed to any appropriate cell within the next production step, providing routing flexibility. However, once a product enters a cell, it typically must pass through all physical production assets within that cell.
3. **Module Level (Level 3)**: The most granular level of production organization, consisting of individual physical production assets such as machines, robots, or workstations. Modules can be manual (operated by workers), semi-automated, or fully automated. They work together within a cell to complete the cell's specific function.

The SEW USOCOME pilot implementation in the MODAPTO project exemplifies this hierarchical structure:

- The complete production process (Step 6) consists of 8 sequential production steps (Steps 6.1-6.8)
- Each production step includes one or more production cells
- Each production cell contains one or more physical production assets
- The physical assets can be manual (operated by workers) or automated

Design Considerations for Production Steps, Cells, and Modules

When designing modular manufacturing systems, several key considerations must be addressed:

1. **Modularity and Reconfigurability**:
    - Design modules to be interchangeable and reusable
    - Enable quick reconfiguration of production lines
    - Allow for addition or removal of modules without disrupting the entire system
    - Define standardized interfaces between modules
2. **Process Flow and Dependencies**:
    - Establish clear sequences and interdependencies between production steps
    - Design buffer zones between production steps to manage workflow
    - Define material handling and transport mechanisms between cells
    - Consider both physical and information flow in the design
3. **Resource Allocation**:
    - Determine appropriate staffing for manual and semi-automated operations

   - Balance workload across cells to avoid bottlenecks
   - Allocate equipment resources optimally
   - Consider scalability in resource planning
4. **Production Scheduling and Routing**:
   - Design systems that support flexible scheduling
   - Enable dynamic routing of products through appropriate cells
   - Incorporate mechanisms for handling production variations
   - Consider queue management and prioritization

The MODAPTO Module Concept

In the MODAPTO framework, a production module is defined as: "An asset that carries 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. It can be a physical asset (e.g., a machine, a robot, etc.) or a logical asset (e.g., a group of machines, a production line, etc.); the latter implies that a production module may itself be composed of other production modules."

The MODAPTO project extends this concept by introducing the "MODAPTO Module," which combines a physical production module with its Digital Twin (DT). This integration enables enhanced capabilities including:

- Self-awareness of the module's status and performance
- Optimization of operations
- (Co-)simulation for testing and validation
- Predictive maintenance
- Analytics on operations

Tools and Methodologies for Design

The MODAPTO framework provides several tools and approaches for designing production steps, cells, and modules:

1. **Design & Reconfiguration Tool**:
   - Allows formal definition of production modules and schemas
   - Provides modeling capabilities for representing production components
   - Enables simulation and testing of different configurations
   - Supports visualization of production layouts
2. **Digital Twin Integration**:
   - Each production module is represented by a digital twin
   - Digital twins enable real-time monitoring, simulation, and optimization
   - Interoperable digital twins facilitate communication between modules
   - Digital twins support virtual commissioning before physical implementation
3. **Production Schema Modeling**:
   - Production schemas define how modules interact within the manufacturing process
   - Models capture dependencies between modules and cells
   - Schemas can be reconfigured to optimize production flow
   - Standard-based models ensure compatibility between components

Case Study: SEW USOCOME Transition to Modular Manufacturing

The SEW USOCOME pilot in the MODAPTO project provides a valuable case study of transitioning from a monolithic to a modular manufacturing system:

Original System Characteristics:

- Monolithic production line with sequential structure
- Multiple interdependent production steps
- Manual effort required despite automation
- Limited flexibility for customization

Transition to Modular System:

- Reorganization into a "small factory" concept with modular components
- Implementation of three-level hierarchy (stage, cell, module)
- Integration of AGVs for flexible material transport
- Enhancement of modules with digital twins for improved monitoring and control

Production Organization:

- Production Step 6.1: Two production cells, each with five physical assets (four manual, one automated)
- Production Step 6.2: Four production cells, each with thirteen manual physical assets
- Production Step 6.3: One production cell with one automated physical asset
- And so on through to Production Step 6.8

This reorganization allowed SEW to achieve significant improvements:

- Reduction in assembly flow lead time from 2 days to 0.42 days
- Improved production capacity from 500 to 800 gearmotors/day
- Enhanced cell utilization rate to 89%
- Reduction in production area required per gearmotor

Best Practices for Designing Production Systems

Based on the MODAPTO pilots, several best practices for designing production systems have emerged:

1. **Standardization of Interfaces**:
    - Define standard interfaces between modules to ensure interoperability
    - Use Asset Administration Shell (AAS) or similar standards for digital interfaces
    - Ensure physical interfaces are compatible across modules
2. **Scalability Planning**:
    - Design systems that can scale up or down as needed
    - Plan for potential expansion or contraction of production capacity
    - Ensure digital infrastructure can support growth

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3. **Data Integration**:
    - Design systems that capture and utilize production data effectively
    - Integrate data sources from different production modules
    - Implement monitoring capabilities at all levels (module, cell, stage)
4. **Optimization Capabilities**:
    - Include optimization functions in the design
    - Enable real-time optimization of production schedules
    - Support predictive maintenance and self-awareness capabilities
5. **Human-Machine Interaction**:
    - Design interfaces that facilitate effective human-machine collaboration
    - Consider ergonomics and user experience in manual operations
    - Enable operators to declare their location and report issues

By applying these principles and approaches, manufacturing organizations can design production steps, cells, and modules that support flexibility, reconfigurability, and efficiency in their operations.

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