Digital Twin Model for Smart Maintenance of Data Center Facilities : *Study Literature Review*

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***Abstract*—Digital twin is a technology that supports the implementation of digital transformation. The digital twin was developed to support decision making in various sectors. The digital twin concept is almost 20 years old and continues to evolve for use cases for the technology in new industries. Maintenance is one of the important points of the product life cycle as the origin of the digital twin. The data center facility is one of the supporters of digital transformation which must be able to guarantee the availability of its services. The availability of data center services is affected by the chosen maintenance strategy. This paper will discuss data centers and maintenance strategies as well as definitions, characteristics to examples of implementing digital twins, especially in the case of implementing intelligent maintenance. It is hoped that with the description of this paper, more specific research opportunities related to optimizing the application of digital twins for maintenance specifically used in data center facilities are expected.**

Keywords—Digital Twin, Digital Transformation, Smart Maintenance, Data Center

I. INTRODUCTION

The data center is a basic facility for implementing an information technology service. Current technological trends such as artificial intelligence technology, big data to high-performance computing systems require data center facilities so that the devices can function properly. In order for systems in data center facilities to always operate properly, data facility services (power supply, cooling and network) must be ensured to be available. One of the things that must be done to ensure that the availability of data center facility services can be maintained is to implement maintenance. Digital twin can be a solution in implementing data center facility maintenance.

Digital twins are increasingly being adopted by several disciplines, including the manufacturing[17], transportation[18], agriculture/livestock[2], agriculture[18] and energy[16] sectors, to address multidisciplinary issues. The concept of digital twin was created by M. Grieves in his white paper, as a unification of virtual and physical assets in product lifecycle management[1], because the field of origin of digital twin is product lifecycle management[3]. As shown in Figure 1, maintenance is one of the points contained in the product life cycle.

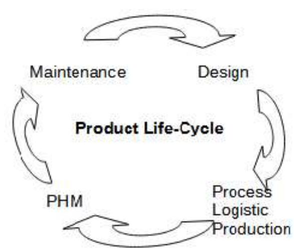

Fig. 1. Product Life Cycle

Gartner has ranked the digital twin in its top 10 strategic trends for 2019[12]. Gartner predicts that by 2021, half of all major industry groups will be using a digital twin, allowing them to increase their effectiveness by up to 10%[12].

This paper will discuss data centers, types of maintenance and clear and specific definitions of digital twins. The definitions described are obtained from several related literatures. In addition, several digital twin applications are also presented in several fields related to maintenance and development opportunities that can be carried out, especially for intelligent maintenance of data center facilities.

II. LITERATURE REVIEW

A. Data Center

Data center is a series of products and solutions that provide computing and storage resources[24]. In general, data center facilities are intended to accommodate computing equipment, data storage and telecommunications equipment. Thus the work of a modern data center is closely related to the process of operating IT equipment and therefore data center quality and security plays an important role as a basic element of IT operations.

1) Data Center Availability Category

The categorical approach to availability of a data center is described in several standard documents such as the Uptime Institute, ANSI/TIA-942 and BICSI best recommendations as well as reference standards of other external organizations. For local Indonesian standards, there is currently an Indonesian National Standard (SNI) 8799:2019 regarding technical specification guidelines, management and data

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center audits. The Ministry of Communication and Informatics (Kemenkominfo) strives for the Indonesian National Standard database to be fully implemented by the organizers of the Data Center Electronic System in Indonesia[21].

The ANSI/TIA-942 standard describes four levels of redundancy and availability, from level I to level IV[24] in detail as follows:

TABLE I. ANSI:TIA-942 DATA CENTER STANDARD

TIER	***Explanation***	***Service Availability Level***
I-Data Center Basic	*Single line for Power supply and cooling system (not redundant)*	*99.67% (28 Hour constraint)*
II-Data Center-Redundant Component	Single track for. power supply and cooling system (with redundancy)	*99.75% (22 Hours constraints planned or not planned)*
III-Data Center-Currently Maintainable	*Dual lines for power supply and cooling systems where only one is active and if maintenance is carried out on one of the lines it does not cause problems with data center operations*	*99.89% (1.6 Hours unplanned constraint)*
IV-Data Center-Fault Tolerance	*Dual lines for power supply and cooling systems, both lines are active, problems with one of the lines do not result in problems with data center operations*	*99.99% (0.8 Hours unplanned constraint)*

2) Data Center Maintenance

Failure in the data center system is a decrease in system performance when compared to the specified minimum system. Data center system failures can result from design errors, faulty system installations, machine failures, operational errors, human errors, or a combination of these errors. If the error mentioned above is not identified then failure can occur. Failures that occur can be the root cause of data center downtime[25].

The traditional approach to avoiding downtime is implementing time-based maintenance (preventive maintenance). The preventive maintenance approach is easy to implement, no need for condition monitoring; decision variable (maintenance life or MTBF) maintenance is performed when the equipment reaches MTBF.

Meanwhile, the strategic maintenance approach is based on conditions by looking at the condition of equipment or systems that can be measured online/offline and continuously from time to time during operation. By using sensors, data is collected so that it can be applied to set trends, predict failures, and estimate the remaining useful life of equipment or systems. Condition-based maintenance actions are performed when data conditions indicate that device performance is degraded or has a high probability of failure.

To avoid data center downtime costs, it is necessary to implement more intensive operations, modern maintenance strategies and experience of data center operators.

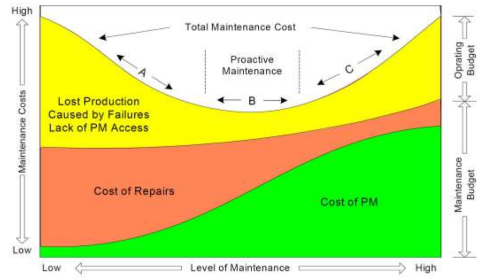

Fig. 2. Total Maintenance Cost Relationship Diagram

Based on the traditional approach of selecting preventive and corrective data centers, low maintenance levels are more likely to be corrective, so production losses caused by system failures will be high. In the data center industry, corrective maintenance is not a consideration. Meanwhile, if excessive preventive maintenance is carried out to reduce the cost of corrective maintenance, the total maintenance cost will be high. Implementing proactive maintenance will optimize preventive and corrective maintenance so that the total maintenance cost will be more efficient.

B. Maintenance

Maintenance is an activity carried out to maintain the condition of an item or equipment, or return it to a certain condition. Maintenance has a big impact on the company's business (resulting in the cessation of the production process), so it is necessary to choose a strategy for maintenance [23].

Various maintenance strategies can be selected when making decisions about when (and what) maintenance activities need to be carried out[23]. The strategies analyzed are as follows:

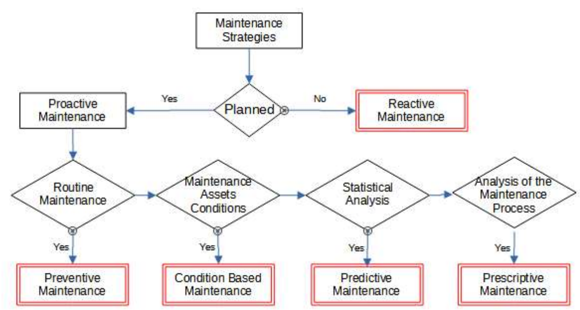

Fig. 3. Maintenance Strategy Diagram

1) Reactive/Corrective Maintenance

This maintenance activity is carried out without planning beforehand. This type of strategy is only suitable for assets or systems that do not have a major impact on the business. This maintenance strategy will causing high maintenance costs, because maintenance activities are focused on updating damaged assets (not increasing assets). In addition, this maintenance strategy can also incur higher costs due to service interruptions caused by these assets, such as penalties due to service interruptions, production delays.

2) Preventive Maintenance

Preventive maintenance strategy is a strategy used to reduce the consequences of reactive maintenance. Preventive maintenance is also known as time base maintenance. Is a proactive approach taken to prevent or reduce failures on assets. This type of strategy is based on the experience of plant/infrastructure/asset managers, who plan different maintenance activities over time with the aim of avoiding service interruption, minimizing the impact of asset damage by planning the maintenance of these assets in advance.

This maintenance strategy ensures the safety and maintenance of services by over-maintaining assets, resulting in high maintenance costs.

3) Condition-Based Maintenance

Condition-based maintenance consists of anticipating maintenance activities based on evidence of degradation and deviation from the normal behavior of assets. This type of maintenance is also known as maintenance based on device anomalies that occur. Anomalies are detected thanks to the maturity of technologies such as IoT and cloud computing, which are applied to monitor asset conditions.

The condition-based maintenance approach can be enhanced with artificial intelligence algorithms to diagnose and obtain detailed device status data.

4) Predictive Maintenance

Predictive maintenance or prognosis maintenance consists of using all the information that composes and surrounds a system. This information is used to be able to predict the remaining useful life of an asset. Several different techniques can be used to combine all available information to make maintenance predictions as accurate as possible.

Predictive maintenance with a data-driven approach is a big data-oriented technique where large amounts of asset status data are required. Such asset status data can be obtained by applying the appropriate sensors. Meanwhile, a model-based approach requires the development of a model that describes assets mathematically. Models can be analytical, physical or numerical models. These models describe the way components are degraded with a high degree of reliability. Predictive maintenance is one of the most intensively researched topics in the current Industry 4.0 movement.

5) Prescriptive Maintenance

Prescriptive maintenance strategy or knowledge-based maintenance refers to optimizing maintenance based on predictions. Apart from using historical and real-time data analysis to predict the status of the required assets, we are also committed to developing an action plan. This results in a change from a preventive maintenance plan to a proactive and intelligent plan. The impact on service, cost and safety is expected to be optimal.

C. Digital Twin

1) Definition of Digital Twin

At present there is no standard understanding related to the definition of a digital twin. The definition of digital twin is adapted to the field of application. Glaessegen et al define a digital twin as a multiphysical, multiscale, integrated probabilistic simulation of a complex product, which serves to mirror the life of its corresponding twin. Grieves defines a digital twin as a set of virtual information constructs that fully describe a potential or actual physical manufacturing product from the micro atomic level to the macro geometric level. Meanwhile, Tao et al define the digital twin as a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between physical and virtual entities.

The initial description defines a digital twin as a virtual representation of a physical product that contains information about the product, with its origins in the field of product life cycle management[3]. Grieves extends this definition by describing the digital twin as a system consisting of three components, namely: a physical product, a virtual representation of the product, and a two-way data connection that enters data from physical to virtual representation and processes from virtual to physical representation[1].

Several descriptions of the definition of digital twin based on its application were obtained from research conducted by Opoku et. al[14] can be seen in table 2.

TABLE II. DEFINITION OF DIGITAL TWIN BASED ON APPLICATION

No	***Year***	***Definition***	***Implementation***
1	2012	*A digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to reflect the life of its twin in real time*	*NASA's integrated simulations*
2	2013	*The digital twin is a structural model that will include quantitative data on material level characteristics with high sensitivity.*	*Structural performance*
3	2014	A lifetime certification and management paradigm in which models and simulations consist of build vehicle status, experience-matched loads and environments, and other vehicle-specific histories to enable high-fidelity modeling of individual space vehicles throughout their lifetime	*Structural health management*
5	2016	*A digital twin is a digital representation of a real world object with a focus on the object itself.*	*Industrial IoT lifecycle management*
6	2017	Independently created and extensible digital copies of real factories, machines, workers, etc., are automatically updated together with real-time availability.	*Shopfloor management*
7	2018	The Building Information Model (BIM) is a digital twin.	*Maintenance of railway station building*
8	2019	*A digital twin is a connected and synchronized digital replica of a physical asset that represents the elements and dynamics of operating systems and devices in their environment throughout their life cycle.*	*Arcitecture for Cyber physical systems*

2) Development of Digital Twin Research

The idea of creating a digital twin as a physical mirror was born in the 1960s. NASA during this period used physical copies of systems on Earth to map and simulate the state of these systems during spacewalks, an approach that was especially useful on the Apollo 13 mission. When one of the oxygen tanks on the spacecraft exploded, NASA engineers simulated and solved technical problems. from the surface of the earth at a distance of 300,000 km from the spacecraft.

It was only in 2009 that publications related to digital twins appeared and the number of publications increased until 2018. Publications are divided into several types including journals, conferences and chapters of a book.

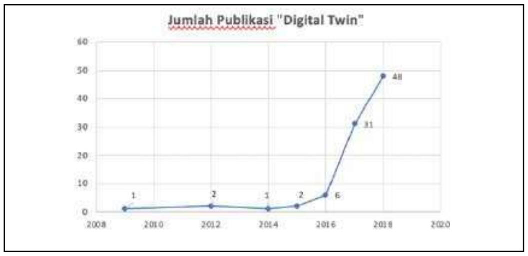

Fig. 4. Number of Digital Twin Publications from 2009 to October 2018

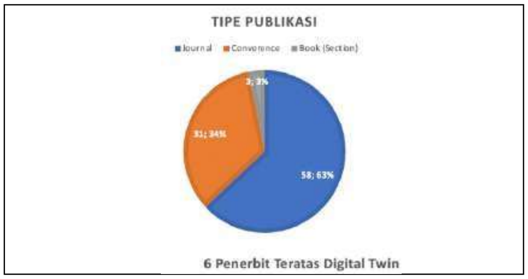

Fig. 5. Review of Types of Publications Related to Digital Twins from 2009 to October 2018

3) Characteristics of Digital Twin

Based on the research conducted[3], the characteristics of the digital twin can be identified as follows:

- Physical Entities, in discussing physical entities, research is usually domain specific, for example: vehicles, components, products, systems, models. The similarities in these entities lie in their existence in the physical world.
- Virtual Entities, like physical entities, virtual entities are also referred to by a number of specific domain names in virtual form, for example: products, models, devices and objects.
- Physical Environment, the physical environment refers to the real-world space in which physical entities are located; real space, real world, and factories. Aspects of this environment are measured and fed into virtual twin environments to ensure an accurate virtual environment, where simulations, optimizations and/or decisions will be made.
- Virtual Environment, the virtual environment exists in the digital domain and is a mirror of the physical environment, with twins achieved through physical (i.e. sensor) metrology. In line with the terms used to describe the physical environment, there are many similar terms used to replace the virtual environment, namely: virtual space, virtual world, data model, multi-domain model.
- Parameter, parameters refer to the type of data, information, and processes passed between the physical and virtual. Examples of parameters mentioned in the corpus that are classified into overarching themes are as follows: form (geometric structure of the entity), functionality (movement and/or goal of the entity), health (actual state of the entity in relation to its ideal state), location (geographical position of the entity), process (activity of entity involvement), time (time required to complete an activity and time of occurrence of an activity), state (current measured status of all entities and environmental parameters), performance (measured operations of the entity compared to its optimal operations), environment (The physical and virtual environment in which the entity resides), e.g. qualitative (Other qualitative information that cannot be measured by traditional Internet-of-Things type sensors.
- Fidelity, The term fidelity describes the number of parameters, accuracy, and level of abstraction transferred between virtual and physical. Terms such as comprehensive physical and functional description, and fully reflecting (physical twin) characteristics and functions are used to describe fidelity.

4) Typologi of Digita Twin

Prior to the usage stage, digital twins can be created to define and simulate the state and behavior of their twins in real life. After the use phase the digital twin will remain conceptually alive and can be used to remember the historical status of real life objects. From research conducted by C. Verdouw et.al. the definition of six typologies of digital twins [2] is obtained as follows:

- Imaginary DT: Conceptual entities that describe objects that do not yet exist in real life;
- DT Monitoring: A digital representation of the actual state, behavior and trajectory of a real-life physical object in near real-time and is used to monitor its condition, operation and external environment;
- Predictive DT: Digital projection of the future state and behavior of physical objects using predictive analytics, such as statistical forecasting, simulation, and machine learning methods;
- Prescriptive DT: Smart digital objects that add intelligence to recommend corrective and preventive actions on real-life objects usually based on optimization algorithms;
- Autonomous DT: Operates autonomously and completely controls the behavior of real-life objects without direct or remote human intervention;
- Recollection DT: Maintains a complete history of physical objects that no longer exist in real life.

D. Digital Twin for Maintenance

1) The use of Digital Twin for predictive maintenance in manufacturing

Monitoring and maintenance of complex industrial equipment must be carried out to avoid unexpected failures and troubleshoot and protect production by knowing the health status of each manufacturing resource[22].

To solve the problem above the method a physical-based simulation model approach and a digital twin concept of predictive maintenance for manufacturing resources using prognostic and health management (PHM) techniques to estimate the Remaining Useful Life (RUL) of manufacturing equipment[22].

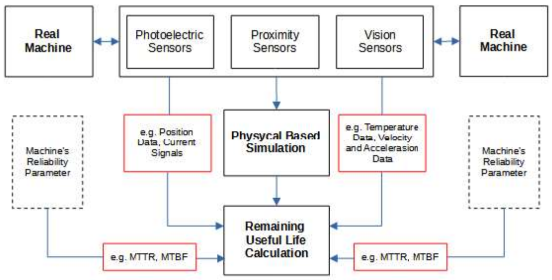

Fig. 6. The Main Concept of Remaining Useful Life (RUL) Calculation

The procedure for applying the physical-based simulation model method/approach and the digital twin concept of predictive maintenance for manufacturing resources includes four stages, namely:

Stage I	:	Machine physical modeling, a set of virtual sensors will be integrated into the machine simulation model.
Stage II	:	Simulated synchronization of a physically based machine model. To avoid possible deviations between real and simulated functionality.
Stage III	:	Physically based model simulation uses input collected by sensors and machine controller data
Stage IV	:	Combining simulation results and monitored machine data, which aims to predict the remaining useful life of the machine (RUL). Engine reliability parameters have been integrated into the simulation model.

III. RESEACH CHALLENGES AND OPPORTUNITIES

A. *Research Challenges*

Currently there are 2,700 data centers within the government sphere, most of which use server space which requires large annual fees[26]. The data center is needed to support the electronic-based government system (SPBE) program to accelerate the digital transformation process. Data centers are built and managed by regional governments and the central government which are divided into groups of data centers with small, medium or large capacities. Regardless of the existing data center capacity group, the data center must always be able to guarantee the availability of its services.

In the government environment, budgeting for data center maintenance is one of the challenges faced. With the limited amount of budget needed for data center management, the availability of data center services is still required in accordance with the specified Service Level Agreement (SLA).

The availability of data center services is of course accompanied by the fulfillment of device redundancies to ensure data center facilities are always operational. Increased operational costs, especially automatic maintenance costs as a result. The effectiveness and efficiency of operational costs, especially data center maintenance costs, is sure to be one of the efforts made by data center managers while maintaining the SLAs given to partners.

B. *Research Opportunities*

Based on research cases obtained at the work institution, the National Innovation Research Agency (BRIN) has data center facilities that are used for external services (Central and Regional Government Partners). One of the obstacles that generally and specifically occurs in data centers (Government or Private) is the strategy for maintaining the facilities. From the description of the case for implementing digital twins, smart maintenance is an effort that can be made to obtain maintenance cost efficiency, so that with the limited facilities available, guarantees the availability of data centers can still be maintained at the agreed service level. The research opportunity that can be carried out is a data center facility maintenance system model so that the process of monitoring, optimizing and predicting the performance of its components uses digital twin technology.

IV. CONCLUSION

Digital twin technology is the impact and necessity of technological developments that have occurred to date. Digital twins are increasingly being adopted by multiple disciplines, including the manufacturing, transport, agriculture/livestock, agriculture and energy sectors, to address multidisciplinary issues. At present there is no standard understanding related to the definition of a digital twin. The definition of digital twin is adapted to the field of application.

Maintenance is one of the points contained in the product life cycle as the origin of the digital twin field. There are maintenance strategies that can be used to maintain the condition of an item or equipment, or return it to a certain condition. Asset maintenance is carried out to avoid a major impact on the company's business (resulting in the cessation of the production process).

To guarantee data center facilities that can properly accommodate and run computing equipment, data storage and telecommunication equipment, it is necessary to implement an appropriate maintenance strategy. An effective maintenance strategy ensures the continuity of the life cycle of supporting facility components and is efficient in terms of maintenance costs.

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