

Integration of SAP Digital Manufacturing with SAP S/4HANA and Non-SAP ERP Systems: A Unified Framework for Manufacturing Execution

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Abstract- The adoption of Industry 4.0 technologies has increased the need for seamless integration between Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) platforms. SAP Digital Manufacturing (SAP DM), built on the SAP Business Technology Platform (BTP), provides a cloud-based solution for managing and optimizing manufacturing operations. While integration with SAP S/4HANA is supported through standardized mechanisms such as IDocs, APIs, and SAP Cloud Integration, integrating SAP DM with non-SAP ERP systems, including Oracle ERP Cloud, Microsoft Dynamics 365, and Infor CloudSuite, presents additional challenges related to data exchange, interoperability, and process synchronization. This paper proposes a unified four-layer integration framework for connecting SAP Digital Manufacturing with both SAP and non-SAP ERP systems. The framework focuses on master data synchronization, production order management, middleware architecture, security governance, and implementation strategy. By analyzing industry practices and documented integration approaches, the study demonstrates how organizations can establish a scalable and standardized manufacturing integration landscape. The paper also discusses future opportunities in event-driven architectures, artificial intelligence-based production planning, and digital twin technologies.

Keywords- Industry 4.0, SAP Digital Manufacturing, Manufacturing Execution System (MES), Enterprise Resource Planning (ERP), SAP Business Technology Platform (BTP), SAP S/4HANA, Non-SAP ERP Integration, Oracle ERP Cloud, Microsoft Dynamics 365, Infor CloudSuite, Middleware Architecture, Master Data Synchronization, Production Order Management, Cloud Integration, Interoperability, Digital Transformation, Event-Driven Architecture, Artificial Intelligence, Digital Twin, Smart Manufacturing.

I. INTRODUCTION

The adoption of Industry 4.0 technologies has increased the need for seamless integration between Enterprise Resource Planning (ERP) systems and Manufacturing Execution Systems (MES). Effective integration enables real-time data exchange, enhanced production visibility, improved traceability, and optimized decision-making across manufacturing operations. Despite advancements in digital manufacturing, many organizations continue to operate heterogeneous system landscapes where ERP, MES, and shop-floor systems function as separate layers, resulting in data silos and operational inefficiencies.

SAP Digital Manufacturing (SAP DM), formerly known as SAP Digital Manufacturing Cloud (SAP DMC), is a cloud-

based MES solution built on the SAP Business Technology Platform (BTP). The platform provides capabilities for production execution, shop-floor monitoring, resource orchestration, quality management, traceability, and manufacturing analytics. SAP DM consists of two primary components: SAP DM for Execution (DMe) and SAP DM for Insights (DMi), enabling organizations to manage and monitor manufacturing operations in real time across multiple production sites.

Integration between SAP Digital Manufacturing and SAP S/4HANA is supported through standardized technologies such as SAP Integration Suite, IDoc-based communication, APIs, and the Data Replication Framework (DRF). These mechanisms facilitate the exchange of master data, production orders, inventory transactions, and production confirmations.

However, many manufacturing enterprises operate heterogeneous ERP environments that include Oracle ERP Cloud, Microsoft Dynamics 365, Infor CloudSuite, and legacy ERP systems. Integrating SAP DM with such systems requires additional middleware capabilities, data transformation processes, custom API mappings, and governance mechanisms to ensure reliable and secure data exchange.

This paper proposes a unified integration framework for connecting SAP Digital Manufacturing with both SAP and non-SAP ERP systems. The framework addresses key integration requirements, including master data synchronization, production order management, middleware architecture, security governance, and implementation strategy. The objective is to provide a scalable and standardized approach that supports diverse manufacturing environments while maintaining interoperability, data consistency, and operational efficiency.

The remainder of this paper is organized as follows. Section II reviews related work and relevant industry standards. Sections III and IV discuss SAP S/4HANA and non-SAP ERP integration approaches, respectively. Section V presents the proposed four-layer integration framework. Section VI discusses implementation considerations, including deployment phases, data governance, security, and monitoring. Section VII evaluates the framework using documented industry use cases. Finally, Section VIII concludes the paper and outlines future research directions.

II. BACKGROUND AND RELATED WORK

A. Foundational Standards

The ISA-95 standard (ANSI/ISA-95/IEC 62264) provides the foundation for MES–ERP integration architectures. It defines hierarchical levels of manufacturing operations and standardizes data exchange between enterprise planning systems (Level 4) and manufacturing operations systems (Level 3). The standard specifies data models for personnel, equipment, materials, and production processes, which align closely with the master data structures used in SAP Digital Manufacturing [4].

MESA International complements ISA-95 by defining key MES functional areas, including resource allocation, production dispatching, data collection, quality management, performance analysis, and product traceability [3]. SAP Digital

Manufacturing supports these functions through its execution and analytics capabilities, enabling integrated manufacturing operations within a cloud-based environment.

B. Industry 4.0 and the Evolution of Cloud MES

Industry 4.0 promotes the integration of cyber-physical systems, industrial connectivity, and real-time data exchange across manufacturing environments [5], [6]. These concepts require seamless communication between enterprise systems, manufacturing applications, and shop-floor equipment to support efficient and data-driven production processes.

Cloud-based Manufacturing Execution Systems (MES) have emerged as a key enabler of Industry 4.0. SAP Digital Manufacturing (SAP DM) provides centralized production execution and analytics capabilities while maintaining connectivity with shop-floor equipment through SAP Plant Connectivity (PCo) and Production Connector services [24]. This architecture enables real-time monitoring, data collection, and process control across multiple manufacturing sites. The rapid growth of Industry 4.0 adoption further highlights the need for scalable and standardized MES integration frameworks [20].

C. Integration Technology Landscape

Modern manufacturing integration architectures increasingly rely on Integration Platform as a Service (iPaaS) solutions instead of traditional point-to-point interfaces. SAP Integration Suite provides cloud integration, API management, event-driven messaging, and connectivity services within the SAP Business Technology Platform (BTP) environment [14]. These capabilities support standardized integration between SAP Digital Manufacturing and enterprise applications.

For organizations using non-SAP ERP systems, middleware platforms such as MuleSoft Anypoint, Dell Boomi, and Microsoft Azure Integration Services offer similar integration capabilities [12], [15]. These platforms support API management, data transformation, orchestration, and secure communication between SAP Digital Manufacturing and external ERP systems. The selection of an integration platform depends on business requirements, existing technology investments, scalability needs, and available technical expertise.

III. SAP S/4HANA TO SAP DIGITAL MANUFACTURING INTEGRATION

A. Technical Architecture Overview

The integration architecture between SAP S/4HANA and SAP Digital Manufacturing (SAP DM) consists of three primary layers: the enterprise planning layer, the integration layer, and the manufacturing execution layer. SAP S/4HANA serves as the system of record for manufacturing master data and production planning activities. SAP Integration Suite, deployed on SAP Business Technology Platform (BTP), acts as the middleware layer responsible for message routing, transformation, and orchestration. SAP Digital Manufacturing operates as the manufacturing execution layer, supporting shop-floor operations and production monitoring.

To enable secure communication, SAP Integration Suite and SAP DM are typically deployed in separate BTP subaccounts. SAP Cloud Connector provides secure connectivity between on-premise SAP S/4HANA systems and SAP BTP through an outbound HTTPS connection, eliminating the need for inbound firewall access while enabling bidirectional data exchange.

B. Master Data Synchronization via Data Replication Framework

Master data synchronization between SAP S/4HANA and SAP DM is performed using the Data Replication Framework (DRF). When master data is created or updated in SAP S/4HANA, the DRF generates IDoc messages that are processed by SAP Integration Suite and delivered to SAP DM through standard integration flows.

The primary master data objects exchanged include:

- Material Master (MATMAS)
- Bill of Materials (BOMMAT)
- Routing and Task Lists (LOIROU)
- Work Centers (CREMAS)
- Production Versions
- Batch Master Data (BATMAS)

These objects provide the foundation for production execution within SAP DM by ensuring consistency of materials, resources, production processes, and traceability information across systems. SAP DM also supports batch characteristic synchronization and inventory management integration to maintain data consistency throughout the manufacturing lifecycle.

C. Transactional Order Integration and Data Flow

Production order integration enables bidirectional communication between planning and execution systems. When a production order is released in SAP S/4HANA, the corresponding LOIPRO IDoc is transmitted through SAP Integration Suite to SAP DM. The order becomes available within Production Operator Dashboards (PODs), where shop-floor personnel can execute manufacturing activities.

During production execution, operators can perform operation confirmations, report yield and scrap quantities, record goods movements, capture quality data, and monitor equipment performance. These transactions are subsequently transmitted back to SAP S/4HANA, ensuring synchronization of production status, inventory records, and operational confirmations.

Figure 2: Bidirectional Data Flow — Sap S/4hana ↔ Sap Digital Manufacturing		
Outbound (S/4hana → Sap Dm)	Data Object / Message Type	Inbound (Sap Dm → S/4hana)
Production Order Release	Loipro / Loirou Idoc	Operation Confirmation
Material Master Data	Matmas Idoc	Goods Issue / Receipt
Bill Of Materials (Bom)	Bommat Idoc	Yield & Scrap Reporting
Routing / Work Centers	Crema / Loirou Idoc	Quality Inspection Results
Batch Numbers & Chars.	Batmas Idoc	Activity Confirmations
Planned Order Data	Odata Rest Api	Inventory Postings

To prevent duplicate order updates, SAP recommends implementing the CO_MES_INT_REDISTRIBUTION Business Add-In (BAI). This configuration prevents unnecessary retransmission of production order changes after the initial release, thereby reducing processing errors and maintaining transactional consistency.

D. Quality Management Integration

SAP Digital Manufacturing provides integrated quality management capabilities through Production Operator Dashboards. Operators can record inspection results, report nonconformances, classify defects, and initiate corrective actions directly from the shop floor.

In process manufacturing environments, machine and sensor data can be integrated through SAP BTP services to support automated quality monitoring. Production parameters collected from manufacturing equipment can be evaluated against predefined thresholds, enabling automatic generation of quality notifications and improving process visibility. This integration supports enhanced product traceability, faster issue detection, and improved manufacturing quality control.

IV. NON-SAP ERP TO SAP DIGITAL MANUFACTURING INTEGRATION

A. Integration Challenges in Heterogeneous ERP Landscapes

Organizations integrating non-SAP ERP systems with SAP DM encounter a qualitatively different set of challenges compared to the SAP-native path. SAP DM's published integration content—IDoc mappings, standard iFlows, and DRF configuration guides—is designed around SAP's own data models and messaging standards. A non-SAP ERP system does not generate IDocs; it uses proprietary APIs, database exports, or middleware-ready message formats that require explicit bridging. The specific challenges that consistently emerge in practice include:

- **Data Model Mismatch:** Object structures for production orders, materials, and work centers differ significantly across ERP vendors. A Microsoft Dynamics 365 work order does not map cleanly onto an SAP production order without purpose-built transformation logic that accounts for field-level semantic differences.
- **Naming Convention Inconsistency:** Material numbers, plant codes, unit-of-measure designators, and work center identifiers follow vendor-specific conventions. A canonical harmonization layer is required before data can reach SAP DM's validation engine.
- **Limited Standard Interfaces:** Non-SAP ERP systems may expose REST or SOAP APIs, OData feeds, or database views, but rarely provide pre-built connectors specifically certified for SAP DM consumption [15].

- **Authentication Heterogeneity:** Different systems support different security protocols—Basic Auth, OAuth 2.0, SAML, API keys—requiring middleware to manage credential translation and token lifecycle.
- **Data Quality and Completeness Gaps:** Non-SAP systems frequently carry incomplete or inconsistently coded master data that requires cleansing and enrichment before it can pass SAP DM's strict validation rules.

B. Middleware-Centric Architecture Pattern

A middleware-centric architecture is commonly adopted for integrating non-SAP ERP systems with SAP Digital Manufacturing (SAP DM). In this approach, an Integration Platform as a Service (iPaaS) solution acts as an intermediary layer responsible for data transformation, orchestration, routing, and monitoring.

The middleware layer performs the following key functions:

- Data extraction from non-SAP ERP systems through APIs, message queues, or scheduled interfaces.
- Validation of incoming data against a predefined canonical data model.
- Transformation of source data into SAP DM-compatible formats such as JSON or XML.
- Data enrichment, including mapping of plant codes, material attributes, and unit-of-measure conversions.
- Secure transmission of data to SAP DM using REST APIs and OAuth 2.0 authentication.
- Exception handling, message retry mechanisms, and error management.
- Logging and monitoring of message transactions for auditing and operational support.

SAP Integration Suite provides native connectivity and integration services for SAP Digital Manufacturing and is widely used in SAP-centric environments [14]. Alternative middleware platforms such as MuleSoft Anypoint, Dell Boomi, and Microsoft Azure Integration Services can also support integration with SAP DM through API-based communication and custom transformation logic [12], [15]. The selection of a middleware platform depends on organizational requirements, existing technology investments, scalability objectives, and integration complexity.

TABLE I: Middleware Platform Comparison for Non-SAP ERP Integration with SAP Digital Manufacturing

Criteria	SAP Integration Suite	MuleSoft Anypoint	Dell Boomi	Azure Integration Svcs
SAP DM Native Support	Native / Full	Third-party Connector	Third-party Connector	Custom Adapter
Pre-built iFlows	Extensive SAP Integration Content	Limited	Limited	Limited
Protocol Support	IDoc, OData, REST, SOAP	REST, SOAP, MQ	REST, SOAP, EDI	REST, SOAP, AS2
Deployment Model	SAP BTP Cloud	Cloud / Hybrid	Cloud / Hybrid	Azure Cloud
Security Standards	OAuth 2.0, SAML, TLS	OAuth 2.0, TLS	OAuth 2.0, TLS	Azure AD, OAuth
Monitoring Tools	SAP Adv. Integration	Anypoint Monitoring	Boomi AtomSphere	Azure Monitor
Best Fit	SAP-centric landscape	Oracle / Salesforce ERP	Mid-market ERP mix	MS Dynamics 365

C. Inventory Management in Non-SAP Contexts

Inventory synchronization is a critical requirement when integrating SAP Digital Manufacturing (SAP DM) with non-SAP ERP systems. Inventory data must be consistently maintained between the manufacturing execution layer and the enterprise planning system to ensure accurate stock visibility and transaction processing. Goods movements generated within SAP DM, including material consumption and production receipts, must be synchronized with the corresponding ERP inventory records through middleware services [2].

The integration layer is responsible for validating inventory transactions, managing data consistency, and preventing

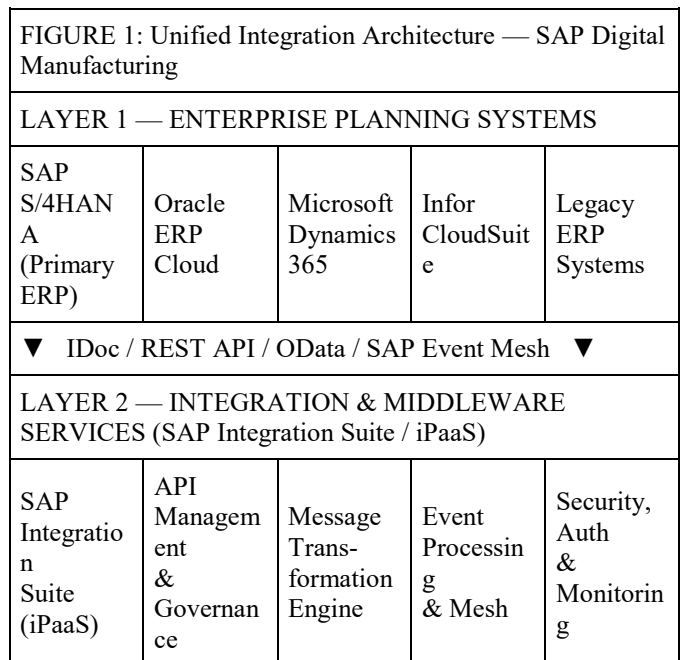
duplicate postings. Effective synchronization mechanisms help minimize inventory discrepancies and ensure alignment between shop-floor operations and enterprise inventory management processes.

V. PROPOSED UNIFIED INTEGRATION FRAMEWORK

A. Design Principles

The proposed framework organizes the manufacturing integration landscape into four interconnected layers: Enterprise Planning Systems, Integration and Middleware Services, SAP Digital Manufacturing, and Shop-Floor Operational Technology. The framework is based on two key design principles: loose coupling and layered security.

Loose coupling enables each layer to communicate through standardized interfaces, allowing organizations to introduce new ERP systems, middleware platforms, or manufacturing sites with minimal impact on the overall architecture. This approach improves scalability, flexibility, and maintainability. The second principle, layered security, applies authentication, authorization, encryption, and monitoring controls across all integration boundaries. This ensures secure communication between enterprise systems, middleware services, SAP Digital Manufacturing, and shop-floor devices while supporting compliance and operational governance requirements.



▼ Secured HTTPS / OAuth 2.0 / SAP Cloud Connector ▼				
LAYER 3 — SAP DIGITAL MANUFACTURING (SAP Business Technology Platform)				
Production Execution (DMe)	Resource Orchestration	Traceability & Batch Mgmt	Manufacturing Analytics (DMi)	Quality Management
▼ SAP Plant Connectivity (PCo) / OPC-UA / MQTT / Modbus ▼				
LAYER 4 — SHOP-FLOOR OPERATIONAL TECHNOLOGY (OT)				
PLCs & CNC Machines	IIoT Sensors & Gateways	SCADA / DCS Systems	Machine Controllers	Quality Instruments

Key functions of this layer include data transformation, message routing, API management, authentication, monitoring, and exception handling. Additionally, event-processing capabilities enable the distribution of manufacturing events, such as machine status updates, downtime notifications, and quality alerts, across multiple enterprise systems. These services ensure reliable, scalable, and secure communication throughout the integration landscape.

D. Layer 3: SAP Digital Manufacturing

SAP Digital Manufacturing (SAP DM) serves as the manufacturing execution layer within the proposed framework. The platform receives data from the integration layer and provides REST APIs for data exchange with enterprise systems. SAP DM consists of two primary components: SAP DM for Execution (DMe), which manages production operations, and SAP DM for Insights (DMi), which provides manufacturing analytics and performance monitoring.

B. Layer 1: Enterprise Planning Systems

The Enterprise Planning Systems layer consists of ERP platforms that serve as the primary source of manufacturing master and transactional data. These systems may include SAP S/4HANA, Oracle ERP Cloud, Microsoft Dynamics 365, Infor CloudSuite, and legacy ERP solutions. Although the data extraction and communication mechanisms vary across platforms, all systems provide the information required for manufacturing planning and execution.

Effective master data governance is essential at this layer. Organizations must clearly define ownership of shared data objects such as materials, plant structures, work centers, and production resources. Establishing data ownership and conflict-resolution policies helps maintain data consistency and prevents synchronization issues across integrated systems.

C. Layer 2: Integration and Middleware Services

The Integration and Middleware Services layer facilitates communication between ERP systems and SAP Digital Manufacturing. For SAP S/4HANA environments, data exchange is typically performed through IDoc-based messaging using SAP Integration Suite. In non-SAP ERP environments, the integration layer supports API-based, event-driven, or scheduled data exchange mechanisms depending on the capabilities of the source system.

Shop-floor personnel interact with the system through Production Operator Dashboards (PODs), which support production execution, quality management, and resource monitoring. The platform also manages operational configurations such as shift calendars, reason codes, nonconformance records, and Overall Equipment Effectiveness (OEE) metrics.

Integration with manufacturing equipment is achieved through SAP Plant Connectivity (PCo) and Production Connector services, enabling data collection from industrial devices and control systems using standard communication protocols such as OPC-UA, MQTT, and Modbus [24]. This capability supports real-time monitoring, traceability, and data-driven manufacturing operations.

E. Layer 4: Shop-Floor Operational Technology

The Shop-Floor Operational Technology (OT) layer consists of physical manufacturing assets, including Programmable Logic Controllers (PLCs), Computer Numerical Control (CNC) machines, Industrial Internet of Things (IIoT) devices, SCADA systems, and quality inspection equipment. These devices generate real-time production and operational data required for manufacturing execution and monitoring.

A key challenge at this layer is the integration of multiple industrial communication protocols, such as OPC-UA, MQTT, Modbus, and PROFINET. SAP Digital Manufacturing

addresses this challenge through machine connectivity services that collect, standardize, and process data from diverse shop-floor systems. The adoption of standardized communication protocols, particularly OPC-UA, can simplify integration and improve interoperability across manufacturing environments.

VI. IMPLEMENTATION CONSIDERATIONS

A. Phased Implementation Approach

A phased implementation strategy is recommended for SAP Digital Manufacturing (SAP DM) deployments to minimize project risk and ensure controlled system adoption. SAP implementation starter kits provide preconfigured content, test scenarios, and deployment guidelines that support a structured rollout process [1].

The proposed framework adopts a phased approach consisting of infrastructure setup, master data synchronization, production order integration, non-SAP ERP connectivity, shop-floor equipment integration, and production deployment. This methodology enables organizations to validate system functionality at each stage, reduce implementation complexity, and improve overall project success rates.

TABLE II: Phased Implementation Roadmap for SAP Digital Manufacturing Integration

Phase	Duration	Key Activities	Success Metrics
— Foundation	Weeks 1–4	SAP BTP tenant setup, Cloud Connector config, subaccount provisioning, user roles	BTP accessible; Cloud Connector heartbeat green
2 — Master Data	Weeks 5–8	DRF setup in S/4HANA; IDoc-based material, BOM, routing, work center replication	Master data sync error rate < 1%
3 — Order Flow	Weeks 9–12	Production order release activation; POD config; operation confirmation testing	Orders reach shop floor < 30 seconds
4 — Non-SAP	Weeks 13–18	Middleware iFlows for Oracle/Dynamics/Infor; data mapping; transformation testing	ERP-agnostic success rate > 98%

Bridge			
5 — OT Connect	Wks 19–22	SAP Plant Connectivity (PCo) setup; machine data ingestion; OEE baselining	Machine data ingested < 5 seconds
6 — Go-Live	Wks 23–26	User acceptance testing; monitoring dashboards; hypercare; performance tuning	Uptime > 99%; MTTR < 2 hours

Master data quality plays a critical role in the success of SAP Digital Manufacturing implementations. Materials, bills of materials (BOMs), routings, and work center records must be validated and standardized before integration testing begins. Incomplete or inconsistent master data can lead to synchronization errors, production order failures, and increased implementation effort. Therefore, organizations should establish robust master data governance processes and perform data validation activities during the early stages of deployment to ensure reliable system integration.

B. Data Governance Requirements

Effective data governance is essential for successful SAP Digital Manufacturing (SAP DM) integration. Master data objects such as materials, bills of materials (BOMs), routings, work centers, and production orders must satisfy predefined validation requirements to ensure reliable data exchange and production execution. In SAP S/4HANA environments, these controls are typically supported through existing master data governance processes. In non-SAP environments, equivalent validation and data quality checks must be implemented within the integration layer before data is transferred to SAP DM.

Organizations should establish a master data governance framework that defines data ownership, quality standards, synchronization procedures, and exception-handling processes. Maintaining clear governance policies throughout the system lifecycle helps improve data consistency, reduce integration errors, and support long-term operational reliability.

C. Security Architecture

Security is a critical aspect of SAP Digital Manufacturing (SAP DM) integration. Secure communication between enterprise systems, middleware platforms, and manufacturing applications should be implemented using industry-standard

authentication and encryption mechanisms. SAP Cloud Connector enables secure connectivity between on-premise systems and SAP Business Technology Platform (BTP) environments without requiring inbound network access.

OAuth 2.0 is commonly used for system-to-system authentication between integration services and SAP DM APIs. In addition, role-based access control (RBAC) mechanisms restrict user and service permissions based on organizational responsibilities and operational requirements.

For regulated industries, comprehensive audit logging and monitoring capabilities are required to support compliance, traceability, and security governance. Maintaining records of system activities, data transactions, and user actions helps organizations meet regulatory requirements while ensuring operational transparency and accountability.

D. Monitoring and Operational Resilience

Effective monitoring is essential for maintaining the reliability and performance of integrated manufacturing systems. Monitoring mechanisms should provide visibility into message processing, data synchronization, system availability, and transaction status across the integration landscape.

Operational dashboards can be used to track key performance indicators (KPIs) such as production order processing, master data synchronization status, and integration success rates. In addition, structured logging and exception management capabilities help identify and resolve integration issues in a timely manner.

For non-SAP ERP integrations, automated error-handling mechanisms, including retry processes and exception queues, can improve system resilience and reduce operational disruptions. These capabilities support continuous system availability and ensure reliable data exchange between enterprise systems and SAP Digital Manufacturing.

VII. RESULTS AND VALIDATION

A. Evidence from Discrete Manufacturing Deployments

Published industry implementations indicate that integrating SAP Digital Manufacturing with ERP and shop-floor systems can improve production visibility, traceability, and operational efficiency. Organizations adopting SAP Digital Manufacturing have reported benefits such as automated production order

execution, real-time quality monitoring, enhanced equipment performance visibility, and improved batch traceability [19].

In discrete and process manufacturing environments, integration between SAP Digital Manufacturing, SAP S/4HANA, and shop-floor equipment enables real-time data exchange and supports faster decision-making. Enhanced traceability capabilities can improve product genealogy tracking, while automated quality monitoring helps identify production deviations at earlier stages of the manufacturing process.

These observations demonstrate the potential operational benefits of integrated manufacturing architectures and support the applicability of the proposed framework across diverse manufacturing environments.

B. Comparative Benefits Analysis

TABLE III: Comparative Benefits by Integration Scenario

Benefit Area	SAP S/4HANA Integration	Non-SAP ERP Integration
Order Processing Latency	Faster due to native integration content	Additional processing through middleware
Master Data synchronization	Standardized DRF-based replication	Standardized DRF-based replication
OEE Visibility Granularity	Near real-time (< 5 sec)	Near real-time (5–30 sec)
Scrap Rate Reduction	15–20% (automotive case)	10–15% (tooling overhead)
Manual Data Entry	Eliminated at shop floor	Requires transformation and mapping
Recall Response Time	Integrated batch traceability	Supported through synchronized data exchange
Implementation Effort	Low (pre-built iFlows)	Medium–High (custom mapping)

The comparison presented in Table III indicates that SAP S/4HANA integration generally requires less implementation

effort due to the availability of standardized integration content and native compatibility with SAP Digital Manufacturing. In contrast, non-SAP ERP integration typically requires additional data transformation, mapping, and middleware configuration activities.

Despite these differences, both integration approaches support key manufacturing capabilities, including production visibility, traceability, quality management, and automated transaction processing. The results suggest that the proposed framework can effectively support both SAP and non-SAP integration scenarios while maintaining interoperability and operational efficiency across the manufacturing environment.

C. Framework Validation

The proposed four-layer framework was evaluated through the analysis of both SAP-centric and heterogeneous ERP integration scenarios. The assessment demonstrated that the framework provides a structured approach for integration planning, data flow management, and interoperability across diverse manufacturing environments.

In SAP S/4HANA environments, standardized integration content and native connectivity simplify implementation and reduce integration complexity. In contrast, non-SAP ERP environments require additional middleware services, data transformation mechanisms, and master data harmonization processes. Despite these differences, the framework remains applicable to both scenarios by providing a consistent architectural model for communication between enterprise systems, middleware platforms, SAP Digital Manufacturing, and shop-floor technologies.

The evaluation indicates that successful integration depends on effective data governance, reliable middleware services, and standardized communication mechanisms. These findings support the suitability of the proposed framework for organizations implementing SAP Digital Manufacturing within both SAP and non-SAP enterprise landscapes.

This study is based primarily on publicly available technical documentation, industry reports, and architectural analysis. As a result, the proposed framework has not been validated through a controlled experimental implementation. Future research may include quantitative validation using real-world manufacturing deployments, performance benchmarking, and comparative analysis across different ERP environments.

VIII. CONCLUSION

This paper presented a unified integration framework for connecting SAP Digital Manufacturing (SAP DM) with both SAP S/4HANA and non-SAP ERP systems. The proposed framework organizes the integration landscape into four layers: Enterprise Planning Systems, Integration and Middleware Services, SAP Digital Manufacturing, and Shop-Floor Operational Technology. This layered approach supports interoperability, scalability, and maintainability across heterogeneous manufacturing environments.

The study showed that SAP S/4HANA integration benefits from standardized interfaces and preconfigured integration content, while non-SAP ERP integration requires additional middleware services, data transformation, and governance mechanisms. Despite these differences, the proposed framework provides a consistent architectural approach for supporting both integration scenarios.

Future research may focus on event-driven manufacturing architectures, artificial intelligence-based production planning, and digital twin integration. These technologies have the potential to further enhance manufacturing visibility, operational efficiency, and decision-making within Industry 4.0 environments.

Acknowledgments

The authors acknowledge the technical documentation and learning resources provided through the SAP Help Portal, SAP Community, and related SAP publications, which supported the development of this research. The authors also acknowledge publicly available industry reports and reference materials used in the analysis of SAP Digital Manufacturing integration approaches.

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