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

3.2.1. Simulation tools for evaluating configurations

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Simulation Tools for Evaluating Configurations

Simulation tools play a critical role in evaluating different configurations of manufacturing systems before physical implementation. This capability is particularly valuable in modular manufacturing environments, where the ability to reconfigure production setups is a key advantage. The MODAPTO project has implemented various simulation approaches across its pilot cases, demonstrating how these tools can support design decisions, optimization, and performance evaluation.

Introduction to Simulation in Modular Manufacturing

In modular manufacturing environments, simulation tools allow manufacturers to:

- Test and validate design concepts without physical prototypes
- Optimize resource allocation and production flows
- Identify potential bottlenecks and constraints
- Evaluate performance against key metrics
- Compare different setups to determine optimal configurations

Within the MODAPTO architecture, simulation serves as a critical smart service that enables users to evaluate the performance of different production module configurations, assess sustainability and operational impacts, and support decision-making through virtual testing.

Simulation Service Capabilities in MODAPTO

The Simulation Service in MODAPTO enables the (co-)simulation of production modules' operation. As detailed in the project architecture: "This service enables the (co-)simulation of the MODAPTO modules' operation. It may refer to a single production asset, a single production process or a collection of assets and processes. It may require input from a single or multiple modules of the manufacturing process as well as data stemming from enterprise and manufacturing information systems and other sources."

The simulation service supports two primary modes:

1. **Individual simulation**: Simulating the operation of a single component
2. **Co-simulation**: Coordinating multiple components being simulated simultaneously

Both types of simulation are designed to return results within a reasonable timeframe (typically within one hour), making them practical for real-world manufacturing decision-making.

Simulation Tools Across MODAPTO Pilots

The MODAPTO project has implemented different simulation tools across its pilot cases, each tailored to the specific requirements of the manufacturing context.

Pilot 1 (FFT): Simulation for Robotic Systems

FFT utilizes a comprehensive suite of simulation tools within their robot design process:

RF::SUITE Tools:

- **RF::ViPer**: Provides behavior simulation for peripheral elements in virtual production systems
- **RF::YAMS**: Delivers dynamic 3D visualization of complex geometries with integrated numerical kinematics simulation
- **RF::SCOUT**: Functions as an analysis tool for process data, featuring signal analyzers and Gantt charts for detailed process analysis
- **RF::Recorder v2**: Records signal sequences for replay and analysis

These tools work together to create a dynamic virtual representation of production modules coupled with real production, enabling comprehensive evaluation of robot design setups. The simulation process facilitates:

- Evaluation of different robot configurations (electric/pneumatic welding guns, small/large robots with roller hemming)
- Assessment of energy consumption and sustainability metrics
- Optimization of robot movements
- Virtual commissioning before physical deployment

Pilot 2 (SEW): Production Line Simulation

SEW employs simulation tools to evaluate different production line configurations:

FlexSim:

- Used to evaluate production schedules and configurations
- Enables testing of different parameters including:
    - AGV loading and unloading times
    - Buffer sizes
    - Worker allocations
    - Production cell configurations

The SEW pilot demonstrates how simulation allows comparison of different production schedules and assessment of key performance indicators such as:

- Utilization rates at cell and step levels
- Production throughput
- Buffer occupation rates
- Lead time optimization

Pilot 3 (CRF/ILTAR): Intralogistics Simulation

This pilot utilizes simulation to optimize kit-holder configurations and plant layouts:

- Simulation of plant setups to assess impact on operations

- Evaluation of different picking sequences for the Kitting Robot System (KRS)
- Analysis of different gravity rack configurations
- Assessment of intralogistics systems

Data Requirements for Simulation

The simulation service requires different types of data depending on the pilot and manufacturing context:

For Pilot 1 (FFT):

- Robot type
- Robot movements
- Energy consumption
- Movement duration/time

For Pilot 2 (SEW):

- Planning horizon (hours, days, weeks)
- Production orders
- Cell capacities
- Shifts schedule

For Pilot 3 (ILTAR/CRF):

- ILTAR: Planning horizon, production orders, shifts schedule
- Stellantis: Set of kit-holders available for picking, production orders, robot movements, movement parameters

The simulation components work with batches of data rather than streams, processing one data batch per execution.

Workflow for Using Simulation Tools

The workflow for using simulation tools to evaluate different configurations typically follows these steps:

1. **Define Simulation Objectives**:
    - Determine what aspects of the configuration need to be evaluated
    - Identify the key performance indicators for comparison
    - Establish the scope and boundaries of the simulation
2. **Configure Simulation Parameters**:
    - Set up the production configuration to be simulated
    - Define input parameters (orders, resources, schedules)
    - Configure simulation settings (time horizon, resolution)
3. **Execute Simulation**:
    - Run the simulation with the defined configuration and parameters
    - Generate performance data for the simulated scenario

4. **Analyze Results**:
    - Evaluate performance against defined KPIs
    - Identify bottlenecks and constraints
    - Compare with baseline or alternative configurations
5. **Refine Configuration**:
    - Adjust parameters based on simulation results
    - Iterate to improve performance
    - Test alternative configurations

Virtual Commissioning

For more detailed simulation, MODAPTO incorporates Virtual Commissioning capabilities: "The virtual commissioning component aims at the setup and initial programming of complex automation systems based on digital models and methods. It integrates Production Modules in a virtual environment including 3D geometry and behavior simulation."

Virtual commissioning provides several advantages:

- Testing control programs in a virtual environment before physical implementation
- Reducing commissioning time and costs
- Minimizing risks during implementation
- Training operators on new systems before they are physically available

Practical Example: Robot Design Simulation in FFT

In the FFT pilot, the workflow for using simulation to examine different robot design setups follows these steps:

1. **Login and Access**: The Robot Simulation User logs into the system
2. **Task Specification**: The user provides task specifications including:
    - Operational constraints (reachability, operation time, quality specifications)
    - Sustainability parameters (energy consumption constraints)
3. **Configuration Retrieval**: The system retrieves available robot design setups
4. **Filtering and Analysis**: The system filters designs that can fulfill the specified task
5. **Comparison and Selection**: The user reviews available configurations and selects the preferred design setup
6. **Detailed Simulation**: The selected configuration undergoes detailed simulation to assess performance

This workflow enables users to make informed decisions based on simulated performance data rather than trial and error in the physical environment.

Co-Simulation Capabilities

MODAPTO extends beyond single-module simulation to co-simulation, allowing:

- Simultaneous simulation of multiple modules
- Analysis of interactions between modules

- System-level performance evaluation
- Assessment of end-to-end processes

Co-simulation is particularly valuable for evaluating complex production systems where the interactions between modules significantly impact overall performance.

Technical Implementation in MODAPTO Architecture

The Simulation/Co-Simulation component in the MODAPTO architecture is designed with specific technical parameters:

- **Objective**: Simulates the execution of MODAPTO module(s) to calculate and return corresponding metrics on their operation
- **Application**: Can be applied to individual production modules or across multiple modules involved in a production decision
- **Performance**: Designed to return results within 1 hour (maximum)
- **Resource Requirements**: Up to 8 CPU cores and 64GB RAM

The simulation component interfaces with:

- Digital Twin components
- Optimization services
- Evaluation and Decision Support tools
- Repository for data storage

Benefits and Outcomes of Simulation Tools

Simulation tools in MODAPTO deliver several key benefits:

- **Risk Reduction**: Test configurations before physical implementation
- **Cost Savings**: Identify optimal configurations without production disruption
- **Time Efficiency**: Accelerate the design and configuration process
- **Performance Optimization**: Maximize productivity and efficiency
- **Sustainability Improvement**: Evaluate and minimize environmental impact
- **Decision Support**: Provide quantitative data for informed decision-making

Through the implementation of simulation tools, the MODAPTO pilots have achieved significant improvements:

- In the SEW pilot, simulation demonstrated potential reduction in assembly flow lead time from 2 days to 0.42 days
- In the FFT pilot, simulation tools were used to optimize robot movements to reduce energy consumption by up to 10%

Future Developments in Simulation Tools

The field of simulation for production design continues to evolve rapidly. Key trends include:

- **Digital Twins with AI**: Enhanced prediction capabilities through machine learning
- **Cloud-based simulation**: Scalable computing resources for complex simulations
- **AR/VR integration**: Immersive visualization of simulation results
- **Real-time simulation**: Faster feedback for operational decisions
- **Standardized interfaces**: Improved interoperability between simulation tools
- **Sustainability metrics**: Integration of energy and environmental impact analysis

By staying abreast of these developments, manufacturing organizations can continue to enhance their simulation capabilities and improve their ability to evaluate different production configurations effectively.

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