

The impact of Application digital twin technology on production efficiency - based on practical experiment

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Abstract:

The study aims to shed light on digital twin technology and its applications, and to examine the relationship and impact of its applications on production efficiency based on a practical experiment conducted by researcher "Arif Furkan Mendi". The study concluded that the application of digital twin technology positively impacts production efficiency, as downtime was reduced by 87.55%, and the time required to complete the same work daily was reduced by 6.01%, making it highly effective, which in turn impacts profitability and revenues.

Keywords: Digital Twin technology; Production Efficiency; Downtime; physical object; virtual object.

JEL Classification Codes : O32; L62; O14; O31.

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Introduction:

Manufacturing has evolved with the development of both the technology used in production and the production of very large quantities. This development is due to the growing global demand for products in general, and products with technological advantages in particular. Production has shifted from the traditional method, in which humans were involved in every stage, to production using machines, known as mechanization. However, this method was able to keep pace with the development of global demand for a certain period, and manufacturing has moved to a stage of speed, quality, and precision, with large quantities that keep pace with the rapid development of global demand. This era is known as the era of automated technology, that is, production using programmed robots. With the advent of the Fourth Industrial Revolution, modern technologies and techniques have been added to achieve production efficiency, including artificial intelligence and digital twins. The latter has proven its effectiveness in the fields in which it has been applied, and is now being applied in the manufacturing sector to address some of the problems that hinder production efficiency.

- Study Problem:

From the above, we can formulate the study's problematic as follows:

What is the impact of applying digital twin technology on production efficiency?

- Study hypothesis:

The main problem of the study is that digital twin technology is among the emerging and advanced technologies that connect the physical world with the virtual world to improve the performance of the physical world. Therefore, the application of this technology has a positive impact on controlling production efficiency.

- Study Objectives:

The study aims to:

- Shed light on digital twin technology for its definition and working mechanism;
- Identify the uses of digital twin technology;
- Verify the impact of applying digital twin technology on production efficiency, based on practical experience.

- Study Methodology:

To answer the study's main problem and verify its hypothesis, the descriptive-analytical and historical approaches were used to shed light on the definition and history of digital twin technology and its relationship to production efficiency. An experimental approach was used to verify the impact of applying digital twin technology on production efficiency, based on practical experience. An experimental approach was used to verify the impact of applying digital twin technology on production efficiency, based on practical experience.

1-Definition and characteristics of Digital Twin:

Twin technology was first used without a precise definition by NASA in the 1960s. The agency used two spacecraft to connect as twins, one at ground level and the other flying in space to perform a space mission. The two were so connected that they were identical and simulated each other in real time. This use was known as "twins" only because the system was physical at the time. The term "digital twin" was first used in 2002 by "Michael Grieves", who coined the term "digital twin" to describe the life cycle of a product, from production to final disposal. Since then, researchers, institutions, and countries have begun using this technology, and it has been developed with the emergence of several other advanced technologies, such as the Internet of Things.

Digital twin is a newly emerging technological term, and we can summarize some important definitions of it as follows:

-A digital twin is a representation of a virtual object or system that accurately mirrors a physical object. The twin may span the lifecycle of the object or system and is built on real-time data, using simulation and machine learning to aid decision-making; (IBM, 2021)

- A digital twin is a virtual replica of an existing object. It contains all the data related to its original. A digital twin can also represent a person, a process, a system, a supply chain, or an entire business ecosystem. A digital twin can only be as accurate or complex as the information it receives from the array of sensors that transmit and monitor its original ; (Gray, 2025)

- A digital twin is a virtual model that accurately mimics an existing physical object or system. This twin represents the object throughout its lifetime and is periodically updated with up-to-date data. By combining modeling language, logical reasoning, and machine learning, it enhances decision-making. (Infocom, 2025)

The previous definitions are very important as they highlight the definition of the digital twin, and through them we can formulate the following definition:

The digital twin is : " a virtual representation that reflects data about a specific physical system or object, to identify its characteristics using simulation to make the right and proactive decision based on the quantity and updating of data, machine learning, modeling language, and logical analysis ".

The definitions of a digital twin allow us to extract its distinguishing characteristics, as follows:

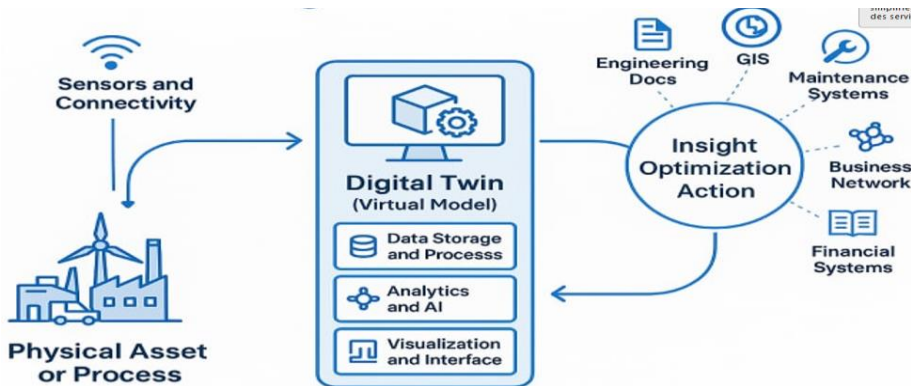
- A digital twin is a virtual digital copy;
- A digital twin virtually mimics a real twin;
- A digital twin is built on machine learning, programming languages, and logical analysis;
- The accuracy of a digital twin copy depends on the amount and frequency of data;
- The goal of a digital twin is to aid in right, proactive decision-making.

2- Digital twin mechanism and its widespread use:

Digital twins function through a continuous data exchange between the physical and digital worlds. Sensors and IoT devices collect real-time data from physical objects or processes, a key information source for digital twins. Other information sources include, but are not limited to, asset documentation (for example, engineering drawings, equipment manuals, operations instructions, SOPs), business network information exchange (for example, track and trace the arrival of spare parts, replacement equipment, field service), geographical information systems, maintenance systems of record, financial systems of record, and much more. The digital twin processes this information, applies analytics or simulation models, and provides insights that can be used to optimize the physical counterpart's performance as well as the performance of teams directly or indirectly supporting the physical object, business process, or system. In the digital twin journey, a bidirectional relationship creates a feedback loop where the physical entity informs the digital model, and the digital model helps improve the physical entity by direct or indirect means through human action. Business value can be generated throughout this journey through trusted information, autonomous information, and AI and security embedded everywhere. The journey towards creating digital twins should be in lockstep with an organization's information management journey. (Opentext, 2025)

The digital twin workflow is summarized in the following figure :

Figure (01): The working mechanism of a digital twin



Source: (Opentext, 2025).

As reported by Argolini et al. (2023), in advanced industries an estimated 75 % of companies have adopted digital twins; however, there is significant variation between industries. In the automobile, aerospace, and defense industries, digital twins are more advanced while in logistics, infrastructure, and energy they are in the earlier stages of adoption. There could be many reasons for the differences, which could include the level of competition in an industry, how costs are borne out by different stakeholders, the

The impact of Application digital twin technology on production efficiency based on practical experiment

DOUADI Beneddine

complexity of a system, and the difference in the costs and benefits of modeling a system using digital twins. Currently, digital twins are used in a number of applications. The largest application, as measured by sale of products/services to implement it, is predictive maintenance, which accounts for 39.9 % of expenditures. The products/services measured are software focused, such as those from Microsoft, Siemens, Amazon Web Services, or Dassault Systemes which have been identified as being among the top digital twin providers. It is important to note that there is some variation in the estimate of what is referred to as the digital twin market. For instance, Market and Markets (2022) estimates the global market size at \$4.5 billion for 2021 while Global Market Insights estimates the market to be \$ 8 billion for 2022. Although the estimates are for different years, it is unlikely that this accounts for all of the difference. The difference in estimates may also be due to data sources and what is considered a digital twin. (Douglas Thomas, 2024, pp. 11, 12)

Figure (02): Percentage of sales of goods and services in sectors that adopted digital twin technology in 2021

Application	Industry							TOTAL (%)	TOTAL (\$Million)
	Automotive and Transportation	Energy and Utilities	Infrastructure	Healthcare	Aerospace	Oil and Gas	Other		
Predictive Maintenance	7.1%	8.0%	6.4%	7.0%	2.0%	6.4%	3.1%	39.9%	1797
Business Optimization	4.2%	2.3%	5.4%	2.0%	5.0%	2.3%	4.1%	25.3%	1137
Performance Monitoring	3.5%	2.7%	0.8%	2.7%	2.5%	1.7%	3.9%	17.8%	801
Inventory Management	1.6%	2.0%	1.4%	1.6%	2.0%	1.4%	2.0%	11.9%	535
Product Design and Development	0.4%	0.3%	0.4%	0.3%	1.5%	0.2%	0.4%	3.4%	155
Other Applications	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.4%	1.6%	74
TOTAL (%)	17.0%	15.5%	14.5%	13.8%	13.2%	12.2%	13.8%	100.0%	
TOTAL (\$Million)	765	697	653	621	594	548	622		4500
NORTH AMERICA TOTAL (\$Million)	299	262	251	218	230	191	236		1688
US TOTAL									1383

Source: (Douglas Thomas, 2024, p. 12).

Predictive maintenance, the largest application for digital twins, can affect product cost, quality, and production time. The maintenance of machinery typically leads to downtime, either planned or unplanned. Unplanned downtime often stems from breakdowns along with increasing defects when machinery operates outside of specification. This can result in production delays and customer dissatisfaction. The increase in unexpected delays often leads to increased inventory throughout the supply chain to deal with uncertainty, which incurs additional costs. (Douglas Thomas, 2024, pp. 11,12).

3-The role of digital twin technology in increasing production efficiency:

The use of digital twin technology is increasing in manufacturing industries, given the scale and complexity of these industries, the large amount of data that makes decision-making difficult, and their interconnected supply chains with other sectors, which necessitates continuous, periodic, and timely problem-solving.

Digital twin technology helps both management personnel and workers or engineers at the Workplace or factory level to make timely and effective decisions. This technology is a tool for development and improvement and is used for: (dilmegani, 2025)

- Assistance to product design:** Digital twin technology helps design a set of products or services that enable an organization to enter or control the market, or increase its share, by providing products that meet all consumer needs;

- Monitoring and improving the performance of production lines:** Through digital twin technology, the performance of production lines can be increased through monitoring and improvement. It helps workers discover incomplete units (defective ones) and areas of low performance ;

- Early detection of faults and predictive maintenance:** Digital twin technology is an effective tool for early detection of potential machine downtime. Thus, the organization reduces these downtimes to increase machine efficiency, by predicting and intervening before any failure occurs ;

- Assisting in the development and establishment of smart factories:** Smart factories rely on data from installed sensors to build digital models that reflect the actual performance of all components of production lines. This is what digital twin technology enables through simulation and control linked to artificial intelligence. Examples of this include planning all paths of robotic machines, conducting real-time inspections, and conducting preventive maintenance.

In addition to all of the above, digital twin technology has the potential to create an environment conducive to the work team's working conditions. This is achieved by providing the necessary data on workplace components, such as temperature and dust levels generated by factory machinery, among other relevant data, with proactive intervention to provide the optimal working environment.

4-Applying digital twin technology to control the effectiveness of mechanisms to achieve production efficiency:

The study is based on a practical experiment conducted by researcher Arif Furkan Mendi, which involves implementing a digital twin system. This system connects physical machines in the automotive industry in Turkey with a virtual twin, using an application that collects and analyzes data to enable early decision-making and issue warning messages in case of potential problems.

According to researcher Arif Furkan Mendi, the objectives of this practical experiment are:

- Maintaining the optimal condition of production machinery to increase productivity;
- Studying and analyzing data that contributes to extending the lifespan of production equipment;
- Providing immediate response in case of risks and emergencies;
- Developing and testing scenarios to generate reliable simulated data;
- Increasing the speed and profitability of the production process by improving efficiency.

The practical experiment was conducted in steps as follows: (Arif furkan mendi, 2022, pp. 5, 10)

- **Different scenarios:** The practical experiment was based on four scenarios, summarized in the following table:

Table (01): Scenarios used in the practical experiment

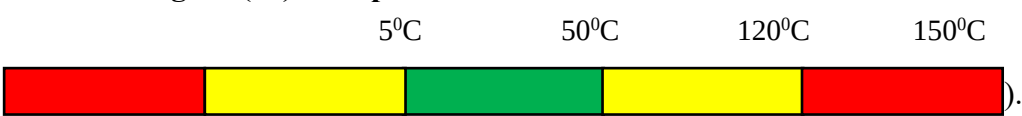
Scenario 01	Continuous monitoring and analysis of the movement patterns of robotic arms.
Scenario 02	Monitoring and analysis of the frequency of (CNC) machines.
Scenario 03	monitoring and analysis of dust density in the factory
Scenario 04	Monitoring the factory temperature

Source: Prepared by the researcher based on : (Arif furkan mendi, 2022, pp. 6, 8).

These four scenarios are of great importance in:

-The temperature of robotic arms is an important factor that contributes to extending their lifespan, and we can summarize the different temperature ranges in the following diagram:

Figure (03): Temperature zones for robotic arms



From Figure 01 above, we can observe that there are three temperature zones for the robotic arms:

- Safe zone: Temperatures range between 50 and 120 degrees Celsius;
 - Unsafe zone: Temperatures range between 5 and 50 degrees Celsius, and between 120 and 150 degrees Celsius;
 - Danger zone: The temperature ranges from less than 5 degrees Celsius to more than 150 degrees Celsius.
- The ideal rotational speed for a CNC machine, which ensures optimal machine performance, should not exceed 1600 RPM; ideally, it should be between 1500 and 1550 RPM.

The impact of Application digital twin technology on production efficiency based on practical experiment

DOUADI Beneddine

- The dust concentration in the workshop affects both the workers and the machinery. Therefore, the dust concentration should not exceed 10% to ensure normal operation without any damage.

-The optimal temperature range for the workshop, for both machinery and workers, is between 0 and 55 degrees Celsius. However, the recommended temperature range for the workers specifically is between 18 and 21 degrees Celsius.

-The material aspect : To conduct the practical experiment according to the previously outlined scenarios, it is necessary to use certain sensors that can capture all the data required for the study. These sensors are as follows:

Table (02): Sensors used in the practical experiment

	sensor	
01	E52-ELP6-50-2-A	To measure the temperature of the machinery and the factory.
02	Telaire smart dust sensor SM-PWM-1C	To measure the dust level.
03	Arduino	To measure the rotational frequency of machines

Source: Prepared by the researcher based on : (Arif furkan mendi, 2022, pp. 8, 9).

-execution : The practical experiment began with the factory operating under normal, daily conditions, with the work team and machinery functioning as usual, and all sensors installed and operational in their designated locations for data collection. The experiment proceeded as follows:

-The sensors started transmitting signals to the MQTT broker, which is an IoT protocol for transferring signals from the physical to the digital domain;

- The "Mosquitto Broker" application receives MQTT signals and then sends them to the "PostgreSQL" database;

- The signals are stored on the "Apache Kafka" platform, an open-source platform for real-time data streaming, and then sent to the "Apache Flink" platform, which processes the continuous stream of data for analysis;

-To visualize the data transmitted by the sensors, the "Unity" platform was used, which allows for creating both 2D and 3D visualizations.

-Application interface design : In this step, an application was developed to provide a visual interface for displaying sensor data. The main functions of this application include:

-Translating data received from sensors (measuring temperature, dust levels, and machine RPM within the factory) into visual representations and color-coded indicators, where the color indicates the current status;

-Processing the incoming data in real time;

The impact of Application digital twin technology on production efficiency based on practical experiment

DOUADI Beneddine

-Sending notifications based on the current status, whether normal or critical. For example, it sends warning messages when a critical condition is detected, and it can also send messages related to production output or efficiency.

We can summarize all of the above as follows :

Figure (04): The application interface and the different status it analyzes, represented by colors



Source: Prepared by the researcher based on : (Arif furkan mendi, 2022, p. 10).

The main objective of the practical experiment is to investigate the impact of applying digital twin technology on production efficiency through the effects of temperature, dust content, and rotation frequency on both downtime and the time required to complete the same work daily .The practical experiment was conducted for a period of six months before the implementation of digital twin technology (September 2020 - February 2021), and six months after the implementation of digital twin technology (July 2021 - December 2021), to identify the differences that would affect production efficiency before and after the implementation of digital twin technology. The practical experiment resulted in the following:

-Downtime: The results of downtime before and after using digital twin technology were as follows:

Table (03): Downtime before and after appliqueing digital twin technology

Before using digital twin technology (minute)	Months	Downtime	After using digital twin technology (minute)	Months	Downtime	Comparison
	September 2020	192		July 2021	29	%84.89-
	October 2020	191		August 2021	25	%86.91-
	November 2020	187		September 2021	23	%87.70-
	December 2020	176		October 2021	22	%87.5-
	January 2021	196		November 2021	21	%89.28-
	February 2021	191		December 2021	21	%89.005-
	Total	1133		Total	141	%87.55-

Source: Prepared by the researcher based on : (Arif furkan mendi, 2022, p. 12).

The impact of Application digital twin technology on production efficiency based on practical experiment

DOUADI Beneddine

The previous table clearly demonstrates the impact of digital twin technology on total downtime. Before implementing the technology, the total downtime was 1133 minutes over six months. However, after implementing the technology, the downtime decreased to 141 minutes over the same period. This clearly shows that the impact of digital twin technology on total downtime is positive, as it decreased by 87.55%, representing a significant reduction of 992 minutes over six months.

-Time required to complete the same task daily: The time required to complete the same task daily was observed throughout the duration of the experiment, and the results were as follows:

Table (04): Time required before and after appliqueing digital twin technology

Before using digital twin technology (minute)	Months	Time required	After using digital twin technology (minute)	Months	Time required	Comparison
	September 2020	10843		July 2021	10252	%5.45-
	October 2020	10895		August 2021	10205	%6.33-
	November 2020	10766		September 2021	10226	%5.01-
	December 2020	10827		October 2021	10191	%5.87-
	January 2021	10909		November 2021	10187	%6.61-
	February 2021	10924		December 2021	10185	%6.76-
	Total	65163		Total	61246	%6.01-

Source: Prepared by the researcher based on : (Arif furkan mendi, 2022, pp. 13, 14).

We observed the impact of digital twin technology on the time required to complete the same tasks daily. Before implementing the technology, the total time spent on these daily tasks over six months was 65,163 minutes. After implementing the technology, this time decreased to 61,246 minutes over the same six-month period, representing a reduction of 3,917 minutes, or 6.01%. This further confirms the positive impact of digital twin technology on reducing the time required for daily tasks.

Practical experience confirms that the application of digital twin technology has a positive impact on production efficiency, reducing downtime by 87.55% and the time required to complete the same work daily by 6.01%. This makes it highly effective, which in turn impacts profitability and revenue.

The impact of Application digital twin technology on production efficiency based on practical experiment

DOUADI Beneddine

Conclusion:

Digital twin technology is among the most important emerging technologies, contributing to the development of various sectors, including the manufacturing sector. This sector has witnessed significant development in recent decades, expanding in scale and scope due to its high-quality production technology. However, it has also suffered from some problems that have impacted the productive efficiency of the manufacturing sector, the most important of which is the problem of downtime and the time required to complete the same work daily.

The study was built from the results of the researcher's practical experience, which addressed the main causes of both downtime and the time required to complete the same work daily using digital twin technology. According to this experience, the main causes were the temperature of the machines and the factory, the dust content generated by the normal operation of these machines, and the rotational frequency of these machines.

The study was built from the results of the researcher's practical experience, which addressed the main causes of both downtime and the time required to complete the same work daily using digital twin technology. According to this experience, the main causes were the temperature of the machines and the factory, the dust content generated by the normal operation of these machines, and the rotational frequency of these machines.

The practical experience was conducted using digital twin technology to simulate the physical reality of the factory by installing sensors to collect data on the aforementioned causes. The digital twin application then analyzed the data and sent warning messages in case of danger, allowing for intervention.

The study reached an important and fundamental conclusion: implementing a digital twin significantly reduced downtime and the time required to complete the same work daily, thereby increasing production efficiency. This confirms the validity of the study's hypothesis.

The study's main finding is that digital twin technology has become an emerging and important technology that simulates the physical aspect for analysis and timely decision-making. Sectors that extensively use technology in the production process should embrace this technology, which is a fundamental pillar for increasing overall production efficiency.

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