

Knowledge-Based Multi-agent System for Smart Factory of Small-Sized Manufacturing Enterprises in Korea

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Abstract. This paper focuses on the development of practical application prototype of information and communication model that can be applied in the field in order to solve the problems of SME manufacturing and manufacturing companies in each manufacturing industry. We are trying to establish a process to implement a smart factory by adding a specialist network through problem-solving data management based on the cases of bad people in the manufacturing process including field workers. It also has the implication of supporting field work by providing Manufacturing Problem Solving (MPS) processes to shop floor workers.

Keywords: SME manufacturing · MPS (Manufacturing Problem Solving) process · KBM (Knowledge-based multi-agent system)

1 Introduction

Large companies can build large-scale smart factories from scratch, but for small and medium-sized enterprises, it is common to expect high cost-effectiveness in addition to existing manufacturing facilities at low cost and in a short period of time. Toyota's production system is a major methodology that enables large corporations to continue to grow. It is a production philosophy that aims for a bigger target condition through continuous improvement [1,2]. Whether it is building a large-scale smart factory or adding it to, existing facilities, the basics of the way in which the project is implemented are the same. It has a purpose, a budget, and a deadline. It sets the scope of execution within it, and makes it clear that the system and the schedule are clear [3].

Fault diagnosis of the manufacturing system is a problem that causes continuous difficulty for the operator at the manufacturing site [4]. IoT technology and manufacturing facilities require investment in developing advanced sensors, connecting software platforms and building equipment. This technological improvement possibility and the method of establishing linking with the existing information database in the manufacturing industry field are meaningful studies in that it is possible to execute efficiently in the investment sector.

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This paper is organized as follows. In Sect. 2, it is composed the 16 fields of industry related to this work, the area of process automation, and smart factories in Korea are classified as basic level, intermediate level, and advanced level. Provides literature review of key topics in manufacturing issues, knowledge representation, PLM (Product lifecycle management) and CBR (Case-Based Reasoning). Section 3 discusses the generated model, which is the basis of the conceptual approach adopted to define the data structures needed to manage manufacturing problem knowledge. Section 4 describes the prototype application developed. This paper concludes with conclusions and future studies.

2 Related Work

The establishment of smart factories in Korean SMEs is more appropriate than the system approach, unlike large corporations, where the factory level diagnosis and the smart factory uptake approach are appropriate. Therefore, in this paper, we will diagnose the smart factory basic level, intermediate level and advanced level according to the field level diagnosis, and propose a plan to build the smart factory at the target level.

2.1 CBR Based Kepner-Tregoe Problem Solving Method

In general, about 6 problem solving methods are used for problem solving method such as defect in manufacturing site [5]. Their common feature is the definition of the problem and the process of problem solving through root cause and various cause analysis [6]. Among them, DMAIC (Define - Measure - Analyze - Improve - Control) method and Shainin method (Define the Project - Establishment effective Measuring System - Generate Clues - List suspect Variables - Statistically designed Experiments - Interaction realistic Tolerances - Irreversible Corrective Decision Analysis - Statistical Process Control-Monitoring Results-Leverage lessons learned) will have similarities in defining the problem or project to be solved in the process and determining and starting the process at the earliest [7–9]. A failure is when part of the manufacturing system does not meet the outage specifications. As a result, production may be discontinued and production goals may not be reached. The gap between the result state and the intended state is defined as the problem. If you see a production problem, you need a detailed process of analyzing the problem and creating a solution [10]. In this paper, Kepner-Tregoe problem solving method and Eight Disciplines (8D) are applied to solving manufacturing problems in order to solve bad problems and to build a smart factory. Kepner–Tregoe problem solving method is composed 4 steps [11]. First is situation analysis. Second is problem Analysis. Third is decision analysis. And the last is potential problem and potential opportunity analysis. Figure 1 represents the definition of manufacturing problem solving definition.

These methods are based on Continuous Improvement Process (CIP) and Manufacturing Problem Solving (MPS) [12]. Obviously, 8D is a problem-solving

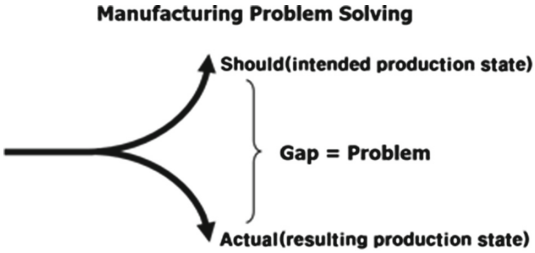


Fig. 1. Kepner-Tregoe MPS (Manufacturing Problem Solving) definition

method that focuses more on solving production problems [13]. In order to support suppliers in the troubleshooting activities developed by Ford Motor in the early 1990s, 8D consists of eight main steps: (1) team definition, (2) problem description, (3) containment actions (4) root cause analysis, (5) definition of potential corrective action and validation, (6) introduction of corrective action, (7) definition of lesson, (8) team celebration. Sharing team members' knowledge and experience is a key element in implementing all troubleshooting methods [14]. These methods provide a structured process that facilitates improvement and discovery of the solution. Nonetheless, training is generally provided to team members, but these methods are only successful when driven by experienced and knowledgeable workers (e.g., provided by software tools). The literature shows that industrial applications of PFMEA (Potential Failure Mode and Effects Analysis) are complex, time consuming and ineffective [15–17]. Also, results are low and results are not corrected in regular improvement activities, and there is a problem maintaining effective feedback. Some of the problems with PFMEA relate to the fact that they are based on a spreadsheet approach that makes reusing results and identifying similarities difficult.

2.2 Knowledge Management System

What is important in smart factory is the accumulation of all manufacturing data and the databaseization of their relevance [18]. Here, we can present a standard model for the establishment of an up-level smart factory through process automation and IoT work in accordance with the problems presented by field workers in order to build a smart factory in Korea. Here we propose a knowledge management (KM) approach [19–21].: • Promoting reuse of PFMEA analysis results • Facilitates the collection and reuse of data and knowledge of the manufacturing level at the factory level or manufacturing process during daily MPS activities related to improving over-all equipment efficiency (OEE). Focuses on product and process quality issues (i.e., quality claims and scrap), unusual production speeds and failures among the various topics considered by OEE • Provide problem solving software tools based on 8D methods to actors in the workplace. This tool can also be used by users with very low knowledge of

the manufacturing system in which they are working. • Supports manufacturing knowledge sharing and integration across multiple manufacturing factories.

2.3 Smart Factory Construction Plan and Process Automation Area Check by Industry

The establishment of a smart factory in Korea starts with selecting which industry in the manufacturing and production factories. The process automation area is checked through the level check according to the screening to determine the level of the smart factory to be completed. In the case of manufacturing industry, smart factory is divided into 1 casting, 2 forging, 3 mold, 4 injection molding, 5 press, 6 welding, 7 precision machining, 8 heat treatment, 9 plating, 10 coating, 11 machine parts assembly, 12 cosmetics, 13 pharmaceuticals, 14 enterprise resource management, 15 product development, and 16 supply chain management.

Table 1. 5 levels for SME smart factory in Korea.

Implementation phase	Automation	Plant operation	Business
Advancement	Automation combined with control automation and digitalidentification	Self-diagnosis and control using CPS,IoT, BigData	Real-time customized service through value chain linkage
Intermediate level	Automation of facility control	Real-time decision making and equipment control	Real-time decision making and control actively responding to market and customer needs
Medium level	Real-time collection of plant data	Performance-oriented factory operating analysis from facilities	Real-time information exchange such as information management based process operation
Foundation level	Barcode and RFID-based basic logistics information collection	Process logistics center performance management	Performance and quality-oriented functions
No ICT	handwork	Handwork	Phone and e-mail collaboration

According to the target stage of SME manufacturing companies in smart factory, SME Smart Factory in Korea is generally composed of 5 levels as shown in Table 1.

- Level 1: Factory level of manual ICT unemployed
- Level 2: Factory level of barcode and RFID-based basic logistics information gathering stage at Foundation level
- Level 3: Factory level of collecting plant data in real time with medium level

– Level 4: Factory level of facility control automation phase with real-time decision making and facility control at intermediate level
– Level 5: At the advanced level, real-time customer service is available at the factory level.

Currently, most of SME factories in Korea are in the level 1 or level 2.

3 Knowledge-Based Multi-agent System

In this paper, the knowledge-based multi-agent system is a solution process for networking of related problem experts by expanding the solution to manufacturing defect and process-related problems occurring in manufacturing factories in Korea at the level of manufacturing workers in factories [19]. At present, the smart factory level of most SMEs in Korea is level 1 or level 2, which is the level of the problem-solving manual in the factory, or sensor information acquisition with RFID. Figure 2 illustrates a knowledge-based MPS for manufacturing failure problems.

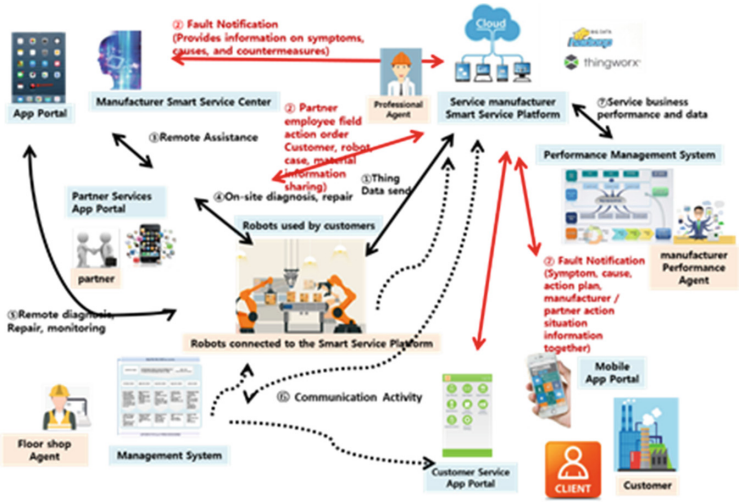


Fig. 2. Knowledge-based MPS model

1. Thing Data send: Step 1 is the step of sending signal data of the manufacturing site from the sensor attached device such as fault report data.
2. Fault Notification (Provides information on symptoms, causes, and countermeasures): In step 2, the failure signal judged by the field worker is transmitted to the failure report as to the failure symptom, the cause of failure, and the corresponding countermeasure.

3. Partner employee field action order (Customer, robot, case, material information sharing): The second stage is also the stage where the partner agent sends the site information at the same time. And share information about the robot, the bad case, and equipment information.
4. Fault Notification (Symptom, cause, action plan, manufacturer/partner action situation information together): Step 2 sends the failure information, which includes information about the failure, the cause of the failure, the action plan, and the situation that the manufacturer and the partner must cope with.
5. Remote Assistance: Step 3 is the Remote Assistance phase.
6. On-site diagnosis, repair: Step 4 is the diagnosis and repair phase at the fault site.
7. Remote diagnosis, Repair, monitoring: Step 5 is the remote diagnosis, maintenance, and monitoring.
8. Communication activity: Step 6 is a step to communicate the solution of the expert on the fault situation and to proceed with the work.
9. Service business performance and data: Step 7 is the step of accumulating and maintaining this data.

First, when a faulty case occurs at the manufacturing site, it is classified into 16 manufacturing sectors (such as welding, manufacturing, supply chain and so on), and the consumer side determines which field of manufacturing expert networking should be connected. When the field is selected, whether the problem is a problem in the process or whether it is a facility problem, and whether it can be used as an automation field, will be understood from the supplier side. In the problem recognition stage, the problem type posted by the field worker is categorized as a problem of the existing type, new type, improvement type through the database search of the CBR method, and if the problem of the product defect is detected, the product manufacturing history management of the PLM system [22]. Once the problem is defined, the process of resolving it is solved by applying the problem-solving process of Kepner-Tregoe. First, the problem definition is defined as the difference between as is and to be, describing the current state and defining the target state. Root cause analysis is performed through the process of presenting various causes of the problem and analyzing it. In the solution presentation stage, the solution is suggested through agent-based networking. Then, it is applied to the field and then it is processed as a process to accumulate it on a case-by-case basis. The characteristic aspect of the proposed system is that it provides a solution through expert networking in solving all the problems presented by the manufacturing worker, so that the whole manufacturing process and efficient process construction.

4 Use Cases

4.1 Manufacturing Problem-Solving Process

Manufacturing problem-solving process is configured as follows:

- Equipment/Logistics Automation
- Infra aspect for smart factory implementation, facility/logistics automation is required together with standardized two-way communication system
- Based on this, smart factory is realized by system intelligence.

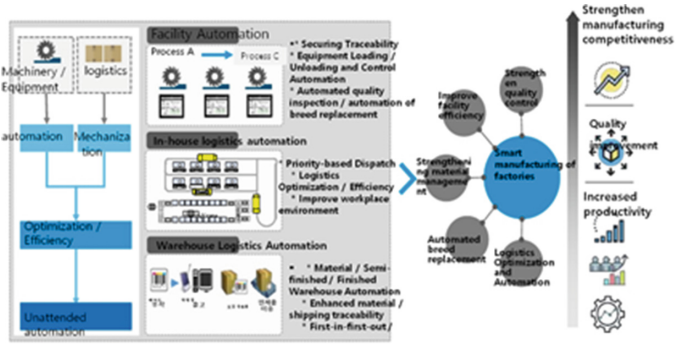


Fig. 3. Equipment/Logistics automation

Figure 3 shows an example of the implementation of a company's equipment and logistics automation system in Korea. It is a top priority to deliver goods to consumers quickly and safely using any means, such as shipping, air, rail or road. Logistics automation systems have fields such as logistics facilities, logistics information systems. The automation system for the logistics facilities is composed of automation warehouses (three-dimensional automatic warehouses, semi-automated warehouses, float rack automation, etc.) and unmanned conveying systems (rail guided vehicles, automatic palletizer systems, conveyors). Logistics information system is composed of automation control system, inventory management system, wireless management system (RFID), automatic classification system, dispatch system, order management system (OMS). Logistics automation is also urgent in terms of efficiency and cost reduction. In logistics warehouse, robotization and ITization are promoted in each of these areas such as admission, storage, inventory management, picking, packing (packaging), shipping, saving and unmanned. In the equipment automation production facility, a flexible conveying system that replaces the conveying line by the fixed facility centering on the conveying line conveyer which supplies parts and materials is being carried out, and the case of using the AGV is increasing. Due to the compactness of the AGV (Automatic Guided Vehicle), the AGV can travel at a maximum driving speed of 120 m/min in a production facility or in a narrow space below. Since the body (driving part) and the turntable for moving are

independent from each other and rotated 360°, it can be introduced into various devices, and is easy to carry. Equipped with a safety scanner that detects obstacles, it is safe to drive multiple vehicles in a narrow passage.

In the case of multiple AGV operations, the entire operation control system such as the optimum allocation is performed, so that it is possible to increase the production capacity and flexibly cope with it. It is a new solution that is used in various production sites and logistics sites with flexible pallet transport system, replacing fixed equipment such as pallet conveying parts and conveyors. Normally, a person walks around and picks up or finds a shelf product, picks out, packages, ships and shuts out the necessary goods. This is a revolution that shipped from the stock to the computer in stock. In the latest automatic warehouse, automation of logistics in the warehouse of logistics bases (logistics centers, warehouses) is also being automated by the technology of forks, traveling cargo conveyors, robots and computer control. As a new movement, the automatic conveying truck lifts the picking shelf up to the designated place, and automation in various fields that does not require the movement of the worker is also performed.

Equipment/Logistics Automation - Process Logistics Automation. AGV means an unmanned vehicle that travels to a destination along the route by installing a necessary induction method on the floor, wall, and ceiling.



Fig. 4. Equipment/Logistics automation - process logistics automation (AGV)

Figure 4 is an example of automated unmanned vehicle and pallet logistics operation operated by a company in Korea. Unmanned vehicle means a vehicle equipped with an induction system including an electro magnetic system, an optical system, and an anti-collision system, which are mainly used for manufacturing facilities and warehouses. Unmanned transportation system is used for material transportation in warehouse, container and semi-conductor LCD process. It is part of automation production system and carries out parts process of each process and movement of logistics between production lines. It is used to ensure flexibility. In the industrial field, the unmanned vehicle carries the role of

material transfer between the processes, and is manufactured in various forms according to the process used. Unmanned vehicles are often called laser-guided vehicles (LGVs) or self-guided vehicles (SGVs). In recent years, the development of a smart digital transfer device replacing a forklift in the logistics center has been active. This transfer robot, which is called an unmanned transfer robot, is designed as an intelligent robot system. It is designed as an intelligent robot system. It is equipped with control technology of driving device using Omni wheel, terrain sensing technology using 3D laser scanner, robot autonomous driving technology and evasion technology, And system integration control technology, it can be used in various fields in the production site. The resulting productivity effect is significant.

Automation of pallet logistics operations. Pallet Logistics automation or pallet transportation system is a unit type automatic warehouse (automatic rack system) that automatically transports pallet unit products or parts and stores them in high-tier racks. It is possible to effectively use the high direction to increase the storage efficiency. Since the input and output instructions of the cargo are computerized, it is easy to manage the first-in, first-out, and leads to quality improvement. Pallets designed in the form of a hand lift. The automated logistics robot is a logistics automation robot for unmanned transportation and is particularly suitable for sites where pallets are frequently transported. In the meantime, people have transported goods on pallets directly to factories and warehouses. More specifically, this operation of pumping the hand lift and transferring the weight of the worker to transfer the heavy weight of the workload imposes a burden on the worker's body, while the work speed is also slow, and it is necessary to calibrate the position several times.

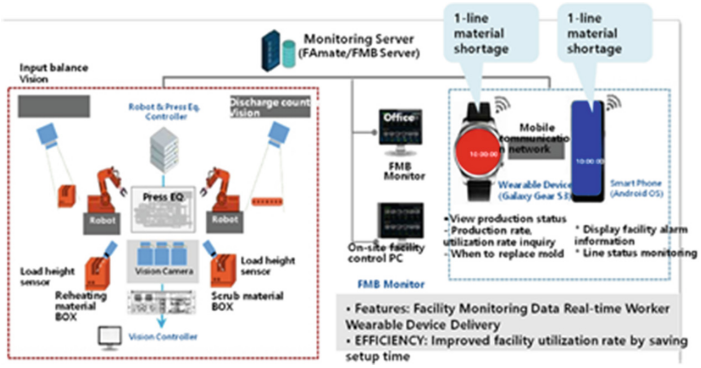


Fig. 5. Communications in smart factory

Figure 5 represents an example of a two-way communication case, in a case where a worker establishes a real-time monitoring system by automatically notifying the wearable device of facility monitoring data (production status, facility alarm information, etc). It represents manufacturing environment and safety. It is composed of some items. System item is press process product. Application

field presents pressing process automobile parts. Robot specifications are 6 axis multi joint type IP67. Gripper item is chunk gripping.

4.2 Manufacturing Neural Networks

Figure 6 represents Visualization and Informatization of Manufacturing Environment/Safety - Manufacturing Neural Networks. By efficiently operating the main utilities of the factory, it is possible to realize cost reduction, quality assurance, and equipment pre-shutdown by precise analysis of major environmental factors (particle, power, vibration, temperature/humidity, etc.)

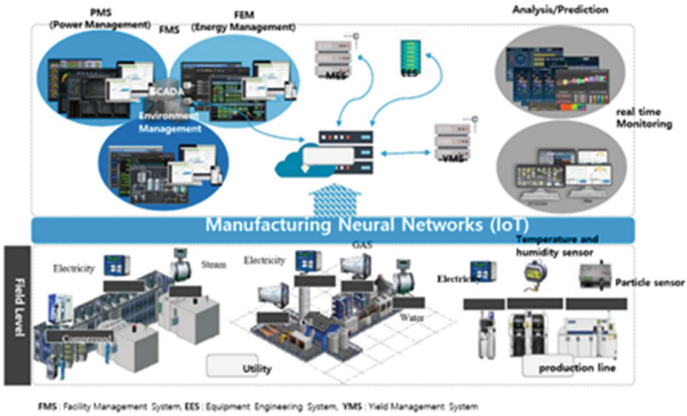


Fig. 6. Manufacturing environment/safety - manufacturing neural networks (IoT)

The proposed system implements the process of establishing manufacturing neural network through real-time monitoring of smart factory manufacturing process information by region through the main GUI.

Figure 6 is an example of manufacturing neural network of a company in Korea. The manufacturing neural network is one of the types of machine learning that enables normal process through abnormal operation signal during abnormal operation through collecting information through IoT sensors for each device in the process, and is used in the manufacturing process.

We use only the data of the devices that are normally operating, i.e., do not need the fault data, and made an abnormal detection model through non-teacher learning. In addition, it is possible to detect anomalies by using a combination of multiple sensors, which may be different from each other in the correlation between the sensors and the types of the sensors. Fault data is required to actually predict the time at which the fault will occur.

It is important to cope with the preventive preservation function because the failure of the work robot stops the production line and lowers the operation rate. It is characterized by the use of the deep learning in the manufacturing factory [20], So that it can be introduced while reducing the burden on the user.

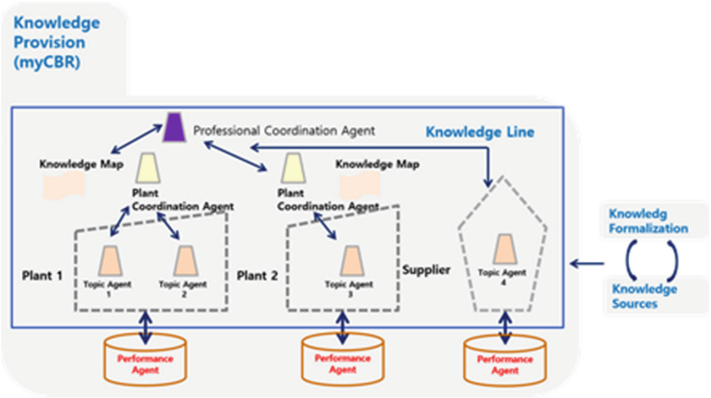


Fig. 7. Manufacturing Troubleshooting System

4.3 Manufacturing Troubleshooting System

Figure 7 represents Manufacturing Troubleshooting System. From the IT perspective, the proposed process model is based on a multi-agent architecture. Figure 7 shows the application to the proposed MPS system. The proposed MPS system architecture supports the deployment of multiple agents in different manufactur-ing factories in the company [21]. It supports the placement of the entire area in various manufacturing processes or production units at each location. In this way, each agent hosted in a specific production unit at a specific location can exchange information with all other agents hosted at different production units and locations through the company's intranet. The multi-agent architecture has been simplified using only the parts that are relevant to this smart factory system. The three agent types include the following in a multi-agent architecture:

- The field agent is extended to include the collection of context information from the PLM system at the plant site to complete the definition of the problem. This type of agent is as many as an MPS system user.
- Manufacturing Performance Management Agent calculates similarities through past cases and similar cases of bad problems that have occurred through the company's bad troubleshooting database and suggests the best solutions based on specific cases. There are as many agents of this type as production units, and each production unit is hosted in the central unit of that production unit.
- Expert Agent coordinates communication among agents and is responsible for selecting the best solution among the solutions proposed by the performance management agent. There are two types. The global reconciliation agent acts as a global reconciliation of the architecture at all connected locations. Coordination agents perform coordination of a single location. Get help from a topic agent in a known location. There is one global coordinator and one fac-

tory coordinator. The Global Coordinator is hosted on the company's central server and the Plant Coordinator is hosted on each location's server.

5 Conclusions

The proposed SME factory construction model showed how the results obtained by the MPS system are available in Korea. The goal of this proposed system is to help the manufacturing site staff, such as line or quality inspectors, perform MPS processes. The MPS process is characterized by knowledge-intensive activities based on experience. The main contribution of this work is an innovative production-oriented approach to MPS by combining classic MPS methods and expert agent groups in agent-based expert architecture and PLM systems. In addition, it is also characterized by the use of agent-based expert group and manufacturing neural network environment in the step-by-step approach for establishing smart factory in Korea. Future research and development work can be summarized as follows.

- It is necessary to develop global best practice by expanding development system by connecting to MES (Manufacturing Execution System) built in Korea.
- A cloud-based, universal platform must be developed to automatically apply the proposed solution to the specific context of each manufacturing process, for example, in a facility or logistics process.
- Development of a database that meets public interest through open source based application data sets with manufacturing facility and process data information through systematic data management of manufacturing system problems in developed systems.

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