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REVAMPING FACILITY ASSET MANAGEMENT (FAM) FOR SMART MANUFACTURING: VARIABLES FOR THEORY AND IMPLEMENTATION

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In the Fourth Industrial Revolution era, the information exchange and integration of the smart factory are highlighted. The facility, including production equipment in smart manufacturing, serves as the fundamental component enabling automated and optimized manufacturing operation and production. Nevertheless, there has yet to be a legitimate definition of facility asset management (FAM) functions which are the firm basis for identifying further information and properties. In order to address this issue, this paper defines three-level hierarchical functions of facility asset management (FAM) by integrating four areas of construction management (CM), asset management (AM), facility management (FM), and operation management (OM). An extensive literature was conducted first to incorporate all relevant concepts and definitions of new trends in facility asset management. A structured FAM definition was then formulated using the classes and properties. Finally, the suggestions for applying the proposed FAM functions are illustrated. Practical implications and lessons learned are briefly introduced as well.

Keywords: Conceptual framework, Industrial plant, Business function, Digital twin.

1 INTRODUCTION

Smart manufacturing in the Fourth Industrial Revolution era is critical in leading and achieving future industrial technology dissemination. The concept of smart manufacturing will eventually enable the cooperation of all connected factories around the world (Schweichhart 2019) by sharing information throughout the "vertical, horizontal, and end-to-end integration" for "flexible and reconfigurable" production (Kagermann *et al.* 2013, Wang *et al.* 2016). Among those enabling technologies for smart manufacturing, the Digital Twin (DTw) is the most representative.

The definition of "digital twin manufacturing" by ISO 23247 states that it "maintains a digital model that continuously updates and changes as the physical counterpart changes to represent manufacturing status, manufacturing conditions, product geometries, resource state, and any other observable status and conditions in a synchronous manner" (ISO/TC 184/SC 4 2021). The elements of digital twin manufacturing include "personnel, equipment, material, process, facility, environment, and product" (Figure 1) (ISO/TC 184/SC 4 2021).

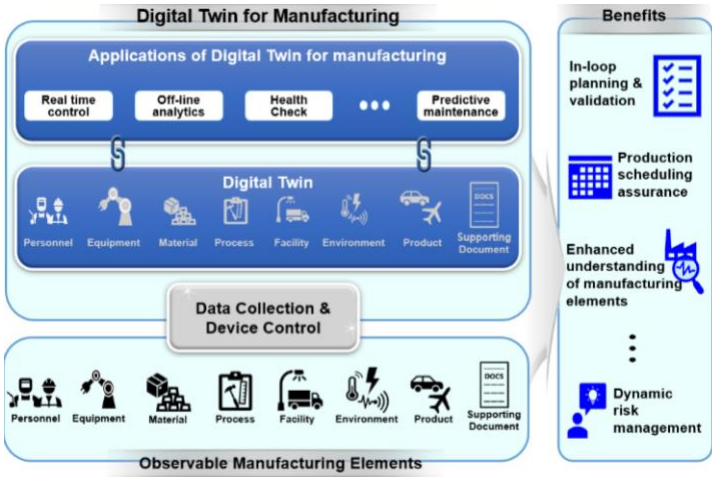

Figure 1. Concept of digital twin manufacturing by ISO 23247-1 (ISO/TC 184/SC 4 2021).

As observed in ISO 23247, the "equipment" and "facility" are the core elements of the digital twin, and the facility itself comprehends all different areas of disciplines, including civil, architectural, electrical, mechanical, communication, and automation systems. In this context, the 'manufacturing facility' in this paper includes the 'equipment' and 'facility' together to form a physical asset for manufacturing infrastructure.

Despite the significance of the 'facility' elements in digital twin manufacturing under ever-changing environments, there have been a few studies in facility asset management, especially for smart manufacturing. In order to address this issue, this paper introduces a revamped issue and concept of 'facility asset management (FAM)' based on the variables of emerging theories and technologies. A set of comprehensive issues are discussed based on a series of studies conducted at Myongji University (Jin *et al.* 2022, Lee *et al*. 2022) through the Korea Institute of Construction Engineering and Management (KICEM.org, an academic society) activities.

2 DRIVING VARIABLES FOR FAM

In order to incorporate the objective of this paper, two significant variables are considered. The first variable explores the integration of two industries: construction and manufacturing. The second variable examines the integration of the related management areas.

Table 1. Variables for defining facility asset management.

Variable	Definition	Constituent	Related Reference
I: Industry	Business perspective	I.1 Manufacturing I.2 Construction	ISO 18101-1 (ISO/TC 184 2019)
A: Management area	Management scope	A.1 Construction management (CM) A.2 Asset management (AM) A.3 Facility management (FM) A.4 Operation management (OM)	Jin *et al.* (2022)

2.1 Industry: Value Proposition toward Operation Management (OM)

The objective of construction management (CM) is to "plan, coordinate, and integrate various business functions throughout the entire life cycle of a facility to improve performance" (Jung 2021). In their structured model of CM definition, the research team of Myongji University further

defines "performance" into four indicators: "cost, time, quality, and value". Notably, the traditional "iron triangle of cost, time, and quality" (Locatelli *et al.* 2014) is expanding to consider the 'value' of a facility. Alarcon and Ashley (1996) highlighted the significance of the 'value' parameter in modeling project performance. A nationwide Korean academic society also strongly stressed this point in formalizing a position paper (Choi 2021) for the construction industry.

Nevertheless, in order to meet the requirements of smart manufacturing, the 'value' needs to be further extended to encompass the business issues of the manufacturers themselves in addition to the facility's value (e.g., sales and production of merchandise). In this regard, ISO 18101-1 defines the "primary business" as the "core operations of a given industry group," while the "secondary business' is the process of "supporting the primary business" (ISO/TC 184 2019).

Traditionally, the principles of construction management (CM) and facility management (FM) have focused on the value of "secondary business". However, the Fourth Industrial Revolution pushes the construction industry to actively merge into the primary business in terms of value creation. In other words, the CM and FM should accommodate the production and operation management (OM) requirements for the manufacturer's primary business.

2.2 Management Area: Overlapped Integration between CM, AM, FM, and OM

Three management areas were discussed earlier: CM, FM, and OM. Another vital management area for facilities is asset management (AM). AM involves "balancing costs, opportunities, and risks against the desired performance of assets to achieve the organizational objective" (ISO/TC 251 2014). As pointed out by Apgar (1995), AM emphasizes the financial perspective in managing an asset portfolio to maximize the benefit of an organization. Therefore, many previous AM studies have focused on buildings and housing (Chotipanich 2004).

Based on the authors' observation of the manufacturing industry, manufacturing firms are getting interested in actively managing their facilities in an advanced manner coupled with Digital Twin technology (Jin *et al.* 2018). Therefore, business functions for comprehensive facility management must also incorporate AM concerns.

This paper emphasizes the need for integrating four management areas of CM, AM, FM, and OM to define facility asset management (FAM) for smart manufacturing. The concept of FAM in this study focuses on the AM and FM from the facility managers of the owner-operator organization. At the same time, it covers CM and OM's partial functions to bridge the four areas.

3 FAM FUNCTIONS

A hierarchical function definition was developed based on the revamped concept of FAM (Jin *et al.* 2022). The first-level FAM function definition is a general model that can accommodate all facility types, including housing, building, industrial plant, and infrastructure. The second and third-level FAM functions specify distinct characteristics for each facility type.

3.1 First-Level FAM Functions

The first level consists of five FAM functions, including "asset portfolio management (FA01), asset development management (FA02), facility operation management (FA03), facility maintenance management (FA04), and facility environment management (FA05)" (Jin *et al.* 2022).

Asset portfolio management (FA01) is the central area of asset management (A.2 in Table 1). Asset development management (FA02) focuses on construction management (A.1). Although the facility is the focal point, facility operation management (FA03) is actively considering production management (A.3), which has yet to be fully considered in traditional CM and FM.

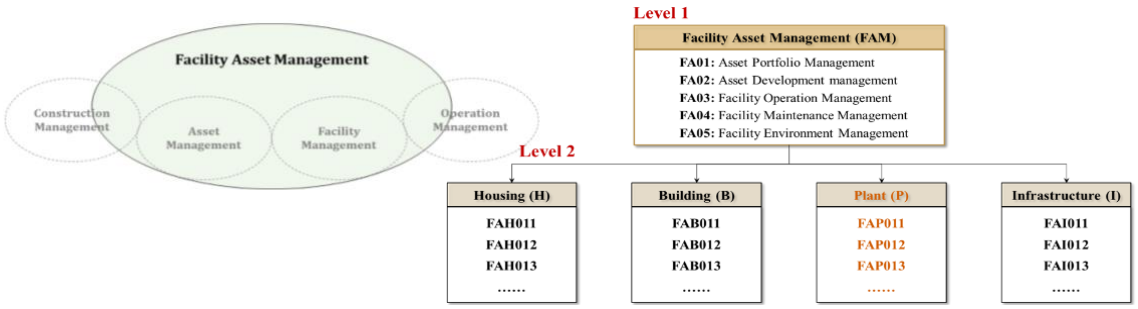

Figure 2. Concept and functions of facility asset management (Jin *et al.* 2022).

Furthermore, facility maintenance management (FA04) in this paper emphasizes equipment maintenance, especially for manufacturing. Finally, facility environment management (FA05) addresses issues from the inside and the outside environment highlighted in ISO 23247-1 (ISO/TC 184/SC 4 2021).

3.2 Second/Third-Level FAM Functions for Plant

Among the five functions shown in Figure 2, two functions for plant facilities (FA03 and FA04) are further introduced to illustrate how the general model can be used for a specific facility type.

Table 2 summarizes the second and third-level constituents for FA03 and FA04 along with the literature review process of identifying those functions (Lee *et al.* 2022). FA03 for 'plant', which is numbered FAP03, has three sub-functions, including "production space management (FAP031), production operation management (FAP032), and automation management (FAP033)". Facility maintenance management (FA04) for 'plant', which is entitled as FAP04, consists of three sub-functions, including "structure maintenance (FAP041), equipment maintenance (FAP042), utility maintenance (FAP043)".

3.3 Smart Manufacturing FAM: Function – Information – Data – Property - Signal

An effort to develop a comprehensive and structured FAM model is undergoing to specify a complete list of three-level functions, information, data, properties, and signals to connect entire FAM processes that would provide a joint base for smart manufacturing. Tools used for this effort include a taxonomy diagram, graph data model (GDM), and metadata publication.

For example, the internal pressure of a chemical pipe is critical information for factory operation. Based on the FAM model of this paper, it is one of the data under the production operation management (FAP03) function. It is in the hierarchical model as follows: (FAP03) Facility Operation Management – (FAP032) Production Operation Management – (FAP0321) Operating Status Management – (FAP03212) Chemical Equipment Operation – (Information) Real-time Status – (Data) Pressure Capacity – (Property) Internal Pipe Pressure – (Signal) Pressure Sensor Signal (Table 2).

The example of the chemical pipe illustrates a hierarchical structure of the function, information, data, property (attribute), and sensor signal. A GDM model adds an ontological relationship to enable machine-readable semantic representation.

4 DISCUSSIONS AND CONCLUSIONS

Although facility asset management (FAM) is a core component for achieving smart manufacturing, there has yet to be a legitimate study of FAM focused on manufacturing facilities.

Table 2. Second/third-level FAM functions for manufacturing plant (Lee *et al.* 2022).

FAM Function			Muther (1973)	MESA (1997)	KATS (2016)	Duffuaa *et al.* (2001)	Ku and Kim (2013)
Lvl 1	**Lvl 2**	**Lvl 3**					
FAP03 Facility OM	**FAP031** Production space mgmt.	**FAP0311** Layout design	Activity relationship Flow of materials Space requirements	Dispatching production units	Design Materials mgmt.		
		FAP0312 Layout redesign	Modifying constraints Alternatives				
		FAP0313 Space utilization mgmt.	Space available	Resource allocation and status			
	FAP032 Production OM	**FAP0321** Operating status mgmt.		Maint. mgmt.	Facility OM Monitoring		
		FAP0322 Historical data mgmt.		Maint. mgmt.	Facility OM		
		FAP0323 Production data mgmt.		Maint. mgmt.	Facility OM		
	FAP033 Automation mgmt.	**FAP0331** Instrument auto.		Data collection /acquisition	Facility data network		
		FAP0332 Production auto.		Detail sched. Quality mgmt. Process mgmt.	Production facility auto.		
		FAP0333 Facility auto.		Maint. mgmt.	Logistics auto. Eval. auto.		
FAP04 Facility maint. mgmt.	**FAP041** Structure maint. mgmt.	**FAP0411** Structure condition mgmt.		Maint. mgmt.	Maint. mgmt.	WO planning	Equip. data WO
		FAP0412 Structure repair mgmt.			Spare parts	Sched. Dspch. Execution	Preventive maint.
	FAP042 Equip. maint. mgmt.	**FAP0421** Equip. condition mgmt.		Maint. mgmt.	Maint. mgmt.	WO planning	Equip. data WO
		FAP0422 Equipment repair mgmt.			Spare parts	Sched. Dspch. Execution	Preventive maint.
	FAP043 Utility maint. mgmt.	**FAP0431** Utility condition mgmt.		Maint. mgmt.	Maint. mgmt.	WO planning	Equip. data WO
		FAP0432 Utility repair mgmt.			Spare parts	Sched. Dspch. Execution	Preventive maint.

[Abbreviations] Auto: Automation, Dspch: Dispatching, Equip: Equipment, Eval: Evaluation, Lvl: Level, Maint: Maintenance, Mgmt: Management, OM: Operation management, Sched: Scheduling, WO: Work order.

This study discusses the issues and needs to incorporate an expanded concept of the FAM. The value from the manufacturing perspective is highlighted in formulating facility asset management.

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