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

13.1.1 Module classification and categorization methods

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Introduction

Module classification and categorization represent fundamental activities in MODAPTO system design, providing systematic approaches to organize and manage the diverse range of manufacturing assets within reconfigurable production environments. Effective classification systems enable rapid identification of suitable modules for specific production requirements, support automated reconfiguration decision-making, and ensure consistent management of module capabilities and constraints across the manufacturing organization.

The primary classification framework for MODAPTO Modules employs a multi-dimensional taxonomy that considers functional capabilities, technical specifications, integration requirements, and operational characteristics. Functional classification categorizes modules based on their manufacturing operations, such as material processing (cutting, forming, joining), assembly operations (insertion, fastening, testing), material handling (transport, positioning, storage), and quality control (inspection, measurement, validation). This functional perspective enables production planners to quickly identify modules capable of performing required operations during reconfiguration planning.

Technical classification addresses the physical and technological characteristics that determine module compatibility and integration requirements.

Key technical parameters include automation level (manual, semi-automated, fully automated), communication protocols (Ethernet/IP, PROFINET, OPC UA), power requirements (voltage, current, compressed air), and physical interfaces (mechanical connections, safety systems, environmental requirements).

Complexity classification provides a structured approach to understanding the sophistication and capability levels of different modules. Simple modules perform single operations with minimal configuration requirements, intermediate modules offer multiple operational modes or require coordination with other system components, while complex modules provide advanced capabilities such as adaptive control, predictive maintenance, or multi-product processing. This classification supports training program development, maintenance planning, and reconfiguration complexity assessment.

Integration classification addresses the ease and requirements for incorporating modules into existing production systems. Intelligent machines with knowledge-based decision models are autonomous, can reconfigure modules, reposition themselves, cooperate on tasks, and accumulate knowledge through perception and communication, with decentralized planning being more flexible in response to demand fluctuations compared to centralized systems. Plug-and-play modules require minimal configuration and can be rapidly deployed, standard modules follow established integration protocols but may require parameter configuration, while custom modules require specialized integration procedures or interface development.

Performance classification categorizes modules based on their operational capabilities and efficiency characteristics. High-performance modules operate at maximum speed and precision for demanding applications, standard performance modules provide balanced capability for typical production requirements, while economy modules offer basic functionality for non-critical applications or cost-sensitive environments. This classification supports capacity planning, quality management, and economic optimization of production configurations.

Categorization methods extend beyond simple classification to provide dynamic grouping capabilities that support operational decision-making and system optimization. Availability-based categorization groups modules according to their current operational status, maintenance requirements, and scheduled availability windows. This dynamic categorization enables real-time reconfiguration decisions that consider both technical compatibility and operational feasibility.

Capability-based categorization organizes modules according to their current functional capabilities, considering factors such as tooling configuration, calibration status, and operator qualification requirements. This approach supports rapid response to production changes by identifying modules that can immediately fulfill new requirements versus those requiring preparation or reconfiguration before deployment.

Geographic categorization addresses the physical location and mobility characteristics of modules within the manufacturing facility. Fixed modules are permanently installed in specific locations, mobile modules can be repositioned within defined areas, while portable modules can be rapidly relocated throughout the facility. This categorization supports layout optimization, workflow planning, and emergency response procedures.

Utilization-based categorization analyzes historical and current usage patterns to identify optimization opportunities and capacity constraints. High-utilization modules may require capacity expansion or load balancing, while underutilized modules present opportunities for redeployment or alternative application development. This analytical approach supports strategic decision-making about module acquisition, retirement, and optimization investments.

References

1. Industrial Digital Twin Association (IDTA). (2023). “Specification of the Asset Administration Shell Part 1: Metamodel IDTA Number: 01001-3-0”
2. Object Management Group. (2011). “Business Process Model and Notation (BPMN) Version 2.0”
3. International Electrotechnical Commission. (2019). “IEC 63278-1 Asset administration shell for industrial applications”
4. Koren, Y., & Shpitalni, M. (2010). “Design of reconfigurable manufacturing systems.” Journal of Manufacturing Systems, 29(4), 130-141