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# Asset Description of Digital Twin for Resilient Production Control in Rechargeable Battery Production

Kyu Tae Park<sup>1</sup>, Yang Ho Park<sup>1</sup>, Yun-Hyok Choi<sup>1</sup>, Moon-Won Park<sup>1</sup>,  
and Sang Do Noh<sup>2,#</sup>

<sup>1</sup> Micube Solution, Inc., Seoul, Republic of Korea

<sup>2</sup> Sungkyunkwan University, Suwon-si, Republic of Korea

**Abstract.** In rechargeable battery production—a component of mass customization—high quality, low cost, efficient delivery, and flexibility must be ensured. Efficient production operation can be achieved by solving the performance degradation problem, which is a limitation of mass customization. This degradation can be prevented through resilience, which can be achieved by satisfying four core functional requirements, which are as follows: (1) selecting robust actions; (2) measuring performance indicators; (3) notifying impermissible fluctuations; and (4) extracting the adjusted reactions. A digital twin (DT) is an advanced virtual asset that represents configuration, reflects functional units, and synchronizes information objects. This article describes DT application to satisfy the four core functional requirements and reflect the operational characteristics of three heterogeneous stations in rechargeable battery production. Analyses of the measures taken to achieve the resilience and operational characteristics of stations in rechargeable battery production are provided to present an appropriate design of the description. The asset description is designed with P4R classes based on this analysis. The designed asset description is applied to stations in rechargeable battery production, and the proposed method is verified with the implemented DT application. The proposed asset description presents an efficient method of satisfying the core activities and technical functionalities corresponding to the DT. The proposed method is an early case of DT usage in rechargeable battery production and can be considered as a reference for smart manufacturing technologies in the manufacturing domain in the future.

**Keywords:** Cyber physical production system; Digital twin; Mass customization; Production control; Rechargeable battery production; Resilience

## 1 Introduction

Rechargeable battery production is a component of mass environment and involves the fabrication of highly diversified products; hence, high quality, low cost, efficient delivery, and flexibility must be ensured [1-5]. However, mass customization often results in performance degradation caused by the complexity of the production processes, dynamic situations, and increased preparation time [6-8]. Therefore, the production process and systematic efficiency must be enhanced to minimize the negative effects of

unpredictable changes and dynamic disturbances by achieving resilience [9-11]. This concept is more effective at dynamically handling the events because robust solutions cannot be considered beforehand for all potential fluctuations [9, 12].

Four core functional requirements must be satisfied for a simulation aspect to achieve resilient production control in rechargeable battery production: (1) selection of robust actions; (2) measurement of performance indicators; (3) notification of impermissible fluctuations; and (4) extraction of the adjusted reactions [9]. These technical functionalities ensure the overall production efficiency improvement and dynamic performance degradation prevention in production operation [9, 12].

A digital twin (DT) is a core element of the cyber physical production system, which is necessary to meet the aforementioned requirements. A DT is an advanced virtual asset that represents a configuration of the physical asset, reflects functional units corresponding to the operational characteristics, and synchronizes the information objects derived from the entire value stream [13-16]. The DT must provide the following three types of execution procedures to satisfy the requirements: virtual commissioning, which is used to select a robust action; prognostic simulation, which is implemented to provide notifications about impermissible fluctuations; and reactive simulation, which is provided to extract the adjusted reactions [17]. The measurement performance indicators are realized by three types of DT-based execution [17, 18]. Similar to other smart manufacturing technologies, the most important aspect of DT is the use of information. Specifically, DT requires a large variety and volume of information elements to provide suitable technical functionalities [3, 15, 19]. The asset description is an abstract information structure that provides specific inputs to the DT. However, the existing asset descriptions of virtual factory technology are required for improved DT implementation [19-25]. In addition, an asset description for rechargeable battery production has not been proposed.

This report proposes an asset description for DT application in rechargeable battery production. This description implements the asset administration shell (AAS) concept with high-level object orientation and “type and instance” concepts. The measures taken to achieve resilience and operational characteristics of stations in rechargeable battery production were analyzed for efficient design of the description. Accordingly, the asset description was designed with the product, process, plan, plant, and resource (P4R) classes based. The designed asset description was applied to stations in rechargeable battery production, and the proposed method was verified with the implemented DT application.

## **2 Research Background**

From a work center perspective, a DT is an advanced virtual factory, which represents a configuration of a physical work center, reflects functional units corresponding to operational characteristics, and synchronizes information objects derived from the entire value stream [13, 26-28]. The DT application creates, synchronizes, and executes a DT and has core elements such as an asset description, operation module, configuration

data library (CDL), and DT engine. **Table 1** presents the detailed descriptions of these elements [17, 19].

**Table 1.** Detailed descriptions of core elements of DT application [17, 19].

Element	Description
Asset description	An information schema that abstracts the inputs to create and synchronize a DT and is instantiated through aggregation from heterogeneous information sources
Operation module	A module that implements the creation, synchronization, and execution procedures. These three procedures are defined as follows: <ul style="list-style-type: none"> <li>▪ The creation procedure represents the configuration and reflects the functional units of a physical work center. This step is classified in resource-centric, process-centric, and hybrid creations.</li> <li>▪ The synchronization procedure synchronizes the input information objects to prepare for the execution of the DT. This step is classified in snapshot and footprint synchronizations.</li> <li>▪ The execution procedure operates the created and synchronized DT and provides technical functionalities. This step includes virtual commissioning, prognostic simulation, reactive simulation, and representation.</li> </ul>
CDL	A library that manages the composition of elements, which are divided into base model, logic, and metadata; it is used in the creation procedures to represent configuration and reflect functional units.

The asset description is a core element for the use of information to create and synchronize the DT. The main components of asset description include core manufacturing simulation data (CMSD); commercial-off-the-shelf simulation package interoperability (CSPI); neutral simulation schema (NESIS); product, process, plan, and resource (P3R); and virtual representation for a digital twin application (VREDI). **Table 2** summarizes the scope, coverage, and characteristics of the asset descriptions [19-25]. All descriptions are classified according to the object-oriented classes to represent the physical assets. However, only VREDI supports vertical integration, which is the most important characteristic of a DT. Further, only VREDI considers the repeated derivation of performance indicators in terms of service composition. Moreover, other descriptions have insufficient interoperability for high-level object orientation and “type and instance” concepts, which are required by AAS principles [19].

**Table 2.** Asset descriptions for virtual factory technology [19-25].

Name	Item	Contents
CMSD [20-22]	Scope	Simulation of operations in the job shop environment
	Coverage	Part information, layout, resource information, production operation, production planning, support
_____	Vertical integration	No specific support

	Horizontal integration	No specific support
CSPI [23]	Scope	Supports interoperability between simulation packages
	Coverage	Entity transfer, shared resource, shared event, shared data structure
	Vertical integration	No specific support
	Horizontal integration	Support for exchange between simulation models
NESIS [25]	Scope	Exchange of simulation models between simulation and other manufacturing applications
	Coverage	Product, process, resource, Sim_List, configuration
	Vertical integration	No specific support
	Horizontal integration	Support for information exchange between simulation models and manufacturing applications
P3R [24]	Scope	Simulation of material flow analysis
	Coverage	Product, process, plant, resource
	Vertical integration	No specific support
	Horizontal integration	No specific support
VREDI [19]	Scope	Implementation of DT with supporting vertical and horizontal integrations.
	Coverage	Product, process, plan, plant, resource
	Vertical integration	Support for information exchange with a physical work center
	Horizontal integration	Support for information exchange between advanced engineering applications.

### 3 Asset Description of Digital Twin in Rechargeable Battery Production

#### 3.1 Concept Definition of Digital Twin in Rechargeable Battery Production

The asset description provides appropriate technical functionalities to enable resilient production control in rechargeable battery production [24, 25]. The proposed DT must satisfy the four core requirements, which were explained earlier.

The DT provides virtual commissioning for alternatives to extract the performance indicators to select robust actions. In addition, the impermissible fluctuation can be predicted by prognostic simulation, and notifications can be provided about the potential negative effects on the performance indicators. Furthermore, the adjusted reactions are extracted based on the reactive simulation, and subsequently, performance indicator degradation is prevented and decreased. The performance indicators are quantitatively measured based on the three types of simulation-related execution.

The technical functionalities require the synchronization of the production plan and schedule alternatives for virtual commissioning. In addition, the dynamic information, which indicates the status of the physical work center, must be synchronized with the DT. The dynamic information, which includes the dynamic fluctuations, ensures that the DT can predict the potential negative effects of the performance indicators. Furthermore, the dynamic information and the reactive plan and schedule alternatives must be synchronized with the DT. The reactive plan and schedule alternatives can be evaluated appropriately based on the dynamic information.

The rechargeable battery production includes three main stations: (1) mixing and electrode production, (2) winding and assembly, and (3) formation. From the analysis results of the manufacturing domain, it can be inferred that these three stations have heterogeneous operational characteristics, which must be transmitted to the DT as functional units. The mixing and electrode production is a hybrid flexible flow shop that involves a batch process, which further enables production with inconsistent process operation. This station produces the cathode and anode electrodes separately and moves the batches to the next station. The mixing process causes the ripple effect owing to the inconsistency of outputs and complexity that result from the sequence-dependent setup time [29]. Furthermore, a massive number of works in process (WIPs) is required to meet the due date of the next station.

The winding and assembly station is a parallel flow shop with the bottleneck processes that are required for the entire rechargeable battery production process. Therefore, this station should efficiently maximize the utilization rate to improve all the performance indicators. The previous station must deliver the required electrodes before the production processes in the next station start. The tardiness values in this station can be used to study the considerable negative effects on the entire production operation. The production plan and schedule for this station should be revised if the order is changed by the customer. Furthermore, the production plan and schedule of the previous station must be adjusted.

The formation station is a reentrant job shop that includes the reentrancy, which is a tray visits identical resource instances [30]. This situation further increases the complexity of managing and controlling this station [30, 31]. Therefore, the performance indicators cannot be measured dynamically and are calculated conceptually using the master information. Additionally, the station faces logistics congestion, which may negatively affect the overall performance indicators.

### 3.2 Design of Asset Description of DT in Rechargeable Battery Production

The proposed asset description was adapted from the VREDI based on the defined concept for the DT [18, 22]. This VREDI applies the AAS concept with high-level object-orientation and the “type and instance” concept. This asset description supports vertical and horizontal integrations, which are the key characteristics of DTs.

The proposed asset description contains the object-oriented P4R classes, as described in **Fig. 1**. The *Product* class contains the information elements of various forms of materials, from slurries to cells. These constitute the batch units and different operational characteristics for each operation. Therefore, the information elements related to the manufacturing domain are considered in the design of this class.

In the *Process* class, the information elements of the process and material handling operations are indicated. The information elements corresponding to rework, defect, and sequence-dependent setup time are included in this class.

The *Resource* class describes the information elements of resource types, such as machine, buffer, material handling conveyor (MHC), and material handling vehicle (MHV).

The *Plan* class describes the information elements that correspond to the maintenance, procurement, and production plans. The business policy is described by the elements in this class, which includes the instance information.

The *Plant* class contains the information elements with the status and dynamic information of the resource instances, including machine, buffer, MHC, and MHV. The WIP and failure status are described in this class, and these information elements are synchronized with the DT dynamically.

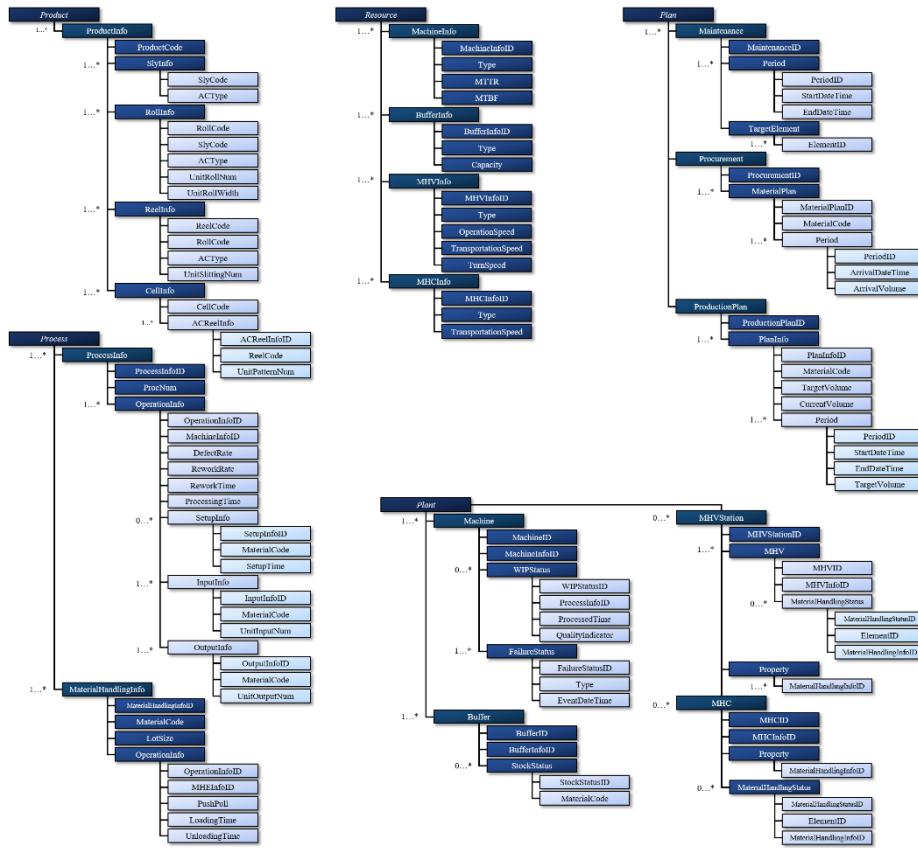


Fig. 1. Asset description for a DT in rechargeable battery production (adapted from Park et al. [18, 22]).

## 4 Industrial Case Study

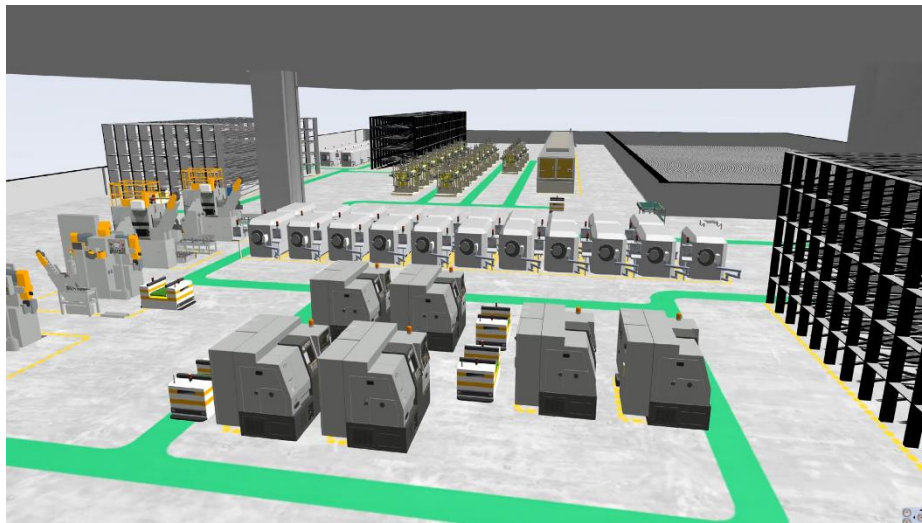
The proposed asset description for the DT in rechargeable battery production was implemented and applied to three stations. The defined concept of the DT and asset description to satisfy the requirements were applied for verification.



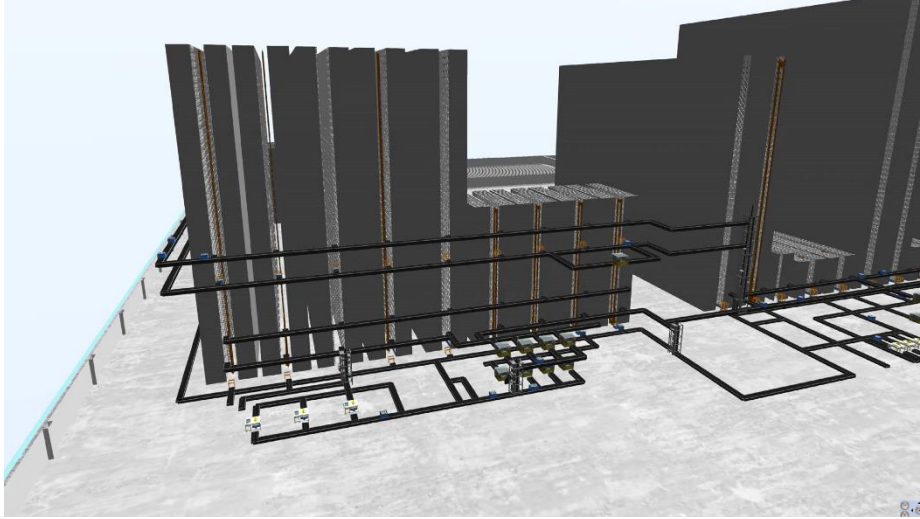
The information objects based on the proposed method were implemented using the JavaScript object notation (JSON) message format. The JSON messages were provided using the service platform, which was implemented using the OSGi framework. This platform enables loosely coupled integration through a web service. The implemented information objects were provided according to the required technical functionalities.

The DT application was implemented based on the S-Prodis engine. This DT engine is a discrete event simulation engine, which is an efficient tool used to predict production-related performance indicators. **Figs. 2 and 3** present the created and synchronized DTs of the implemented DT application. The creation and synchronization procedures were selected for resource-centric creation and snapshot synchronization. Resource-centric creation improves the decision-making process because the elements are more intuitive than those corresponding to other creation types. The proposed asset description enables snapshot synchronization. The information objects, which were based on the P4R classes with dynamic information, were synchronized with the DT application.

The virtual commissioning, prognostic simulation, and reactive simulation were provided in the execution procedures. These execution types are required to achieve resilience, as described in section 3.1. Furthermore, the operational characteristics of the three stations in the rechargeable battery production are represented in the proposed method. The proposed asset description indicates the sequence-dependent setup time, WIPs, due date, and reentrancy for appropriate simulation-based technical functionalities. Consequently, the proposed method satisfies the four core requirements.



**Fig. 2.** Created and synchronized DTs in mixing and electrode production station.



**Fig. 3.** Created and synchronized DTs in formation station.

## 5 Conclusion

The four core requirements defined in section 1 must be satisfied for resilient production control. The DT must perform three primary execution procedures to satisfy the requirements: virtual commissioning, prognostic simulation, and reactive simulation. The measuring performance indicators are realized by the three DT-based executions.

The proposed asset description enables the DT to support the core requirements. This description implements the AAS concept with the high-level object orientation and “type and instance” concepts. These concepts improve the interoperability and efficiency of information management. This description was adapted from VREDI [22], which was previously proposed by the authors. Furthermore, the operational characteristics of three heterogeneous stations in rechargeable battery production were considered in the design of this description. The specific requirements corresponding to the manufacturing domain were generalized and projected onto the description.

The proposed asset description presents an efficient means of satisfying the core requirements and technical functionalities corresponding to the DT. Suitable technical functionalities and input information objects are necessary to satisfy each requirement. The proposed method is an early case of DT usage in rechargeable battery production, and the results of this study can be used as reference information in the smart manufacturing technology domain in the future. In addition, the adaption of asset descriptions for specific manufacturing domains can contribute to DT application in various manufacturing domains. The architectural design of the DT application in rechargeable battery production is required for robust and efficient application to the manufacturing domain in future research.

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