Chapter 1

4th Industrial Revolution Smart Factory Innovation Activities

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1.1 Smart Factory Based on the Fourth Industrial Revolution

(1) Overview of Implementation

The Fourth Industrial Revolution (Industry 4.0) is an industrial innovation paradigm that intelligentizes manufacturing, services, and industries as a whole, based on digital technologies such as ① AI (Artificial Intelligence) and the Internet of Things, ③ Big Data, ④ Cloud, ⑤ Robotics, and ⑥ Cyber Physical Systems (CPS).

A Smart Factory is a core embodiment of this Fourth Industrial Revolution; it is an intelligent manufacturing system that connects production facilities with information systems to enable the factory to independently collect, analyze, judge, and optimize data.

In other words, it is a future-oriented manufacturing innovation system that realizes ① Automation, ② Digitalization, ③ Connectivity, ④ Intelligence, and ⑤ Autonomy. In particular, the plant or process industry has significant characteristics such as ① continuous processes, ② large-scale facilities, ③ high energy consumption, and ④ the importance of process safety, so smart factory-based manufacturing innovation becomes the core of manufacturing competitiveness.

(2) Definition of the Fourth Industrial Revolution

1) Definition

The Fourth Industrial Revolution refers to a new stage of industrial revolution that realizes hyper-connectivity and hyper-intelligence-based industrial innovation by integrating digital technology with physical manufacturing systems.

2) Key Features

① Hyper Connectivity: Refers to an environment where connections go beyond people to people, and all entities including people, objects, devices, and machines are densely connected through networks to interact in real time.

② Super Intelligence: Refers to an intelligent system where Artificial Intelligence (AI) and Big Data combine to surpass or assist human learning, reasoning, and judgment capabilities.

③ Smart Automation: Going beyond traditional mechanical and simple repetitive automation, it refers to an intelligent automation system where AI and the Internet of Things (IoT) combine to enable machines to independently recognize situations, make judgments, and learn to derive optimal results.

④ Big Data Analytics: Refers to a core driving force that creates new value and economic momentum through hyper-connectivity and super-intelligence, going beyond simply processing vast amounts of data.

⑤ Autonomous Operation: Refers to an intelligent autonomous control system in which artificial intelligence (AI), the Internet of Things (IoT), and big data are combined to enable machines or systems to independently recognize and judge situations, derive optimal results, and execute them without direct human intervention.

(3) Stages of Industrial Revolution Development and Characteristics

① 1st Industrial Revolution: Machinery

② 2nd Industrial Revolution: Mass Production

③ 3rd Industrial Revolution: Automation

④ 4th Industrial Revolution: Intelligence

(4) Definition of Smart Factory

1) Definition

A smart factory refers to an intelligent factory that optimizes the entire production process in real time by connecting equipment, processes, logistics, quality, and energy based on IoT and AI.

2) Main Objectives

① Productivity Improvement: Productivity per person, productivity per hour, productivity added

② Quality Stabilization: Zero Defects, ③ Breakdown-Free: Breakdown Zero

④ Energy Saving: Energy Cost Saving

⑤ Safety Assurance: Achieving Zero Accidents (Smart SHE)[1)]

(5) Key Components of a Smart Factory

① IoT: Real-time data collection, ② AI: Analysis, prediction, and judgment

③ Big Data: Manufacturing data analysis, ④ CPS: Cyber Physical System

⑤ Cloud: Integrated platform, ⑥ Robotics: Smart automation

(6) Characteristics of Smart Factory Operation

① Production: Smart Production (an intelligent production method where all equipment and systems within the factory are connected to IoT and AI, allowing them to independently assess situations based on data and optimize manufacturing processes).

② Quality: AI Quality Control (referring to an intelligent manufacturing paradigm that integrates the Internet of Things (IoT), big data, and artificial intelligence to predict and prevent defects in the production process in advance, and to inspect and automatically control quality in real-time using visual data).

③ Equipment: Predictive Maintenance (a maintenance strategy that utilizes IoT sensors and AI to collect and analyze equipment data in real-time to predict failure times and take preemptive measures).

④ Logistics: Smart Logistics (a system that integrates IoT, AI, and big data throughout the manufacturing process to automate and intelligentize the logistics process from material procurement to product shipment).

⑤ Energy: Smart Energy (an eco-friendly operation method that utilizes IoT sensors and AI to monitor, analyze, and optimize energy consumption within the factory in real-time to reduce waste).

⑥ Safety: It is characterized by intelligent SHE (referring to a system that integrates advanced ICT technologies such as IoT, AI, and big data into the field to manage workers' safety, health, and environment in real time and predict and prevent accidents in advance).

(7) Stages of Smart Factory Development and Characteristics

① Basic Automation: Equipment Automation

② Digitalization: Data Collection, ③ Connectivity: System Integration

④ Intelligence: AI Analysis, ⑤ Autonomy: Autonomous Factory

(8) Characteristics of Smart Factory in Plant Industry

① Continuous Process: Continuous manufacturing process

② Large-scale Equipment: Plant-type large-scale equipment

③ Energy: Energy-intensive type, ④ Process Safety: Smart PSM[1)]

⑤ Quality Management: Real Time Quality

※ Explanation: 1. Smart PSM (Smart Process Safety Management)

(9) Linking C-TPM Activities with Smart Factories

① Autonomous Maintenance: Smart Autonomous Maintenance

② Planned Maintenance: Predictive Maintenance

③ Quality Maintenance: AI Quality

④ Individual Improvement: Digital Individual Improvement

⑤ SHE: Intelligent Safety, Health, and Environment

(10) Expected Effects of Smart Factory

① Productivity: Increased production volume, ② Quality: Reduced defects

③ Equipment: Prevention of breakdowns, ④ Energy: Cost reduction

⑤ Safety: Prevention of accidents, ⑥ Operations: Real-time optimization

(11) Future Directions of Smart Factories

① AI Factory: AI-centric operation, ② Dark Factory: Unmanned factory

③ Intelligent Factory: Self-learning factory

④ Hyper Automation: Hyper-automation (all processes capable of automation are subject to automation)

⑤ ESG Factory: Eco-friendly manufacturing

(12) Summary of Key Implementation Points

The Smart Factory of the Fourth Industrial Revolution is a hyper-connected and hyper-intelligent manufacturing innovation system based on AI, IoT, and Big Data.

A Smart Factory is an intelligent manufacturing system that optimizes all areas in real time, including ① production, ② quality, ③ equipment, ④ logistics, ⑤ energy, and ⑥ safety.

In particular, the core of Smart Factory C-TPM is the system of ① Predictive Maintenance, ② AI quality management, ③ Digital improvement, ④ Smart SHE, and ⑤ ESG manufacturing innovation.

In the plant industry, ① continuous process optimization, ② process safety enhancement, ③ energy saving, ④ non-stop production, and ⑤ AI-based operation are very important.

In other words, the key is to realize a future-oriented Smart Factory based on 'AI manufacturing → autonomous optimization → increased manufacturing competitiveness' by establishing a manufacturing innovation system based on ' Fourth Industrial Revolution + Smart TPM → intelligent manufacturing.

1.2 Measures to Revitalize Manufacturing Competitive-ness in Smart Factories

(1) Implementation Overview

Recently, many companies have been pursuing ① the establishment of smart factories, ② the introduction of automation equipment, ③ the implementation of MES and ERP systems, and ④ the application of AI and IoT.

However, the effects on fundamental competitiveness improvement in actual manufacturing sites often fall short of expectations.

Chapter 2

Basic Concepts for Implementing C-TPM Activities

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2.1 Characteristics of C-TPM Activities in Smart Factories within the Processing Industry

(1) Overview of Implementation

The processing industry (encompassing sectors such as automotive, machinery, electrical/electronics, semiconductors, metal processing, and assembly) involves the processing and assembly of diverse products centered on individual equipment and production lines; consequently, equipment productivity, quality, flexibility, and the ability to meet delivery schedules are key factors determining corporate competitiveness.

In the era of smart factories, C-TPM (Competitive Total Productivity Management) has evolved beyond the equipment-centric maintenance activities of traditional TPM into a competitiveness-oriented management system that integrates innovations in productivity, quality, cost, and digital technology.

C-TPM in the processing industry is characterized by a focus on line-based production innovation, improvements in Overall Equipment Effectiveness (OEE), the ability to handle high-mix production, and the utilization of smart manufacturing technologies.

(2) Implementation Concept of C-TPM for Smart Factories in the Processing Industry

Basic Concept: Productivity Innovation + Quality Innovation + Cost Innovation + Smart Innovation → Enhancement of Manufacturing Competitiveness

(3) Key Characteristics of C-TPM Activities for Smart Factories in the Processing Industry

1) Production Line-Centered Innovation

In the processing industry, improving the balance and flow of the entire production line is more critical than focusing on individual processes.

Key activities include ① production line optimization, ② ensuring inter-process balance, ③ improving bottleneck processes, and ④ reducing lead times.

2) Maximizing Overall Equipment Effectiveness (OEE)

Productivity is maximized by improving equipment availability, performance efficiency, and the yield rate of good products.

Implementation measures include ① achieving zero breakdowns, ② addressing speed losses, ③ reducing minor stoppages, and ④ minimizing defects.

3) Adapting to High-Mix, Low-Volume Production

A production system is established to respond rapidly to market changes.

Implementation measures include ① rapid product changeovers, ② reducing setup/changeover times (SMED[1]), ③ establishing a flexible manufacturing system (FMS), and ④ standardizing work procedures.

※ Explanation: 1. SMED: Single Minute Exchange of Die

4) Operations Based on Automation and Digitalization

Smart factory technologies are utilized to make production and maintenance operations intelligent.

Applied technologies include ① IoT-based equipment monitoring, ② MES (Manufacturing Execution System), ③ AI-based quality prediction, ④ digital twins, and ⑤ industrial robots.

5) Equipment-focused Autonomous Maintenance and Planned Maintenance

Operators and the maintenance department collaborate to enhance equipment reliability.

Key activities include ① Autonomous Maintenance, ② Planned Maintenance, ③ Predictive Maintenance, and ④ Smart Maintenance.

6) Eliminating Losses through Focused Improvement

Eliminate all losses related to equipment, operations, quality, and costs.

Targets for improvement include ① the 8 major equipment losses, ② the 5 major human-related losses, and ③ the 3 major unit-consumption losses.

7) Strengthening Quality Maintenance

Prevent defects by optimizing equipment and process conditions.

Key activities include ① eliminating equipment-related defects, ② improving process capability (Cpk), ③ AI-based quality prediction, and ④ standardizing condition management.

8) Convergence of People and Smart Technology

Continuous improvement is driven by combining on-site experience with digital technology.

Key initiatives include: ① enhancing worker capabilities, ② data-driven decision-making, ③ improvement using AI, and ④ operating smart quality circles.

(4) Key Focus Areas and Details of C-TPM for the Processing Industry

① Productivity: Improving OEE, increasing production volume

② Quality: Zero defects, improving yield

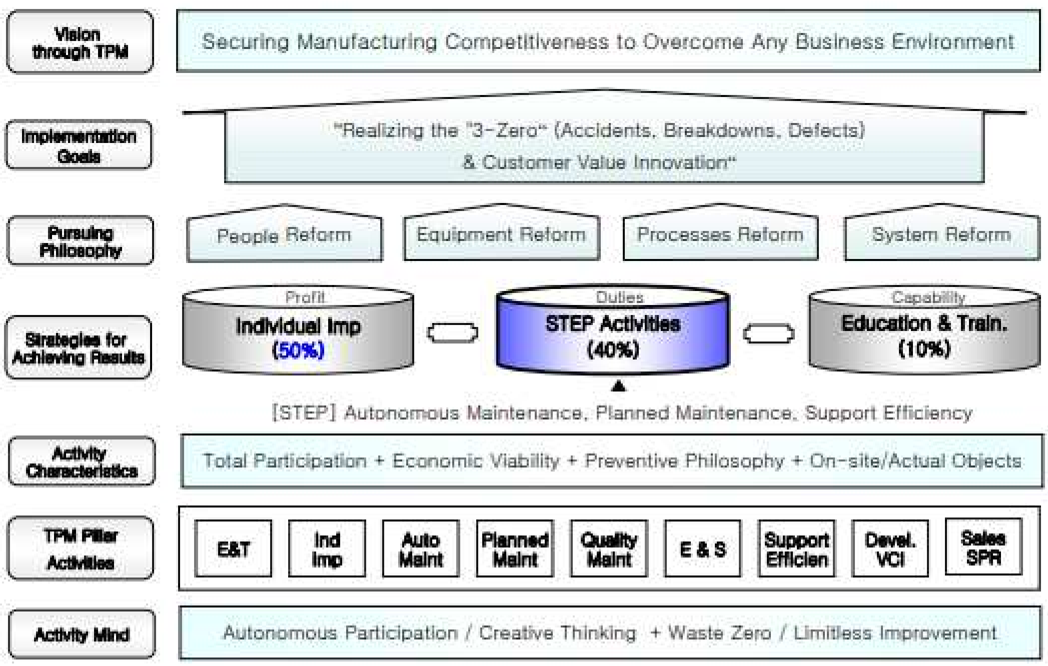
③ Cost: Eliminating losses, reducing manufacturing costs

④ Delivery: Shortening lead times, meeting delivery schedules

⑤ Maintenance: Autonomous, planned, and predictive maintenance

⑥ Safety: Establishing an accident-free workplace

⑦ Smart Transformation: AI, IoT, MES, Digital Twin



[Figure 2.1] Establishing C-TPM Innovation Strategies for Manufacturing Enterprises [Case Study: Mid-sized Enterprise]

(5) Differences between conventional TPM and C-TPM for smart factories in the processing industry

Category	Conventional TPM	Smart Factory C-TPM
Objective	Improving equipment efficiency	Enhancing manufacturing competitiveness
Scope of Management	Equipment-focused	All areas: production, quality, cost, sales, and development
Maintenance Method	Preventive & planned maintenance	Predictive & AI-based smart maintenance
Management Approach	Shop-floor-centric	Data-driven real-time management
Technologies Used	Manual records & standard management	IoT, AI, MES, Digital Twin

(6) C-TPM implementation framework for smart factories

C-TPM implementation proceeds through the following sequence: ‘Management Goals → Securing Manufacturing Competitiveness → C-TPM Implementation → Innovation in Productivity, Quality, Cost, and Delivery → Integration of IoT, AI, MES, and Digital Twins → Continuous Competitiveness Enhancement.’

(7) Expected benefits

① Improved productivity and increased output
② Enhanced Overall Equipment Effectiveness (OEE)
③ Reduced defect rates and stabilized quality
④ Reduced manufacturing costs
⑤ Improved delivery responsiveness
⑥ Advanced smart factory operational capabilities
⑦ Secured sustainable manufacturing competitiveness

(8) Summary of key implementation aspects

C-TPM for smart factories in the processing industry is a comprehensive productivity management system that expands upon equipment-centric TPM to encompass competitiveness innovation activities centered on the production line.

In particular, it is a smart factory innovation methodology that simultaneously enhances competitiveness in productivity, quality, cost, and delivery by focusing on: ① production line optimization, ② improved Overall Equipment Effectiveness (OEE), ③ adaptability to high-mix production, ④ utilization of smart manufacturing technologies, ⑤ autonomous, planned, and predictive maintenance, and ⑥ company-wide loss elimination.

2.2 C-TPM in the Processing Industry: Applicable Sectors and Operational Characteristics

(1) Overview of Implementation

The processing industry involves manufacturing final products by cutting, forming, assembling, and processing raw materials or components; consequently, a company's success hinges on equipment productivity, quality, delivery performance, and cost competitiveness.

In the era of smart factories, C-TPM (Competitive Total Productivity Management) transcends the equipment maintenance focus of traditional TPM; it represents a competitiveness-driven approach to total productivity management that integrates productivity, quality, cost, delivery, safety, environmental sustainability, and digital innovation.

C-TPM in the processing industry focuses on production-line-centered innovation, improving Overall Equipment Effectiveness (OEE), accommodating high-mix production, and leveraging smart manufacturing technologies.

(2) C-TPM Applicable Manufacturing Sectors

1) Automotive Industry

① Applicable Sectors:

ⓐ Finished vehicle manufacturing, ⓑ Automotive/EV parts

ⓒ Battery module assembly

② Key Innovation Activities:

ⓐ Establishing automated production lines

ⓑ Improving OEE (Overall Equipment Effectiveness), ⓒ Robotic automation

ⓓ Zero defects

Chapter 3

Activities to Establish the Basic Framework for C-TPM Implementation

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(13) Goal Deployment (Cascade, Drill-down) System

① Company Goals: Company-wide KPIs

② Divisional Goals: Divisional KPIs (R&D, Materials, Production, Maintenance, Logistics, Sales, etc.)

③ Team Goals: Team KPIs, ④ Individual Goals: Individual KPIs

(14) Key Factors for Successful Goal Setting

① BM Accuracy: Rationality in setting hierarchical KPI targets based on clear calculation criteria

② Realism: Achievable targets

③ Phased Approach: Driving continuous improvement combining maintenance and enhancement through a step-by-step process

④ Real-time Management: Monitoring and managing data in real-time using smart technologies such as IoT and AI

⑤ AI Analysis: Utilized for setting KPI targets

(15) Summary of Key Implementation Strategies

The approach of establishing annual targets based on C-TPM fundamental policies and the BM (current status) represents a phased manufacturing innovation framework structured around the progression of "Current Status → Target Achievement → Improvement Execution → Innovation."

In essence, the core objective is to secure smart manufacturing competitiveness founded on manufacturing excellence, productivity, and sustainability by systematically executing the following steps: ① analyzing the current status (BM), ② identifying issues, ③ setting annual KPI targets, ④ managing smart factory objectives, and ⑤ aligning with ESG goals.

3.6 C-TPM Overlapping Small-Group System with Full Participation

(1) Overview of Implementation

The core elements of C-TPM (Competitiveness-Total Productive Management) are: ① Total Participation, ② Autonomous Improvement, ③ Horizontal & Vertical Linkage, and ④ Field-based Innovation.

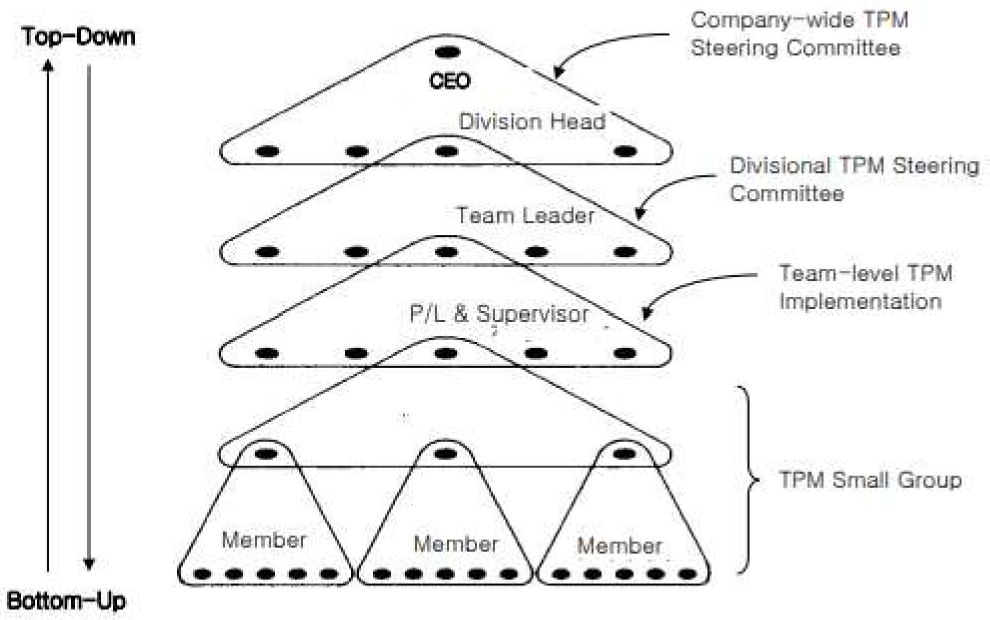
In the era of smart factories, in particular, areas such as ① production, ② quality, ③ maintenance, ④ logistics, ⑤ safety, and ⑥ AI/digital technologies are organically interconnected; therefore, organizational operations that facilitate connections across different departments and hierarchical levels are crucial.

Accordingly, C-TPM employs an "overlapping small-group system with vertical linkages" to ensure that ① top management, ② middle management, ③ supervisors, and ④ frontline workers all participate in innovation activities as part of a unified, interconnected chain.

(2) Definition of the Vertical Linkage-Type Small Group

A vertical linkage-type small group[1] is a hierarchical innovation organization in which each level connects with ① higher-level organizations, ② lower-level organizations, and ③ units in other sectors to share common goals and carry out improvement activities.

In other words, it is a structure where connections flow from top to bottom, while improvements are communicated from bottom to top.



[Figure 3.2] Example of Overlapping Small-Group Organizational Operation

(3) Why is a vertically linked organizational structure necessary?

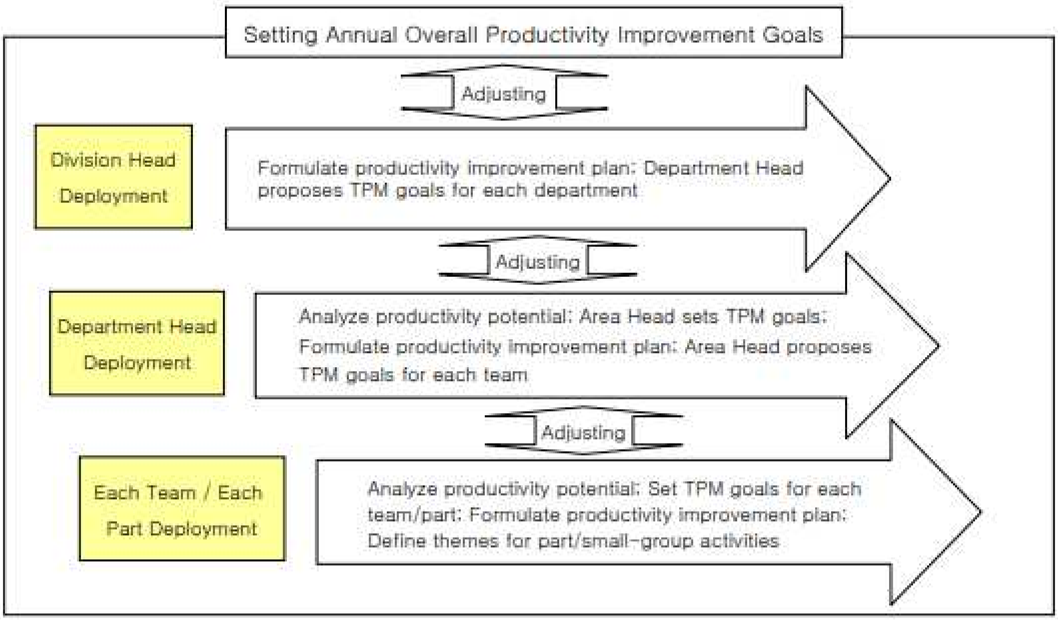
① Goal Alignment: Need for clear linkage between upper- and lower-level goals through goal deployment

② Enhanced Communication: Need for two-way dialogue (back-and-forth exchange) across all levels (vertical and horizontal)

③ Rapid Problem Solving: Direct participation and guidance-based problem solving

④ Field-focused Innovation: Activities prioritizing the actual workplace, actual objects, and actual conditions and emphasizing thoroughness and attention to detail

⑤ Culture of Continuous Improvement: Securing manufacturing competitiveness through the sustained pursuit of both "maintenance" and "improvement"



[Figure 3.3] Example of goal deployment dialogue (catch-ball) across organizational levels

(4) Issues with Existing Organizational Operations

① Departmental Fragmentation: Presence of the "silo effect."

② Vertical Disconnect: Presence of a "vertical gap."

③ Failure to Incorporate Field Feedback: Lack of input from the actual worksite; reliance on one-way, top-down directives.

④ Superficial Activities: Initiatives are often one-off events rather than part of a process for continuous improvement.

⑤ Lack of Collaboration: A critical need exists for cross-departmental and cross-hierarchical collaboration to effectively resolve complex problems.

(5) Principles of a Vertical Linkage-Based Organizational Structure

① Universal Participation: Involvement across all departments and hierarchical levels

② Hierarchical Linkage: Use of overlapping small groups to connect upper and lower levels

③ Cross-Functional Collaboration: Utilization of a matrix organizational structure

④ Shop-Floor Focus: Organizational operations prioritized to drive change at the actual worksite

⑤ Autonomous Operation: A shop-floor-centric approach where workers go beyond merely following instructions to become active agents who independently assess and improve the status of equipment and processes

(6) Organizational Structure and Roles

① Steering Committee: Policies and guidelines

② Specialized Subcommittees: Technical support

③ Team-based Structure: Innovation by team

④ Line Small Groups: On-site improvements

⑤ TFT (Task Force Team): Temporary organization for resolving specific issues

(7) Vertical Linkage and Operational Mechanism

① Deployment of Management Policy: Top-down (President → Division Head → Team Leader → Individual)

② Proposal of On-site Issues: Bottom-up (Individual → Team Leader → Division Head → President)

③ Consultation on Improvements: Cross-functional Meetings (Ad-hoc operation of CFTs)

④ Performance Sharing: KPI Review (Improvement → Cost reduction/Productivity increase/High value-added/Sales growth → Profit)

⑤ Standardization: Standardizing improvement results is crucial for continuous improvement activities, which combine maintenance and improvement.

(8) Role Structure by Hierarchical Level

① Top Management: Vision and Policy

② Middle Management: Coordination and Management

③ Supervisors: Execution and Guidance

④ Operators/Workers: Improvement and Implementation

(9) Field-Oriented Small-Group C-TPM Activities

① Autonomous Maintenance (Production Staff): Step-based autonomous maintenance for production equipment

② Autonomous Maintenance (Utility): Step-based autonomous maintenance for utility equipment

③ Autonomous Maintenance (Environmental Facilities): Autonomous maintenance for environmental facilities (e.g., wastewater treatment)

④ Planned Maintenance (Maintenance Staff): Step-based planned maintenance in maintenance workshops

⑤ Support Efficiency (Logistics/Testing Equipment): Autonomous maintenance for support functions (logistics, testing, etc.)

⑥ Development VCI (R&D/Design Staff): Step-based Development VCI activities in R&D departments

⑦ Sales SPR (Sales/Service Staff): Field-based Sales SPR activities for sales and service personnel

⑧ Individual Improvement (All Departments): Thematic improvements and resolution of on-site inefficiencies

⑨ Education & Training (All Departments): Staff training, maintenance fundamentals training, smart technology training, etc.

(10) Smart Factory Integrated Operations

① IoT: Real-time data acquisition, ② AI: Predictive Maintenance (PdM)

③ MES: Production operations via Manufacturing Execution System

④ Dashboard: KPI status management

⑤ Digital Twin: Simulation in a virtual environment

(11) Overlapping Sub-group Meeting Operation System

① Daily Meeting: Routine management

② Weekly Meeting: Weekly improvement progress

③ Monthly Meeting: Review of performance and achievement against KPI targets

④ Management Meeting: Strategic review regarding manufacturing competitiveness (C-TPM, cost reduction, profit growth, etc.)

(12) Performance Measurement and Management System

① Participation Rate: Participation rate by team/small group relative to the total; activity rate by C-TPM category

② Number of Improvements: Number of thematic improvements; number of rectifications/improvements regarding inefficiencies or defects

③ Productivity: Productivity per person; productivity per hour; value-added productivity

④ Quality: Defect rate by line/product; inspection failure rate

⑤ Safety, Health, and Environment: Accident indicators related to industrial safety and health regulations

(13) Key Factors for Successful Operation

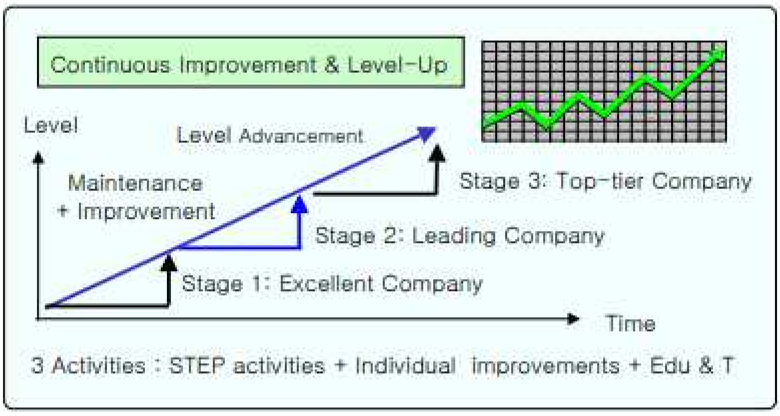
① Leadership: Exercising leadership, presenting a vision, and clearly articulating policies

② Communication: Two-way communication across all levels and departments

③ On-site Engagement: Participation from all divisions (production, R&D, sales, support, etc.) and organizational management focused on transforming the shop floor

④ Data-driven Approach: KPI management utilizing smart technologies

⑤ Sustained Operation: Achieving high growth by driving continuous improvement based on a "maintain-and-improve" approach



[Figure 3.4] Enhancing manufacturing competitiveness through "maintain-and- improve" continuous improvement

(14) Expected Effects

① Organizational Revitalization:

ⓐ Transparent communication, ⓑ Field-led innovation

ⓒ Fostering a sense of ownership

② Productivity Improvement:

ⓐ Increased Units Per Hour (UPH), ⓑ Minimized resource waste

ⓒ Improved work productivity

ⓓ Reduced losses hindering production efficiency

③ Quality Innovation: Zero defects, reduced failure costs

④ Cost Reduction: Increased cost savings

⑤ Smart Innovation: Promotion of Digital Transformation (DX)

(15) Summary of Key Implementation Aspects

The C-TPM operating system, characterized by company-wide participation and a "vertical linkage" small-group structure, is an integrated, enterprise-wide innovation framework based on a combination of top-down, bottom-up, and cross-functional approaches.

In essence, the core objective is to secure smart manufacturing competitiveness driven by a cycle of "participation across all departments and levels → continuous improvement → smart factory realization" by linking top management, middle management, supervisors, and frontline workers through vertical connections to collaboratively engage in activities such as goal sharing, problem-solving, continuous improvement, and "Smart Innovation."

Chapter 6

Competitiveness Enhancement: C-TPM Activities by Element

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④ Reduction in quality defects, ⑤ Extension of equipment lifespan
⑥ Establishment of a smart autonomous management system
⑦ Strengthening of manufacturing competitiveness.

(6) Key Implementation Summary

Autonomous maintenance within the C-TPM framework for smart factories in the processing industry is implemented through a 7-step process: ① Initial cleaning → ② Countermeasures for sources of contamination and hard-to-access areas → ③ Establishment of standards for cleaning, lubrication, and inspection → ④ Gross Equipment inspection → ⑤ Autonomous inspection → ⑥ Standardization → ⑦ Autonomous management.

In particular, Step 4 (Gross Equipment Inspection) involves a systematic check across six areas machine elements, drive systems, lubrication systems, pneumatic/hydraulic systems, electrical equipment, and instrumentation and can be executed in stages over six-month periods by grouping two or three areas together as needed.

Furthermore, the core approach in a smart factory is to upgrade the traditional TPM model into a data-driven, smart autonomous maintenance system by leveraging IoT, AI, MES, and mobile inspection technologies.

6.4.2 C-TPM Autonomous Maintenance Step Activities for Smart Factories in the Machining Industry

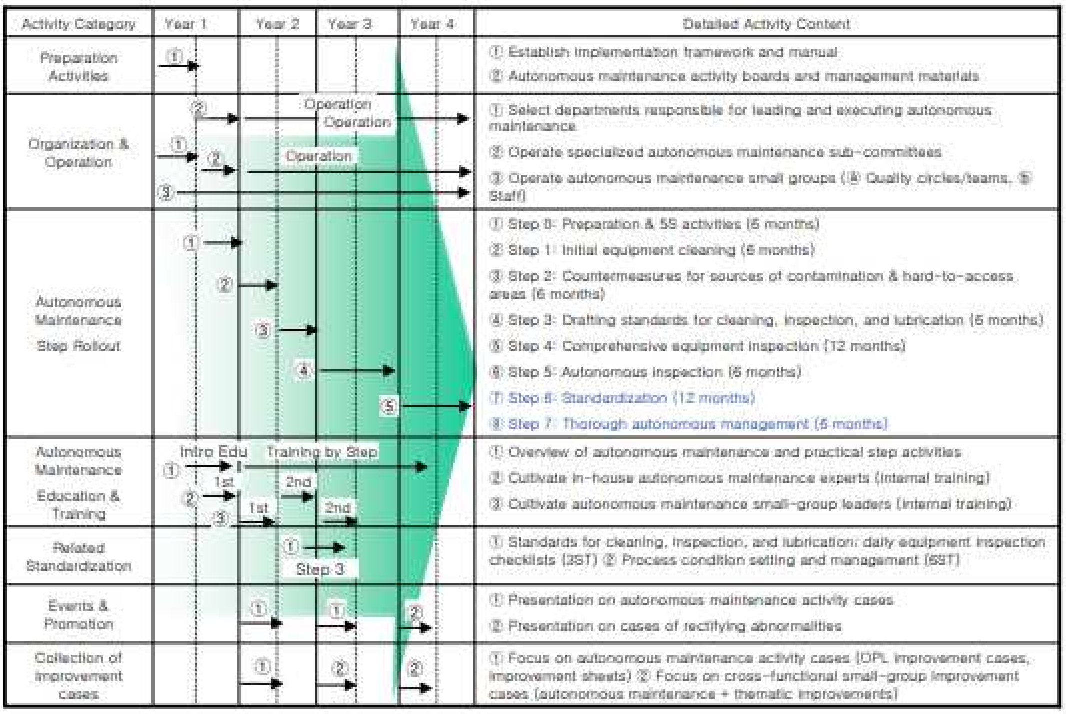
(1) Overview of Implementation

C-TPM autonomous maintenance step activities for smart factories in the machining industry are phased improvement initiatives designed to achieve zero breakdowns, zero defects, and zero accidents.

Operators accomplish this by maintaining basic equipment conditions (cleaning, lubrication, and tightening) and eliminating forced equipment deterioration.

These step activities are carried out according to a defined sequence for each stage: ① Concept → ② Activity Sequence → ③ Detailed Activity Methods → ④ Activity Assessment.

Progression to the next stage occurs only after passing an assessment upon the completion of the current stage.



[Figure 6.11] Example of a Master Plan for Autonomous Maintenance Implementation in the Machining Industry

(2) Framework for Autonomous Maintenance Step Activities in the Machining Industry

STEP	Activity Name	Key Implementation Details
STEP 1	Initial Cleaning	Removing equipment contamination and detecting abnormalities
STEP 2	Countermeasures for Sources of Contamination and Hard-to-Access Areas	Eliminating contamination sources and improving workability
STEP 3	Establishing Standards for Cleaning, Lubrication, and Inspection	Setting and standardizing autonomous maintenance criteria
STEP 4	Gross Equipment Inspection	Thorough inspection of equipment functions and components
STEP 5	Autonomous Inspection	Routine inspections and abnormality management by operators
STEP 6	Standardization	Standardizing management criteria and work procedures
STEP 7	Autonomous Management	Establishing autonomous management and continuous improvement

(3) Autonomous Maintenance: Step-by-Step Activities

1) STEP 1. Initial Cleaning

① Concept: An activity to restore equipment to its original state by thoroughly cleaning it and discovering defects or abnormalities hidden beneath contamination.

Objectives include: ① removing contamination, ② discovering latent defects, and ③ restoring basic conditions.

② Activity Sequence:

ⓐ Select target equipment, ⓑ Establish cleaning plan

ⓒ Disassemble and clean equipment, ⓓ Identify problem areas

ⓔ Attach tags for issues/defects, ⓕ Restoration and improvement

③ Detailed Activity Methods:

ⓐ Remove dust and metal chips, ⓑ Check for oil and water leaks

ⓒ Check for loose bolts, ⓓ Check for abnormal sounds, ⓔ Check for cracks

ⓕ Remove corrosion, ⓖ Restore equipment appearance

④ Activity Assessment:

ⓐ Functional cleaning completion rate, ⓑ Number of issues identified

ⓒ Tag resolution rate, ⓓ Basic condition restoration rate

ⓔ Operator participation rate

Category	Implementation Details	In Charge		Jan.	Feb.	Mar.	Apr.	May	Jun.	In Charge
		Staff	Mem.							
Step 1 Preparatory Activities	Training on Step 1 (Initial Equipment Cleaning) Manual	●	○	••						
	Establish Step 1 (Initial Equipment Cleaning) Schedule		○	•••						
	Designate Equipment Cleaning Zones	○	●	•••						
	Prepare Cleaning Tools & Study Characteristics	○	●	•••••						
Equipment Functional Cleaning	Perform Functional Cleaning & Check for Abnormalities (by category)		●		••••••					
	Training on Cleaning Methods & Safety Precautions	●	○		•••					
Identify & Record Abnormalities	Identify Abnormalities (Defects, Sources, Hard-to-Access Areas) & List Findings					••••••				
Implement Corrective Actions	Implement Minor Repairs & Maintenance (In-house) ▶ Mechanical Elements & Drive Systems ▶ Lubrication & Pneumatic/Hydraulic Systems ▶ Electrical & Instrumentation Systems	○	●				•••••	•••••		
	Request Major Repairs & Maintenance (Maintenance Dept.)	○	●				•••••	•••••		
	Document Minor Improvement Cases (C/F, TPM Sheets)		○				•••••	•••••		
Visual Management	Implement Visual Management for Equipment	○	●					••••••	•••	
Activity Board	Recording performance data and managing countermeasures on the activity board	○	●	•••	•••	•••	•••	•••	•••	
Act. Diagnosis	Team leader's Diagnosis of Step 7 activities	○		△	△	△	△	△	△	

[Figure 6.12] Examples of specific activities (Step 1)

2) STEP 2. Countermeasures for Sources of Contamination and Hard-to-Access Areas

① Concept: Activities to improve equipment maintainability by addressing sources of contamination and areas that are difficult to clean or inspect.

② Activity Sequence:

ⓐ Survey sources of contamination, ⓑ Survey hard-to-access areas

ⓒ Analyze causes, ⓓ Formulate improvement plans

ⓔ Implement improvements, ⓕ Verify effectiveness

③ Detailed Activity Methods:

ⓐ Mitigate cutting fluid splashing, ⓑ Prevent chip scattering

ⓒ Address oil leaks, ⓓ Install covers, ⓔ Install inspection windows

ⓕ Secure workspace, ⓖ Enhance safety

④ Activity Assessment:

ⓐ Reduction rate of contamination sources

ⓑ Improvement rate of hard-to-access areas

ⓒ Reduction in cleaning time, ⓓ Reduction in inspection time

ⓔ Improvement in workability

Category	Implementation Details		In Charge: Staff	In Charge: Mem.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	In Charge
Step 2 Preparatory Activities	Training on Step 2 (Countermeasures for sources of contamination & hard-to-access areas) manual		●	○							
	Establishing the Step 2 schedule			○							
Listing Problems	Listing sources of contamination and hard-to-access areas (by zone)			○							
Clarifying Issues	Clarifying the status of unresolved defects (major defects) from Step 1, sources of contamination, and hard-to-access areas			○							
Establishing Improvement Plans	Establishing schedules for addressing issues (major defects, sources of contamination, etc.)		○	●							
Implementation	Autonomous Maintenance Sub-group Self-resolution	Execution after theme registration (Joint resolution items for sub-groups)	○	●							
		Routine improvements - Small-scale improvements		○							
	Resolution via Request	Resolution with support after maintenance request	○	●							
	Accumulating Improvement Cases	Creating Improvement OPLs and Improvement Sheets		○							
Maintenance Education & Training	TPM Techniques	Conducting "Know-Why" (5-Why) analysis	○	●							
	Maintenance Skills Training	Basic on-site maintenance skills training	○	●							
Activity Board	Recording performance data and managing countermeasures on the activity board		○	●							
Act. Diagnosis	Team leader's Diagnosis of Step 7 activities		○		△	△	△	△	△	△	

[Figure 6.13] Examples of specific activities (Step 2)

[Photo 6.2] Examples of Autonomous Maintenance activities (conducted in parallel with Specialized Maintenance support)

3) STEP 3. Establishing Standards for Cleaning, Lubrication, and Inspection

① Concept: An activity to standardize the criteria for cleaning, lubrication, and inspection in order to maintain equipment in optimal condition at all times.

② Activity Sequence:

ⓐ Select management items, ⓑ Determine inspection intervals

ⓒ Establish standards, ⓓ Create inspection checklists

ⓔ Conduct training, ⓕ Implement on-site

③ Detailed Activity Methods:

ⓐ Set cleaning standards, ⓑ Define lubrication methods

Category	Implementation Details	In Charge		Jan.	Feb.	Mar.	Apr.	May	Jun.	In Charge
		Staff	Mem.							
Step 3 Preparatory Activities	Training on Step 3 (Drafting standards for cleaning, inspection, and lubrication) implementation manual	●	○	••						
	Establishing the schedule for Step 3		○	•••						
Initial Item Listing	Listing cleaning, inspection, and lubrication points	○	●	•••						
Understanding Equipment Principles	Collecting data and understanding equipment principles	○	●		•••••	•••••				
Cleaning, Lubrication, & Inspection Training	① Training on cleaning and inspection procedures ② Training on lubrication management (oil, grease) and lubrication basics ③ Training on inspection procedures	●	○			••• ••• •••				
Secondary Item List Refinement	Refining and updating the list of cleaning, inspection, and lubrication points	○	●			•••				
Drafting Equipment Management Standards	Drafting standards for cleaning, inspection, and lubrication; creating daily equipment inspection checklists	○	●				•••••	•••••		
Execution & Addressing Issues	Carrying out tasks based on cleaning, inspection, and lubrication standards		○						••••••	
	Identifying operational issues and implementing revisions/improvements	○	●						••••••	
Activity Board	Recording performance data and managing countermeasures on the activity board	○	●	••	••	••	••	••	••	
Act. Diagnosis	Team leader's Diagnosis of Step 7 activities	○		△	△	△	△	△	△	

[Figure 6.14] Example of specific activity details (Step 3)

⑥ Customer: Customer requirement incorporation rate

(8) Expected Benefits of Development VCI

① Development Aspect: Reduced development time, lower development costs, improved development quality

② Business Aspect: Enhanced market responsiveness, improved product competitiveness, increased profitability

③ Smart Factory Aspect: Establishment of digital engineering, realization of Smart R&D

(9) Ultimate Goal

Zero Development Loss + Improved Development Productivity + Digital Development Innovation → Smart Development

(10) Summary of Key Implementation Steps

The Smart Factory C-TPM Development VCI system improvement initiative (an 8-step process) is carried out in the following stages: 'Optimizing the development environment → Analyzing development processes → Eliminating development losses → Standardizing development → Improving development efficiency → Revitalizing development activities → Establishing a digital development system → Advancing Smart Development.'

Through this process, waste in the development sector is eliminated, and a digital R&D system utilizing PLM, PDM, CAD/CAE, Digital Twin, and AI is established, ultimately completing a Smart Development system that simultaneously enhances customer value and reduces costs.

6.10.3 C-TPM Development VCI EVE Theme Improvement Activities

(1) Overview of Implementation

The EVE theme improvement activity within Development VCI (Value Cost Innovation) is a value innovation initiative designed to maximize customer value and minimize costs by systematically analyzing the functions and costs of products, equipment, processes, and services.

EVE (Economic Value Engineering) is an improvement technique that adapts traditional VE (Value Engineering) to the smart factory environment; its objective is to eliminate unnecessary costs while maintaining or enhancing the product's essential functions.

In particular, within the smart factory C-TPM framework, this activity is carried out using a Cross-Functional Team (CFT) approach involving relevant departments such as Development, Production Technology, Quality, Purchasing, Production, and Sales.

(2) Basic Concepts of EVE (Value Engineering)

1) Definition of Value

Value is expressed as the relationship between function and cost.

Value = Function/Cost; in other words, value increases as functions are enhanced and costs are reduced.

2) EVE Objectives

Performance Improvement + Cost Reduction → Value Innovation

(3) Implementation Framework for Development VCI EVE Theme Improvements

Stage	Activity Name	Key Content
Stage 1	Establishing the Theme Improvement Plan	Selecting the Target
Stage 2	Collecting Information on VE Targets	Information Analysis
Stage 3	Defining Functions	Identifying Functions
Stage 4	Organizing Functions	Establishing the Functional Hierarchy
Stage 5	Analyzing Function Costs	Cost Analysis
Stage 6	Function Evaluation and Prioritization of Improvements	Selecting Targets for Improvement
Stage 7	Generating & Evaluating Ideas	Creating Improvement Proposals

Stage	Activity Name	Key Content
Stage 8	Refining & Elaborating Ideas	Detailing Improvement Proposals
Stage 9	Detailed Idea Evaluation	Economic Feasibility Review
Stage 10	Review and Finalization of Improvement Plan	Final Decision
Stage 11	Implementation Planning	Preparation for Execution

(4) Phased Activities for VCI EVE Theme Improvement

1) Phase 1. Establishing the Theme Improvement Plan

① Objective: Select VE themes with high potential for improvement and establish an implementation plan.

② Key Activities:

ⓐ Select target product, ⓑ Select target process, ⓒ Select target equipment

ⓓ Set improvement goals, ⓔ Form project team

③ Selection Criteria:

ⓐ Cost proportion, ⓑ Customer complaints, ⓒ Quality issues

ⓓ Productivity issues, ⓔ Competitiveness issues

④ Outputs:

ⓐ Project plan, ⓑ Goal management chart, ⓒ Implementation schedule

2) Phase 2. Collecting Information on VE Targets

① Objective: Systematically collect information regarding the target product and process.

② Key Activities:

ⓐ Technical information: Design drawings, specifications, technical standards

ⓑ Cost information: Material costs, processing costs, purchasing costs

ⓒ Quality information: Defect data, customer claims

ⓓ Production information: Production volume, yield, process capability

③ Outputs: ⓐ Information analysis report, ⓑ Cost breakdown chart

3) Step 3. Defining Functions

① Objective: Clearly define the primary function that the subject must perform.

② Principle of function definition: Express functions in the format of "do [object] [action]" (or "[Action] [Object]").

③ Function classification: ⓐ Basic Function, ⓑ Secondary Function

4) Step 4. Organizing Functions

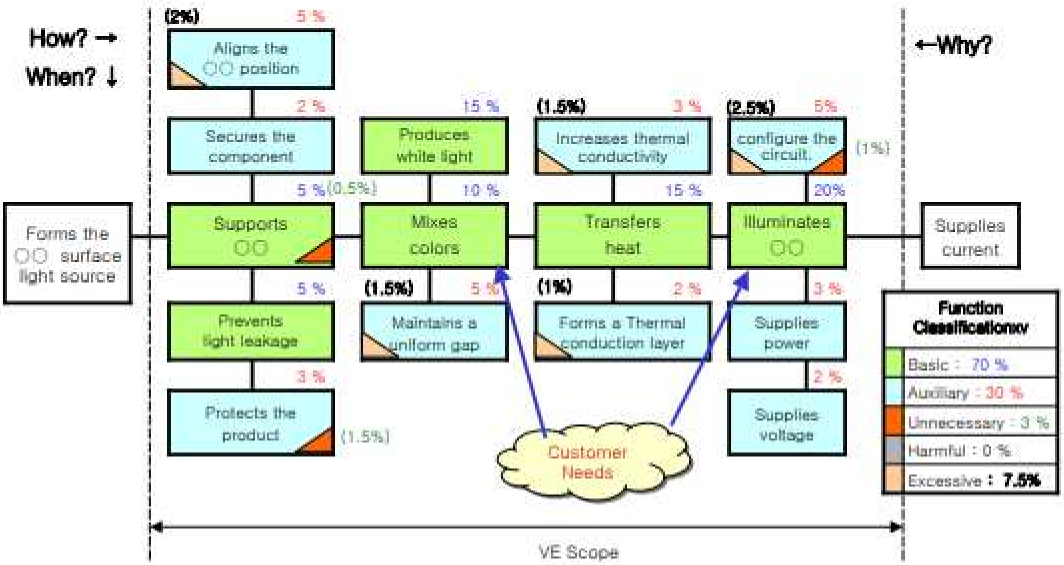
① Objective: Systematically organize the relationships between functions.

② Key activities:

ⓐ FAST Analysis (Function Analysis System Technique): Analyze the "Why" and "How" relationships between functions

ⓑ Creation of a function hierarchy diagram: e.g., "Protect product → Absorb shock → Use cushioning material"

③ Outputs: ⓐ Function hierarchy diagram, ⓑ FAST Diagram



[Figure 6.30] Example of function analysis using FAST

5) Step 5. Analyzing Function Costs

① Objective: To identify opportunities for improvement by analyzing costs associated with specific functions.

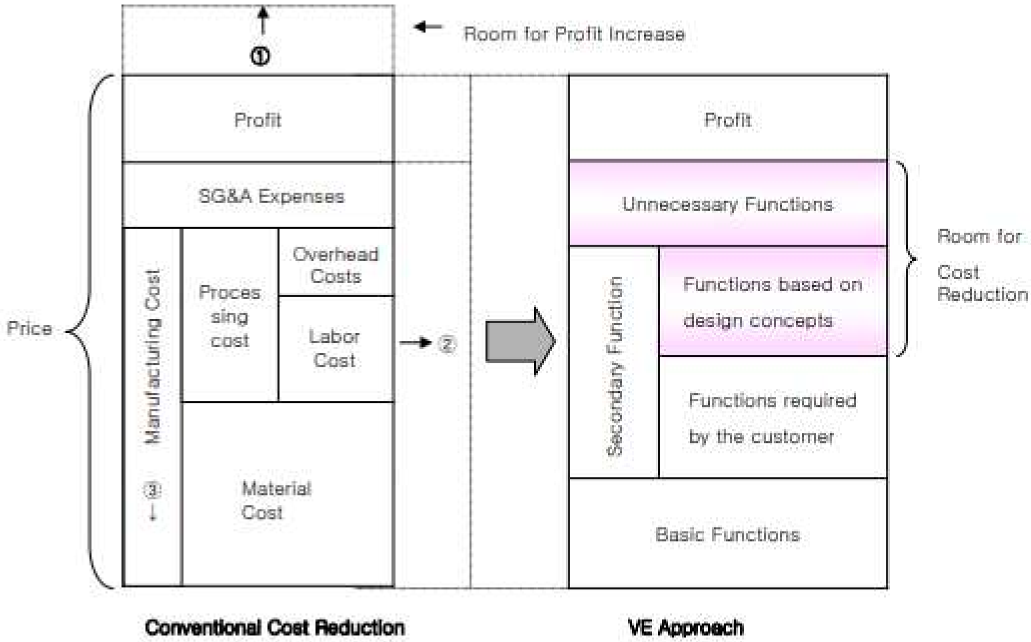
② Key Activities:

ⓐ Cost analysis by function: Basic functions: XX Won, Auxiliary functions: XX Won

ⓑ Value analysis: Value = Function / Cost

ⓒ Analysis results: Identification of high-cost/low-value functions, unnecessary functions, excessive functions, etc.

③ Function-cost analysis techniques: FD Method, DARE Method, AHP Method



[Figure 6.31] Characteristics of cost reduction strategies in EVE compared to conventional methods

Functional Area		Comparative Evaluation (Pairwise Comparison) Compare function combinations: assign 1 if higher importance, 0 if lower						Sum (Sum + 1)	Importance (W)	Evaluated Value (F')
Fno	Function									
F1	Forms the body	0 1 0 1 0 0						3 (2)	0.10	2461.91
F2	Forms ○○○	1	1 0 1 1 1					6 (5)	0.23	5662.39
F3	Forms an identification tag	0	0	0 0 0 0				1 (0)	0.04	984.764
F4	Forms ○○○	1	1	1	1 1 1			7 (6)	0.25	6154.78
F5	Secures the body	0	0	1	0	0 0		2 (1)	0.07	1723.34
F6	Inspects characteristic values	1	0	1	0	1	1	5 (4)	0.17	4185.25
F7	Performs shipping inspection and packaging	1	0	1	0	1	0	4 (3)	0.14	3446.67
Total								28	1.0	**24619.1**

[Figure 6.32] Example of the FD Method (Forced Decision Method)

Functional Area		Comparative Evaluation (Pairwise Comparison) Value Diagnosis of the upper item relative to the lower item (set to 1) in the combination matrix							R (Final Value: 1)	Adjusted Value K	Importance (W)	Tentative Value (F')
Fno	Function											
F1	Forms the body	0.5							0.5	0.57	0.07	1825.5
F2	Forms ○○○	1	1.2						1.2	1.15	0.15	3651.0
F3	Forms an identification label		1	0.5					0.5	0.96	0.12	3042.5
F4	Forms ○○○			1	2				2	1.92	0.25	6085.1
F5	Secures the body				1	0.8			0.8	0.96	0.12	3042.5
F6	Inspects characteristic values					1	1.2		1.2	1.2	0.15	3803.2
F7	Performs shipping inspection and packaging						1		1.0	1.0	0.13	3169.3
Total										7.72	1.0	**24619.1**

[Figure 6.33] Example of the DARE Method (Decision Alternative EVE Ratio Evaluation Method)

	F1. Form the body	F2. Form the light source unit	F3. Form the identification label	F4. Form the optical system	F5. Secure the body	F6. Inspect characteristic values	F7. Perform shipping inspection and packaging	Geometric Mean	Importance	Weighted Value (F')
F1. Form the body	1	1/5	3	1/9	3	1/3	1/3	0.30	0.05	1353.8
F2. Form the ○○○	5	1	5	1/7	3	3	1	0.38	0.07	1700.2
F3. Form the identification label	1/3	1/5	1	1/9	1/3	1/3	1	0.31	0.06	1377.0
F4. Form the ○○○	9	7	9	1	9	9	9	3.00	0.55	13494.6
F5. Secure the body	1/3	1/3	3	1/9	1	1/3	1	0.33	0.06	1499.4
F6. Inspect characteristic values	3	1/3	3	1/9	3	1	3	0.58	0.11	2597.0
F7. Perform shipping inspection/packaging	3	1	1	1/9	1	1/3	1	0.58	0.11	2597.0
Total	-	-	-	-	-	-	-	**5.48**	**1.0**	**24619.1**

* Geometric mean : $G = \sqrt[n]{x_1 \times x_2 \cdots \times x_n}$

[Figure 6.34] Example of the AHP Method (Analytic Hierarchy Process Method)

6) Step 6. Function Evaluation and Prioritization of Improvements

① Objective: Determine the priority of improvements.

② Evaluation Criteria:

ⓐ Cost reduction effect, ⓑ Quality improvement effect,

ⓒ Productivity improvement effect, ⓓ Customer value enhancement

③ Priority Determination: Improvement Effect × Feasibility

7) Step 7. Generating & Evaluating Ideas

① Objective: Generate creative ideas for improvement.

② Techniques Used:

ⓐ Brainstorming, ⓑ Brainwriting, ⓒ TRIZ, ⓓ SCAMPER[1], ⓔ Benchmarking

③ Key Activities:

ⓐ Function substitution, ⓑ Material change, ⓒ Structural change,

ⓓ Process change

④ Goal: Idea Quantity → Idea Quality

※ Explanation: 1. SCAMPER: S (Substitute) C (Combine), A (Adapt), M (Modify, Magnify, Minify), P (Put to other use), E (Eliminate), R (Rearrange, Reverse)

8) Step 8. Refining & Elaborating Ideas

① Objective: Develop the generated ideas into actionable plans.

② Key Activities:

ⓐ Drafting designs, ⓑ Simulation, ⓒ Technical review, ⓓ Cost review

③ Review Criteria:

ⓐ Functionality, ⓑ Quality, ⓒ Safety, ⓓ Environmental impact

9) Step 9. Detailed Idea Evaluation

① Objective: Select the optimal improvement plan.

② Evaluation Criteria:

ⓐ Value: Customer value, ⓑ Cost: Cost reduction effect

ⓒ Quality: Quality level, ⓓ Productivity: Production efficiency

ⓔ Investment: Investment scale

③ Economic Feasibility Assessment: ROI = Improvement effect / Investment cost

10) Step 10. Review and Finalization of Improvement Plan

① Objective: Select and approve the final improvement plan.

② Key Activities:

ⓐ Management review, ⓑ Technical review, ⓒ Quality review

ⓓ Investment review

③ Outputs: ⓐ Final improvement plan, ⓑ Investment approval document

11) Step 11. Implementation Planning

① Objective: Implement the selected improvement plan.

② Key Activities:

ⓐ Establishing the implementation plan: Scheduling, budgeting, and assigning personnel

ⓑ Pilot application: Pilot testing and verification/evaluation

ⓒ Mass production application: Standardization and rollout

③ Deliverables:

ⓐ Implementation plan document, ⓑ Implementation schedule

ⓒ Effectiveness forecast report

(5) Future Direction of Smart Factory-style EVE

① Utilization of Digital Engineering: CAD, CAE, PLM

② Utilization of Digital Twin: Virtual verification and virtual production

③ Utilization of AI: Cost forecasting, design optimization, and recommendation of alternatives

(6) Expected Benefits

① Cost: Reduction in manufacturing costs, ② Quality: Quality improvement

③ Development: Shortened development time

④ Production: Productivity enhancement, ⑤ Customer: Enhanced customer value

⑥ Competitiveness: Securing market competitiveness

(7) Ultimate Goal

Maximum Value + Minimum Cost → Maximized Competitiveness

(8) Summary of Key Implementation Steps

The Smart Factory C-TPM development and VCI EVE theme improvement activities are carried out through an 11-step framework: ‘Planning → Information Gathering → Function Definition → Function Organization → Functional Cost Analysis → Prioritization → Idea Generation → Conceptualization → Detailed Evaluation → Final Review & Approval → Implementation Planning.’ Through this process, the company realizes function-oriented value analysis and cost innovation.

Furthermore, by establishing a Smart EVE (Value Engineering) system that leverages AI, Digital Twins, and PLM, it can simultaneously enhance customer value and secure cost competitiveness.

6.10.4 Implementation Method for Theme Improvement Using TRIZ in Development VCI

(1) Implementation Overview

Product development in the smart factory era is a complex innovation activity that must simultaneously satisfy requirements such as ① enhanced functionality, ② higher quality, ③ cost reduction, ④ shortened development cycles, and ⑤ eco-friendliness.

However, in actual development environments, "technical contradictions" frequently arise such as cost increases accompanying functional enhancements, productivity declines associated with quality improvements, reduced strength resulting from lightweighting, and higher equipment costs due to automation.

To address these issues, the Smart Factory Development VCI conducts theme improvement activities utilizing TRIZ (Theory of Inventive Problem Solving) techniques.

(2) Definition of TRIZ

TRIZ is a problem-solving methodology for invention that analyzes technical problems and contradictions to systematically derive ① creative solutions, ② innovative improvements, and ③ optimal technological alternatives.

In essence, it is a smart engineering innovation technique aimed at ① eliminating technical contradictions, ② enhancing "Ideality," and ③ creating innovative value.

(3) Objectives of Using TRIZ in Development VCI

① Resolving technical contradictions, ② generating innovative ideas

③ enhancing functionality, ④ reducing costs, and ⑤ improving quality

(4) Concept of Linking Smart Factory Development (VCI) with TRIZ

① Value Innovation: Creative problem-solving

② Cost Reduction: Deriving technical alternatives

③ Quality Improvement: Resolving contradictions

④ Function Optimization: Enhancing ideality

⑤ Smart Development: AI-based analysis

(5) Core Concepts of TRIZ

1) Technical Contradiction

This refers to a trade-off relationship where improving one characteristic of a system causes another characteristic to deteriorate simultaneously.

To resolve such technical contradictions, TRIZ utilizes the "40 Inventive Principles" derived from global patents to systematically generate ideas.

Examples: Representative examples and meanings of technical contradictions

① Automobile fuel efficiency and vehicle weight:

ⓐ Meaning: A contradiction where making the vehicle body lighter to improve fuel efficiency (improvement) leads to reduced safety or structural integrity (deterioration).

ⓑ Solution approach: Using new materials like aluminum or carbon fiber to reduce weight while maintaining strength.

② Production process speed and quality:

ⓐ Meaning: A contradiction where increasing production speed boosts productivity (improvement) but raises the defect rate, thereby lowering quality (deterioration).

ⓑ Solution approach: Introducing new machining technologies or automation systems that allow for speed increases while maintaining control over accuracy.

③ Smartphone screen size and portability:

ⓐ Meaning: A contradiction where enlarging the screen to improve visibility (improvement) makes the device larger, thereby reducing portability (deterioration).

ⓑ Solution approach: Applying foldable display technology to achieve both portability and a large screen simultaneously.

2) Physical Contradiction

This refers to a state where the same system or component is required to possess two mutually exclusive properties simultaneously. In other words, it is a contradiction where a single variable must hold different values at the same time.

Representative examples of physical contradiction:

① Airplane landing gear (utilizing time separation):

ⓐ Contradiction: Wheels are necessary during takeoff and landing (requiring them to be large and heavy). However, during flight, they should be absent to reduce air resistance (requiring them to be light and streamlined).

ⓑ Solution: Deploy the wheels during takeoff and landing, and retract them during flight, thereby resolving the contradiction through time separation.

3) Ideality

Ideality = Useful Functions / (Cost + Harmful Functions)

It represents a state where maximum functionality is achieved with minimal cost and minimal problems.

4) Inventive Principles

TRIZ derives solutions primarily by utilizing tools such as ① the 40 Inventive Principles and ② the Technical Contradiction Matrix.

(6) Areas of Application for TRIZ in Smart Factory Development

① Product design, ② Process design, ③ Automation design

④ Quality improvement, ⑤ Cost reduction, ⑥ Eco-friendly design (Eco-Design[1])

※ Explanation: 1. Eco-Design: "Eco" is an abbreviation for "Ecology" and is used to signify "environmentally friendly."

(7) Stages of the TRIZ-based Improvement Process

① STEP 1: Problem Definition, ② STEP 2: Technical Contradiction Analysis

③ STEP 3: Ideality Analysis, ④ STEP 4: Application of TRIZ Inventive Principles

⑤ STEP 5: Derivation of Improvement Solutions

⑥ STEP 6: Prototype Verification

⑦ STEP 7: Mass Production Implementation and Optimization

(8) Implementation Methods by Step

1) STEP 1: Problem Definition

Key Activities: ① Identifying the problem phenomenon, ② Loss analysis, ③ Customer requirement analysis, ④ Setting improvement goals

2) STEP 2: Technical Contradiction Analysis

Key Activities: ① Analysis of improvement factors, ② Analysis of worsening factors, ③ Identifying contradiction parameters, ④ Applying the Contradiction Matrix

3) STEP 3: Ideality Analysis

Key Activities: ① Functional analysis, ② Harmful factor analysis, ③ Cost analysis, ④ Ideality assessment

4) STEP 4: Application of TRIZ Inventive Principles

Examples of key inventive principles: ① Segmentation, ② Preliminary action, ③ Composite structure, ④ Lightweighting, ⑤ Automation

5) STEP 5: Derivation of Improvement Proposals

Key activities: ① Evaluation of proposals, ② Economic analysis, ③ Technical review, ④ Selection of the optimal solution

6) STEP 6: Prototype Verification

Key activities: ① Prototype fabrication, ② Functional testing, ③ Quality verification, ④ Reliability assessment

7) STEP 7: Mass Production Implementation and Advancement

Key Activities: ① Mass production implementation, ② Standardization, ③ AI data analysis, ④ Smart engineering

(9) Characteristics of TRIZ in Smart Factories

① AI-based Analysis: The convergence of smart factories and TRIZ (Theory of Inventive Problem Solving) serves as a core methodology for resolving contradictions on the manufacturing floor based on data. Through AI-based analysis, TRIZ's 40 inventive principles are automatically applied in real-time, enabling rapid and optimized problem-solving that transcends human limitations.

② Digital Twin: This refers to technology that creates an exact virtual replica or "twin" of a physical building, city, or manufacturing facility, utilizing real-time data to simulate and optimize environmental impacts.

③ Utilization of Big Data: TRIZ (Theory of Inventive Problem Solving) a key element of smart factories drives manufacturing innovation by resolving contradictions and optimizing processes. This TRIZ-based innovation culminates in the Digital Twin, which creates a physical twin of the factory in a virtual space and integrates real-time data to automate decision-making.

④ Smart Engineering: This refers to the process of resolving technical contradictions in manufacturing using TRIZ to make systems intelligent, while integrating this process with enterprise-wide data and ICT to generate optimal value.

⑤ Characteristics of TRIZ in Smart Factories: TRIZ is the "Theory of Inventive Problem Solving" developed by the Russian theorist Genrich Altshuller through the analysis of a vast number of patents. When applied to smart factories, it exhibits the following characteristics:

ⓐ Resolution of Technical Contradictions (Utilizing Inventive Principles): It resolves contradictions where two goals are difficult to achieve simultaneously such as the trade-off between productivity and quality (e.g., increased speed leading to a higher defect rate) by applying the 40 inventive principles.

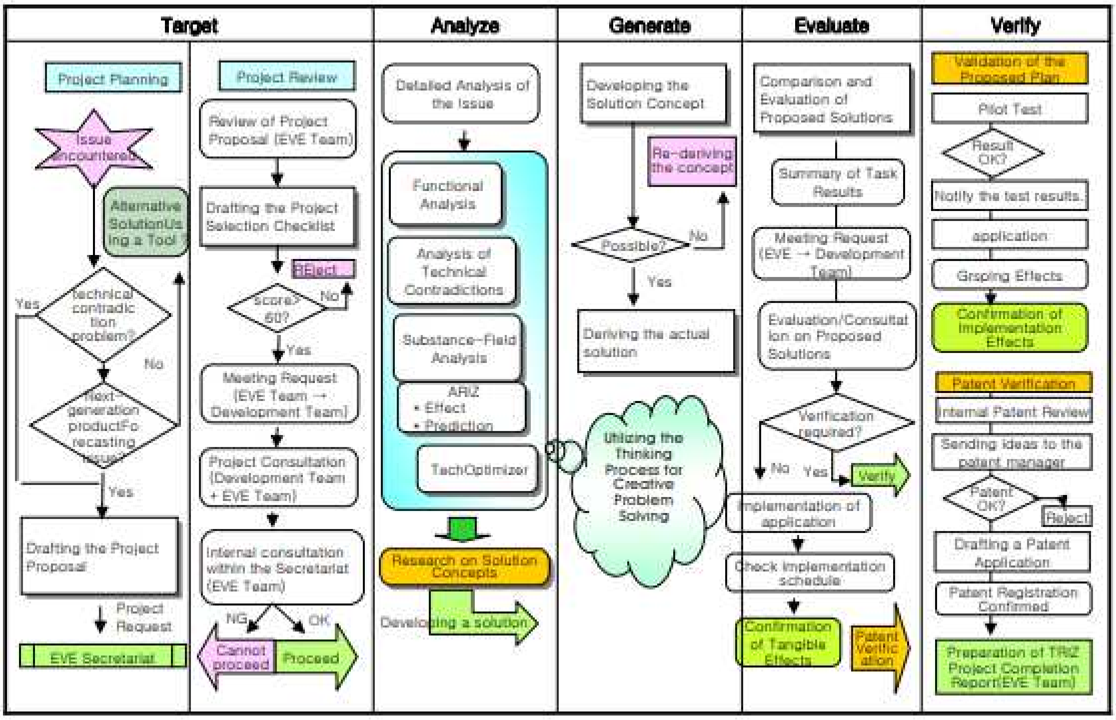
ⓑ System Optimization and Automation: It transforms manual processes into automated ones utilizing IoT devices and robots by applying principles such as "replacement with a mechanical system" and "preliminary action." ⓒ Data-driven insight generation: By analyzing changes in physical process characteristics and resources, ideas are derived for a smart environment where AI can make autonomous judgments and control operations.

⑥ Definition of Smart Engineering: Smart Engineering is realized when the problem-solving capabilities of TRIZ converge with digital technologies (such as AI, digital twins, and cloud computing).

ⓐ Maximizing value realization: It goes beyond the simple application of "smart technology (ICT)" to realize value in terms of time, cost, and accuracy across the entire lifecycle of product planning, design, and production.

ⓑ Implementation of Smart Thinking: This refers to the level of engineering intelligence that supports data-driven, optimal decision-making through methodologies such as Design Thinking and TRIZ.

⑦ Predictive Analysis: In a smart factory, the core of TRIZ (Theory of Inventive Problem Solving) lies in the structural analysis of data and system contradictions to enable predictive analysis. In a manufacturing context, predictive analysis refers to intelligent decision-making that identifies and responds to future situations or issues in advance based on collected real-time data.



[Figure 6.35] Case study on establishing the implementation method for EVE theme improvements using TRIZ

(10) Linking C-TPM Activities with TRIZ

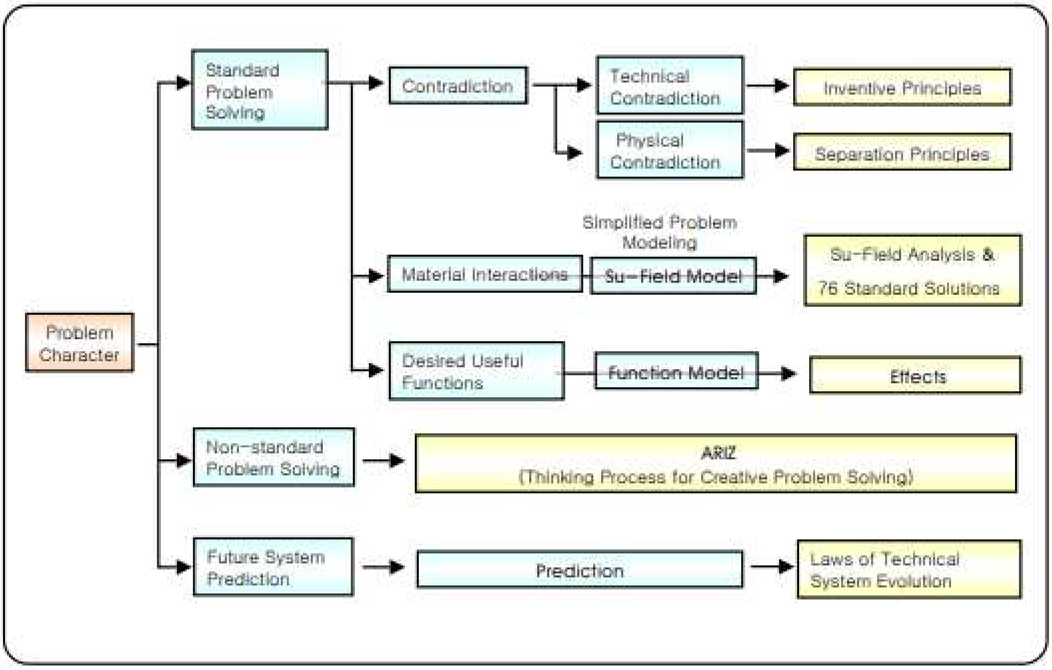
① Initial Management: Innovative design

② Quality Maintenance: Quality problem resolution

③ Individual Improvement: Creative improvement

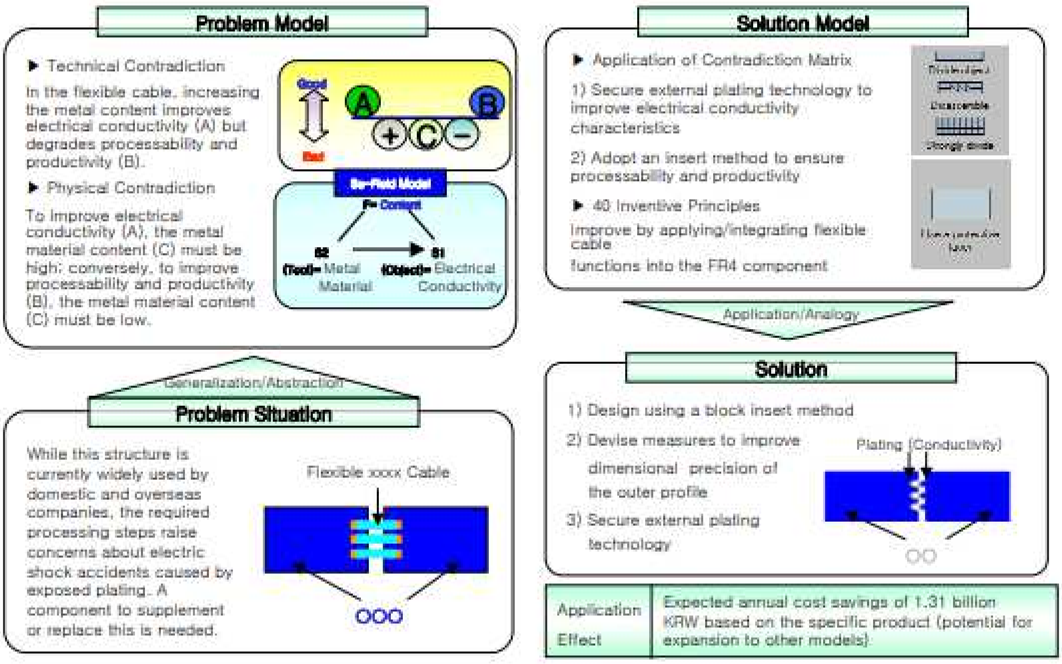
④ Planned Maintenance: Improving maintainability

⑤ Education & Training: Enhancing creative capabilities



[Figure 6.36] TRIZ Problem-Solving Principle Hierarchy

(11) Case Study of EVE Theme Improvement Using TRIZ



[Figure 6.37] Case Study of Problem-Solving Using TRIZ

(12) Key Success Factors for TRIZ Application

① Clarification of problem definition, ② Analysis of technical contradictions
③ Cross-functional activities (CFT), ④ Data-driven approach
⑤ Continuous improvement

(13) Expected Benefits

① Development of innovative products, ② Cost reduction
③ Quality improvement, ④ Strengthening of technological competitiveness
⑤ Shortening of development lead times

(14) Summary of Key Implementation Aspects

The theme-based improvement activities utilizing TRIZ and VCI for smart factory development are innovation-driven initiatives focused on ① resolving technical contradictions, ② creative problem-solving, ③ functional optimization, ④ cost innovation, and ⑤ AI-based smart engineering.

In essence, the core objective is to establish a smart development framework built on the synergy of "TRIZ + VCI + AI → Smart Innovation" hereby realizing smart factory manufacturing innovation driven by a cycle of "Innovation → Product Excellence → Enhanced Manufacturing Competitiveness."

6.11 Sales Process Reengineering (SPR)

6.11.1 Concept of C-TPM Sales SPR

(1) Overview of Implementation

Manufacturing innovation in smart factories is not achieved through production innovation alone.

Today, manufacturing companies require a company-wide innovation system extending to the sales division to respond to environmental changes such as ① diversified customer demands, ② requirements for shorter delivery times, ③ higher quality standards, ④ intensified global competition, and ⑤ the expansion of digital markets.

Chapter 7

Measuring the Effectiveness of C-TPM for Competitiveness Enhancement

☆ Index ☆

Cost, Delivery) metrics

③ Internal Process perspective: Indicators related to P·Q·C·D·S·E (Productivity, Quality, Cost, Delivery, Safety, Environment)

④ Learning and Growth perspective: Indicators related to M (Manpower/People)

(9) Comprehensive Model for Measuring C-TPM Effectiveness in Process Industry Smart Factories

Manufacturing Competitiveness → Productivity + Quality + Cost + Delivery + Safety & Environment + Talent Development + Smart Transformation

(10) Ultimate Goal

Continuous Improvement + Data-Driven Management + Total Participation → Achieving World-Class Manufacturing Competitiveness

(11) Key Implementation Summary

The effectiveness measurement indicator system for C-TPM in plant industry smart factories must be established as an enterprise-wide KPI framework that integrates management across productivity, quality, cost, delivery, safety & environment, talent development, smart transformation, and ESG.

In particular, by establishing a hybrid performance management system that links visual management centered on activity boards with digital management centered on KPI dashboards, it is possible to objectively measure C-TPM performance outcomes and achieve continuous improvement in manufacturing competitiveness.

7.2 C-TPM Effectiveness Measurement: Calculating Overall Equipment Effectiveness (OEE)

(1) Overview of Implementation

The core objectives of C-TPM activities are to maximize equipment efficiency, improve productivity, stabilize quality, reduce costs, and secure manufacturing competitiveness.

To achieve this, manufacturing sites utilize the Overall Equipment Effectiveness

(OEE) metric to quantitatively evaluate the actual operational efficiency of equipment.

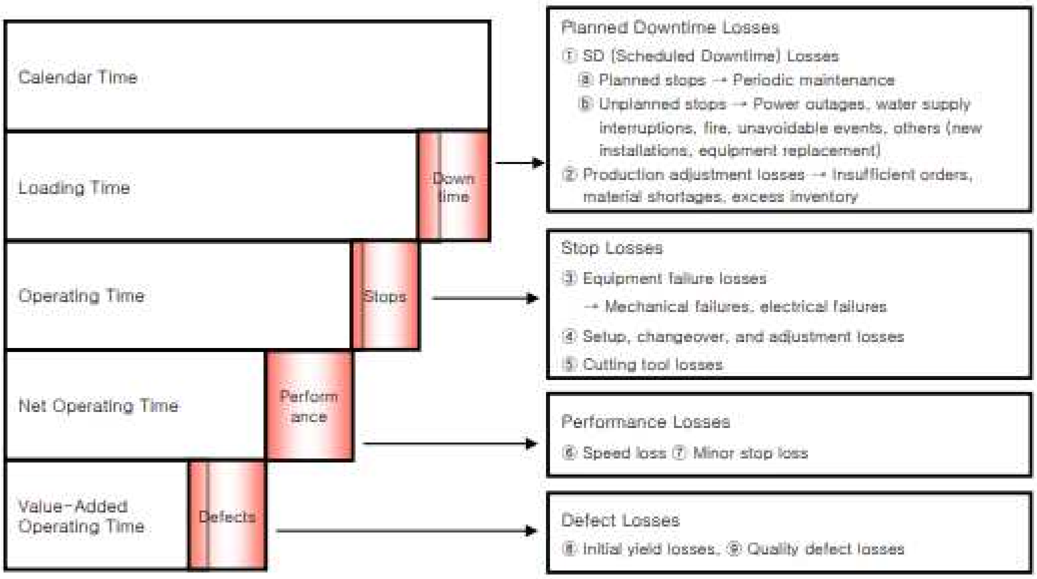
Notably, in the manufacturing sector, the methods for calculating efficiency differ depending on the equipment characteristics specifically distinguishing between traditional machining/assembly equipment and process-type equipment (used in continuous processing industries).

For traditional equipment, efficiency management focuses on individual units, whereas for process-type equipment, the focus is on production efficiency centered on continuous processes.

(2) Calculating Overall Equipment Effectiveness (OEE) for Processing-Type Equipment

The relationship between the structure of the six major losses in processing-type equipment and Overall Equipment Effectiveness (OEE) is shown in [Figure 1].

Processing-type equipment refers to equipment?such as machining equipment or batch-processing equipment?that does not necessarily operate continuously.



[Figure 7.1] Six Big Losses and OEE Calculation for Processing-Type Equipment

OEE is calculated by multiplying three factors: availability (time efficiency), performance efficiency (speed efficiency), and quality rate.

It serves as a comprehensive metric indicating the extent to which the equipment contributes to value-added production, taking into account its status regarding time and speed, as well as the quality of the output.

Time Availability=(Load time−Downtime)÷Load time
=Operating time÷Load time
Performance Availability
=[(Production Volume×Actual Cycle Time)÷Operating Time]×
(Theoretical Cycle Time[1]÷Actual Cycle Time)]
=(Theoretical Cycle Time×Production Volume)÷Operating Time
Quality Rate=Quantity of Good Products÷Input Quantity
Where: Quantity of Good Products=Input Quantity−(Initial Defects+Process Defects+Rework Quantity)
Overall Equipment Effectiveness (OEE)=Time Availability×Performance Availability×Quality Rate

[Figure 7.2] Six Big Losses and OEE Calculation for Processing-Type Equipment

※ Explanation:

1. Theoretical cycle time

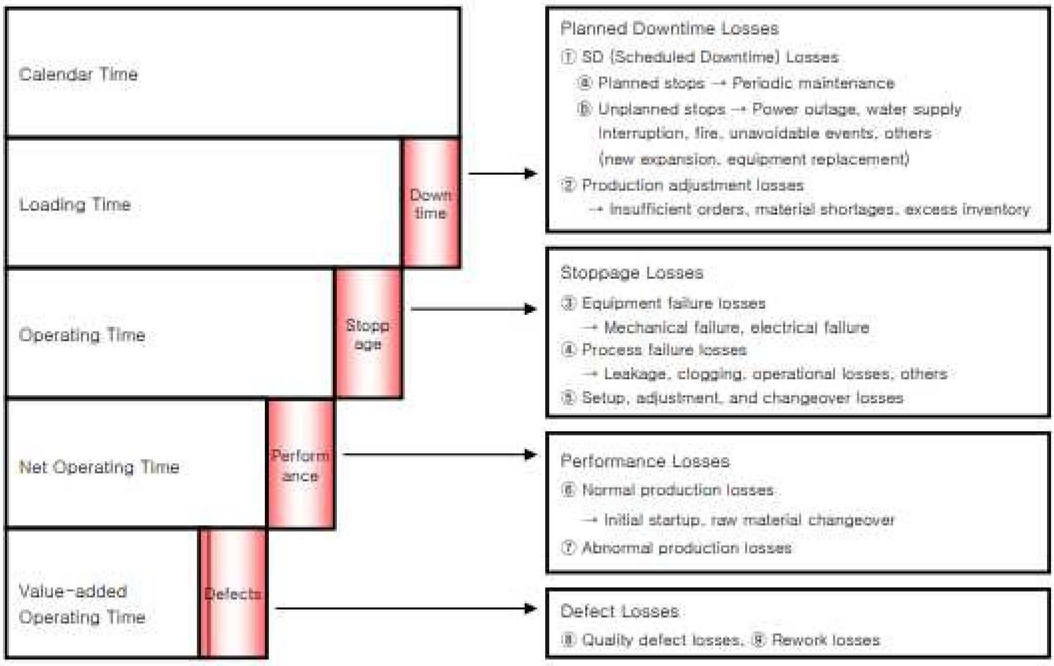
① Theoretical cycle time (min/unit) also known as standard cycle time is the reciprocal of theoretical production rate (units/min).

② Theoretical cycle time represents the shortest achievable time required to produce a single unit (units: min/unit, sec/unit, etc.).

(3) Calculation of Overall Plant Efficiency for Process-Type Equipment

Equipment that operates continuously due to the nature of the operation is referred to as process-type equipment (e.g., chemical processing units, steelmaking facilities, etc.).

The relationship between the structure of the eight major losses and the overall plant efficiency for process-type equipment is shown in [Figure 3].



[Figure 7.3] Structure of the Eight Major Losses for Process-Type Equipment

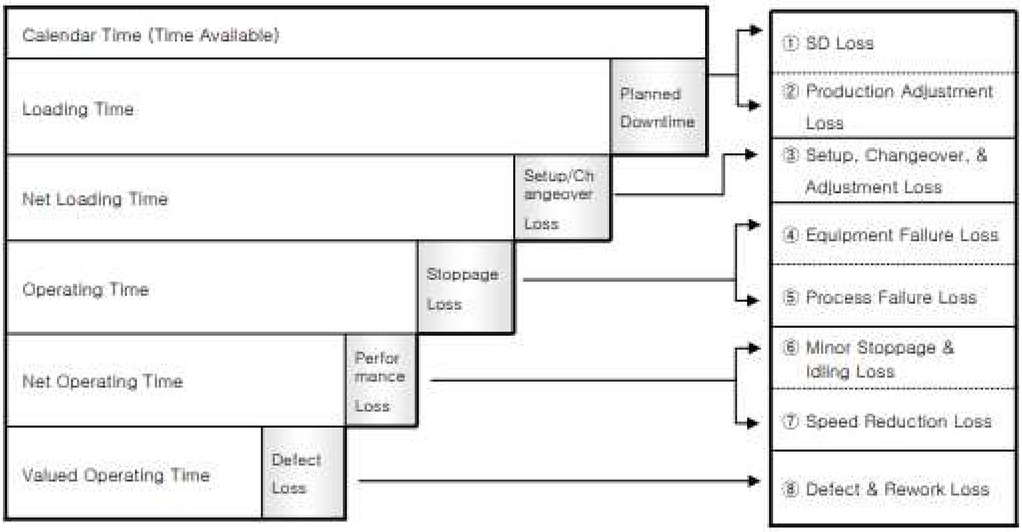
Overall Plant Efficiency (also known as Overall Production Efficiency)

= Load Factor×Overall Equipment Efficiency

= Load Factor×Time Availability×Performance Efficiency×Quality Rate

(4) C-TPM: Advanced System for Calculating Overall Equipment Effectiveness (OEE) Applicable Across All Industries

1) Structure of Time Losses Hindering Equipment Efficiency



Source: Ph.D. Dissertation by Dr. Kwon O-un (Korea University)