# SMART MANUFACTURING SYSTEMS AND OPERATIONAL EFFICIENCY: MEDIATION OF DATA INTEGRATION CAPABILITY AND MODERATION OF DIGITAL MATURITY

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## Abstract

*The rise of Industry 4.0 has brought smart manufacturing systems (SMS) to the forefront of operational efficiency in manufacturing organizations. This study investigates the impact of SMS on operational efficiency, examining the mediating role of data integration capability (DIC) and the moderating effect of digital maturity. A quantitative survey was conducted among 250 manufacturing professionals, and data were analyzed using PLS-SEM. Findings indicate that SMS adoption significantly enhances operational efficiency, with DIC partially mediating this relationship by enabling effective utilization of integrated data for informed decision-making. Furthermore, digital maturity positively moderates the SMS–operational efficiency link, suggesting that firms with higher digital readiness derive greater benefits from SMS implementation. The study contributes to the literature by integrating technological and organizational factors in explaining operational performance improvements and offers practical guidance for managers to invest in data integration and digital transformation initiatives to maximize the effectiveness of smart manufacturing systems in enhancing efficiency.*

**Keywords**: *Smart Manufacturing Systems SMS, (DIC), Digital Maturity, Efficiency.*

## Introduction

The advent of Industry 4.0 has revolutionized manufacturing processes by introducing smart manufacturing systems (SMS), which leverage cyber-physical systems, IoT, big data analytics, and automation to improve operational efficiency (Lu, 2017). Operational efficiency in manufacturing encompasses production speed, quality, cost optimization, and resource utilization (Gunasekaran et al., 2017). While SMS promise substantial performance improvements, their impact is influenced by complementary capabilities such as data integration and organizational attributes like digital maturity (Zhong et al., 2017).

Data integration capability (DIC) refers to the organization's ability to collect, harmonize, and analyze data from heterogeneous sources to support decision-making (Chen et al., 2021). Effective data integration ensures that SMS can provide actionable insights, reduce redundancy, and enhance production coordination, ultimately improving operational efficiency. Digital maturity, which reflects the extent to which an organization has embraced digital technologies and processes, can moderate SMS effectiveness by facilitating adoption, reducing resistance, and improving strategic alignment (Kane et al., 2019).

This study examines the relationship between smart manufacturing systems and operational efficiency, with data integration capability as a mediator and digital maturity as a moderator, using survey data from 250 manufacturing professionals and analyzed via Smart-PLS.

## Literature Review

Smart manufacturing systems have been recognized as a core enabler of operational excellence in contemporary manufacturing environments. These systems integrate advanced technologies such as cyber-physical systems, artificial intelligence, robotics, and IoT devices to optimize production processes (Lu, 2017). Studies have shown that SMS adoption can improve process visibility, reduce errors, and enhance

responsiveness to market demands, thereby significantly improving operational efficiency (Gunasekaran et al., 2017). However, successful SMS implementation depends not only on the technology itself but also on complementary organizational capabilities, particularly data integration.

Data integration capability (DIC) refers to an organization's capacity to combine data from multiple sources into a coherent framework for informed decision-making (Chen et al., 2021). High DIC enables real-time monitoring, predictive maintenance, and dynamic production scheduling, allowing organizations to leverage the full potential of smart manufacturing systems (Dalenogare et al., 2018). Empirical research indicates that DIC mediates the relationship between technology adoption and operational outcomes, as the effective integration of data ensures that insights generated by SMS are actionable and timely (Li et al., 2020). Without strong DIC, organizations may face fragmented information, delayed decision-making, and inefficiencies despite deploying advanced manufacturing technologies.

Digital maturity further influences the effectiveness of SMS. Digital maturity reflects an organization's readiness to adopt digital processes, technologies, and mindsets, including workforce competence, IT infrastructure, and strategic alignment (Kane et al., 2019). Organizations with high digital maturity can exploit the benefits of SMS more effectively, whereas low-maturity firms may experience resistance, poor adoption, and underutilization of resources (Vial, 2019). Research suggests that digital maturity moderates technology-performance relationships, strengthening the positive effects of SMS on operational efficiency in digitally mature environments (Zhang et al., 2020).

The theoretical foundation of this study combines Resource-Based View (RBV) and Socio-Technical Systems Theory. RBV posits that firm-specific resources, such as DIC and SMS, are key drivers of sustainable competitive advantage (Barney, 1991). Socio-Technical Systems Theory emphasizes the interplay between technological systems and human or organizational factors, suggesting that digital maturity shapes how effectively technology improves operational outcomes (Baxter & Sommerville, 2011). Collectively, these perspectives support the conceptual model where SMS positively influences operational efficiency, mediated by data integration capability and moderated by digital maturity.

Despite growing research, gaps remain in empirically testing these mechanisms in manufacturing contexts, particularly using structured data from industry professionals. This study addresses this gap by examining how DIC and digital maturity jointly influence SMS effectiveness in enhancing operational efficiency.

**Theoretical Framework**
**Conceptual Model:**
Smart Manufacturing Systems → Operational Efficiency
        ↓
    Data Integration Capability (Mediator)

Digital Maturity (Moderator on SMS → Operational Efficiency)

**Hypotheses:**
- **H1:** Smart manufacturing systems positively affect operational efficiency.
- **H2:** Data integration capability mediates the relationship between SMS and operational efficiency.
- **H3:** Digital maturity moderates the relationship between SMS and operational efficiency, strengthening the effect.

## Methodology

**Research Design:** Quantitative, cross-sectional survey.

**Population & Sample:** Manufacturing professionals; n = 250 (Krejcie & Morgan, 1970).

**Data Collection:** Structured questionnaire using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree).

**Variables:**
- Independent: Smart Manufacturing Systems (SMS)
- Mediator: Data Integration Capability (DIC)
- Moderator: Digital Maturity (DM)
- Dependent: Operational Efficiency (OE)

**Data Analysis:** PLS-SEM using Smart-PLS for mediation and moderation analysis.

## Data Analysis
### Measurement Model Assessment

| Construct | Cronbach's Alpha | Composite Reliability | AVE |
|---|---|---|---|
| Smart Manufacturing Systems | 0.90 | 0.92 | 0.68 |
| Data Integration Capability | 0.88 | 0.91 | 0.64 |
| Digital Maturity | 0.86 | 0.89 | 0.61 |
| Operational Efficiency | 0.91 | 0.93 | 0.67 |

*Interpretation:* Cronbach's alpha >0.7, CR >0.7, and AVE >0.5 confirm reliability and convergent validity.

### Structural Model Assessment

| Path | Beta | t-value | p-value | Result |
|---|---|---|---|---|
| SMS → Operational Efficiency | 0.42 | 5.98 | 0.000 | Supported |
| SMS → Data Integration Capability | 0.60 | 8.70 | 0.000 | Supported |
| DIC → Operational Efficiency | 0.38 | 4.90 | 0.000 | Supported |
| SMS → Operational Efficiency (via DIC) | 0.23 | 3.85 | 0.000 | Mediated |
| Digital Maturity × SMS → Operational Efficiency | 0.19 | 3.05 | 0.002 | Moderated |

*Interpretation:*
- SMS significantly enhances operational efficiency (H1).
- DIC partially mediates the SMS–operational efficiency link (H2).
- Digital maturity positively moderates the SMS–operational efficiency relationship (H3).

## Conclusion and Discussion

The findings confirm that smart manufacturing systems improve operational efficiency in manufacturing organizations. Data integration capability strengthens this effect by ensuring that system-generated insights are actionable and timely. Digital maturity further enhances the effectiveness of SMS, highlighting the importance of a digitally capable workforce and infrastructure.

**Implications:**
- **Theoretical:** Integrates RBV and socio-technical perspectives in explaining SMS effectiveness.

- **Practical:** Firms should invest in data integration tools and digital transformation initiatives to maximize SMS benefits.

**Recommendations:**
1. Enhance data integration infrastructure to leverage SMS data.
2. Implement digital maturity assessments and training programs.
3. Align organizational strategies with Industry 4.0 adoption for sustainable operational efficiency.

**Limitations:**
- Cross-sectional design limits causal inference.
- Data collected from a single industry sector may limit generalizability.

**Future Research:**
- Conduct longitudinal studies to observe long-term SMS impacts.
- Explore additional mediators (e.g., analytics capability) or moderators (e.g., organizational agility).
- Compare effects across different manufacturing sectors and geographic regions.

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