IMPROVING PRODUCTION AND QUALITY OPERATIONS MANAGEMENT IN SMALL AND MEDIUM-SIZED MACHINING ENTERPRISES USING IEC/ISO MANUFACTURING OPERATIONS MANAGEMENT FRAMEWORK AS A REFERENCE MODEL

by

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ABSTRACT

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Under the Supervision of Professor Dah-Chuan Gong

Production performance and product quality are core indicators of operational effectiveness in the manufacturing industry. The activity model for Manufacturing Operations Management (MOM), established by the IEC/ISO 62264 standard, has become a widely adopted framework across global manufacturing sectors. This model integrates several key management activities—including definition management, resource management, production planning, dispatching, execution control, data collection, tracking, and performance analysis—enabling systematic and continuous improvement of operational efficiency. The Manufacturing Execution System (MES) plays a critical role in resource allocation, scheduling, execution control, data acquisition, integrated analysis, tracking, and performance evaluation, ...etc, providing essential technical support for the implementation of the MOM framework. This study adopts a Process

Reengineering approach and selects a representative small-to-medium-sized machining manufacturer—Company W—as the research object. Based on the activity reference model defined in IEC/ISO 62264-3, the study systematically examines potential deficiencies in the company's Production Operations Management (POM) and Quality Operations Management (QOM). Specific improvement strategies and reengineered process proposals are subsequently developed. Following joint evaluation by senior cross-functional executives of the case company, including the CEO, the proposed strategies and process reengineering have received preliminary endorsement and recognition. The study outcome demonstrates the high valuable and practical feasibility of the proposed strategies, exceeding the case company's expectations and meet the study target and significantly enhancing operational maturity and management performance. laying a solid foundation for the subsequent implementation of production and quality operations management improvements.

Keywords: Manufacturing Operations Management (MOM), Manufacturing Execution System (MES), Process Reengineering, Production Operations Management (POM), Quality Operations Management (QOM).

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CHAPTER I: INTRODUCTION

1.1 Research Background

In the era of Industry 4.0 and rapid digital transformation, manufacturing enterprises are under increasing pressure to deliver high-quality products in shorter lead times while enhancing their manufacturing operations management capabilities. Industry 4.0, first introduced in Germany in 2011, promotes the integration of cyber-physical systems, smart automation, and data exchange across all levels of the manufacturing process. As enterprises strive for competitiveness, smart factories have become a key objective, aiming to utilize real-time data, artificial intelligence, and interconnected systems to optimize operations.

To address this trend, international standards such as IEC/ISO 62264 jointly published by International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) or also known as ISA-95 by International Society of Automation (ISA) provide a comprehensive framework for Manufacturing Operations Management (MOM), helping enterprises establish consistency and interoperability between Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) (Shojaeinasab et al. 2022). The IEC/ISO 62264 (abbreviated as IEC 62264) series covers functional models, operation definitions, and resource relationships, serving as a foundational reference for smart manufacturing system design and integration.

Note**:** The IEC/ISO 62264 series standards were jointly developed by IEC SC65E and ISO TC184, and published as a dual-logo international standard to reflect their harmonized status.

Among the many objectives of smart manufacturing, ensuring production performance and product quality is both a fundamental requirement and a significant challenge - particularly for small and medium-sized machining enterprises (SMEs) engaged in metalworking operations using Computer Numerical Control (CNC) lathes grinding and milling machines. These SMEs typically operate in highly competitive markets and are expected to deliver high-performance, high-quality precision components with stringent dimensional tolerances and long service life, such as metal machined parts for automobiles, motorcycles, robots, and medical equipment, etc. Low production performance and high-quality defects not only compromise customer satisfaction but also lead to increased costs due to rework, scrap, and delivery delays.

Despite the growing availability of digital tools, many SMEs still face significant obstacles when attempting to implement comprehensive MOM systems. These obstacles include insufficient IT expertise and challenges in integrating digital systems with existing shop floor operations. Therefore, there is an urgent need for a practical, reference model to help these enterprises gradually enhance their MOM processes in alignment with exemplary frameworks.

International standards IEC/ISO 62264 or ANSI/ISA-95 (abbreviated as ISA-95) provide a framework for enterprise control system integration. These standards define structured models and terminology that categorize manufacturing operations into four key domains: production, inventory, maintenance, and quality. These MOM activities are critical for maintaining process stability and ensuring that final products meet predefined specifications.

In this context, standardized Production Operations Management (POM) and Quality Operations Management (QOM) models - established under the IEC 62264 or ISA-95 MOM framework - can serve as reference architectures for SMEs seeking to enhance production performance and quality-related workflows. By aligning existing operations with internationally recognized models, enterprises can progressively introduce consistency, traceability, and accountability into their production and quality management practices.

This study proposes a reference model for POM and QOM based on the MOM framework, specifically tailored to the operational characteristics of SMEs in the metalworking industry. By implementing this model through a structured process reengineering approach, companies can identify existing deficiencies related to production performance and quality operations, redesign their workflows, and establish an information architecture that supports continuous improvement.

1.2 Research Motivation

The motivation of this study is to enhance the production and quality operations performance of small and medium-sized enterprises in the precision metalworking industry through production process reengineering, guided by the POM and QOM models defined in the IEC/ISO 62264-3 (or ANSI/ISA-95.00.03) standards.

This study does not focus on implementing a fully functional MOM or Manufacturing Execution System (MES), but rather emphasizes the development of reference models for POM and QOM. This study proposes a set of practical guidelines that SMEs can follow to improve the performance of their production and quality operations. The MOM reference model is very helpful for manufacturers to understand the key activities of production and quality operations. By developing the reference models and practical guidelines proposed in this study, the research aims to:

1. Provide small and medium-sized enterprises with a standardized framework for executing and managing production and quality-related operations.
2. Facilitate information integration and consistency in the processing of production and quality data.
3. Enable SMEs to align their current processes with standardized models in preparation for future implementation of MOM and Manufacturing Execution Systems.

1.3 Research Outline

This research is organized as follows: 5 chapters (refer to Figure 1.3-1):

I: Introduction

This chapter provides a concise overview of the research background, focusing on the emergence of Industry 4.0 and the pivotal role of MES in realizing the concept of a smart factory. It examines the current state of traditional MOM practices among SMEs, and highlights the IEC 62264-3 (or ISA-95.00.03) international standard as a foundational framework for improving both POM and QOM.

II: Literature review

This chapter provides an overview of key concepts and standards in Manufacturing Operations Management (MOM), with emphasis on the IEC 62264 (ISA-95) framework, Manufacturing Execution Systems (MES), and production process reengineering methodologies. This chapter also examines the practical application of POM and QOM models. Furthermore, it compares MES functionalities with the MOM models defined in IEC 62264 (or ISA-95), highlighting their structural and functional correspondences.

III: Methodology

This chapter outlines the research methodology, including the research framework, key assumptions, and the foundational model of MOM. It also elaborates on the development process of the POM and QOM reference models, constructed in accordance with the IEC 62264 standard.

IV: Application

This chapter applies the proposed guideline and the MOM reference model to a real-world case study—a small CNC-based metalworking enterprise in Taiwan. The current state of its POM and QOM is analyzed to identify key issues, upon which a reengineered improvement plan is proposed.

V: Conclusion and future research

The final chapter summarizes the research findings and discusses the contributions and limitations of the study. In addition, it proposes directions for future research, including further exploration of the maintenance operations management and inventory operations management models as defined in IEC 62264-3 (or ISA-95.00.03).

This thesis anticipates that SMEs will be able to adopt the MOM model and the proposed process reengineering approach as a roadmap to enhance production operations, improve quality consistency, reduce defect rates, and establish a solid foundation for future digital transformation initiatives.

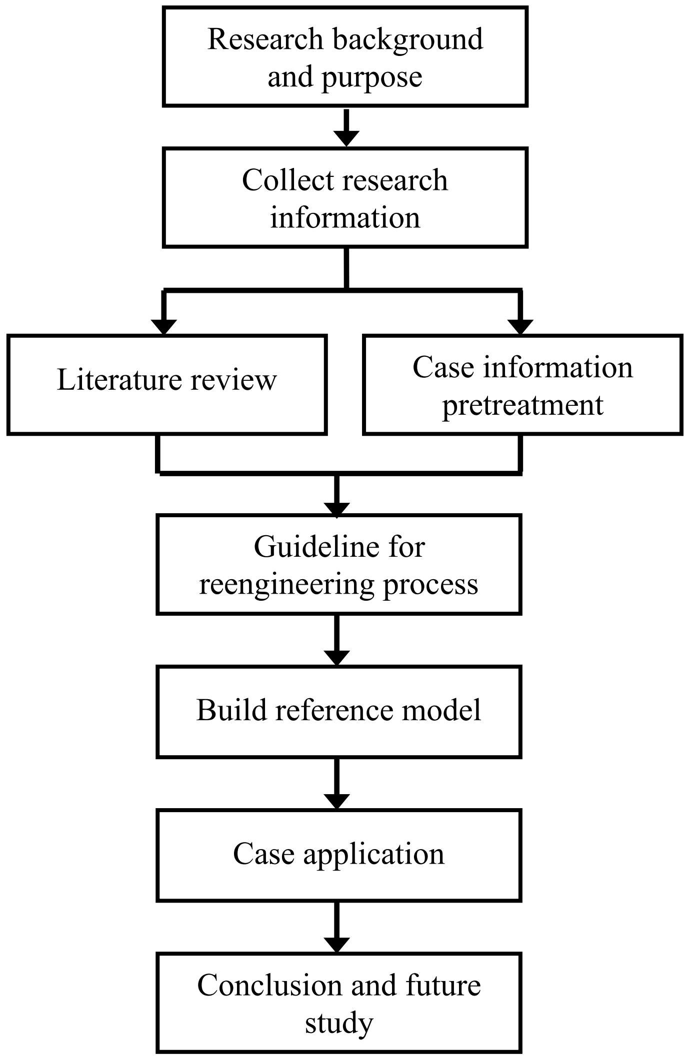


Figure 1.3- 1 Research flow chart

CHAPTER II: LITERATURE REVIEW

This chapter primarily reviews the core concepts and standards related to Manufacturing Operations Management (MOM), with a particular focus on the IEC/ISO 62264 (ANSI/ISA-95) framework, Manufacturing Execution Systems (MES), and methodologies for reengineering production processes.

2.1 Manufacturing Operations Management

The concept of "Enterprise–Control System Integration" was first introduced as a standardization initiative by the International Society of Automation (ISA) in the mid-1990s. The standard, formally designated as ANSI/ISA-95 Enterprise–Control System Integration, was subsequently adopted by the IEC and ISO as IEC/ISO 62264. In 1995, ISA approved the first edition of ISA-95 with the aim of resolving critical challenges, including the absence of a unified model, data inconsistency, and the complexities of cross-vendor integration between enterprise systems (e.g., Enterprise Resource Planning -ERP) and control systems (e.g., Supervisory Control and Data Acquisition-SCADA, Distributed Control System-DCS, Programmable Logic Controller-PLC). (ISA, 2025)

The ANSI/ISA-95 "Enterprise–Control System Integration" series of standards has now expanded to eight parts, whereas the IEC/ISO 62264 series has been developed up to the first six parts. (ISA, 2025; IEC, 2025)

Part 1: Models & Terminology –Defines common vocabulary for enterprise–control integration.

Part 2: Object Models & Attributes – Defines data structures exchanged between ERP and MOM.

Part 3: Activity Models – Covers MOM's four functional domains: Production, Quality, Maintenance, and Inventory.

Part 4: Objects & Attributes for MOM Integration – Specifies integration details for manufacturing operations.

Part 5: Business-to-Manufacturing Transactions – Standardizes the conversion of ERP orders into MOM activities.

Part 6: Messaging Service Model – Outlines communication mechanisms between systems.

Part 7: Alias Service Model – Supports flexible referencing of system elements.

Part 8: Information Exchange Profiles – Ensures reliable and interoperable data exchange across platforms.

Today, the "Enterprise–Control System Integration" series has been established as an international standard and has also been adopted as a national standard by many major countries, as illustrated in Table 2.1-1.

Table 2.1-1 Equivalent or modified standards corresponding to IEC/ISO 62264

(source: IEC and national standards bodies; compiled by this study)

Standard System	Standard Number	Correspondence	Notes
International	IEC/ISO 62264	Original international standard	Developed jointly by IEC/ISO; It is published as a dual-logo standard
United States	ANSI/ISA-95 (ISA-95)	ISA first introduced as US national standard	Published by ISA and approved by ANSI.
Europe (EU)	EN IEC 62264	Equivalent adoption of IEC/ISO 62264	Adopted by CENELEC as the European EN standard
Germany	DIN IEC 62264	Equivalent adoption of IEC/ISO 62264	Germany national standard
United Kingdom	BS EN 62264	Equivalent adoption of IEC/ISO 62264	Published by BSI as part of the European EN standard
China	GB/T 20720	Equivalent adoption of IEC/ISO 62264	Example: GB/T 20720.3 is equivalent to IEC 62264-3
Japan	JIS X 62264 (selected parts)	Equivalent adoption of IEC/ISO 62264	Japanese Industrial Standards (JIS), mainly for MES/MOM and ERP integration
Korea	KS X IEC 62264	Equivalent adoption of IEC/ISO 62264	Example: KS X IEC 62264-3

The IEC 62264 (or ISA-95) provides a standardized framework for integrating enterprise -level business planning with manufacturing control systems. Part 1 (IEC 62264-1or ISA 95.00.01) divides enterprise control into five levels, ranging from Level 0 (physical process) to Level 4 (business planning and logistics). Level 3, known as MOM, acts as the bridge connecting enterprise activities with shop floor operations.

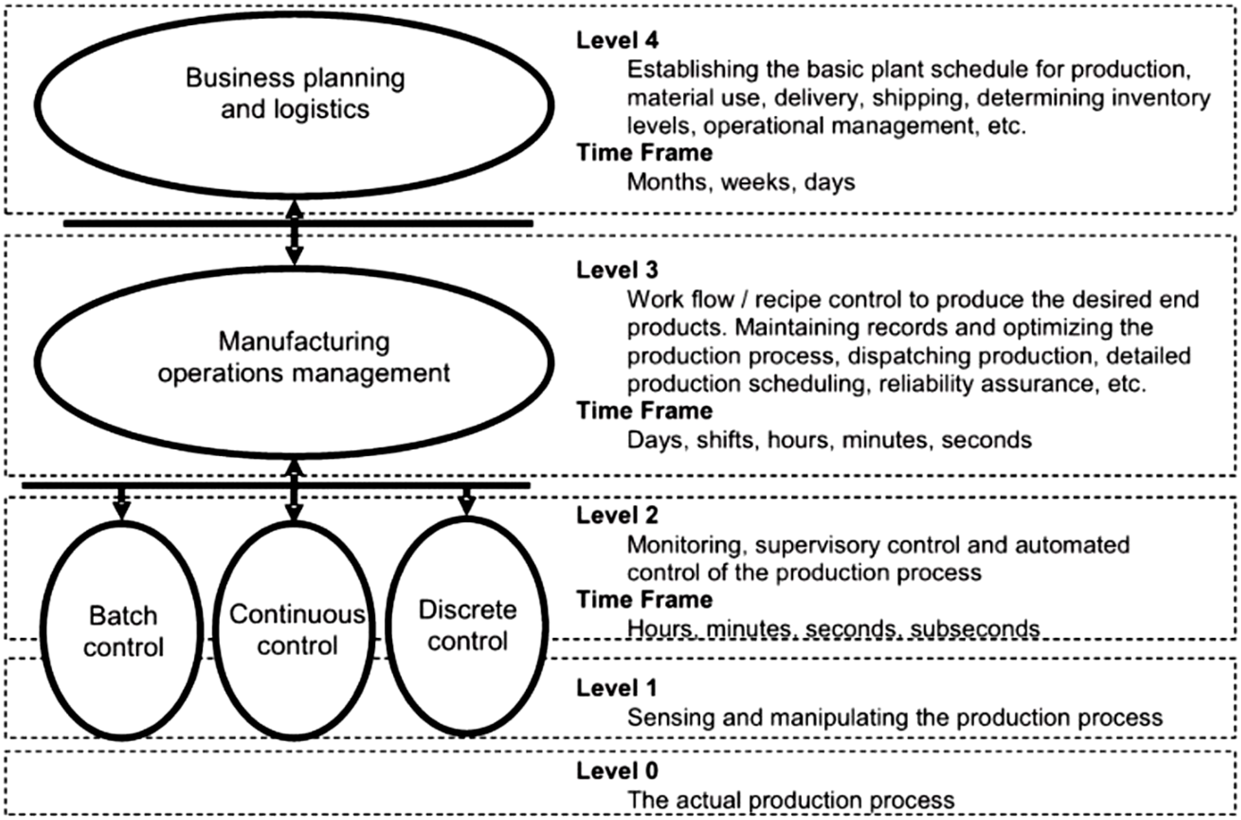


Figure 2.1-1 IEC 62264-1 Multi-level functional hierarchy of activities (IEC 62264-1, 2013)

Each level of IEC 62264-1 carries distinct responsibilities and timeframes. Level 0 represents physical production processes; Level 1 encompasses sensing and manipulating activities; Level 2 involves real-time monitoring and control; Level 3 coordinates workflows, schedules, and execution over seconds to days; and Level 4 manages enterprise-level functions, such as order processing and logistics, typically operating on a weekly or monthly basis (see Figure 2.1-1).

Figure 2.1-2 illustrates the interface between IEC/ 62264 Level 3 and Level 4, highlighting 11 general activities, and four categories of Manufacturing Operations Management (MOM) at

Level 3, as indicated by the shaded areas. Each function or activity is represented by a labeled ellipse. The bold dotted line denotes the boundary between Level 3 and Level 4.

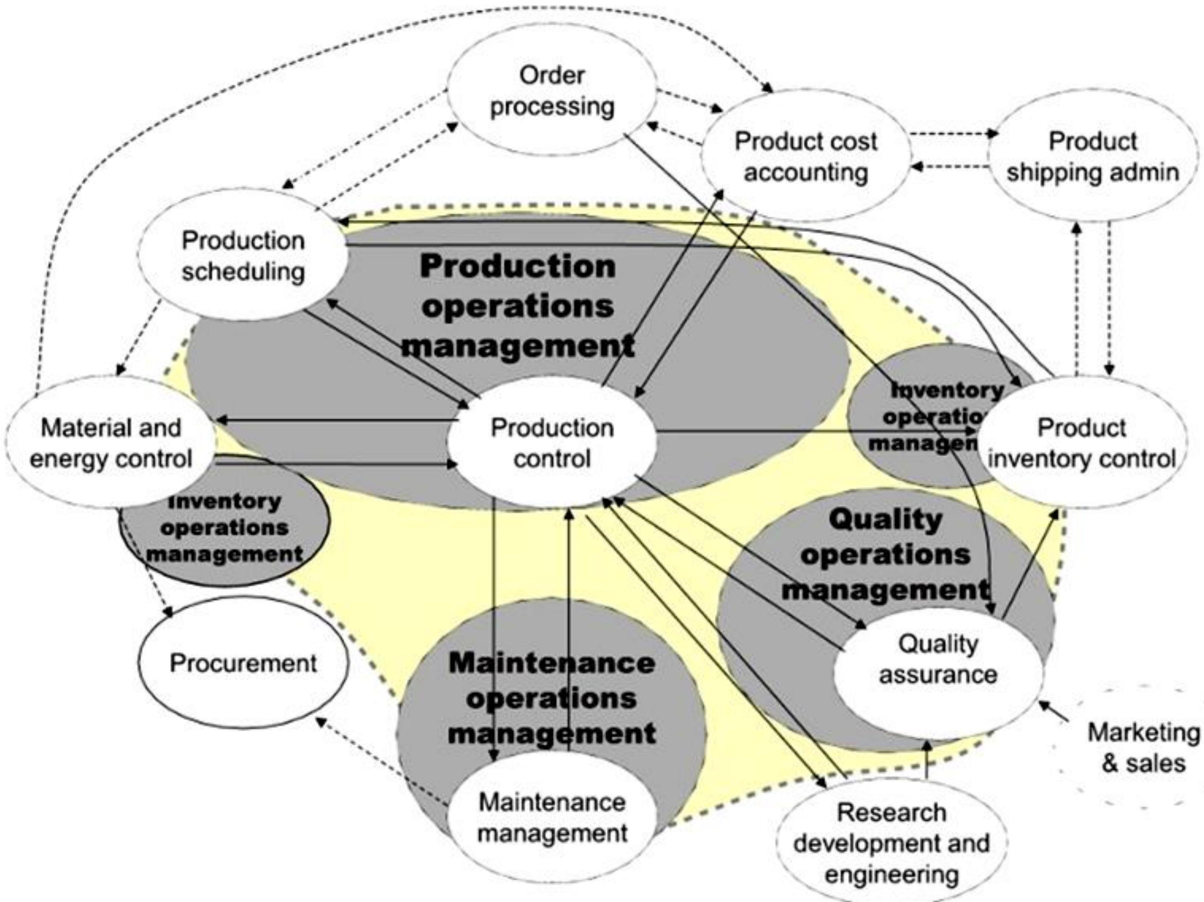


Figure 2.1-2 IEC 62264-1 MOM model and Level3/Level 4 interface (IEC 62264-1, 2013)

MOM sits in the middle layer (Level 3), acting as the bridge between enterprise planning and shop-floor execution. IEC 62264 (or ISA-95) Part 3 further defines MOM into four main management areas: Production operations, maintenance operations, quality operations, and inventory operations (see Figure 2.1-2).

a) Production Operations Management (POM)

Coordinate, manage, and monitor the use of raw materials, energy, equipment, personnel, and information to produce products that meet specified cost, quality, quantity, safety, and delivery requirements.

b) Maintenance Operations Management (MTOM)

Coordinate, manage and monitor maintenance activities for equipment, tools, and assets to ensure their availability for manufacturing.

c) Quality Operations Management (QOM)

Coordinate, manage, and monitor quality measurement, testing and reporting activities.

d) Inventory Operations Management (IOM)

Coordinate, manage, and monitor inventory and material flow throughout manufacturing operations.

The IEC 62264-3 standard also provides a generic activity model consisting of eight activities: (1) Definition management, (2) Resource management, (3) Detailed scheduling, (4) Dispatching, (5) Execution management, (6) Data collection, (7) Tracking, and (8) Performance analysis (IEC 62264-3, 2016). (see Figure 2.1-3 and Table 2.1-2)

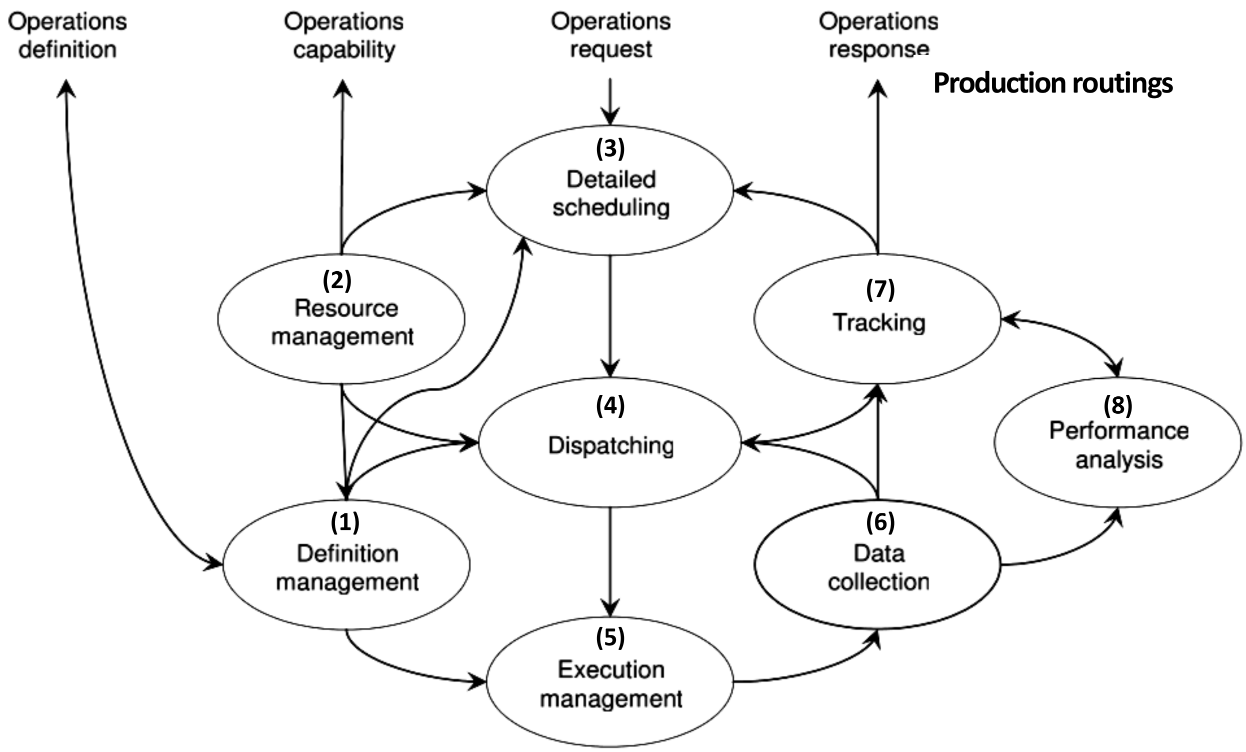


Figure 2.1-3 Generic activity model of MOM (IEC 62264-3, 2016)

Table 2.1-2 IEC/ISO 62264 MOM generic activities

(source: IEC 62264-3, 2016; compiled by this study)

MOM Generic Activities	**Description**
1) Definition management	Covers defining products, routings, and process requirements to support scheduling and execution.
2) Resource management	Involves defining equipment, tools, and human resources, and maintaining availability data.
3) Detailed scheduling	Converts high-level plans into detailed production schedules that optimize resource usage.
4) Dispatching	Assigns specific tasks, jobs, and resources, issuing work orders for execution.

5) Execution management	Directs the actual execution of scheduled jobs and ensures adherence to instructions.
6) Data collection	Gathers information during production to support monitoring and traceability.
7) Tracking	Reports production status and progress, ensuring alignment with enterprise plans.
8) Performance analysis	Evaluates performance data to support continuous improvement.

The IEC 62264 MOM framework schematic diagram, please refer to Figure 2.1-4.

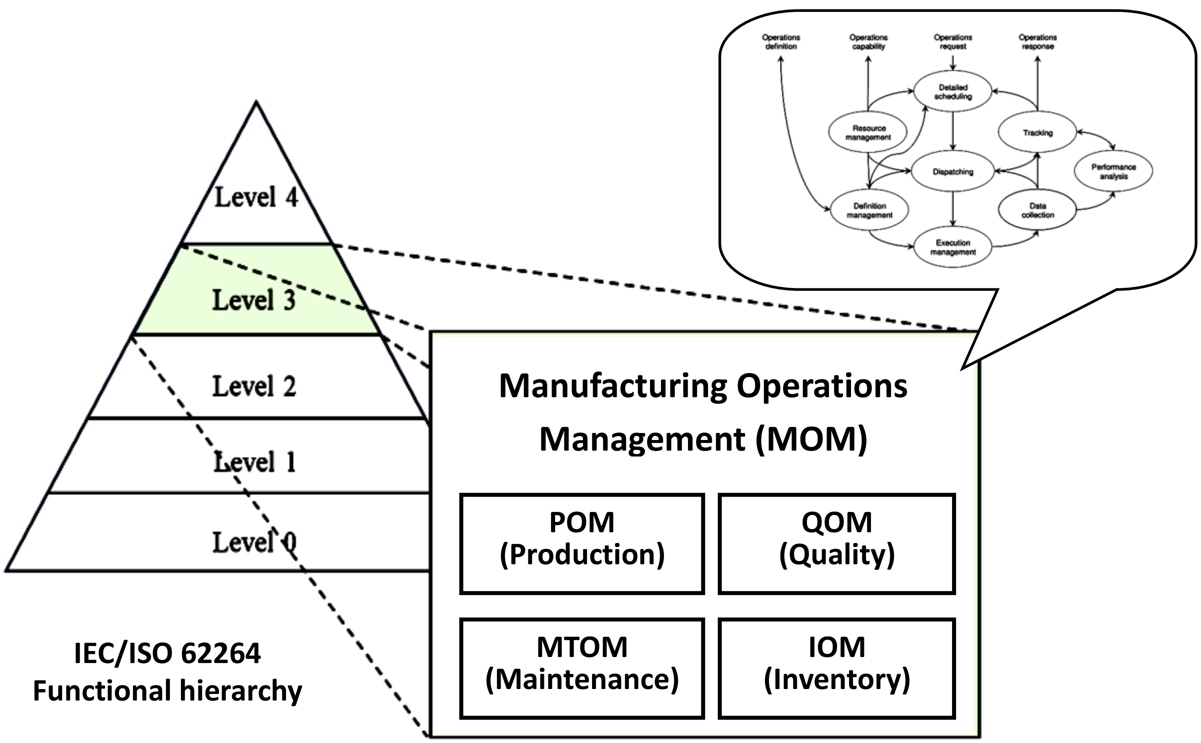


Figure 2.1-4 IEC 62264 MOM framework schematic diagram

(source: IEC 62264-3, 2016; compiled and graphed by this study)

MOM constitutes a foundational element of contemporary manufacturing enterprises, functioning as a critical enabler of production process continuity and efficiency. Conceptually, MOM provides an integrated framework for the comprehensive coordination and supervision of manufacturing activities, extending from shop-floor operations to the delivery of finished products. Within this framework, MOM consolidates a range of essential functions—including production planning, scheduling, quality management, and inventory control—thereby facilitating organizational coherence and sustained performance improvement (Madis K, 2024).

Panetto, H. et al.(2007) explain that IEC 62264 Level 3 (MOM) serves as a bridge between enterprise systems and shop-floor controls. It is responsible for scheduling, resource allocation, quality monitoring, and data integration. Common systems at this level include Execution Systems (MES), Laboratory Information Management Systems (LIMS), and Warehouse Management Systems (WMS), which exchange information with ERP and Advanced Planning & Scheduling (APS) systems to enhance decision-making efficiency and production agility.

The significance of MOM lies in its ability to (Madis K, 2024) :

- Optimize resources

  Maximize utilization, reduce waste and downtime, and lower costs.

- Improve quality and compliance

  Enforce rigorous controls, ensure traceability, and protect reputation.

- Support decision-making

  Provide real-time data for agile and informed management.

- Enhance customer satisfaction

  Ensure timely delivery of high-quality products, fostering loyalty.

- Facilitate continuous improvement

  Enable ongoing process refinement to boost productivity.

In essence, MOM strengthens operational efficiency, product quality, and strategic responsiveness, making it indispensable for competitive manufacturing. (Madis K, 2024)

2.2 Manufacturing Execution System (MES)

Manufacturing involves a complex integration of materials, processes, facilities, people, information and decisions (Gong, D.-C., & McGinnis, L. F, 2010).The concept of MES first appeared in 1992 through Advanced Market Research (Chen, X., & Voigt, T, 2020). MES is a production information management system designed for the shop floor, enabling real-time tracking, monitoring, and management of manufacturing activities. It achieves this through data collection, integration, and analysis, which provides visibility of machine conditions, raw materials, production progress, and resource utilization (D'Antonio, Bedolla, & Chiabert, 2017). MES functions as a critical link between business planning systems, such as ERP, and shop floor control devices like Programmable logic controllers (PLC) and Supervisory control and data acquisition (SCADA). By connecting these levels, MES enhances coordination and supports Industry 4.0 objectives of transparency, efficiency, and competitiveness.

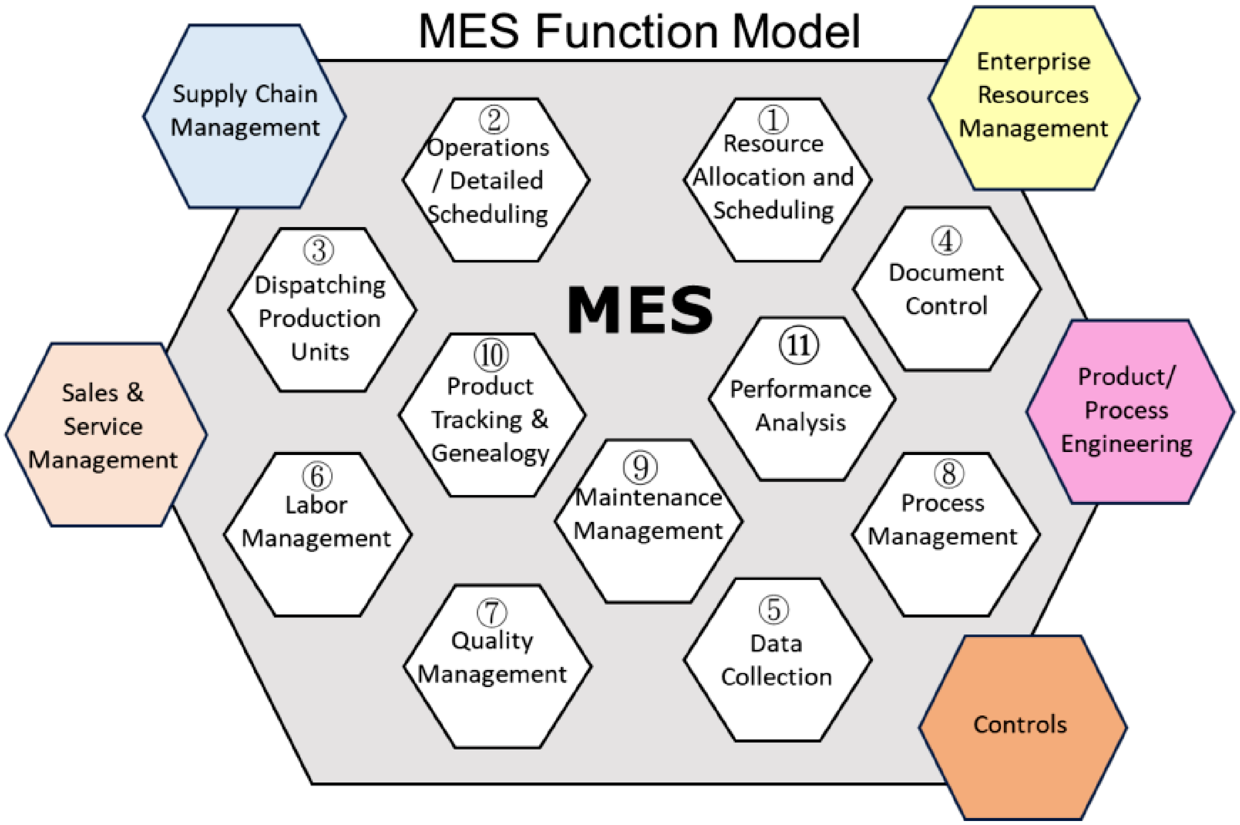


Figure 2.2-1 MES Function model (MESA International 2023)

MESA International (1997a) proposed a functional model of MES that identifies 11 major functionalities (see Figure 2.2-1 and Table 2.2-1) :

Table 2.2-1 MES major functionalities (source: MESA, 2023; compiled by this study)

MES Major Functionalities	**Description**
1) Resource allocation and scheduling	Ensures that resources such as machines, tools, and operators are allocated properly, providing setup history and real-time availability updates.
2) Operations / detail scheduling	Focuses on sequencing operations according to priority or resource constraints to minimize setup time and improve throughput.

3) Dispatching production units	Directs the release and movement of jobs, batches, or lots on the shop floor, updating schedules dynamically to respond to disturbances.
4) Document control	Manages and distributes essential records, including work instructions, drawings, and part programs, while maintaining historical archives.
5) Data collection / acquisition	Gathers process and production data either automatically or manually to provide accurate real-time visibility.
6) Labor management	Tracks worker availability, certification, and time, supporting optimal assignment of labor resources.
7) Quality management	Provides real-time monitoring and analysis of product quality, enabling corrective action and managing inspection procedures.
8) Process management	Supervises process execution, adjusting operations automatically or supporting operators in decision-making.
9) Maintenance management	Tracks equipment conditions, schedules preventive maintenance, and records repair activities.
10) Product tracking and genealogy	Provides traceability of materials, batches, and production history for compliance and transparency.
11) Performance analysis	Generates reports on resource utilization, cycle times, and schedule adherence, enabling performance comparison.

According to MESA International (1997b), the adoption of MES results in reduced cycle times, lower work-in-progress, and fewer setup interruptions. For example, in machining operations, when engineers know the next scheduled job, they can prepare the necessary tools, programs, and jigs in advance, thereby reducing downtime. Mehta and Reddy (2015) emphasized additional benefits: (1) reduced scrap and waste due to consistent processes, (2) more accurate cost capture through data collection, (3) increased uptime by optimizing scheduling and maintenance, (4) reduced inventory through real-time visibility, and (5) improved customer satisfaction by enabling faster responses to urgent demands.

Mantravadi et al. (2022) argue that MES can be interpreted as an application of MOM, while Dutta et al. (2022) suggest that MOM represents an evolved, enterprise-wide extension of MES. Despite differing perspectives, the two concepts are highly complementary and often implemented together.

When comparing MESA’s MES functional model (1997a) and IEC 62264's MOM activity model (2016), significant overlaps emerge. For instance, MES’s labor management corresponds to MOM’s resource management; MES’s scheduling maps to MOM’s detailed scheduling; MES’s dispatching mirrors MOM’s dispatching; and MES’s performance analysis parallels MOM’s analysis. Moreover, MES’s quality and maintenance management correspond to MOM’s quality and maintenance management. This comparison demonstrates that while IEC 62264 offers a more comprehensive integration framework, MES remains a practical shop-floor tool for realizing MOM activities.

In summary, a comparison between the MES functional model and the MOM model reveals that most of their functionalities can be mapped correspondingly, with no significant differences at the practical functional level(please refer to Table 2.2-2). However, the Manufacturing Operations Management (MOM) model defined by IEC 62264 (or ISA-95) has been widely adopted as a standard framework both internationally and by most major industrial nations (please refer to Table 2.1-1). whereas the MOM model provides a more comprehensive description of enterprise-wide control systems.

Table 2.2-2 MES functionalities vs. MOM activities/management functions

(source: IEC 62264-3, 2016 and MESA, 2023; compiled by this study)

MES Functionalities (MESA)	**Corresponding MOM Activities (IEC 62264/ISA-95)**
1) Resource allocation and scheduling	3) Detailed Scheduling
2) Operations/detail scheduling	3) Detailed Scheduling
3) Dispatching production units	4) Dispatching
4) Document control	1) Definition management (partial approximation)
5) Data collection/acquisition	6) Data Collection
6) Labor management	2) Resource Management
7) Quality management	Quality Operations Management (QOM)
8) Process management	5) Execution Management
9) Maintenance management	Maintenance Operations Management (MTOM)
10) Product tracking and genealogy	7) Tracking
11) Performance analysis	8) Performance Analysis

2.3 Reengineering Production Process

Reengineering a production process entails a fundamental redesign of existing workflows to achieve substantial improvements in key operational areas such as production efficiency, product quality, and inventory management. According to Liao, Gong, and Zeng (2024), the reengineering process comprises three distinct stages (see Figure 2.3- 1), (Liao, Gong and Zeng , 2024).

Step 1: Problem identification

The initial stage involves recognizing the main factors contributing to the problems. To accurately understand the current state (as-is), it is essential to systematically document and visualize existing workflows, role assignments, and technology applications. After collecting possible causes, the issues are organized, and causal relationships are mapped using tools such as fishbone diagram (identifies possible causes of a problem), causal loop diagram (visualizes interactions and feedback among system variables), why-tree analysis (traces root causes through successive "why" questions) (Stewart, 2020).

Step 2: Examination of current production process

The second stage requires a detailed review of the company's existing production workflow. By mapping the current process, managers can identify weak points or missing steps that hinder efficiency. This also helps highlight common bottlenecks. For example, production or quality workers may overlook certain tasks, which could result in lower product quality or delays (Chen & Voigt, 2020).

Step 3: Application of the reference model

In the final stage, the identified problems are addressed by integrating activities from the reference model developed in this research. Based on IEC 62264 and MES functionalities, the reference model provides practical modules that can be embedded into the company's workflow. Applying these modules and develop the future-state (to-be) process to ensures that issues discovered in earlier steps are resolved systematically, thus supporting process improvement (Dutta et al., 2022).

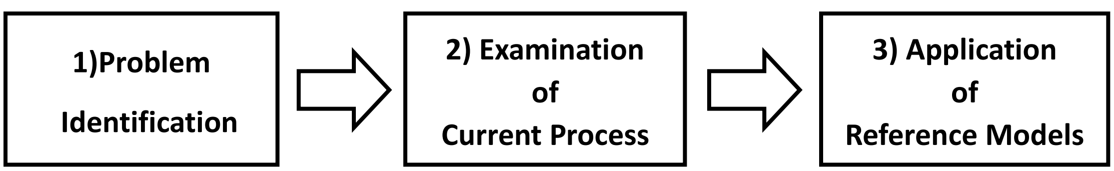


Figure 2.3-2 Three steps of reengineering production process

(Liao, Gong and Zeng , 2024)

CHAPTER III: METHODOLOGY

3.1 Methodology Framework

The methodological framework of this study, as illustrated in Figure 3.1-1, integrates reengineering concepts with the application of POM/QOM reference models and encompasses the following key activities.

1. Case status investigation and analysis (covering organizational structure, human resources, production equipment, inspection equipment, product characteristics, and machining processes).
2. Establishing a guideline for production process reengineering, providing a concrete and executable step-by-step approach;
3. Problem identification and discussion (cause-and-effect analysis of core problems).
4. Constructing reference models for POM and QOM based on the IEC 62264-3 standard, and using them to assess the current state of the case company.
5. Proposing improvement recommendations tailored to the case company
6. Process reengineering for manufacturing management processes, covering both re-design and implementation proposals.
7. Feasibility assessment conducted by the case company's assessment team.
8. Compilation of feedback and opinions from the case company to serve as a foundation for

subsequent implementation of the improvement project.

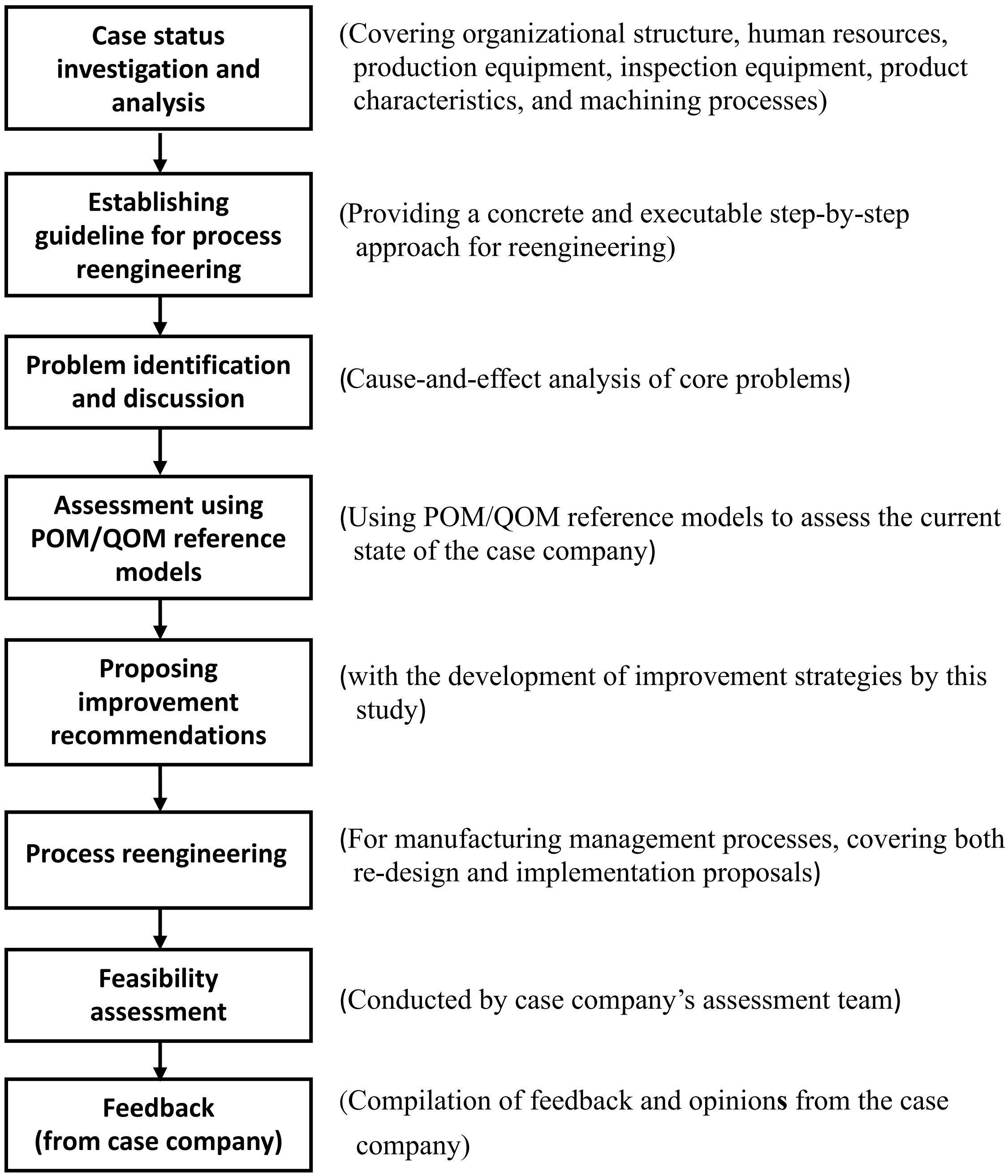


Figure 3.1-1 Methodological framework of this study

3.2 Guideline for Reengineering the Production Process

This study presents a guideline to help SMEs improve production and quality performance through process reengineering. The three-stage model by Liao, Gong, and Zeng (2024), applied to a metalworking SME, aligns with the study's objectives and was therefore adopted (Liao, Gong, and Zeng, 2024).

Step 1: Problem identification

The initial stage involves recognizing the main factors contributing to the problems. This is usually done through brainstorming sessions with internal personnel, which enable staff to share perspectives on potential inefficiencies. After collecting possible causes, the problems are organized, and causal relationships are mapped using tools such as fishbone diagram, causal loop diagram, why-tree analysis (Stewart, 2020).

Step 2: Examination of current production processes

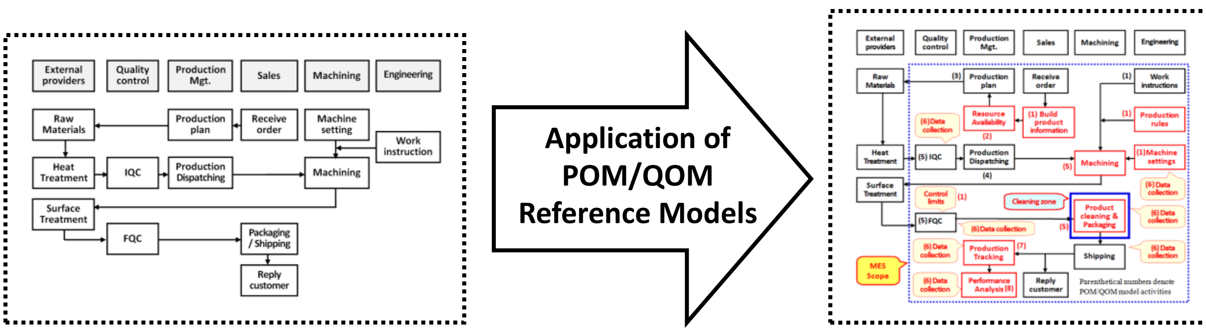
The second stage requires a detailed review of the company's existing production workflow. By mapping the current process, managers can identify weak points or missing steps that hinder efficiency.

Step 3: Application of the reference model

In the final stage, the identified problems are addressed by integrating activities from the reference model developed in this research. Based on IEC 62264-3 (POM & QOM) and MES functionalities, the reference model provides practical modules that can be embedded into the company's workflow.

In short, this guideline provides a structured approach for SMEs to reengineer their production processes. By systematically identifying problems, analyzing current workflows, and applying a standardized reference model, companies can significantly improve their operational performance.

Figure 3.2-1 presents the fundamental schematic of the reengineered production process, incorporating the application of the POM/QOM reference models.



(AS-IS Production Process) (TO-BE Production Process)

Figure 3.2-1 Fundamental schematic of the reengineered production process

3.3 Reference Model

IEC 62264-3 (or ISA 95.00.03) defines MOM as comprising four key categories: production, quality, maintenance, and inventory operations. Given the focus of this study on enhancing production and quality performance, only the domains of POM and QOM are selected as the foundational basis for constructing the reference model (see Figure 3.3-1).

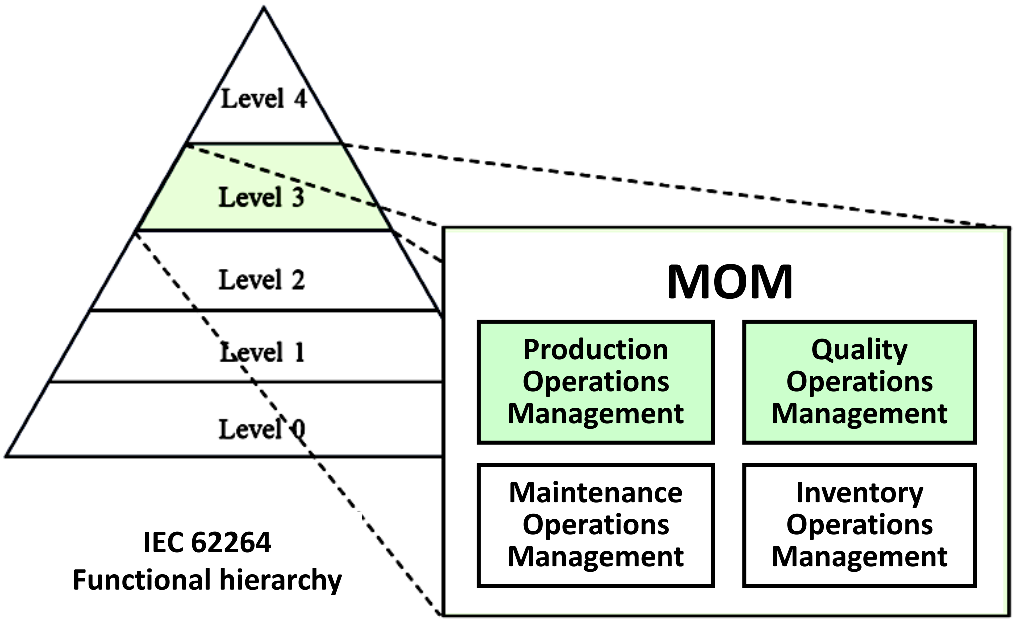


Figure 3.3-2 IEC 62264 Functional hierarchy and MOM categories diagram

IEC 62264-3 defines the MOM into eight activities. These eight activities will serve as the primary framework for constructing the reference model in this study.

3.4 Activity Model of POM

POM can be described as the integrated set of activities responsible for coordinating, directing, controlling, and monitoring the functions that utilize raw materials, energy, equipment, human resources, and information. Its purpose is to ensure the production of goods that meet the required standards of cost, quality, quantity, safety, and delivery timeliness.

In accordance with the IEC 62264-3 standard, the activity model for POM is illustrated in Figure 3.4-1. Each ellipse denotes an activity, and the connecting lines represent information flow. The model consists of eight activities: (1) Product definition management, (2) Production resource management, (3) Detailed production scheduling, (4) Production dispatching, (5) Production execution management, (6) Production data collection, (7) Production tracking, and (8) Production performance analysis. (IEC 62264-3, 2016)

In the POM Activity Model, information exchanged between Level 3 and Levels 1-2 functions includes: :a) Equipment and process specific production rules; b) Operational commands; c)Operational responses; and d) Equipment and process specific data.

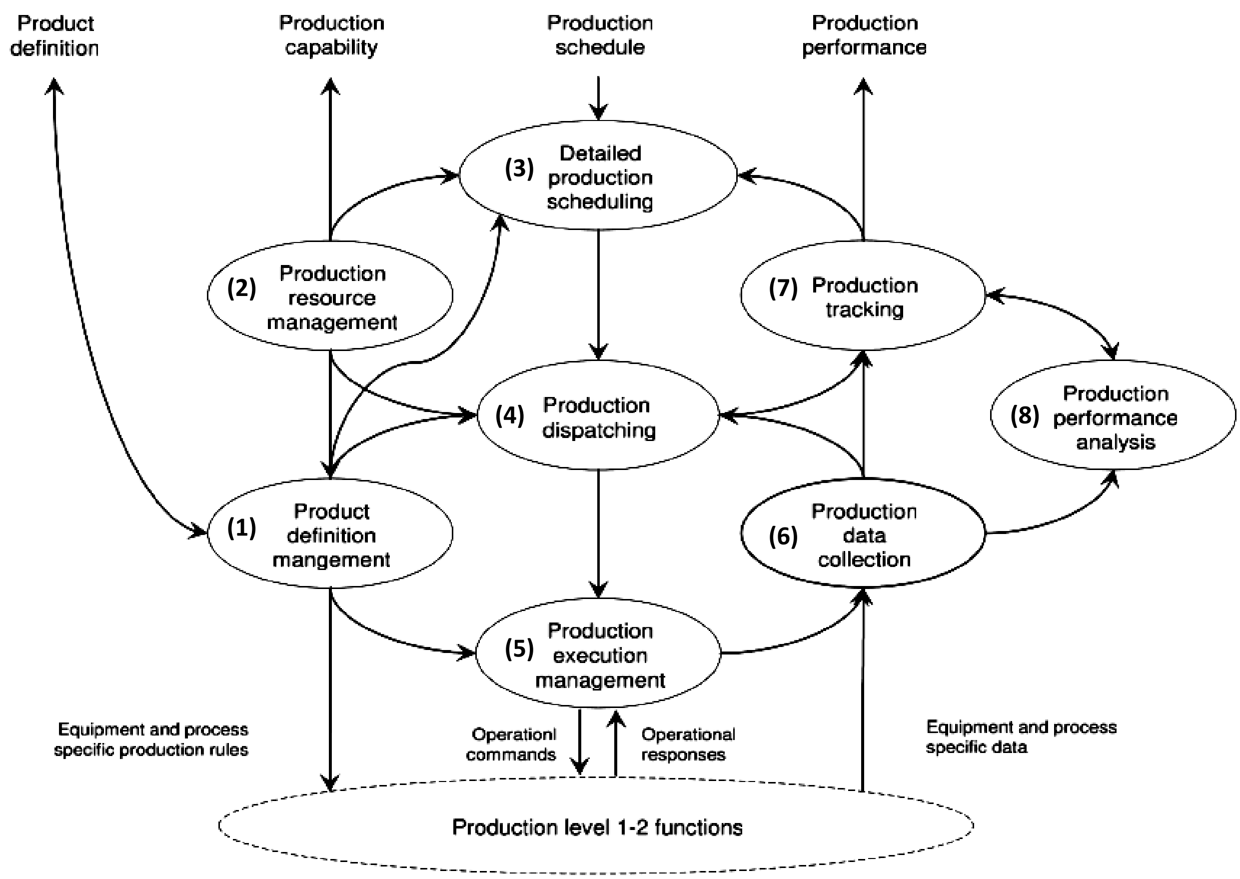


Figure 3.4-1 Activity model of POM (IEC 62264-3, 2016)

3.4.1 Product definition management

1. Product definition

Product definition encompasses essential information required for manufacturing, including basic product information, product structure, and production routings. Basic product information may be derived from Level 4 and typically include customer, material, and product type. The product structure specifies component composition, usually documented in a Bill of Materials (BOM). Production routings define the sequence of machining steps, manufacturing methods, and equipment selection, serving as the foundation for subsequent scheduling, dispatching, and execution activities.

2. Product definition management

Product definition management refers to the collection of activities that manage all Level 3 product-related information necessary for manufacturing. This includes overseeing the rules that govern product production. Such information is organized and shared across three key elements: product production rules, the bill of materials (BOM), and the bill of resources (BOR). Among these, the product production rules play a central role by providing explicit instructions to production operations on how the product should be produced.

Figure 3.4.1-1 illustrates the information structure of product definition management. This information should be documented and managed during the product development phase. For initial production runs, details such as setup time, processing time, and standard capacity must be recorded to support subsequent scheduling activities. Incomplete or missing product definition related information may adversely affect future production scheduling accuracy.

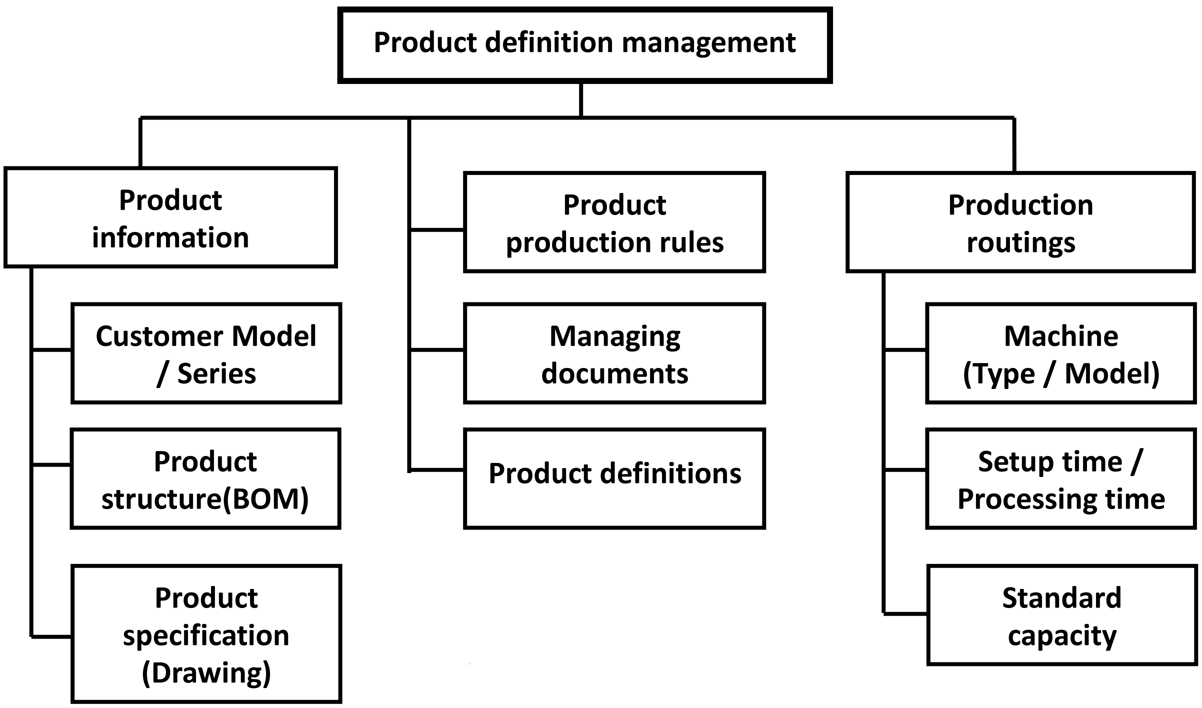


Figure 3.4.1-1 Information structure of the product definition management

(source: IEC 62264-3, 2016; compiled and graphed by this study)

Figure 3.4.1-2 illustrates the information flow within product definition management activities. Typically, upon receiving a new order, the Sales department creates the initial product information and communicates it to the Engineering, Production management, and Machining departments. Based on the product information provided by the Sales team, the Engineering department develops detailed machining information—such as production rules and process routes—for the Machining department. The Production management department then issues a production dispatching list to the Machining department in accordance with the production schedule. This flowchart should be adjusted according to actual operational conditions. Variations may exist across different companies.

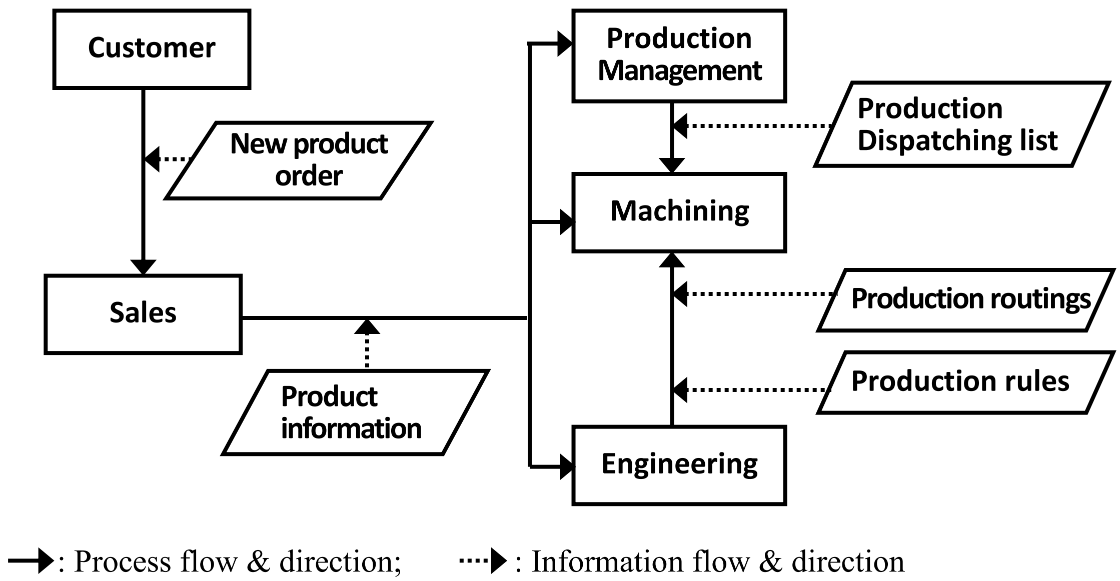


Figure 3.4.1-2 Information flow in the activity of product definition management

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.4.2 Production resource management

Production resources include all elements employed in the production process, such as machines, tools, personnel, materials, and energy. The primary tasks of production resource management are defining production resources and providing information on resource capability. Defining production resources involves specifying their application scope, operating conditions, and quantities—such as the number of available machines, operators, engineers, and materials within the facility (Liao, P. Y, 2023). Providing information on resource capability concerns the operational status of equipment (e.g., in production, setup, idle, or under maintenance) and workforce availability, including absence or leave data supplied by the human resources department. This capability information serves as a critical input for scheduling activities. Figure 3.4.2-1 shows the information structure of production resource management.

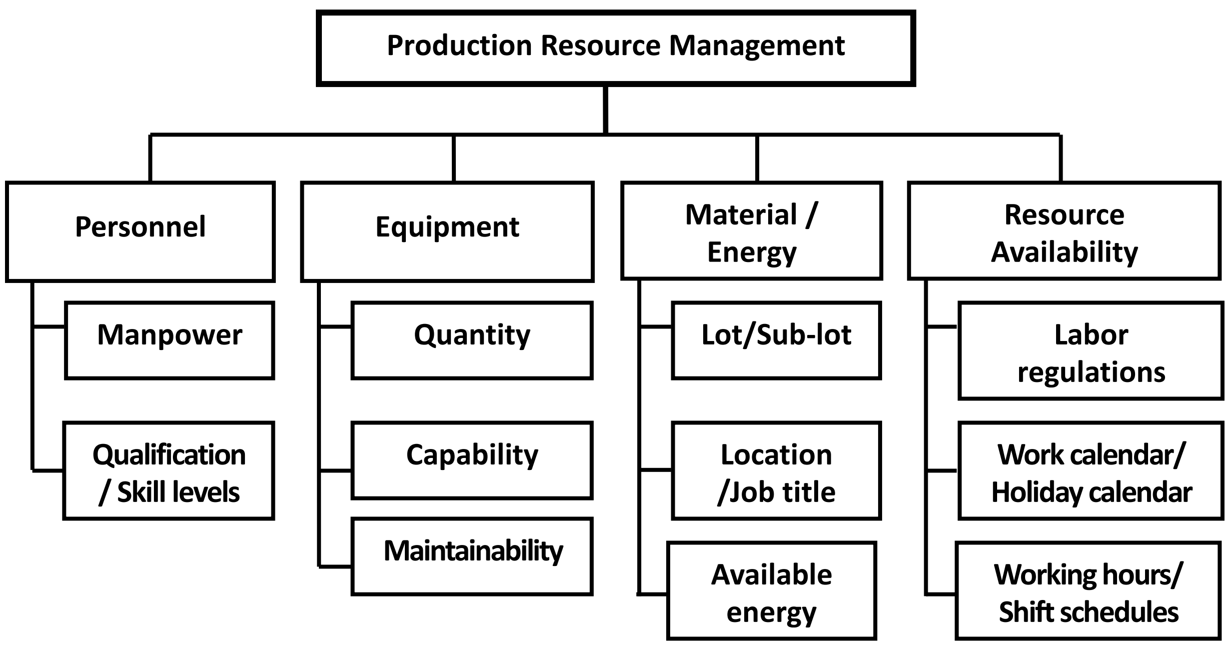


Figure 3.4.2-1 Information structure of production resource management

(source: IEC 62264-3, 2016; compiled and graphed by this study)

Figure 3.4.2-2 illustrates the information flow related to resource management. Resources may vary across different companies. In this figure, the human resources department provides employee-related information, including manpower availability, qualifications, and skill levels. The warehouse or inventory management department supplies material-related data, while the engineering department contributes equipment capabilities and operational parameters to the production management department. The production management department then integrates these inputs to establish a resource availability database, which serves as the basis for issuing work orders to the machining department in accordance with the production schedule. This flowchart should be adjusted according to actual operational conditions. Variations may exist across different companies.

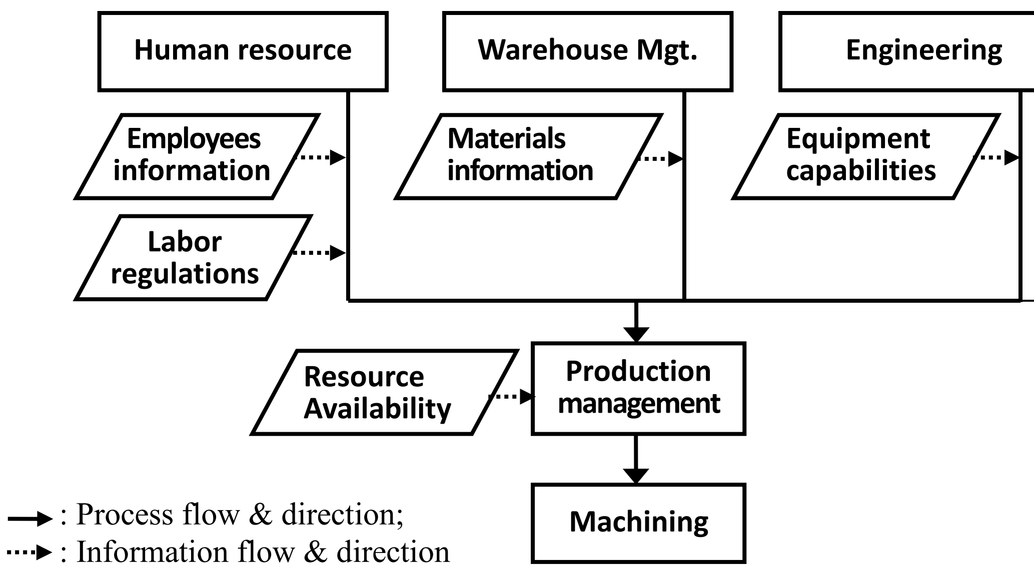


Figure 3.4.2-2 Information flow in the activity of resource management

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.4.3 Detailed production scheduling

Detailed production scheduling can be defined as the set of activities that refine the overall production schedule by determining the most effective allocation and utilization of resources to meet production requirements. These activities may involve sequencing orders to minimize equipment setup or cleaning, consolidating orders for better equipment utilization, and dividing orders when necessary due to batch size limitations or restricted production rates. This scheduling process also considers local conditions and the actual availability of resources.

The production plan generated by the ERP system (Level 4) typically includes only high-level information, such as delivery dates and overall production timelines, but lacks detailed schedules for intermediate operations. Detailed production scheduling refines this plan by incorporating product definitions and production resource information. This activity establishes a detailed schedule that may involve splitting or merging production schedule as necessary. The required information for developing a detailed production schedule, as show in Figure 3.4.3-1.

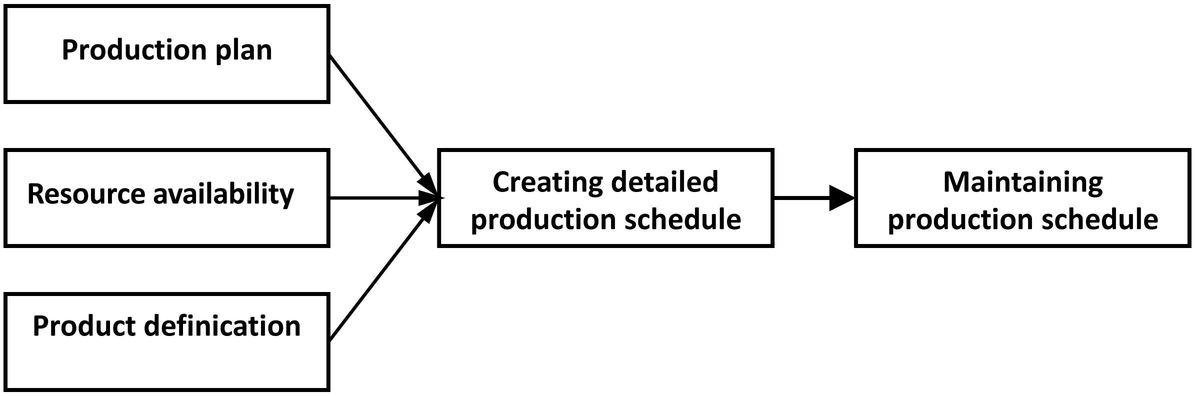


Figure 3.4.3-1 The required information for developing a detailed production schedule

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.4.4 Production dispatching

Production dispatching allocates scheduled jobs to available resources by assigning the required materials, equipment, and personnel for each work order. The necessary information for generating the dispatch list is illustrated in Figure 3.4.4-1.

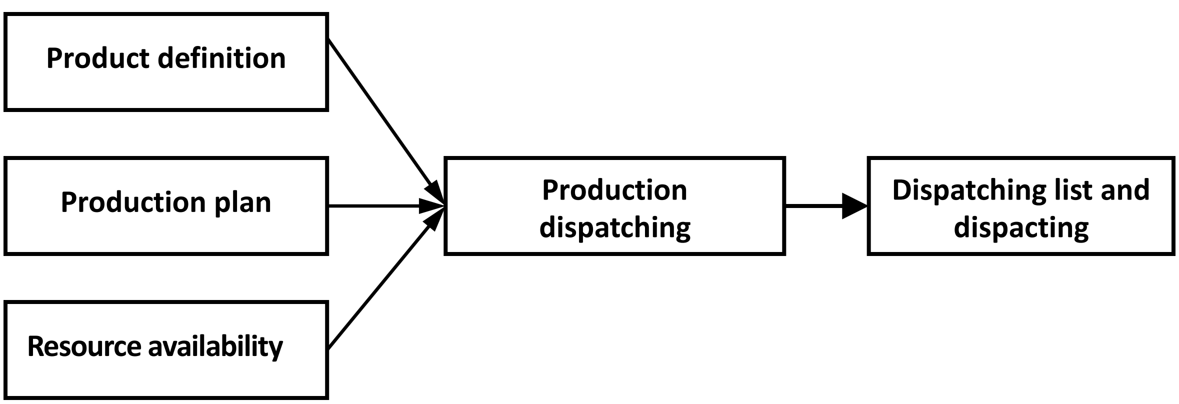


Figure 3.4.4-1 Required information for production dispatching

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.4.5 Production execution management

Production execution management involves directing the tasks outlined on the dispatch list. Figure 3.4.5-1 shows information flow in production execution management.

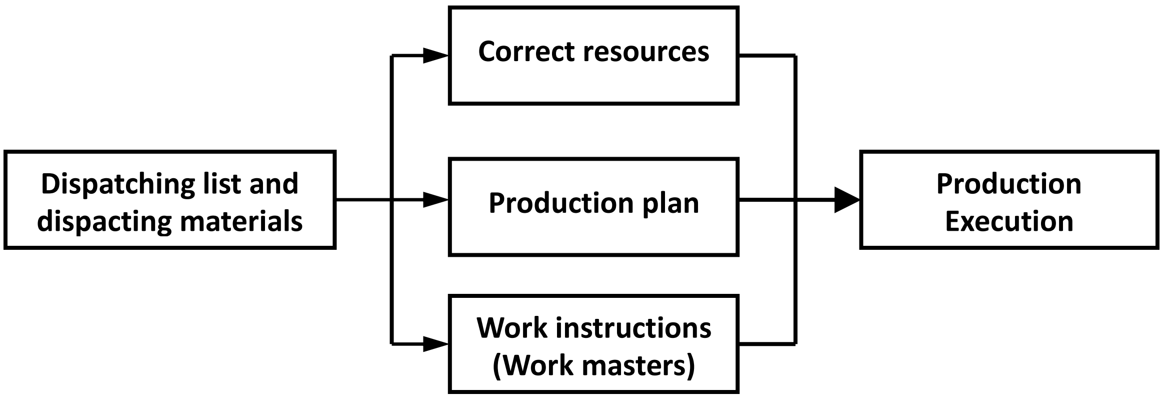


Figure 3.4.5-1 The required information for production execution

(source: IEC 62264-3, 2016; compiled and graphed by this study)

Upon receiving the dispatch list from the Production management department, the Engineering department begins executing the engineering-related tasks specified in the production list, such as defining production rules. During the execution phase, the production unit requires support from job/work instructions (see Figure 3.4.5-2). These job/work instructions are established during the product definition activities. Once the Engineering department completes its tasks, it reports back to the Production management department, which then issues the work order to the Machining department for execution by production personnel.

Operators typically also require access to job/ work instructions during task execution. This flowchart should be adjusted according to actual operational conditions. Variations may exist across different companies.

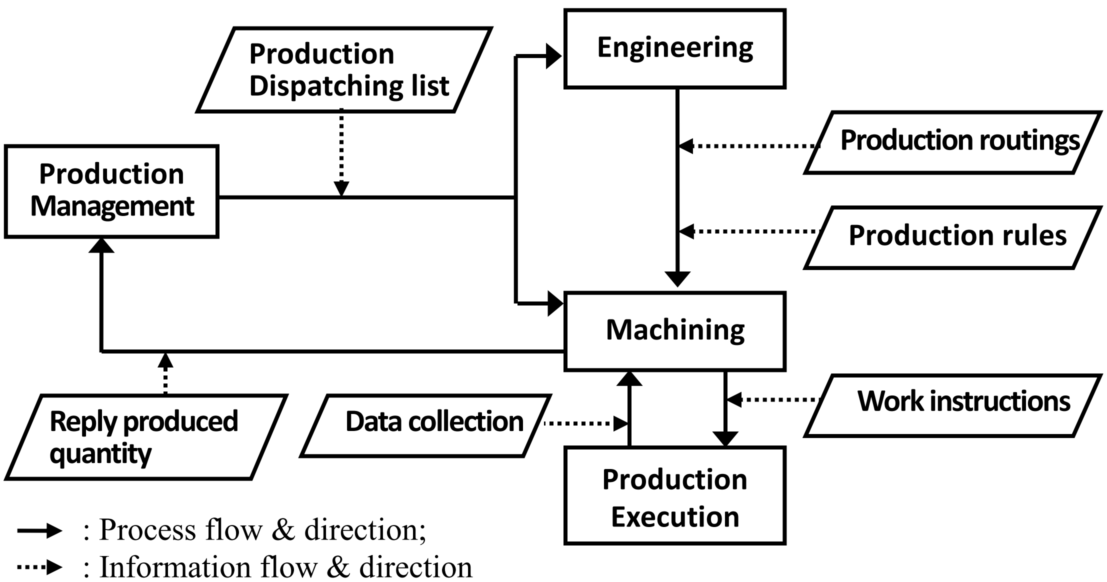


Figure 3.4.5-2 Information flow in the activity of production execution management

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.4.6 Production data collection

Production data collection is defined as the set of activities dedicated to gathering, compiling, and managing data associated with specific work processes or production requests. Typically, manufacturing control systems capture both process-related information—such as quantities (e.g., weight, units) and their attributes (e.g., rates, temperature)—and equipment-related information, including controller, sensor, and actuator status.

The scope of collected data may include sensor outputs, equipment states, event records, operator inputs, transactional data, operator actions, system notifications, model-derived calculations, and other information relevant to product manufacturing. Data collection activities are inherently time-based or event-based, meaning that timestamps or event markers are attached to provide contextual meaning to the data.

As illustrated in Figure 3.4.6-1, production data collection integrates information such as equipment status, process parameters, quality data, and tracking records. It also establishes interfaces with production line control systems, laboratory information management systems, and production management systems, thereby enabling the automated acquisition and exchange of critical information.

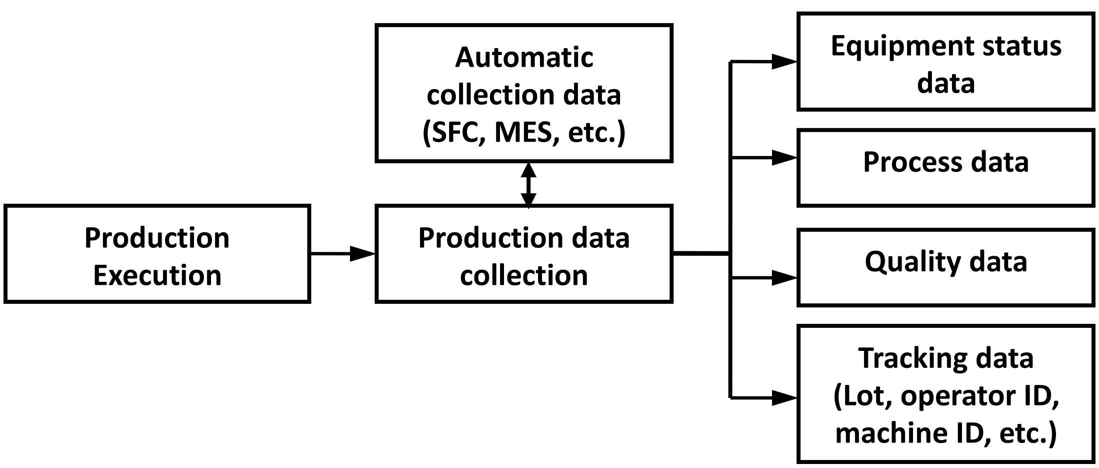


Figure 3.4.6-1 The activities flow of production data collection

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.4.7 Production tracking

Production tracking utilizes data collected during production to generate performance reports transmitted to Level 4. This activity summarizes the actual resources used and production results, providing feedback to the scheduling activity. Information such as current output and work-in-progress (WIP) quantities enables scheduling personnel to adjust production plans accordingly. The activities flow of production tracking, as show in Figure 3.4.7-1.

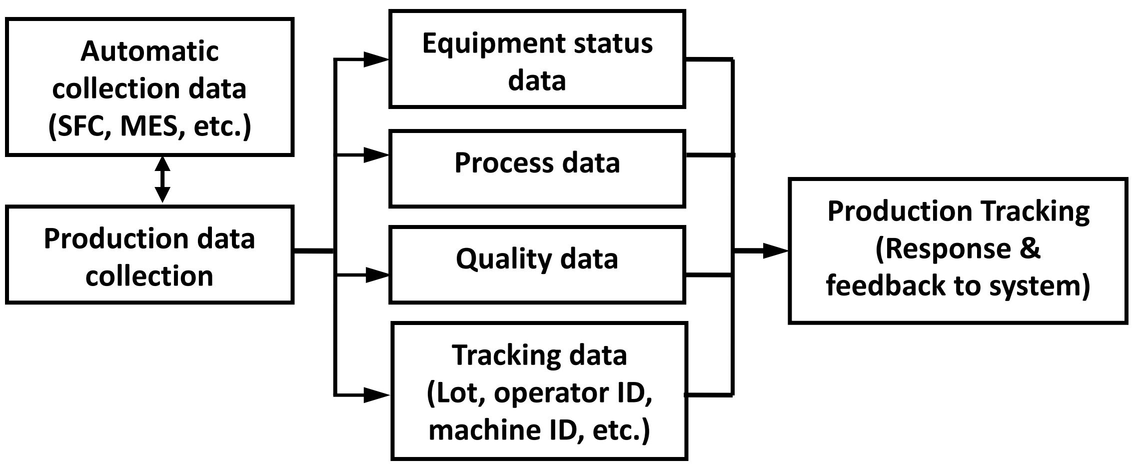


Figure 3.4.7-1 The activities flow of production tracking

(source: IEC 62264-3, 2016; compiled and graphed by this study)

Figure 3.4.7-2 illustrates the information flow for data collection and production tracking. In a typical production process, the execution unit collects production data along with equipment-generated data and reports them to the machining department. The machining department then submits daily production status updates to the production management department. If necessary, the production management department may consider adjusting the production schedule based on actual production conditions. Should adjustments be required, the revised schedule is communicated to the sales department, which in turn informs customers of any changes to delivery timelines. Additionally, the production management department provides performance reports and completed order production information to the sales department. This flowchart should be adjusted according to actual operational conditions. Variations may exist across different companies.

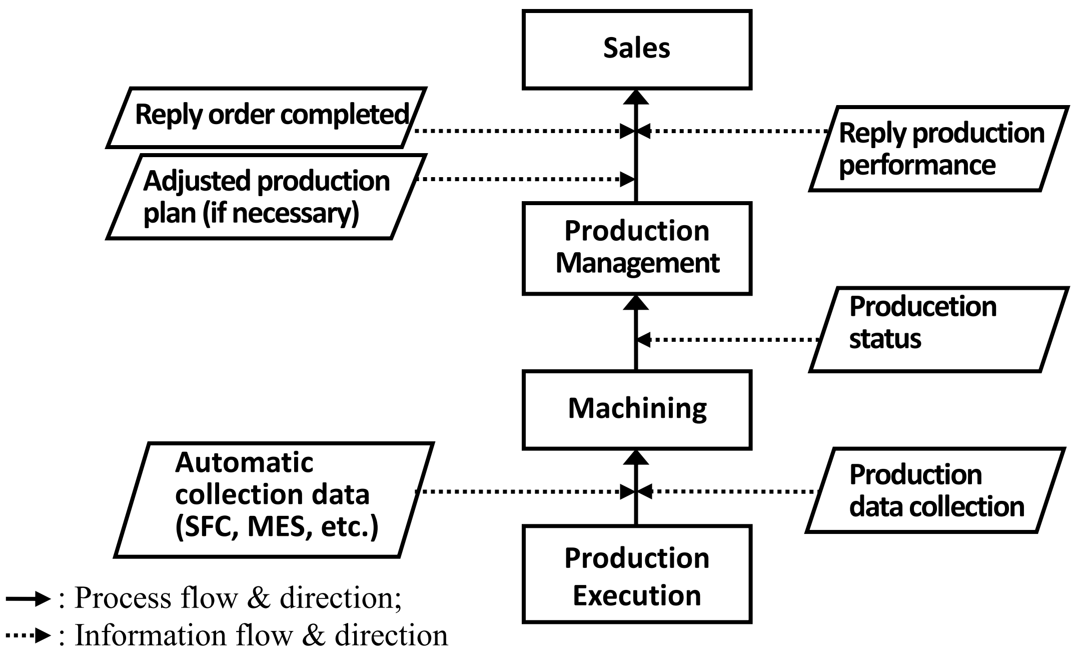


Figure 3.4.7-2 Information flow in the activities of data collection & production tracking

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.3.8 Production performance analysis

Production performance analysis can be defined as the set of activities that evaluate and report production performance information for use in business systems. This includes analyzing data related to production unit cycle times, resource utilization, equipment utilization, equipment efficiency, procedural effectiveness, and production variability (see Figure 3.4.8-1).

In addition, the relationships among these analyses can be leveraged to generate key performance indicator (KPI) reports. Such information is essential for optimizing production processes and resource allocation. The resulting analysis reports also provide technical personnel with a foundation for improving and refining future manufacturing operations.

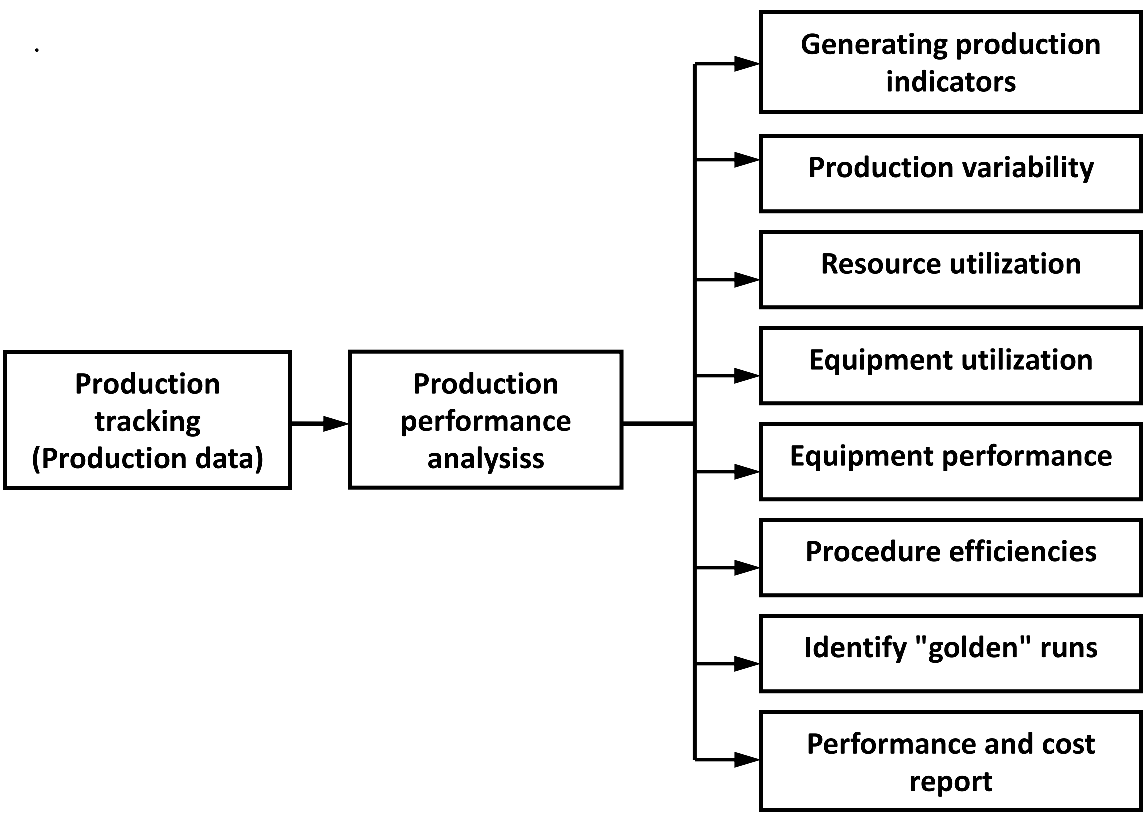


Figure 3.4.8-1 The activities flow of production performance analysis

(source: IEC 62264-3, 2016; compiled and graphed by this study)

This study focuses on developing a standardized POM model based on the MOM framework defined in IEC 62264-3. Particular emphasis is placed on the activity of "Production performance analysis," aiming to provide a reference architecture for optimizing production performance in small and medium-sized machining enterprises. Figure 30 illustrates the interfaces related to production performance analysis (IEC 62264-3, 2016).

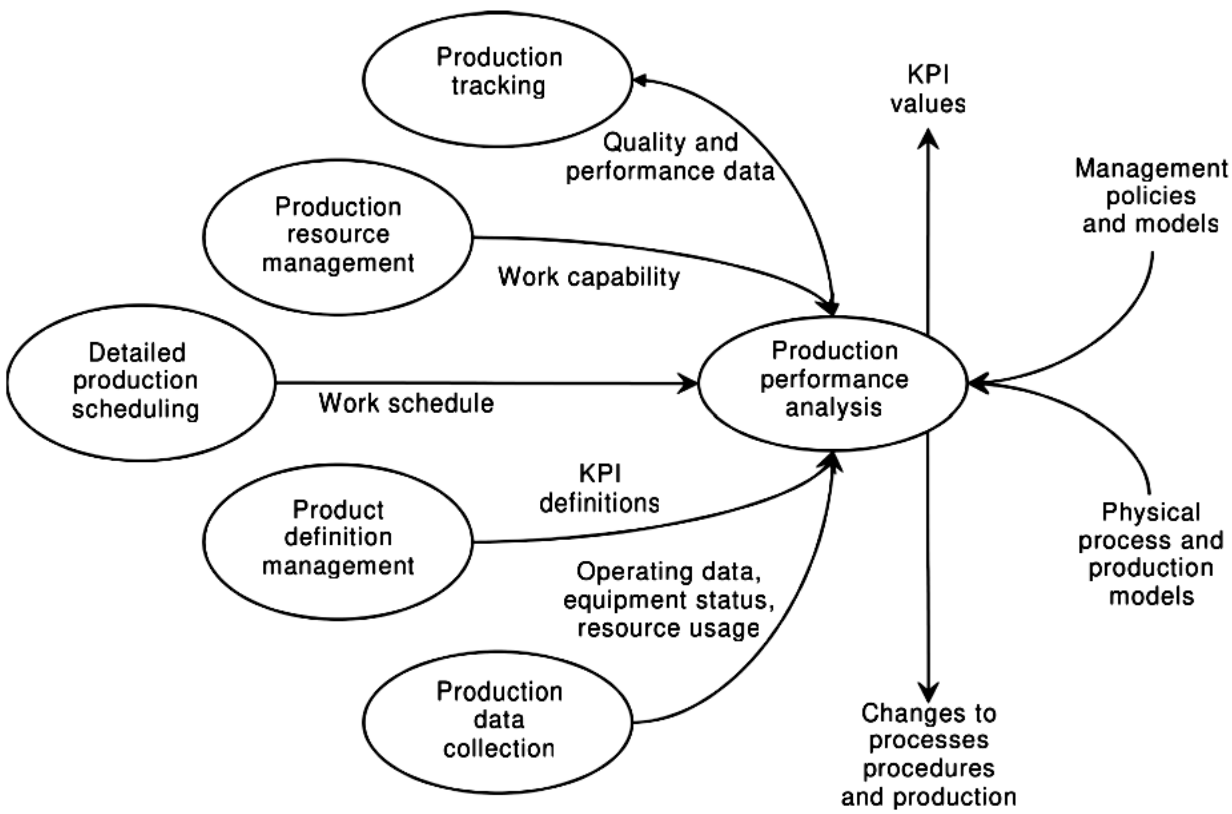


Figure 3.4.8-2 Production performance analysis activity model interfaces

(Source: IEC 62264-3, 2016)

One of the core aspects of production performance analysis lies in the establishment of key performance indicators (KPIs). Among various management objectives, ensuring and enhancing production performance is not only a fundamental requirement but also a significant challenge—particularly for SMEs engaged in high-precision metalworking using CNC lathes and milling machines. These SMEs often operate in highly competitive markets and are required to deliver high-performance, high-quality precision components. As such, demonstrating excellent process capability (Cp, Cpk) and process performance (Pp, Ppk) becomes essential. These metrics, therefore, serve as critical indicators in this study's exploration of production performance.

Figure 3.4.8-3 illustrates the integrated information flow of the aforementioned eight activities, providing a comprehensive view of the information exchange throughout the production process.

When customer submits a new order along with product information, the sales department formulates a delivery plan and creates internal product information, which are then forwarded to the engineering and production management departments. The engineering department defines production rules and process routes, while the production management department consolidates equipment, personnel, and material information to develop a production plan and issue dispatching list to the machining department. The production execution units are responsible for execution, collecting production data and reporting it back to the production management department, which in turn updates the sales department on order fulfillment status. This enables the sales team to provide customer with delivery updates, thereby completing the overall production information flow.

It should be emphasized that variations may exist across different companies or industries; therefore, this information flow diagram has been constructed based on the context of the machining industry.

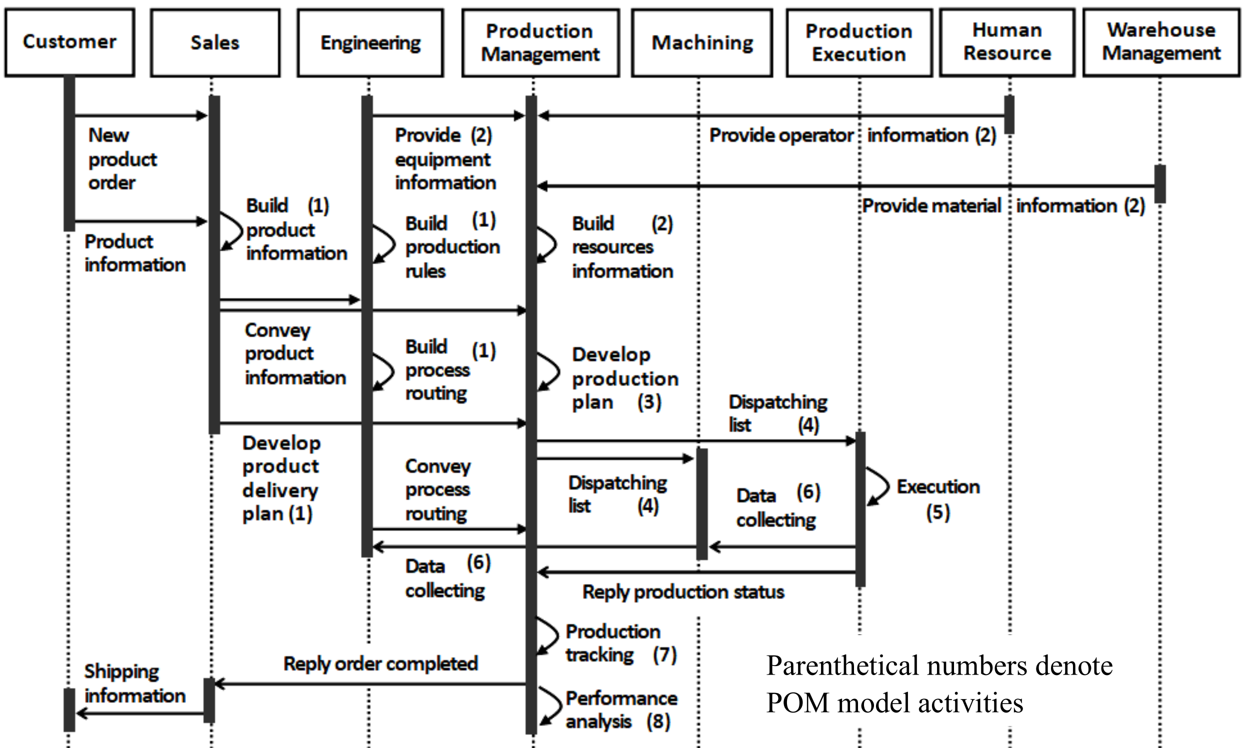


Figure 3.4.8-3 Information flow of production process

Table 3.4-1 summarizes the main tasks associated with the eight core activities defined in the POM reference model, providing a structured framework and practical guidance for systematic POM.

Table 3.4-1 Summary of main tasks in the POM reference model

(source: IEC 62264-3, 2016; compiled by this study)

POM activity	**POM main Task**
1) Product definition management	Build the product definition, including: Product information, Product production rules, and Production routings. (refer to Figure 3.4.1-1)
2) Production resource management	Production resources management includes: Personnel, Equipment, Material / Energy, and Resource Availability (refer to Figure 3.4.2-1)
3) Detailed production scheduling	Make the production schedule based on : Production plan, Product definition, and Resource availability (refer to Figure 3.4.3-1)
4) Production dispatching	Assign a resource to the job, then make a dispatch list based on Production plan, Product definition, and Resource availability (refer to Figure 3.4.4-1)
5) Production execution management	Executing the job on the dispatch list correctly based on the Correct resources, Production plan, and Work instructions (Work masters) (refer to Figure 3.4.5-1)
6) Production data collection	Collect the specific data within the production process, including: Equipment status, process data, quality data, and data for tracking(Lot, operator ID, machine ID, etc.) (refer to Figure 3.4.6-1)
7) Production tracking	Know the production situation and report to level 4 and scheduling activity. Includes: Equipment status, process data, quality data, and data for tracking(Lot, operator ID, machine ID, etc.) (refer to Figure 3.4.7-1)

8) Production performance analysis	Analyze production performance, including Resource utilization, equipment utilization, equipment performance, procedure efficiencies, production variability, generating production indicators, and the Performance & cost report identify "golden" runs. (refer to Figure 3.4.8-1)

3.5 Activity Model of QOM

QOM is defined as the set of activities that coordinate, direct, manage, and monitor the functions responsible for measuring and reporting on quality. Its scope encompasses both the execution of quality operations and the oversight of those operations, to ensure that incoming, in-process and finished products meet required quality standards (IEC 62264-3, 2016) .

According to IEC 62264-3, the quality operations scope are limited to the management of quality test operations. Activities such as establishing and issuing standards and methods from Level 4 to manufacturing or testing laboratories—based on technology, marketing, or customer requirements—are not considered (IEC 62264-3, 2016) .

Quality test operations management forms an essential component of QOM, and the generic model applies to testing activities (IEC 62264-3, 2016). QOM functions may be required across any Level 3 activities to ensure that quality objectives are achieved (IEC 62264-3, 2016) .

Based on IEC 62264-3, the quality operations management activities include :

a) Raw materials evaluation : Incoming testing. b) Evaluation of product : In-process testing and finished product testing. c) Testing of classification and certification. d) Measurement validation. e) Laboratory and automatic analysis (IEC 62264-3, 2016) .

A critical element of quality operations is testing and inspection, which may occur at different stages and locations within the manufacturing process. Examples include:

a) In-line testing, b) At-line testing, c) Off-line testing.

3.6 Quality Test Operations Management Activity Model

The QOM model described in IEC 62264-3 is further elaborated into a more detailed activity model for quality test operations management, as illustrated in Figure 3.6-1. This model specifies the activities associated with inspections and testing operations, as well as the sequence in which these quality test activities should be performed (IEC 62264-3, 2016).

Within the quality test operations activity model, quality requests and quality responses do not always crocess the boundary between Level 3 and Level 4 systems. quality test requests are frequently generated internally within Level 3 systems (IEC 62264-3, 2016). These may take the form of individual quality test requests and responses or be grouped into organized sets. A structured set of quality test requests represents a quality test schedule, whereas a structured set of quality test responses constitutes a quality test performance (IEC 62264-3, 2016).

In the activity model of quality test operations management, information exchanged between Level 3 and Levels 1-2 functions includes: :a) Quality parameters and procedures; b)Test commands; c) Test responses; and d) Quality-specific data (IEC 62264-3, 2016).

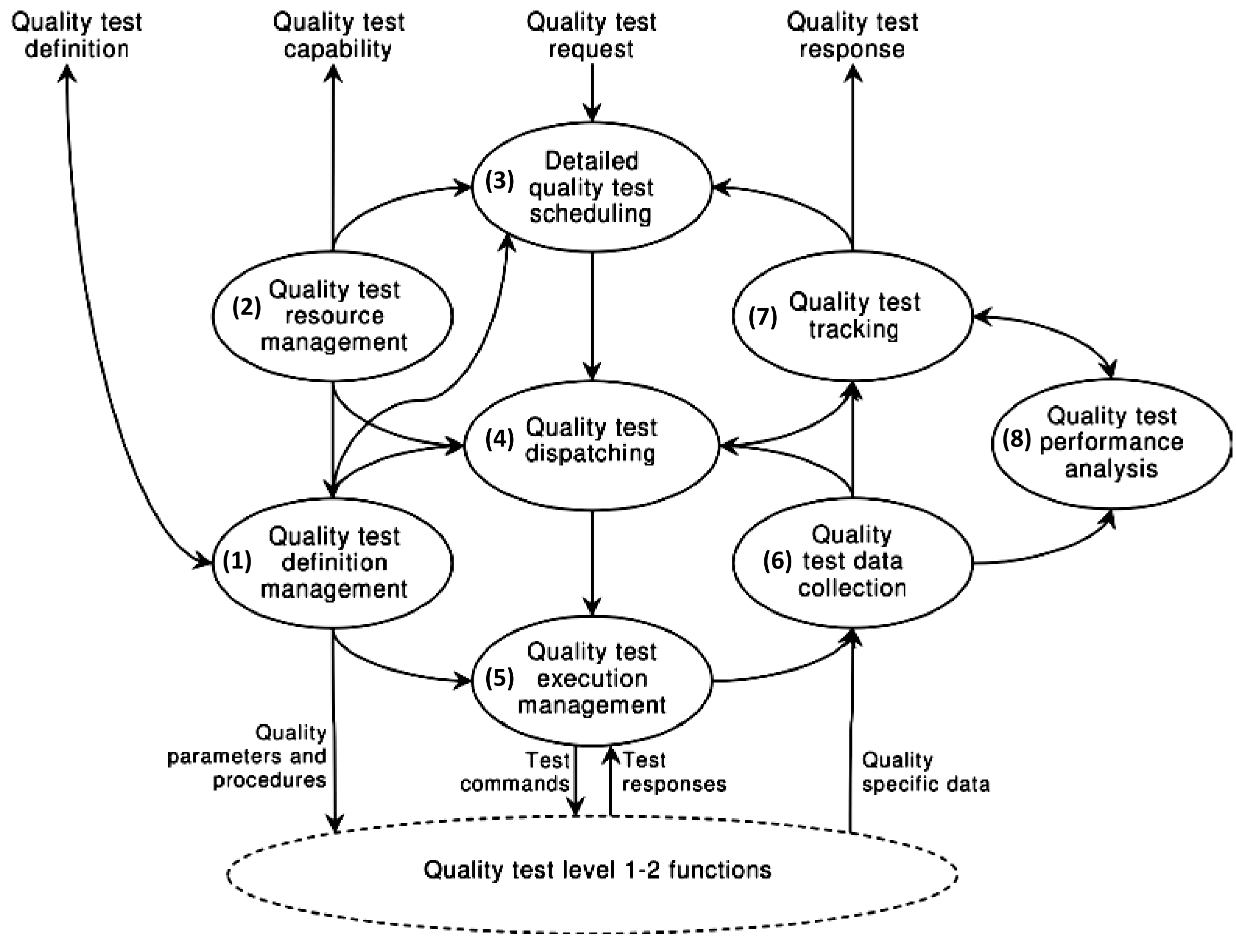


Figure 3.6-1 Activity model of quality test operations management (IEC 62264-3,2016)

3.6.1 Quality test definition management

Quality test definition management refers to the set of activities that establish and oversee the qualifications of personnel, test procedures, and work instructions contained within work masters that are required to carry out quality tests.

This function encompasses the specification of required test procedures, sampling frequencies (or sample plans), and material or resource specifications, including tolerance limits. Supplier testing frequencies may differ based on supplier performance.

The scope of test definitions may include testing methodologies, calculation methods, and detailed work instructions documented as Standard Test Procedures (STPs). In addition, quality test definition management ensures proper coordination of version control, effective dates, material disposition, approvals and approval history, and release status for each test definition.

As illustrated in Figure 3.6.1-1, the information structure of quality test definitions incorporates the required test procedures in work masters, sample frequencies, and specifications for materials and resources (including tolerances). It also encompasses the establishment and distribution of standards and methods from Level 4 activities to manufacturing and testing laboratories, aligned with requirements arising from technical specifications, marketing needs, and customer expectations.

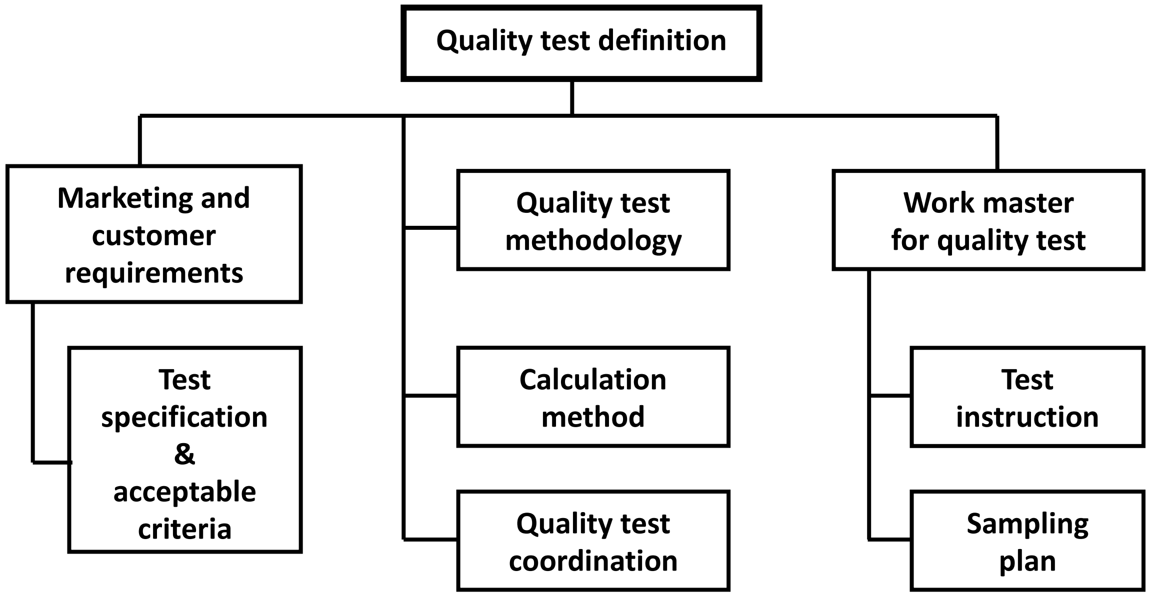


Figure 3.6.1-1 The information structure of the quality test definition

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.2 Quality test resource management

Quality test resource management shall be defined as the collection of activities that manage the resources and relationships between resources needed to perform quality tests. These resources include: test material, test equipment, and test personnel.

Figure 3.6.2-1 illustrates the information structure of quality test resources. Test materials shall include all necessary consumables. Test equipment must specify its capabilities and applicability across On-line, At-line, and Off-line testing scenarios. Personnel resource management for quality testing shall encompass manpower allocation, required skill sets, certifications, and authorization levels.

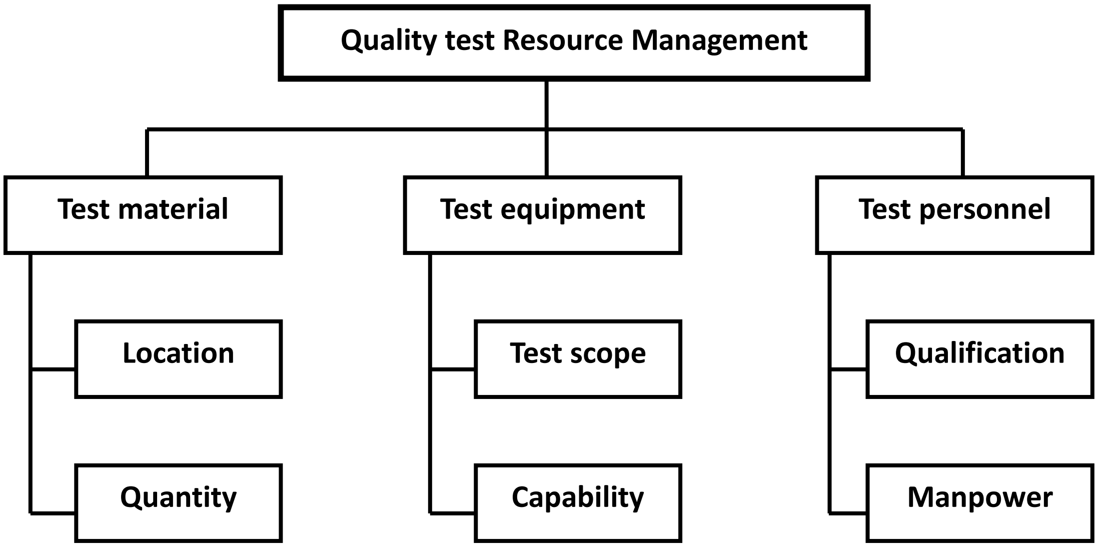


Figure 3.6.2-1 The information structure of the quality test resource

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.3 Detailed quality test scheduling

Detailed quality test scheduling is defined as the set of activities responsible for planning and allocating resources for the execution of quality testing tasks. This scheduling process considers local operating conditions, the availability of resources, and any necessary preparations required to conduct the tests effectively.

The primary tasks of detailed quality test scheduling include:

a) Establishing and maintaining a comprehensive schedule for quality testing;

b) Comparing actual test execution against the planned test execution;

c) Determining the committed capacity of each resource to support the overall quality test management function.

Figure 3.6.3-1 presents the required information for developing a detailed quality test schedule. To create such a schedule, the test plan (based on production plan), resource (equipment, material and test personnel) availability, and necessary preparations must be taken into account. Maintaining the quality test schedule also requires comparing actual test execution against the planned schedule to ensure alignment and timely performance.

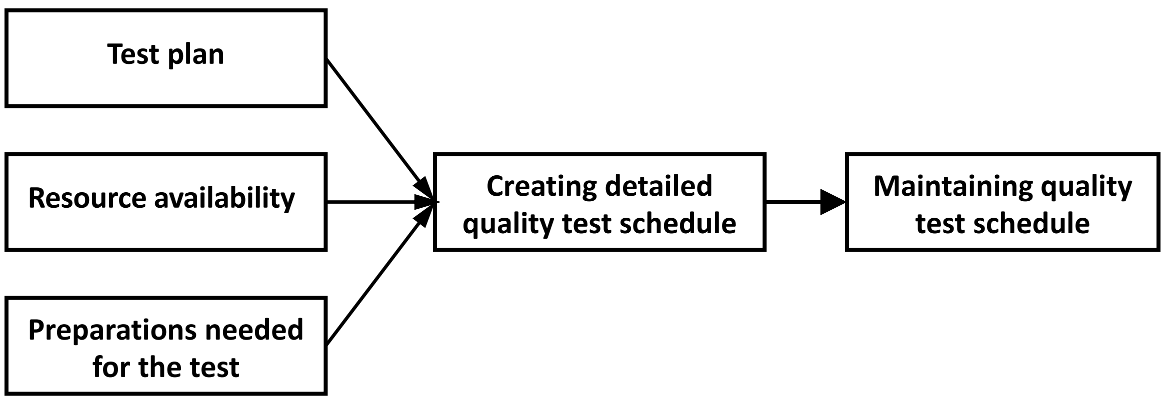


Figure 3.6.3-1 The required information for developing a detailed quality test schedule

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.4 Quality test dispatching

Quality test dispatching refers to the set of activities that assign and release quality test job orders to the appropriate resources, as determined by the test schedule and test definitions. This function communicates which tests are to be conducted, specifies the resources to be used, and may also include transferring materials to the designated testing resources for execution.

In cases where certain resources are not pre-assigned within the detailed quality test schedule, they can be allocated during the dispatching process. Each quality test job order defines the specific tasks and elements to be performed by the quality operations team.

Quality test dispatching is driven by the established test plan or schedule, the defined testing procedures, and the availability of resources, resulting in a structured dispatch list. As illustrated in Figure 3.6.4-1, this process may also encompass the coordination of material movement to support scheduled testing activities.

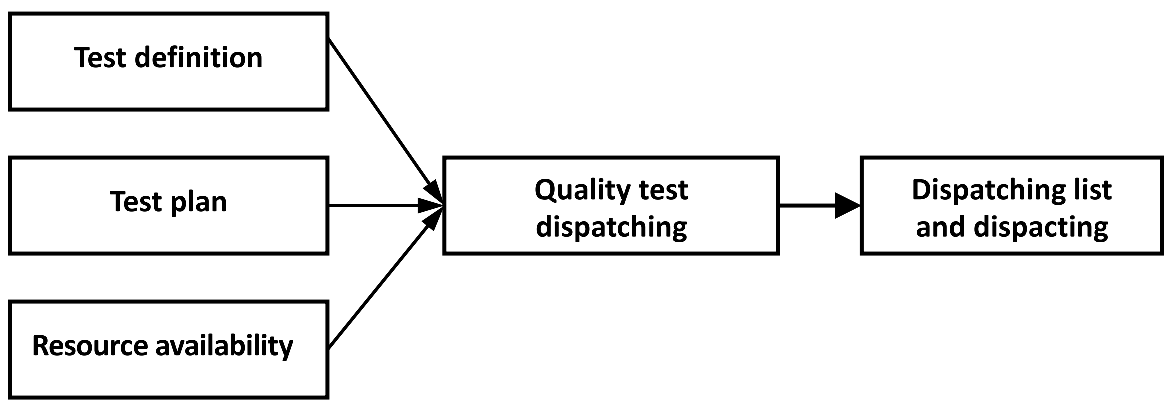


Figure 3.6.4-1 The required information for quality test dispatching

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.5 Quality test execution management

Quality test execution management is defined as the set of activities responsible for directing and overseeing the actual performance of quality tests. This function ensures that the appropriate resources—including equipment, materials, and personnel—are allocated and utilized correctly. It also verifies that testing is carried out in compliance with established quality standards and that products may be released under the specified conditions.

Examples of quality test activities include: a) In-line testing, b) At-line testing, c) Off-line testing, d) Pass/fail testing, e) Measurement testing, f) Retesting, and g) Blind sample testing.

As illustrated in Figure 3.6.5-1, quality test execution is guided by the dispatch list, which specifies the materials to be delivered to the designated testing resources. In alignment with the test plan, the required resources are assigned, and the testing must be performed according to the defined quality procedures. Where applicable, the release of test results may be authorized under controlled conditions.

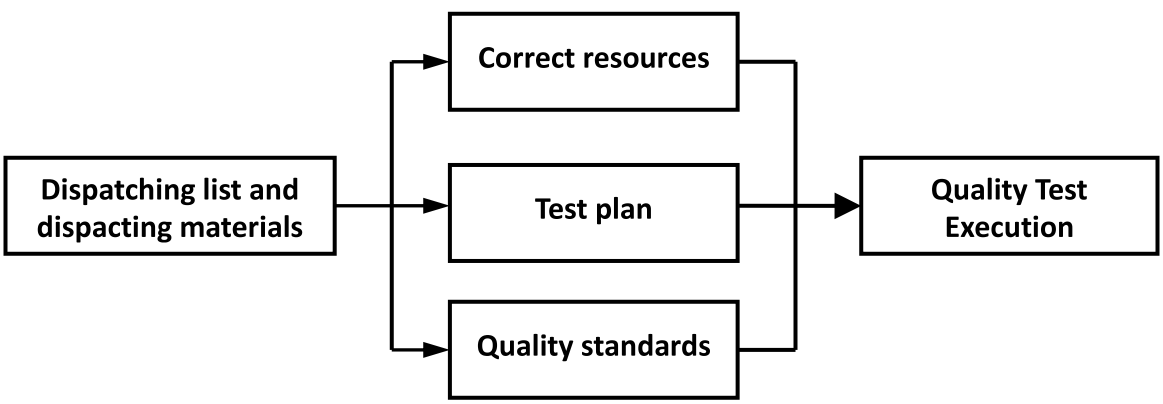


Figure 3.6.5-1 The required information for quality test execution

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.6 Quality test data collection

Quality test data collection refers to the set of activities that gather test results and make them accessible for further use. These results may consist of manually entered data or data directly captured from testing equipment.

This function also involves generating standardized or on-demand reports for manufacturing personnel, clearly indicating the status of the data. Test data can be categorized as either final or intermediate:

1. Final data has been approved and is ready for distribution.
2. Intermediate data is non-approved, may be shared internally, and may still require further testing.

As shown in Figure 3.6.6-1, quality test data collection manages the flow of test results obtained from execution activities. These results can be used to determine pass/fail status. Approved final data is distributed, while intermediate data may serve as input for internal process improvement or as an indicator of the need for additional testing..

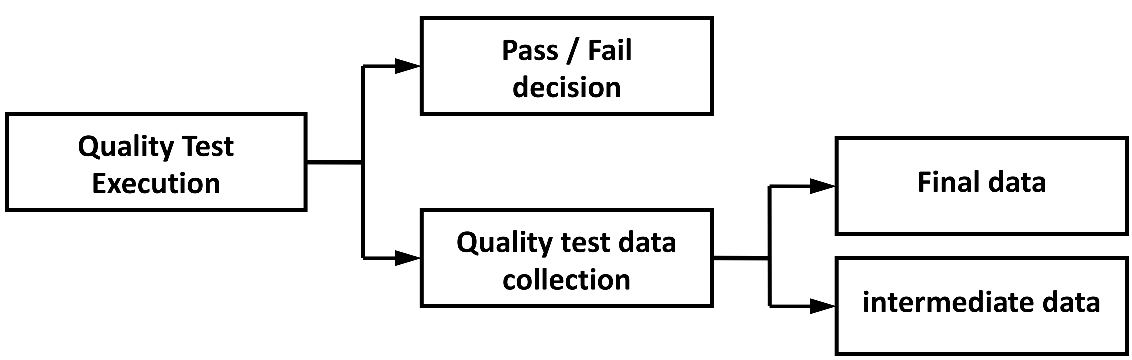


Figure 3.6.6-1 The activities flow of quality test data collection

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.7 Quality test tracking

Quality test tracking is defined as the set of activities that consolidate test results into responses, distribute those responses, and manage information related to the utilization of resources required to perform the tests.

This function provides essential feedback on quality performance to both Level 3 and Level 4 systems. Such feedback may be delivered on a scheduled basis, after production runs or batches, or upon request.

Quality test tracking also involves monitoring tests conducted at different times and across various points in the production process. In addition, it includes the generation or updating of work records associated with executed tests, which may serve regulatory compliance or broader quality management requirements.

As illustrated in Figure 3.6.7-1, test results can be used to determine pass/fail status. Final data may be approved and distributed, while intermediate data can be retained as internal references for improvement efforts or as indicators for additional testing. Quality test tracking, therefore, plays a critical role in ensuring timely responses and delivering quality-related feedback to higher-level systems.

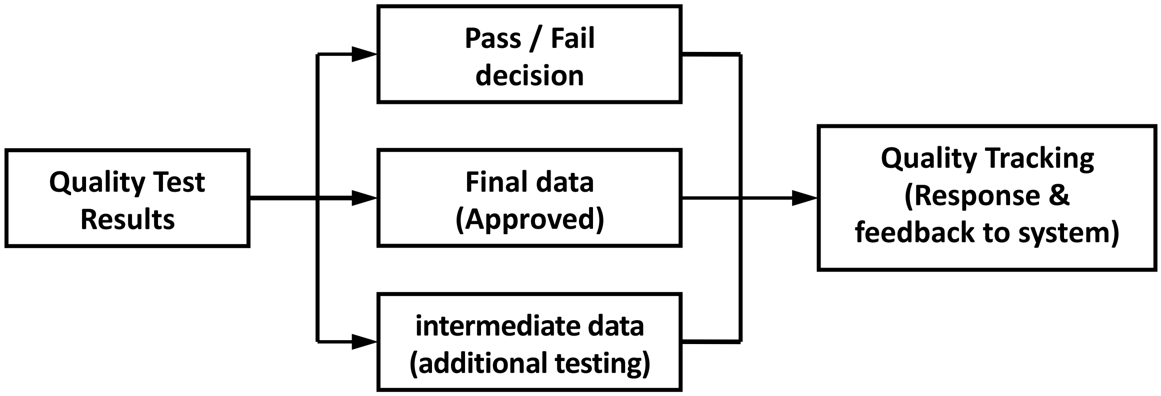


Figure 3.6.7-1 The activities flow of quality test tracking

(source: IEC 62264-3, 2016; compiled and graphed by this study)

3.6.8 Quality test performance analysis

Quality test performance analysis is defined as the set of activities that evaluate quality test results and overall testing performance to identify ways to improve product quality. This includes analyzing factors such as quality variability, cycle times within the quality department, resource and equipment utilization, and the efficiency of testing procedures. In many cases, quality performance analysis is carried out as a continuous business process.

A key aspect of this activity is the generation of quality indicators. These indicators may be used internally within manufacturing operations to drive process improvements and optimization. When required, the same information can also be transmitted to higher-level business processes to support broader analysis and strategic decision-making.

As illustrated in Figure 3.6.8-1, quality test performance analysis involves systematically reviewing both test results and testing performance to uncover opportunities for enhancing product quality. The resulting quality indicators can thus serve as inputs for continuous improvement at the operational level or as valuable data for higher-level business planning.

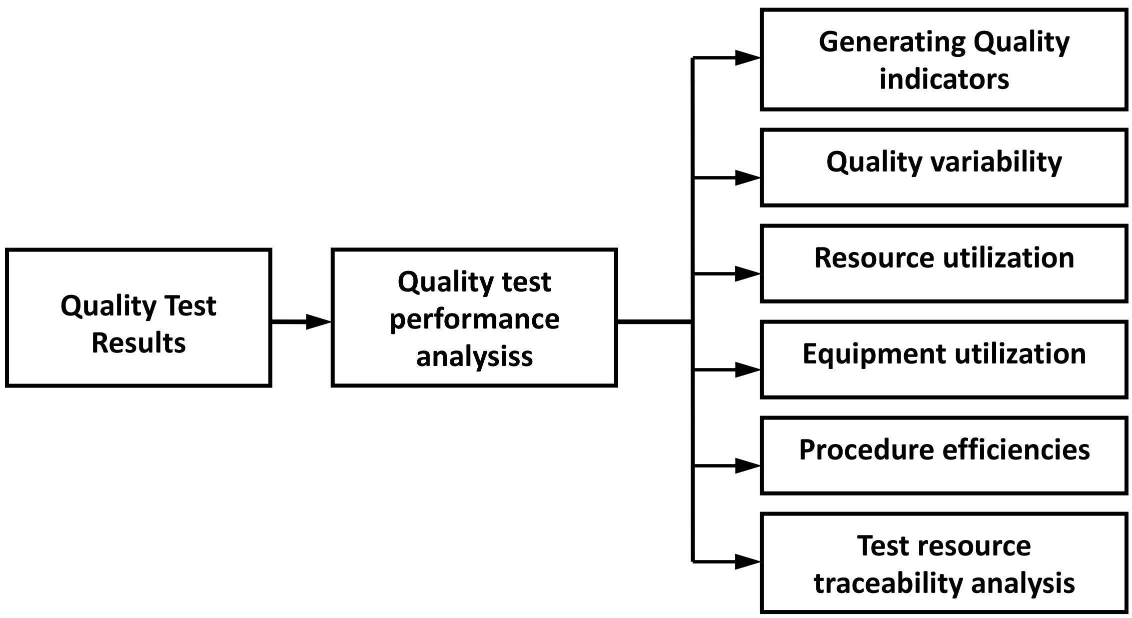


Figure 3.6.8-1 The activities flow of quality test performance analysis

(source: IEC 62264-3, 2016; compiled and graphed by this study)

Developing a standardized QOM model based on the MOM framework as defined in IEC 62264-3 is another key focus of this study. The core of the research lies in the systematic analysis of the "Quality test performance analysis" activity. The objective is to provide small and medium-sized machining enterprises with a referable framework for optimizing quality performance, thereby enhancing their quality management effectiveness and operational competitiveness.

One of the core aspects of quality testing performance analysis lies in the establishment of key performance indicators (KPIs). Among various management objectives, ensuring and enhancing product quality is not only a fundamental requirement but also a significant challenge for SMEs, particularly those engaged in high-precision machining using CNC lathes and milling machines. These enterprises often operate in highly competitive markets and are required to deliver high-performance, high-quality precision components while demonstrating robust quality control capabilities. Such capabilities are reflected through metrics, including in-line testing, at-line testing, off-line testing, and first-time quality (FTQ). Accordingly, these quality performance indicators serve as critical foundations for this study's exploration of quality testing performance.

Figure 3.6.8-2 illustrates the integrated information flow of the aforementioned eight activities, providing a comprehensive view of the quality testing information flow within the production process.

Upon receiving new product information and specifications from the customer, the sales department formulates a delivery plan and creates internal product information, which are then forwarded to the quality engineering and production management departments. The quality engineering team defines quality parameters and develops test plans and procedures. The production management team consolidates equipment, inspection personnel, and material data to prepare a production plan and issue dispatching list to IQC and FQC. IQC and FQC report inspection results back to the production management team, which in turn updates the sales department. This enables the sales team to inform the customer of delivery progress, completing the overall quality testing information flow.

It should be emphasized that variations may exist across different companies or industries; therefore, this information flow diagram has been constructed based on the context of the machining industry.

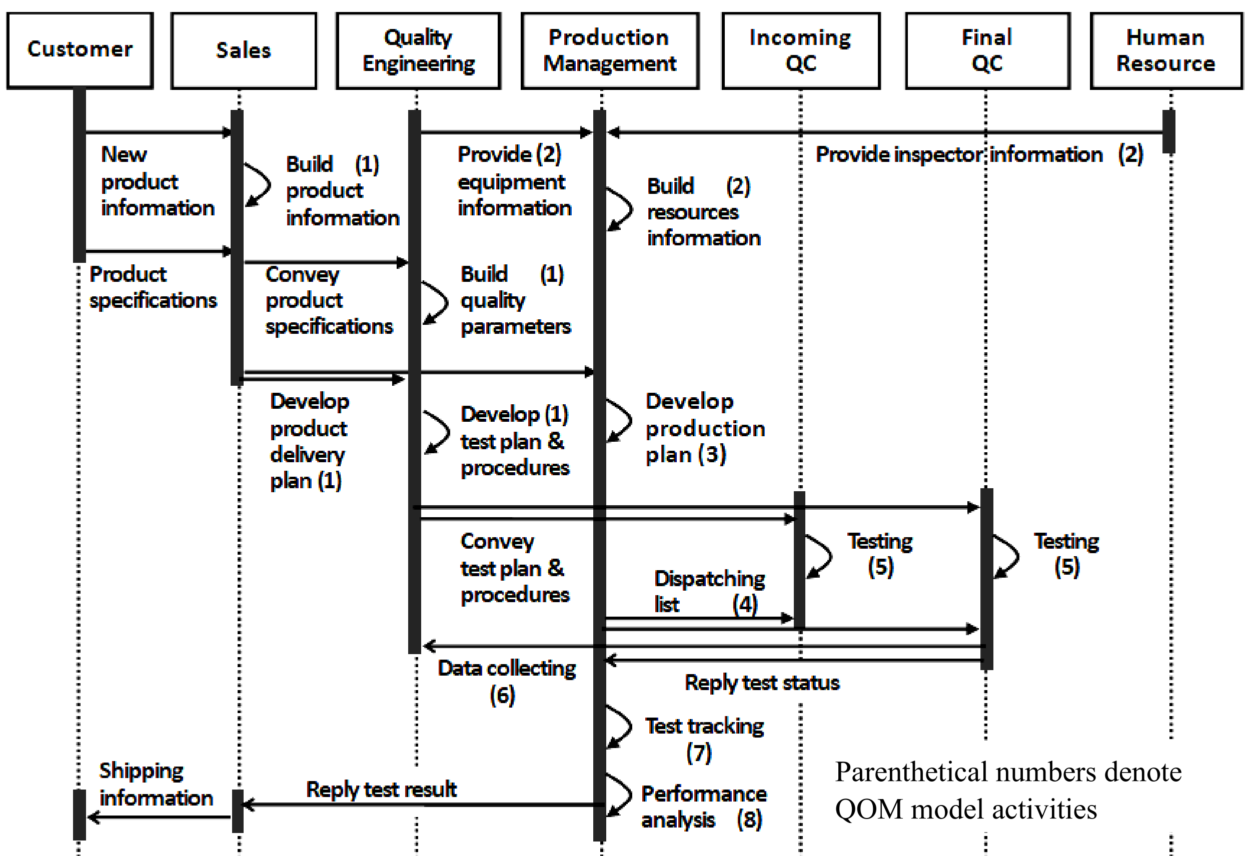


Figure 3.6.8-2 Information flow of quality test process

Table 3.6-1 summarizes the main tasks associated with the eight core activities defined in the QOM reference model, providing a systematic framework and practical guidance for managing quality testing operations.

Table 3.6-1 Summary of the main tasks in QOM reference model

(source: IEC 62264-3, 2016; compiled by this study)

QOM activities	**QOM main task**
1) Quality test definition management	Build the quality test definition, including: Marketing and customer requirements, Quality test methodology, Simulation /calculation, Quality test Coordination and Work master for quality test. (refer to Figure 3.6.1-1)
2) Quality test resource management	Quality test resources management, including: Test material, test equipment, and test personnel (refer to Figure 3.6.2-1)
3) Detailed quality test scheduling	Make the detailed quality test schedule based on : Test plan, resource availability, and preparations needed for the test (refer to Figure 3.6.3-1)
4) Quality test dispatching	Make a quality test dispatch list based on test plan/schedule, test definitions, and resource availability (refer to Figure 3.6.4-1)
5) Quality test execution management	Execute the test job on the dispatch list correctly based on the test plan, correct resources, and quality standards (refer to Figure 3.6.5-1)
6) Quality test data collection	Collect the specific data within the quality testing, including: final data and intermediate data. (refer to Figure 3.6.6-1)

7) Quality test tracking	The results of the quality test (final data & intermediate data) may be used to determine pass or fail status. Quality test tracking also provides response and feedback about quality to Level 3 and Level 4 systems. (refer to Figure 3.6.7-1)
8) Quality test performance analysis	Analyze quality test performance, including Generating quality indicators, resource utilization, equipment utilization, procedure efficiencies, quality variability, and Test resource traceability analysis. (refer to Figure 3.6.8-1)

CHAPTER IV: APPLICATION

Chapter 4 focuses on the application of the proposed research methodology. By incorporating relevant information from the case company and referencing the IEC/ISO Manufacturing Operations Management (MOM) model, this study integrates process reengineering techniques to progressively assist the case company in improving its Production Operations Management (POM) and Quality Operations Management (QOM).

This case study introduces the background of the case Company W in Section 4-1. Subsequently, it reengineers the company's operational processes by following the three-step guideline proposed in Section 3.2 (Guideline of reengineering production process). Sections 4-2 to 4-4 correspond to each of these three steps, respectively. Section 4-5 presents the feasibility evaluation of the proposed improvement strategies and the feedback from the case company.

4.1 Case Company Introduction

This study focuses on "Production and quality operations management improvement based on the IEC 62264-3 MOM reference model," selecting Company W as the case subject due to its typical characteristics of small and medium-sized manufacturing enterprises (SMEs) in Taiwan—namely, its emphasis on enhancing production performance and product quality. However, SMEs in Taiwan often lack standardized MOM expertise and resources, and may have a limited understanding of the concepts of digital transformation and digitization.

This study uses a SME in Taiwan, specializing in metal processing and manufacturing, as a case example. In this study, the company is referred to as "Company W". Company W's product range includes automotive, motorcycles, bicycle parts, and medical device components. Its core business lies in providing machining services, and it does not engage in proprietary product design. All analytical data used in this research were provided by Company W and are based on its operational records.

4.1.1 Organizational structure

The organizational structure of Company W, as illustrated in Figure 4.1.1-1, represents a typical configuration commonly found among SMEs in Taiwan. At the top level, the company is led by the President (CEO), who is responsible for overseeing the operations of each departments, including the administration department (human resources, general affairs, and warehouse management), the finance department (accounting and financial management), the sales department, the engineering department (production technology and document control), the machining department, and the quality control department (incoming quality control, final quality control, and quality engineering). The machining department is further subdivided into the turning (lathe) section and milling section, based on the machining processes employed.

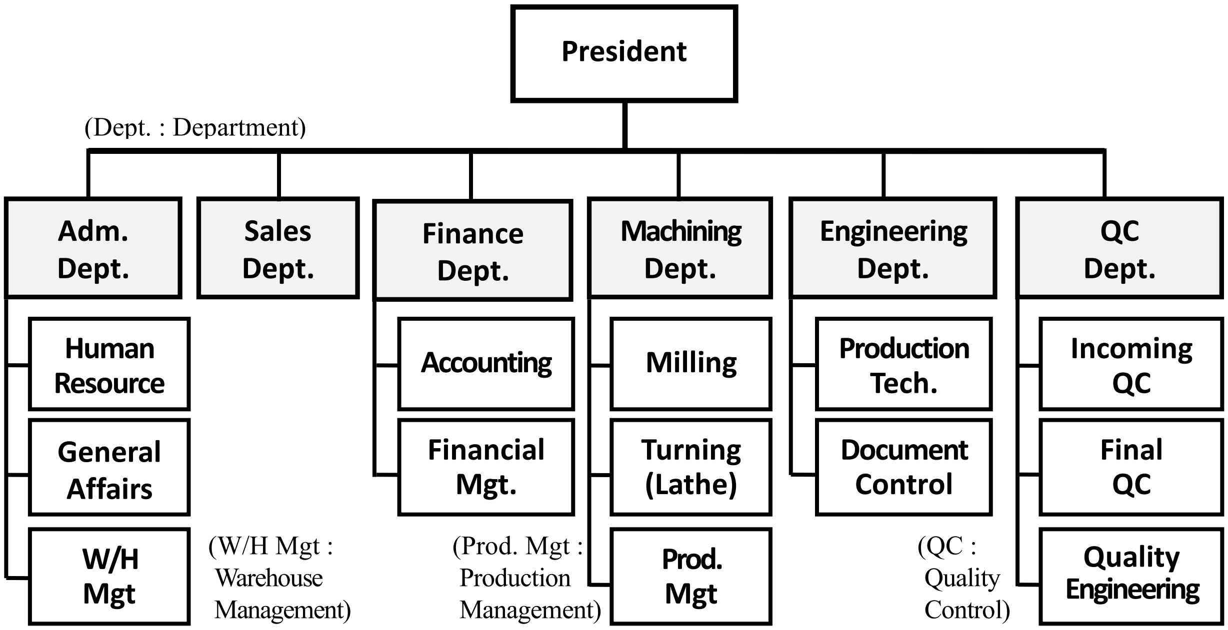


Figure 4.1.1-1 Organization chart of Company W (source: Company W, 2025)

4.1.2 Major machining equipment

The primary machining equipment of Company W is listed in Table 4.1.2-1. When performing production dispatching operations, the following equipment attributes should be comprehensively considered to ensure machining efficiency and product quality stability:

a) Machine brand, equipment condition, and age:

Including the manufacturer's technical support capabilities, maintenance history, and degree of equipment aging.

b) Machining range (X/Y/Z axis travel) and structural performance: Encompassing machine rigidity, design precision, dynamic stability, and load capacity, to determine suitability for specific workpiece dimensions and machining requirements.

c) Controller system (brand/model/version) and automatic compensation settings: Covering tool compensation, thermal displacement compensation, and spindle positioning accuracy, all of which affect machining precision and integration with automation systems.

This information serves as a critical basis for production dispatching decisions and should be incorporated into resource module management and scheduling algorithms to enhance overall manufacturing performance.

Table 4.1.2-1 Major machining equipment list of Company W (source: Company W, 2025)

Code	**Machine type**	**Brand**	**Model**	**Controller**	**X/Y/Z axis range**	**Year**
A01	Lathe	Victor Taichung	VT Plus/15	FANUC	210mm(X) / 270mm(Z)	2006
A02	Lathe	Victor Taichung	VT Plus/15	FANUC	210mm(X) / 270mm(Z)	2006
A03	Lathe	Victor Taichung	Vturn-20	FANUC	115mm(X) / 600mm(Z)	2006
A04	Lathe	Victor Taichung	Vturn-20	FANUC	115mm(X) / 600mm(Z)	2006
A05	Lathe	Victor Taichung	Vturn-20	FANUC	115mm(X) / 600mm(Z)	2006

A06	Lathe	Tongtai	TNL-100T	FANUC	200mm(X) / 400mm(Z)	2008
A07	Lathe	Tongtai	TNL-100T	FANUC	200mm(X) / 400mm(Z)	2008
A08	Lathe	Tatung-okuma	L150G-II-e	FANUC	300mm(X) / 230mm(Z)	2014
A09	Lathe	Tatung-okuma	L150G-II-e	FANUC	300mm(X) / 230mm(Z)	2014
A10	Lathe	Liouy-hsing	CNC-200L	FANUC	165mm(X) / 540mm(Z)	2017
A11	Lathe	Liouy-hsing	CNC-200L	FANUC	165mm(X) / 540mm(Z)	2019
L01	Milling	Maxdrill	VX850	FANUC	800mm(X) / 510mm(Y) / 610mm(Z)	2017
L02	Milling	Victor Taichung	Vcenter-55	FANUC	600 mm(X) / 410 mm(Y) / 510 mm(Z)	2018
L03	Milling	Victor Taichung	Vcenter-85	FANUC	850mm(X) /520 mm(Y) / 560 mm(Z)	2018
L04	Milling	Tongtai	VP-8	FANUC	850mm(X) /520 mm(Y) / 560 mm(Z)	2019
L05	Milling	Maxdrill	VX850	FANUC	800mm(X) / 510mm(Y) / 610mm(Z)	2019

4.1.3 Major inspection equipment

The primary inspection equipment and corresponding inspection items of Company W are listed in Table 4.1.3-1

Table 4.1.3-1 Major inspection equipment list of Company W (source: Company W, 2025)

Instrument Name	**Brand**	**Model**	**Inspection Items**
Coordinate Measuring Machine (CMM)	ZEISS / HEXAGON	CONTURA / GLOBAL	Geometric dimensions, positional accuracy, form error
Optical Vision Measuring Machine	MIT / Chuan Hong	MV-3020 / MT-2000	2D dimensions, distance, angle, radius, curvature
Surface Roughness Tester	MITUTOYO / Taylor Hobson	SJ-410 / Surtronic S100	Surface roughness parameters: Ra, Rz, Rt, etc.
Hardness Tester	INNOVATEST / SHIMADZU	NEXUS 4300 / HMV-G	Rockwell, Vickers, Brinell hardness
Profile Projector (Contour Measuring)	NIKON / STARRETT	V-12B / HD400	Contour, angle, distance, form deviation
Granite Surface Plate	Chuan Hong / Zongxin	JB/T 7975	Flatness, perpendicularity, and parallelism reference
3-Point Bore Micrometer	MITUTOYO	Series 368 / Holtest II	Internal diameter, roundness, taper, concentricity
Bore Gauge (Micrometer)	HAAS Tooling	09-0408	Internal diameter.

4.1.4 Human resources

Company W currently employs approximately 75 personnel, the majority of whom are frontline machining operators. Production plans are dynamically adjusted based on order requirements, and certain machine types operate under a two-shift or three-shift system to meet capacity demands.

When executing production dispatching operations, personnel attributes must be comprehensively considered, including:

a) Work experience and technical skills

Encompassing operational proficiency, equipment handling capabilities, and mastery of machining processes.

b) Product or domain expertise

Each operator should be clearly associated with specific product types or areas of specialization to enable precise dispatching and resource allocation.

This personnel data serves as critical inputs for dispatching decisions and should be integrated into the human resource module and scheduling algorithms to enhance production efficiency and quality stability.

4.1.5 Primary product instruction

This study aims to enhance management effectiveness in production performance and product quality in SMEs by applying the MOM reference model defined in IEC 62264-3. The primary product selected for analysis is the engine valve rocker arm manufactured by Company W (as illustrated in Figure 4.1.5-1, with the left side showing the pre-machining state and the right side showing the post-machining result). These products account for approximately 65% of the company's total revenue. Among them, the monthly demand from client BXP reaches 80,000 units, making it the highest revenue-contributing product line for Company W.

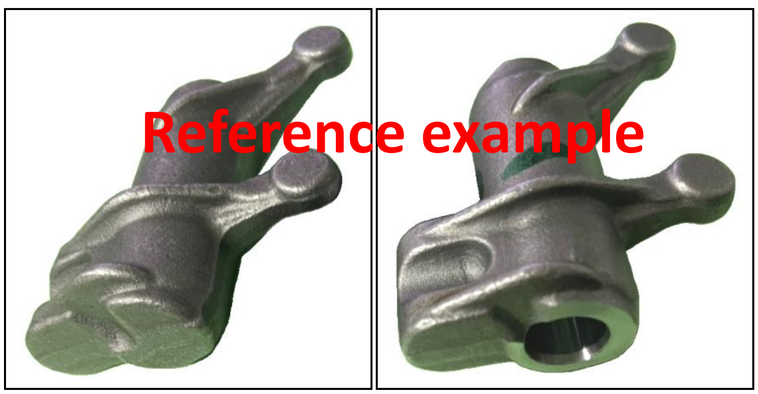


Figure 4.1.5-1 Engine valve rocker arm, pre-machining (left) and post-machining (right) (source: Company W, 2025)

BXP is a recreational vehicles manufacturer specializing in snowmobiles, all-terrain vehicles (ATVs), side-by-side off-road vehicles, motorcycles, and personal watercraft. The engine valve rocker arm is a critical internal engine component (as shown in Figure 4.1.5-2) of recreational vehicles, requiring high precision and long-term durability (reliability). These stringent requirements pose significant challenges to Company W's MOM, necessitating systematic approaches for breakthrough and improvement.

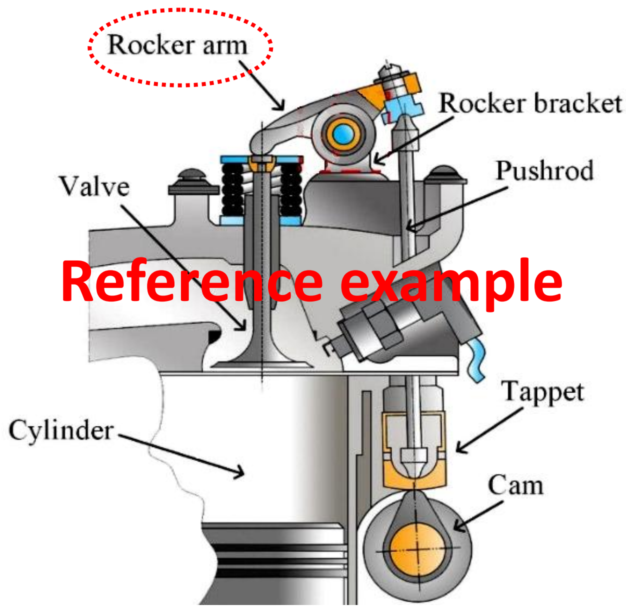


Figure 4.1.5-2 Schematic diagram of basic engine structure(source: Company W, 2025)

In addition to material properties, dimensional accuracy, and heat treatment quality, another critical factor affecting engine durability (service life) is the cleanliness of internal engine components. According to VDA (Verband der Automobilindustrie) standards, the cleanliness requirements for automotive fuel systems are defined as follows (see Table 4.1.5-1):

In the context of automotive fuel systems, aluminum particles typically begin to cause problems when their size exceeds 1,000 μm (possibly due to the oxide skin on the surface). Tin chippings already caused malfunctions if they had a size of 600 μm or more. Particles larger than 1,000 μm are not permitted because they are considered to be functionally critical to the fuel system, even if they are non-metallic (VDA 19.1, 2025).

For a production site without any environmental dust or contamination control measures, meeting this requirement is difficult to ensure.

Table 4.1.5-1 Particle size and acceptable criteria by class (VDA 19.1, 2025)

Particle size class	All particles (excluding fibers)	Particles with metallic shine
100 ≤ x < 150 μm	80	not specified
150 ≤ x < 200 μm	40	not specified
200 ≤ x < 400 μm	20	8
400 ≤ x < 600 μm	6	2
600 ≤ x < 1000 μm	2	0
x ≥ 1000 μm	0	0

4.1.6 General product processing flow

The general product processing flow of Company W is outlined as follows (see Figure 4.1.6-1). First, Company W procures raw materials from qualified suppliers and sends them to a heat treatment facility according to customer specifications. Heat treatment is primarily used to modify the mechanical properties of the material, including increasing hardness, strength, toughness, and wear resistance, or reducing brittleness and internal stress, thereby making the material suitable for specific applications or easier for subsequent machining.

After heat treatment is completed, the materials are returned to Company W for incoming quality control (IQC). Once the materials pass IQC inspection, the production management engineer issues work orders for machining operations. Upon completion of machining, the finished products are sent to a surface treatment facility for processes such as anodizing, abrasive blasting, baking paint, or deburring to alter the surface condition of the products. Finally, the products undergo final quality control (FQC) within the factory before shipment and are packaged accordingly.

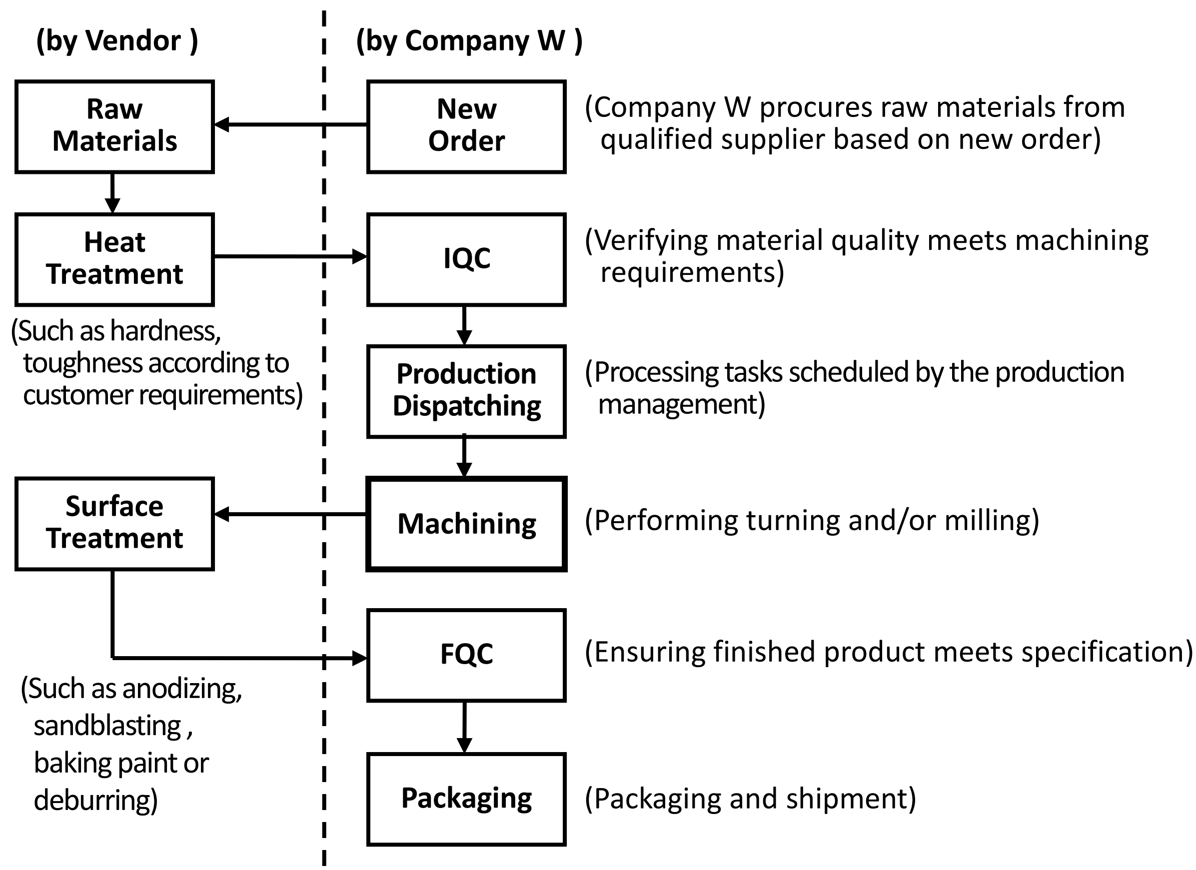


Figure 4.1.6-1 General product processing flow of Company W (2025)

Machining operations using milling machines and/or lathes—aimed at delivering high-precision and high-reliability products—constitute the core business of Company W and represent its primary source of revenue. General machining routes of Company W please refer to Figure 4.1.6-2. Rough-precision boring, using CNC machines with boring tools (or heads), is performed as required by the customer.

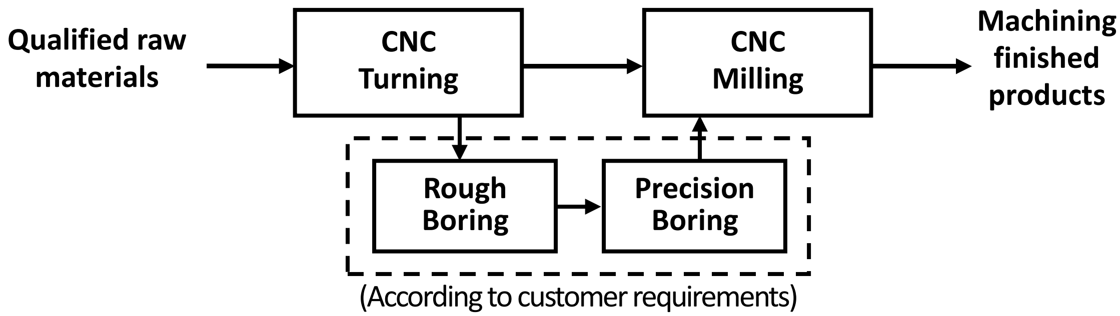


Figure 4.1.6-2 General machining routes of Company W (2025)

This study focuses on machining processes and investigates improvements in production performance and product quality within the metalworking industry, based on the IEC 62264-3 MOM reference model. Heat treatment or surface finishing operations performed by subcontractors are not the primary focus of W Company's production performance and product quality improvement efforts.

4.2 Problem Identification and Discussion

The "engine valve rocker arm" products manufactured by Company W (as shown in Figure 4.1.5-1, with the left side representing the pre-machining state and the right side the post-machining state) are critical components used in engine assembly of recreational vehicles and motorcycles by the key customer, BXP Company (refer to Figure 4.1.5-2). These components require high-dimensional precision and must exhibit long service life and high reliability to ensure optimal engine performance and durability.

4.2.1 Cause-and-effect analysis for precision control

Both Company BXP and Company W agree that the variation in inner diameter dimensional (as indicated in Figure 4.2.1-1) is the primary factor affecting product quality. Figure 4.2.1-2 presents a cause-and-effect diagram (also known as a fishbone diagram) analyzing this variation. Senior personnel from Company W's engineering, machining, and quality control departments participated in a brainstorming session to identify potential root causes with high relevance. These include (the remaining factors were minimally correlated):

a) CNC workstation machine brand (goodwill & reputation)

This includes factors such as the controller functions and performance, the machine's structural rigidity, design precision, and manufacturing quality of the equipment, all of which directly affect machining stability and dimensional consistency.

b) Equipment age and condition

The duration of equipment usage and its maintenance status influence geometric errors and positioning accuracy, thereby impacting the stability of machined dimensions.

c) Automatic compensation settings

The precision and responsiveness of the tool wear compensation settings in the CNC workstation controller play a critical role in maintaining machining dimensional accuracy.

d) Employee skills / Qualification certification

Inadequate implementation of employee technical competency and qualification certification may result in insufficient operational experience among newly recruited personnel in tool wear compensation procedures, thereby increasing the risk of compensation inaccuracies.

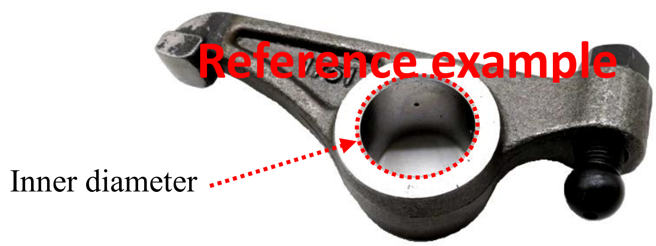


Figure 4.2.1-1 Variation analysis of inner diameter tolerance – Engine valve rocker arm

(Source: Company W, 2025)

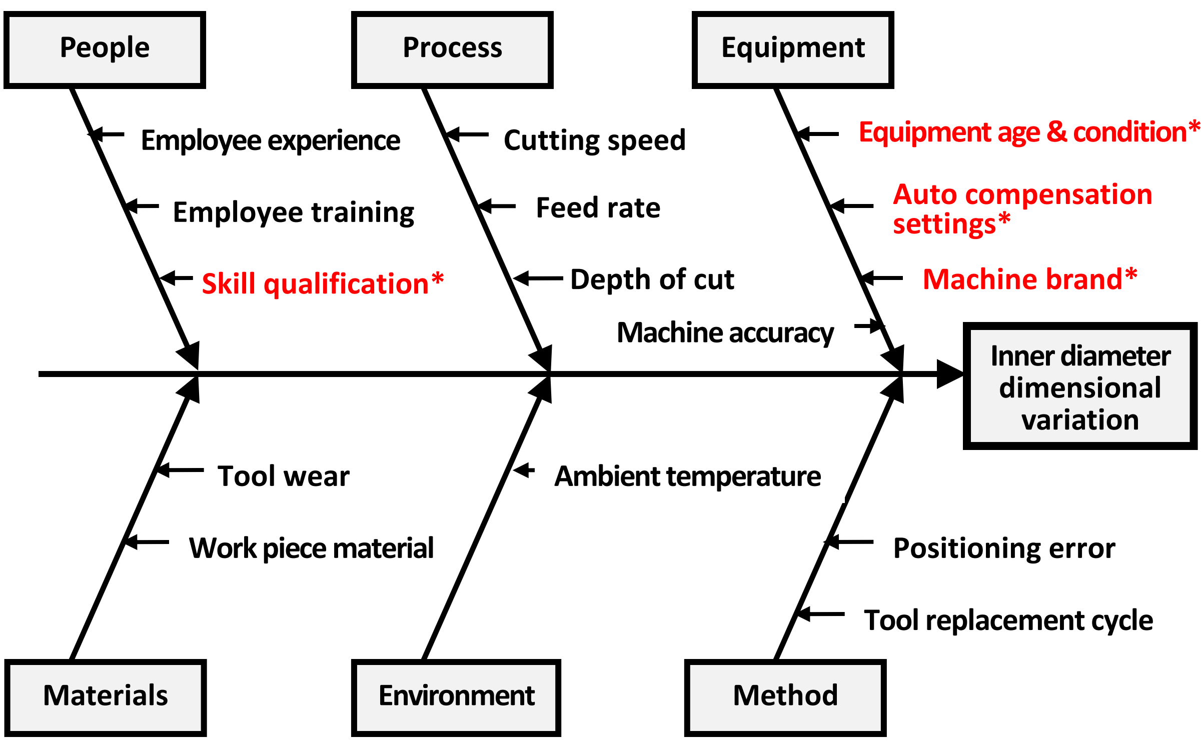


Figure 4.2.1-2 Fishbone diagram for engine valve rocker arm inner diameter variation

(source: Company W, 2025; compiled and graphed by this study)

These factors are highlighted in Figure 4.2.1-2, marked with red asterisks (*), and are considered major contributors to the production performance and quality stability of the engine valve rocker arm products, the remaining factors contributed extremely low. These factors will be incorporated into subsequent improvement measures and quality control priorities.

4.2.2 Cause-and-effect analysis for durability (service life)

The engine valve rocker arm is one of the critical components within the engine's main structural assembly. During operation, it must rock at high speed in synchronization with the engine valve and possess sufficient durability to withstand prolonged dynamic loads. Figure 4.2.2-1 presents a cause-and-effect diagram (fishbone diagram) developed to analyze the durability (service life) of this type of rocker arm product. This analysis was jointly conducted by senior personnel from Company W's Engineering, Machining, and Quality assurance departments. Through a structured brainstorming approach, the team systematically identified potential influencing factors that are highly correlated with product longevity. In addition to the previously mentioned “inner diameter dimensional variation,” the major factors identified include (the remaining factors were minimally correlated) :

a) Insufficient material rigidity.

b) Ineffective heat treatment (performed by a qualified subcontractor and not the primary focus of this study).

c) The working environment exhibited particulate and dust contaminations, with no dust-control zones established for effective isolation and management.

d) Inadequate cleaning prior to final packaging.

e) Poor design of dust-proof packaging for finished products.

These major factors have been marked with red asterisks (*) in Figure 4.2.2-1 and are considered major risk sources affecting the durability of engine valve rocker products. They will be incorporated into subsequent improvement actions and quality control priorities.

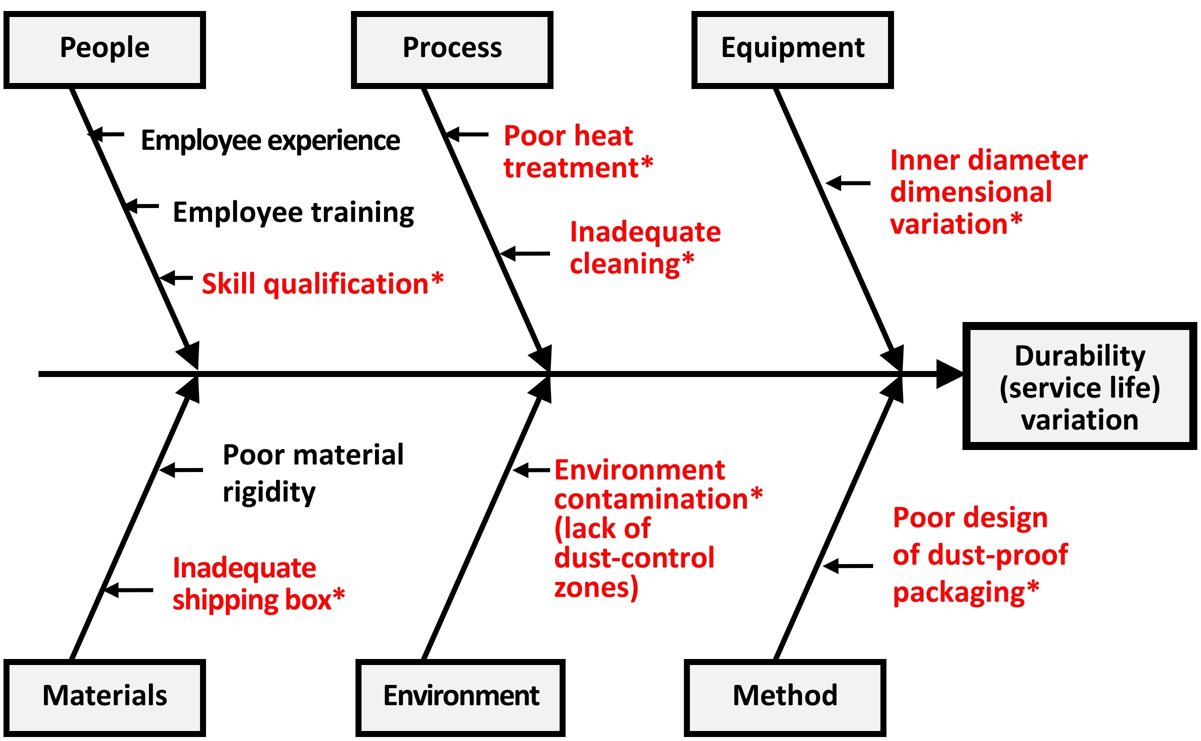


Figure 4.2.2-1 Fishbone diagram for engine valve rocker arm durability variation

(source: Company W, 2025; compiled and graphed by this study)

Note: Certain aspects of problem identification and discussion in this study involve the case company’s operational secrets and proprietary key technologies. For confidentiality reasons, these details are not disclosed or examined in depth in this paper. The related improvement measures will be planned and implemented internally by the case company, based on the framework and methodology proposed in this study.

4.3 Improvement Proposals for Existing MOM

During the previous brainstorming session, several potential factors were initially identified that may contribute to excessive variation in inner diameter tolerances and are highly correlated with product service life. As the second step, this study systematically outlines the current production process of Company W and investigates possible issues embedded within the workflow, including activities that fail to meet the requirements of MOM. Figure 4.3-1 illustrates the current production process of Company W.

This study focuses on small and medium-sized manufacturing enterprises that primarily utilize CNC lathes and milling machines for metalworking operations. Based on the MOM framework defined in IEC 62264-3, standardized models for POM and QOM are introduced.

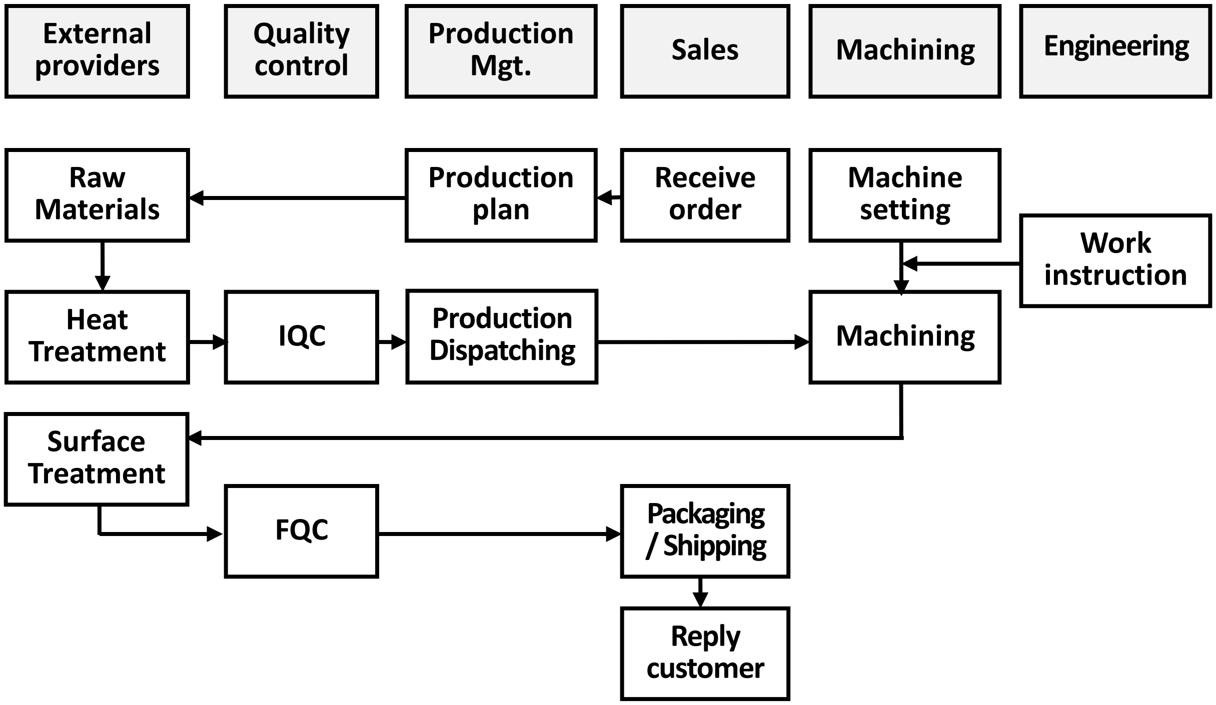


Figure 4.3-1 Existing production process flow of Company W

(source: Company W, 2025; compiled and graphed by this study)

The core objective of this study is to identify critical barriers within the POM and QOM processes that may impact production performance and product quality. Using engine valve rocker arm components as a case example, the research investigates potential factors contributing to variations in inner diameter dimensions and discrepancies in product durability (service life).

This study further proposes concrete improvement strategies and key quality control measures aimed at enhancing overall manufacturing efficiency and product durability. To achieve this, a systematic analysis of W Company's current POM processes is conducted, referencing the internationally recognized MOM framework to extract key areas within POM and QOM that require urgent improvement.

4.3.1 Improvement proposals for Company W's POM

1) Product definition management

According to IEC/ISO 62264-3, product definition encompasses basic product information, product structure, and the production route (or processing route). Company W should refine the formulation of its production routes by carefully evaluating the required machining steps and their appropriateness. This includes settings for automatic tool compensation, equipment selection (such as machine condition, processing capability, and age), to ensure that each machining step is well aligned with product requirements, thereby improving production efficiency and ensuring quality consistency.

2) Production resource management

Production resources encompass all essential elements required throughout the manufacturing process, including machinery, facilities, human resources, materials, and energy. Company W can enhance its production resource management through the following measures:

a) Implement equipment qualification and approval protocols

Ensure that selected equipment meets process requirements by adopting evaluation mechanisms such as Gauge Repeatability and Reproducibility (GR&R) analysis and equipment capability indices (e.g., Cmk), thereby improving measurement accuracy and machining stability.

b) Strengthen employee technical competencies and certification systems

Establish standardized training and qualification procedures, particularly for critical skills such as configuring automatic tool compensation parameters, to ensure personnel are capable of proper operation and adjustment.

c) Control environmental contamination in the workplace

Address potential pollutants such as dust and particulates by constructing designated clean zones and implementing effective isolation and environmental monitoring measures to maintain process cleanliness.

3) Production scheduling and dispatching

Production scheduling and dispatching for products with stringent cleanliness requirements—such as engine valve rocker arms—remains one of the major challenges for Company W. The existing production facilities and environment pose significant risks in meeting these high cleanliness standards. Company W should carefully assess and assign dedicated dust-controlled production lines, assigning these products to be manufactured within designated "clean zones." In parallel, the company should define dust concentration control standards for these work zones and implement real-time monitoring systems to continuously track environmental contamination levels. These measures ensure that process cleanliness meets the quality requirements of the product.

4) Production execution management

For products with high cleanliness requirements - such as engine valve rocker arms - Company W should strengthen final cleaning procedures before packaging. Standardized work instructions should be developed to guide production execution teams, ensuring the effectiveness and consistency of the cleaning process. In addition, a comprehensive evaluation of dust-proof packaging design should be conducted, taking into account material selection, sealing integrity, and protection level. These measures aim to effectively prevent contamination from particulates or dusts, ensuring that product cleanliness is maintained throughout subsequent storage and transportation stages.

5) Production data collection

The scope of production data collection encompasses equipment status, process data, quality records, and product traceability information. While Company W has established a preliminary mechanism for production data acquisition, further efforts are needed to enhance data integrity and analytical depth. It is recommended to incorporate the following key data elements:

a) Personnel skills and qualification records

Including multi-skilled worker competency matrices, training histories, and certification records to support workforce allocation and skill management.

b) Equipment calibration and approval information

Such as measurement system repeatability and reproducibility (GR&R), and equipment capability indices (Cmk), to ensure measurement accuracy and equipment reliability.

c) Process capability and performance analysis data

Including process capability indices (Cp, Cpk) and process performance indices (Pp, Ppk), used to evaluate process stability and quality consistency.

6) Production traceability

Production traceability serves as a preparatory measure to respond effectively to manufacturing anomalies and quality issues. Its core objective is to establish a complete and traceable data chain. Traceability data may include equipment codes, personnel identifiers, raw material batch numbers, finished product lot numbers, production date codes, quality inspection results, and shipping dates. To enable automated data collection and real-time integration, production traceability systems are typically interfaced with the following information platforms (This is also a major challenge for Company W):

a) Shop floor control (SFC)

Provides real-time monitoring of process nodes and operational workflows.

b) Laboratory information management system (LIMS)

Supports integration and analysis of quality inspection data.

c) Manufacturing execution system (MES)

Serves as the central platform, integrating key production elements - man, machine, material, method, and environment - to achieve end-to-end traceability.

Currently, Company W has significant room for improvement in its traceability mechanisms. This study recommends enhancing system integration capabilities and data structure design to improve information transparency and traceability efficiency.

7) Production performance analysis

Production performance analysis is a critical activity that quantitatively evaluates manufacturing processes and feeds the results back into enterprise management systems. The scope of analysis may include production unit cycle time, resource and equipment utilization rates, equipment performance indicators, operational efficiency, production variability, identification of stable and high-efficiency "Golden Runs," and production cost data. These analytical outcomes serve as the foundation for establishing Key Performance Indicator (KPI) reports, supporting enterprise decision-making and continuous improvement initiatives. Company W should further assess the relevance of its current production performance indicators and precisely define a KPI framework that aligns with actual production characteristics and managerial requirements, thereby enhancing the accuracy and effectiveness of performance monitoring.

A summary of key tasks in Company W's POM improvement framework is presented in Table 4.3.1-1.

Table 4.3.1-1 Summary of key tasks in Company W's POM improvement framework (source: Company W, 2025; compiled by this study)

POM activities	POM key tasks
1) Product definition management	Refine production routing accuracy by systematically analyzing each required processing step and its alignment with the overall manufacturing workflow. This involves configuring machine auto-compensation parameters and selecting equipment that best matches process requirements.
2) Production resource management	Enhance production resource management through the following measures: a) Establish equipment qualification and approval protocols. b) Strengthen employee technical competency and certification systems. c) Control environmental contamination in the workplace. d) Enforce the final product cleaning procedure before packaging.
3) Detailed production scheduling and 4) Production dispatching	a) Carefully assess and assign dedicated dust-controlled production lines. b) Define dust concentration control standards for the clean zone.

	c) Implement real-time monitoring systems to continuously track environmental contamination levels.
5) Production execution management	a) Optimize pre-packaging cleaning procedure. b) Perform a holistic assessment of dust-proof packaging design.
6) Production data collection	It is recommended to incorporate the following key data elements: a) Personnel skills and qualification records. b) Equipment qualification and approval data. c) Process capability and performance analysis data.
7) Production tracking	This study recommends enhancing system integration capabilities and data structure design, with the timely implementation of the following systems: a) Shop floor control system (SFC). b) Laboratory information management system (LIMS). c) Manufacturing execution system (MES).
8) Production performance analysis	Conduct a comprehensive evaluation of its current production performance indicators to ensure alignment with operational realities and strategic goals. Key metrics may include: • Production unit cycle time. • Resource and equipment utilization rates. • Equipment performance indicators (e.g., OEE). • Operational efficiency across production stages. • Production variability and process stability. • Identification of high efficiency "Golden runs". • Detailed production cost data and cost-per-unit analysis.

4.3.2 Improvement proposals for Company W's QOM

1) Quality test definition management

According to IEC 62264-3, the definition of quality tests encompasses key elements specified in the work master, including test procedures, sampling frequency (sampling plans), and technical specifications for materials and resources (including tolerance ranges). This definition supports the standardization of product quality control, ensuring consistency and traceability across testing activities. Company W should carefully evaluate its current quality test management framework, particularly for items requiring high precision or involving critical dimensions. It is recommended to establish accurate control limits and incorporate them into the work master to enhance the precision and consistency of quality control.

2) Quality test resource management

Quality test resource management refers to a series of systematic activities aimed at effectively allocating and coordinating the resources required for executing quality tests and managing their interrelationships. These resources can be categorized into three main groups: test materials, test equipment, and test personnel. Through standardized management practices, testing efficiency and accuracy can be improved, while traceability in quality control is strengthened.

For Company W's current quality test resource management framework, it is recommended to enhance the competency of quality personnel in applying the six exemplary quality tools: APQP (Advanced product quality planning), SPC (Statistical process control), MSA (Measurement system analysis), FMEA (Failure mode and effects analysis), PPAP (Production part approval process), and CP (Control plan).

These tools are standardized methodologies developed by the Automotive Industry Action Group (AIAG), known for their high practicality and operational applicability. It is advised that Company W adopt a structured approach by referencing the official AIAG manuals for each tool, conducting targeted training, and institutionalizing their implementation to improve the overall effectiveness and technical maturity of quality test resource management.

3) Quality test scheduling and dispatching

Quality test scheduling refers to a series of systematic activities designed to effectively plan and allocate the resources required for quality testing operations. The scheduling process must consider on-site conditions, resource availability, test preparation tasks, and testing priorities to ensure a smooth and traceable workflow.

Dispatching focuses on clearly communicating the testing tasks and the required resources. It may also include the logistical arrangement for transporting test materials to the designated testing equipment or personnel. This process contributes to improved accuracy and consistency in test execution.

To improve the current quality test scheduling and dispatching mechanism at Company W, it is recommended to strengthen the completeness of the quality test definition. The definition should, at a minimum, include the following elements:

a) Test procedures**:**

Clearly define each testing step and method based on the master work file.

b) Test frequency

Establish a standardized sampling plan, including transition rules between tightened, normal, and reduced inspection levels.

c) Material and resource specifications

Specify material characteristics, equipment capabilities, and personnel qualifications, along with acceptable tolerance ranges.

Structured management of the above information will enhance the accuracy and efficiency of scheduling and dispatching, while also supporting subsequent quality analysis and continuous improvement efforts.

4) Quality test execution management

Quality test execution management aims to ensure that testing activities are conducted using appropriate resources - including equipment, materials, and personnel - and are performed in accordance with established quality testing standards and procedures. This management mechanism supports enhanced consistency, accuracy, and assurance of product quality, serving as a critical basis for release decisions under defined conditions.

To strengthen W Company's current quality test execution process, the following two key areas are recommended:

a) Establish durability testing methods

Conduct technical evaluations focused on product durability characteristics and develop standardized testing methods to improve the scientific rigor and reproducibility of reliability verification.

b) Test instructions improvement

Based on defined quality testing requirements, prepare detailed test instructions that clearly specify testing procedures and methods, acceptance criteria, measurement uncertainty, and resource utilization guidelines. These instructions should serve as a reference for quality testing personnel to ensure consistent execution.

By implementing the above measures, Company W can noticeably enhance the standardization and operational consistency of its quality testing activities, thereby reinforcing the credibility of product release decisions.

5) Quality test data collection

The core objective of quality test data collection is to systematically capture and consolidate test results, ensuring traceability and enabling subsequent analysis, improvement, and decision-making. Data sources may include manually entered records as well as automatically acquired data from equipment, both of which must be accurate and consistent.

To enhance Company W's current quality test data management practices, it is recommended to strengthen the evaluation and collection of the following data types:

a) Equipment qualification and approval data

This includes measurement system analysis (e.g., gauge GR&R) and equipment capability indices (e.g., Cmk), to ensure that testing equipment meets required levels of accuracy and stability.

b) Process capability and performance analysis data

This includes statistical indicators such as Cp, Cpk, Pp, and Ppk, which are used to assess process stability and conformance.

By implementing structured collection and management of the above data, Company Wcan improve the scientific rigor of its quality testing and strengthen the credibility of its manufacturing quality assurance.

6) Quality test traceability

Quality test traceability aims to systematically record and manage various testing activities conducted across different time points and stages of the manufacturing process. Test data can be categorized based on its purpose and level of completion:

- Final data: Approved data that can be distributed both internally and externally, serving as a basis for quality verification and decision-making.
- Intermediate data: Data that has not yet completed the full testing process, intended for internal reference only or requiring further validation.

To enhance data traceability and real-time responsiveness, quality test traceability can be integrated with the following systems:

a) Laboratory information management system (LIMS):

Supports sample management, test scheduling, and result recording.

b) Manufacturing execution system (MES):

Connects process nodes with quality inspection activities, enabling automated data capture and process monitoring.

Currently, Company W has significant growth potential in the integration of quality test traceability systems and data management. It is recommended to implement documented testing workflows and data classification structures, and to strengthen interoperability between LIMS and MES systems to improve overall traceability capabilities.

7) Quality performance analysis

Quality performance analysis may encompass the following key aspects: quality variability, cycle time of the quality department, utilization of inspection equipment, and efficiency of inspection operations. This analysis is a continuous business process aimed at identifying improvement opportunities and supporting decision-making. The results can be further utilized to establish Key performance indicator (KPI) reports for quality management, enabling quantification of performance and tracking of improvement outcomes.

It is recommended that Company W conduct a comprehensive evaluation of its quality performance indicators and precisely establish representative KPIs aligned with the company's specific needs, such as:

- FTQ (First time quality).
- Inspection error rate.
- Expedited inspection efficiency.
- Customer complaint resolution efficiency.

By implementing standardized metrics and continuous monitoring mechanisms, Company W can effectively enhance quality performance and operational resilience.

A summary of key tasks in Company W's QOM improvement framework is presented in Table 4.3.2-1.

Table 4.3.2-1 Summary of key tasks in Company W's QOM improvement framework (source: Company W, 2025; compiled by this study)

QOM activities	**QOM key tasks**
1) Quality test definition management	a) Conduct an assessment of the current quality testing management framework, with particular focus on items requiring high precision or involving critical dimensions. b) Corresponding control limits should be accurately defined based on statistical analysis and process capability indices (e.g., Cpk) and incorporated into the master routing or test definition file to ensure standardized and consistent quality control.
2) Quality test resource management	Strengthen the competency of quality personnel in the effective application of the six core quality tools: ● APQP (Advanced Product Quality Planning), ● SPC (Statistical Process Control), ● MSA (Measurement System Analysis), ● FMEA (Failure Mode and Effects Analysis), ● PPAP (Production Part Approval Process), and ● CP (Control Plan).

3) Detailed quality test scheduling and 4) Quality test dispatching	Enhance the completeness of quality test definitions. At a minimum, it should include the following key elements: a) Test Procedures Clearly define each testing step and method, referencing the master work file to ensure consistency and traceability. b) Test Frequency Establish a standardized sampling plan, including transition criteria between tightened, normal, and reduced inspection levels, in alignment with applicable quality standards. c) Material and Resource Specifications Specify material characteristics, equipment capabilities, and personnel qualifications, along with acceptable tolerance ranges.
5) Quality test execution management	It is recommended to strengthen the evaluation and collection of the following data elements: a) Equipment Qualification and Approval Data Include measurement system analysis (e.g., gauge GR&R) and equipment capability indices (e.g., Cmk) to ensure that testing equipment meets the required levels of accuracy and stability. b) Process Capability and Performance Analysis Data Include statistical indicators such as Cp, Cpk, Pp, and Ppk to assess process stability and conformance to specifications.
6) Quality test data collection	It is recommended to incorporate the following key data elements: a) Equipment qualification and approval data. b) Process capability and performance analysis data.

7) Quality test tracking	This study recommends enhancing system integration capabilities and data structure design, with the timely implementation of the following systems: a) Laboratory information management system (LIMS). b) Manufacturing execution system (MES).
8) Quality test performance analysis	It is recommended that Company W conduct a comprehensive evaluation of its quality performance indicators and establish representative KPIs with precision, such as: ● FTQ (First time quality). ● Inspection error rate. ● Expedited inspection efficiency. ● Customer complaint resolution efficiency.

4.4 Reengineering the Manufacturing Management Process

In the first two steps, potential deficiencies in POM and QOM at Company W were preliminarily identified, along with corresponding improvement proposals. The third step focuses on integrating key activities from the MOM reference model into the current manufacturing process to enable process reengineering in response to the identified issues. Newly added or modified activities are highlighted with red or blue borders for easy identification. Figure 4.4-1 illustrates the reengineered manufacturing process of Company W.

The reengineering of Company W's manufacturing process also aligns with the generic activity model of MOM, comprising eight activities: (1) Definition management, (2) Resource management, (3) Detailed scheduling, (4) Dispatching, (5) Execution management, (6) Data collection, (7) Tracking, and (8) Performance analysis. Within the flow chart, each of the eight activities is denoted by a number in parentheses.

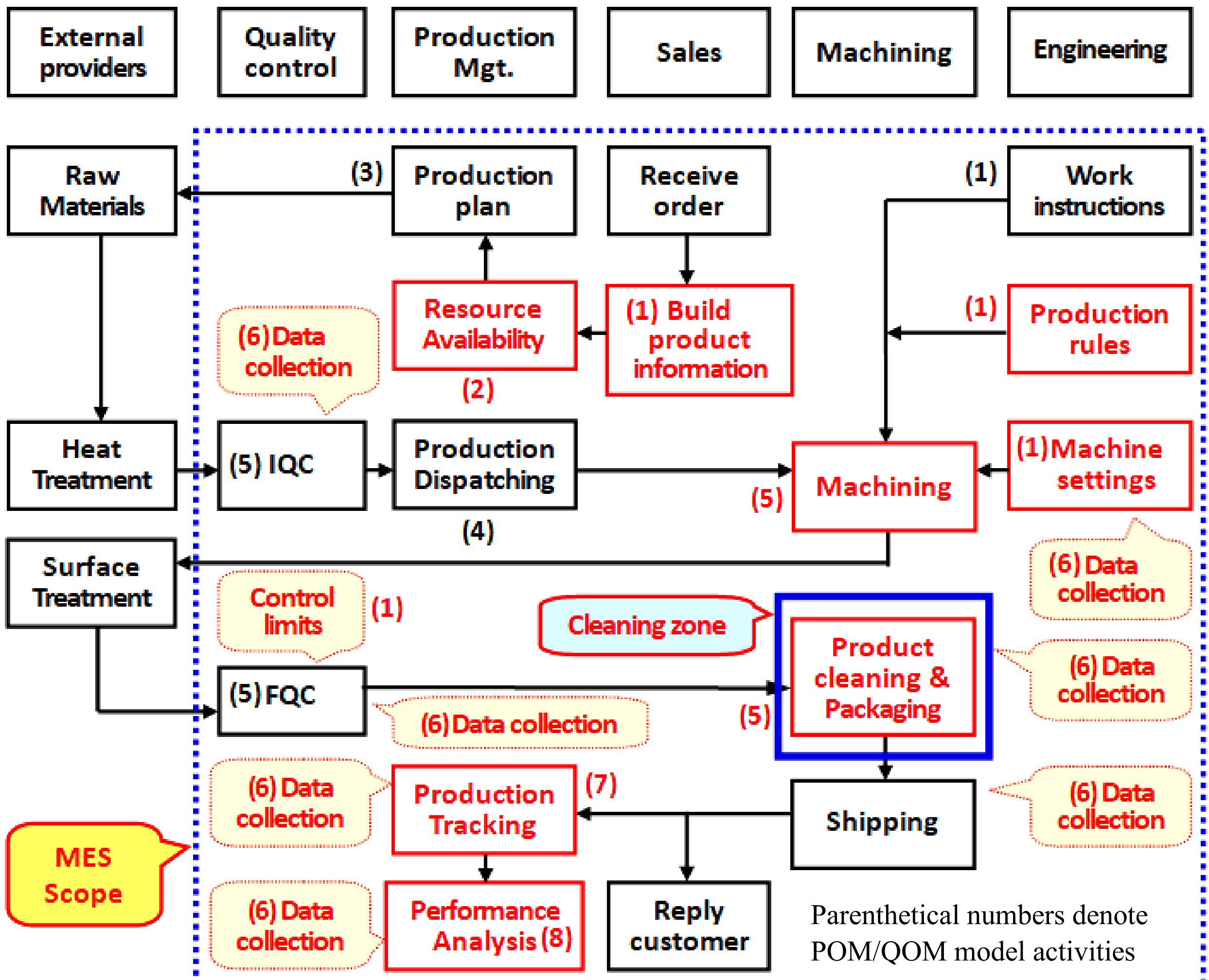


Figure 4.4-1 Reengineering the manufacturing process flow of Company W

(source: Company W, 2025; compiled and graphed by this study)

The core of Company W's reengineering process lies in a systematic analysis of possible issues embedded within the current workflow and the identification of operational activities that fail to meet the requirements of MOM. The key improvement initiatives are as follows:

1. Addition of critical operational activities

To fulfill MOM requirements, the following activities have been added or enhanced: a) Establishment of product definitions and product information. b) Configuration of production rules. c) Assurance of resource availability, including equipment, facilities, human resources, materials, and energy. d) Implementation of production tracking and traceability mechanisms. e) Execution of performance analysis for production and quality. f) Enhancement of data collection and management related to manufacturing and quality operations.

2. Data collection

a) Production-related data**,** as required, may include but is not limited to the following:

Personnel qualification/approval records; Raw material lot number & quantity; Operator ID code; Machine ID code; Equipment approval records; Machine setup parameters; Production status; Finished product serial number; Product shipping lot number & quantity; Production performance indicators (KPI) – such as, Overall Equipment Effectiveness (OEE), C_{mk} , and other related indicators.

b) Quality testing-related data, as required, may include but is not limited to the following:

Personnel qualification/approval records; Inspector ID code; Incoming material inspection records; Outgoing/shipment inspection records with control limits; Instrument calibration records; Quality indicators (KPI) – such as, Inspection error rate, FTQ, C_{pk}, P_{pk}, Gauge GR&R, and other related indicators.

The Production Management Department assigns work based on approved equipment (Machine ID code), workforce lists (Personnel ID code), and materials that have passed IQC inspection (Part number, Lot number, and Quantity). Engineers are responsible for completing and recording equipment parameter settings; the Machining Department provides feedback on production status; FQC issues product inspection reports and controls machining accuracy according to control limits. The Cleaning and Packaging stations must identify product lot numbers, quantities, and serial numbers for shipment tracking. Finally, the Production Management Department consolidates and analyzes the collected data to perform KPI evaluation.

3. Dust control for precision components

A dedicated dust-controlled area for precision parts will be established, along with improved pre-packaging cleaning procedures and dust-proof packaging design, to enhance product cleanliness and protective performance.

4. Machine settings management

Equipment setup tasks are reassigned to certified engineers within the engineering department to reduce process deviations and quality risks caused by improper machine settings.

5. Definition of control limits for precision dimensions

Control limits for critical dimensions are defined by considering measurement uncertainty and variation within the measurement system, thereby improving reliability and decision accuracy.

6. Modular implementation of a local MES system

A modular MES with integrated production and quality tracking capabilities will be introduced to support real-time monitoring, traceability, and alignment with MOM architecture.

4.5 Feasibility Assessment and Feedback

4.5.1 Feasibility assessment

To specifically evaluate the feasibility of the improvement strategies, this study uses the engine valve rocker arm product manufactured by Company W as a case example. An evaluation team formed by Company W conducted a systematic comparison and feasibility assessment between the current state of MOM and the improvement recommendations proposed in this study for POM and QOM.

The evaluation team is composed of senior personnel from each department of W Company, including the chief executive officer (leader), engineering, machining, quality control, production management, sales, and administration (covering human resources and general affairs). The team members with cross-functional expertise, enabling them to effectively support the comprehensiveness and depth of the evaluation process.

Each evaluation result is categorized referring to the VDA "traffic light system," based on compliance level, satisfaction degree, or risk severity. It defines three levels:

- Red light: Indicates non-compliance, extreme dissatisfaction, or high risk.
- Yellow light: Indicates partial compliance, moderate satisfaction, or medium risk.
- Green light: Indicates full compliance, high satisfaction, or low risk.

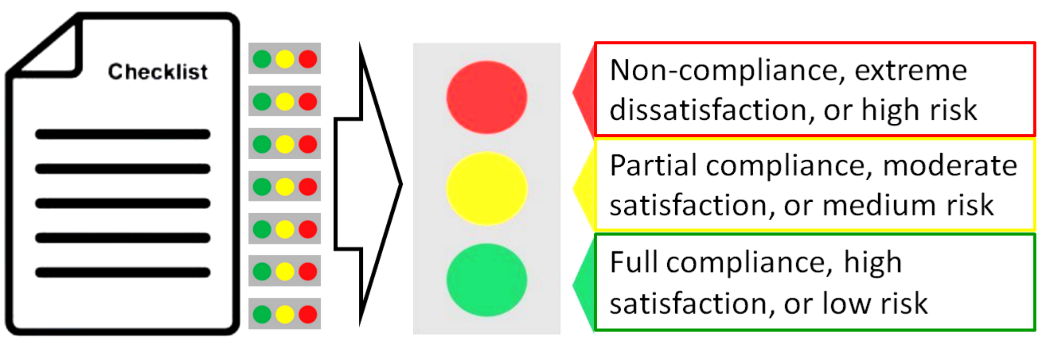


Figure 4.5.1-1 Definition of traffic-light colors for assessment

(source: VDA MLA, 2022; graphed by this study)

This classification mechanism enhances evaluation efficiency, improves consistency in judgment, and supports prioritization in subsequent improvement actions. (VDA MLA, 2022; VDA 6.3, 2023; VDA 6.8,2024.,)

A systematic comparison and effectiveness evaluation were conducted between the current state of MOM and the improvement proposals proposed in this study for POM and QOM. The consolidated results are presented in Table 4.5.1-1 and Table 4.5.1-3, serving as a basis for validating the feasibility and practical applicability of the proposed improvement strategies.

Table 4.5.1-1 Overview of Company W's POM evaluation results

(source: Company W, 2025; compiled by this study)

POM Activities	**POM Assessment items**	**Current situation**	**This study proposal**
1) Product definition management	a) Production routing (machining steps and their appropriateness)	🟡	🟢
2) Production resource management	a) Equipment qualification and approval protocols.	🟡	🟢
	b) Employee technical competency & certification systems.	🟡	🟢
	c) Control environmental contamination in the workplace.	🔴	🟢
3) Detailed production scheduling; 4) Production dispatching	a) Assign dedicated dust-controlled production lines.	🔴	🟡
	b) Define dust concentration control standards.	🔴	🟢
	c) Real-time contamination levels monitoring systems.	🔴	🟢

5) Production execution management	a) Pre-packaging cleaning procedure.	🟡	🟢
	b) Dust-proof packaging design.	🟡	🟢
6) Production data collection	a) Personnel skills and qualification records.	🟡	🟢
	b) Equipment qualification and approval data.	🟡	🟢
	c) Process capability & performance analysis data.	🟡	🟢
7) Production tracking	a) System integration and data structure design	🔴	🟢
8) Production performance analysis	a) Alignment of production performance indicators with operational realities and strategic objectives	🟡	🟢

Table 4.5.1-2 Summary of Company W's POM evaluation targests and results

(source: Company W, 2025; compiled by this study)

POM Assessment	**Current situations**		**This study proposals**		**This study targets**	
Assessment results	🟢	**0**	🟢	**13**	🟢	not specified
	🟡	**9**	🟡	**1**	🟡	**< 3**
	🔴	**5**	🔴	**0**	🔴	**0**

Summary of POM evaluation results by Company W (see Table 4.5.1-1 and Table 4.5.1-2)

This study was conducted in alignment with Company W's expectations, targeting zero red-light indicators and fewer than three yellow-light indicators. An assessment of the current state of POM revealed 5 red-light indicators and 9 yellow-light indicators, indicating that several operational areas require improvement. After implementing the POM improvement strategies proposed in this study, the evaluation results shifted to 1 yellow-light and 13 green-light indicators. This outcome demonstrates the high valuable and practical feasibility of the proposed strategies, meet the study target and significantly enhancing operational management performance.

Table 4.5.1-3 Overview of Company W’s QOM evaluation results

(source: Company W, 2025; compiled by this study)

QOM Activities	**QOM Assessment items**	**Current situation**	**This study proposal**
1) Quality test definition management	a) Quality testing framework for high-precision-machined parts.	🟡	🟢
	b) Define control limits for high-precision or critical dimensions.	🔴	🟢
2) Quality test resource management	a) The proficiency of quality personnel in applying core quality tools effectively.	🟡	🟢
3) Detailed quality test scheduling; 4) Quality test dispatching	a) The completeness of quality test definitions.	🟡	🟢
5) Quality test execution management	a) Evaluation and analysis of equipment qualification (e.g., gauge GR&R and Cmk).	🟡	🟢
	b) Evaluation and analysis of process capability and process performance (e.g., Cp, Cpk, Pp, and Ppk).	🟡	🟢

6) Quality test data collection	a) Equipment qualification & approval data.	🟡	🟢
	b) Process capability and process performance analysis data.	🟡	🟢
7) Quality test tracking	a) System integration of production data and quality data tracking.	🔴	🟢
8) Quality test performance analysis	a) Alignment of quality performance indicators with operational realities and strategic objectives.	🟡	🟢

Table 4.5.1-4 Summary of Company W’s QOM evaluation targests and results

(source: Company W, 2025; compiled by this study)

QOM Assessment	**Current situations**		**This study proposals**		**This study targets**	
Assessment results	🟢	**0**	🟢	**10**	🟢	not specified
	🟡	**8**	🟡	**0**	🟡	**< 3**
	🔴	**2**	🔴	**0**	🔴	**0**

Summary of QOM evaluation results by Company W (see Table 4.5.1-3 and Table 4.5.1-4)

This study was conducted in alignment with Company W’s expectations, targeting zero red-light indicators and fewer than three yellow-light indicators. An assessment of the current state of QOM revealed 2 red-light indicators and 8 yellow-light indicators, indicating that several operational areas require improvement. After implementing the POM improvement strategies proposed in this study, the evaluation results shifted to 10 green-light indicators. This outcome demonstrates the high valuable and practical feasibility of the proposed strategies, meet the study target and significantly enhancing operational management performance.

4.5.2 Feedback from Company W

Company W expressed strong affirmation of the proposals proposed in this study, recognizing their high practical relevance and reference value. The findings support the adoption of internationally recognized MOM frameworks, enabling the establishment of standardized workflows for POM and QOM. These proposals serve as a valuable reference for small and medium-sized manufacturing enterprises seeking to enhance production performance and product quality management.

The specific feedback from Company W regarding the proposals of this study is as follows:

a) Machine setting management

Currently, the automatic compensation function is setup by on-site operators. However, due to the large number of personnel and high turnover rate, variations in experience and technical proficiency often lead to inconsistent settings and process deviations. To improve setup accuracy, Company W is considering assigning this task to certified engineers from the Engineering department, thereby reducing the risk of errors and deviations caused by improper machine settings.

b) Planning for a dust-controlled zone setup

Considering personnel flow, material logistics, and financial resources, Company W initially plans to implement a basic dust control measure by using plastic sheeting to isolate the existing work area. This approach aims to achieve fundamental dust protection. In the future, depending on resource availability and operational needs, the Company Will further evaluate the establishment of a cleanroom with a higher cleanliness level to enhance environmental control, improve process stability, and ensure product quality.

c) Pre-Packaging cleaning and dust-proof packaging design

Currently, products are cleaned using an air gun and then placed into zip-lock bags for basic dust protection. In the future, Company W plans to adopt ultrasonic cleaning followed by drying, and subsequently apply vacuum sealing using protective pouches before placing the products into packaging boxes. This approach aims to enhance cleanliness, reduce particulate contamination risks, and improve protection during transportation and storage.

d)Definition of control limits for precision dimensions

In this case, the OEM specifies the dimensional specification for the inner diameter of the engine valve rocker arm as ϕ12.000 mm, with a tolerance range of -10 μm to -40 μm. A negative-only tolerance is applied due to the tendency of the inner diameter to increase over time with usage. Currently, Company W follows the OEM specification for process control. However, moving forward, the company plans to incorporate factors such as measurement uncertainty and measurement system variation. Based on statistical analysis, the control limits will be redefined to a narrower range of -15 μm to -35 μm. Systematic offline sampling inspections will be conducted by the Final Quality Control (FQC) team. If any sample approaches the control boundaries, the Engineering department will be notified immediately for corrective action or process adjustment, to prevent the generation and outflow of defective products.

e) Planning for production and quality tracking improvements

Currently, production and quality data are recorded manually, without an integrated management system, resulting in information gaps and limited traceability. Based on the proposals of this study, Company W is evaluating local MES providers suitable for small and medium-sized metalworking enterprises. The key evaluation criteria include:

- Modular implementation

  The MES should support phased deployment, allowing gradual expansion based on budget and operational needs.

- Quality traceability functions

  The system must comply with VDA and APQP requirements, featuring modules for quality history and batch tracking.

- Interface and local support

Considering the need for technical assistance during the initial implementation phase, preference will be given to vendors offering Chinese-language interfaces and local consulting services.

The following local MES vendors have been shortlisted for consideration (Table 4.5.2-1):

Table 4.5.2-1 Local MES vendors have been shortlisted for consideration

(source: Company W, 2025; compiled by this study)

Brand Name	**Key Modules & Advantages**	**Price Range (USD)**	**Remarks**
DINGHUA Smart MES	Highly customizable; machine connectivity; work order tracking; quality traceability; full Chinese UI	Approx. $10,000–$50,000	Modular deployment; ideal for CNC workshops
ARES ciMES	Production scheduling; quality management; equipment integration; analytics; VDA/ISO support	Approx. $15,000–$50,000	Suitable for precision machining and multi-stage processes

Conclusion:

This chapter presents an in-depth analysis of the embedded issues and improvement strategies in MOM at a small-to-medium-sized machining factory - Company W. It examines the root causes and the structure of the current manufacturing process. After identifying potential deficiencies in POM and QOM, this study applied the internationally recognized MOM framework to systematically reengineer Company W's manufacturing process. Following a comprehensive evaluation by key departments - including the CEO, Engineering, Machining, Quality assurance, Production management, Sales, and Administration (covering Human resources and General affairs) - the proposed improvement strategies and reengineered process have received strong recognition and endorsement. A dedicated project team has been formally established to drive subsequent implementation. This study outcome surpassing the case company's expectations, achieving the study target, and significantly improving operational management performance—laying a solid foundation for future enhancements in production and quality operations management.

CHAPTER V: CONCLUSION AND DISCUSSION

Production performance and product quality are core indicators of operational effectiveness in the manufacturing industry. This study adopts the internationally standardized framework of MOM as a reference model to systematically examine the current state of POM and QOM in small-to-medium-sized machining enterprises and proposes targeted improvement strategies.

Focusing on a representative SME—Company W—this study investigates the underlying issues and improvement needs within its manufacturing operations, analyzing both root causes and the structure of its existing production processes. Based on the deficiencies identified in POM and QOM, the study applies the MOM framework to conduct a systematic process reengineering of Company W's manufacturing workflow.

Following a joint evaluation by senior personnel across multiple departments - including the CEO - Company W has preliminarily endorsed the proposed improvement strategies and reengineered process framework, laying a solid foundation for future implementation. The study outcome demonstrates the high valuable and practical feasibility of the proposed strategies, exceeding the case company's expectations and meet the study target and significantly enhancing operational management performance. laying a solid foundation for the subsequent implementation of production and quality operations management improvements.

5.1 Research Contributions

Despite the increasing availability of digital tools, many SMEs still face multiple challenges in implementing a comprehensive MOM system. These challenges include insufficient information technology expertise and difficulties in integrating digital systems with existing shop-floor workflows. Therefore, there is an urgent need for a model that combines international standards with practical applicability to help these enterprises progressively strengthen their MOM processes.

The standardized POM and QOM models, established under the IEC 62264 MOM framework, can serve as a reference architecture for SMEs to optimize their production performance and quality-related workflows. By aligning existing operations with internationally recognized models, enterprises can gradually embed consistency, traceability, and accountability mechanisms into their production and quality management practices.

For SMEs engaged in metalworking operations using CNC lathes and milling machines—often operating in highly competitive markets, there is a constant demand to deliver high-performance, high-quality precision components that meet stringent dimensional tolerances and ensure long service life. Such components are widely used in applications including automobiles, motorcycles, robots, and medical equipment. For these enterprises, adopting internationally standardized MOM is particularly critical.

This study adopts a small-sized machining factory as a case example. By applying the constructed reference model and implementation guidelines, carried out process reengineering, contributing to the following:

1. Provide SMEs with a standardized framework for executing and managing production and quality-related operations.
2. Facilitate information integration and consistency in the processing of production and quality data.
3. Enable SMEs to adjust existing processes in alignment with the standard model, thereby preparing for the future implementation of MOM and MES.
4. Demonstrating a successful POM and QOM improvement case that exceeded the case company's expectations and fulfilled the study objectives.

The POM and QOM improvement strategies and process reengineering plan proposed in this study have received strong recognition and endorsement from W Company, exceeding the case company's expectations and meet the study target, laying a solid foundation for subsequent implementation. Furthermore, the proposed improvement methodology developed in this study can also serve as a reference for other small and medium-sized enterprises seeking to optimize their MOM.

5.2 Research Limitations

This study is subject to certain limitations in its analysis and findings due to the following objective and subjective factors:

1. The primary research target of this study is a single case company. Although the proposed improvement methodology offer substantial reference value for most SMEs, the research findings and conclusions may not be fully applicable to all SMEs.
2. The research subjects and information sources are primarily derived from the case company. In consideration of confidentiality, and without compromising the research motivation or methodology, no in-depth investigation was conducted into aspects related to its operational secrets and proprietary key technologies.
3. Long-term and continuous improvement is essential for enhancing POM/QOM. The findings of this study have been highly recognized and affirmed by the case company; however, due to time constraints, the study was unable to track and evaluate the outcomes of the subsequent improvement actions implemented by the case company.
4. Without compromising the research motivation and methodology, this study obtained sufficient information related to the supplier and customer sides; however, certain limitations remain. As a result, a comprehensive understanding of the actual operations

and complete information of the overall supply chain could not be fully achieved, which imposed some constraints on the breadth and depth of the analysis and discussion.

5.3 Future Research

This study focuses on two key domains within the MOM framework: POM and QOM. Based on the research findings and analysis, the following topics are proposed as directions for future exploration, with the aim of contributing to the ongoing development and improvement of MOM for SMEs :

1. Extending the research scope to include Maintenance Operations Management (MTOM) and Inventory Operations Management (IOM).
2. Extend the research scope to encompass the follow-up tracking and evaluation of the case company's subsequent improvement actions; where financial considerations are involved, incorporate analyses of improvement costs and benefits, in order to enhance the completeness and coherence of the research findings.
3. Expanding the research scope to encompass the external supply chain, thereby covering a more comprehensive manufacturing and operational ecosystem.
4. To focus on improving the case company's POM/QOM, this study did not explore the interface relationships among the eight POM/QOM activities in depth, which remains a direction for future research.

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