

Digital Twin for Smart Manufacturing: Systematic Literature Review Using Vos Viewer and Recommendations for Future Research

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Abstract

This study conducts a literature review on the application of digital twin in smart manufacturing. Using VOS Viewer as the analytical tool, a total of 286 Scopus-indexed articles published between 2016 and 2024 were analyzed. The results provide a comprehensive overview of conceptual relationships, research trends, and contributions from relevant studies. Findings reveal an exponential growth of digital twin research since 2016, peaking in 2024. The analysis identifies crucial factors such as smart manufacturing, systems, and applications. Furthermore, the overlay visualization highlights emerging research focuses, including Human-Robot Collaboration and Intelligent Manufacturing Systems in the 2022–2024 period. Future research is recommended to expand the digital twin concept to cover broader aspects of the manufacturing industry, including Flexible Manufacturing, Competitiveness, Automation, and Sustainable Manufacturing.

Keywords: Digital Twin, Smart Manufacturing, Bibliometric Analysis, VOS Viewer

I. INTRODUCTION

Intelligent manufacturing brings significant transformation in the context of production and operations, delivering positive impacts on product quality, productivity, cost, and flexibility, while guiding industries toward a more efficient and adaptive future. In today's digital era, digital transformation has become a key driver in enhancing efficiency and productivity across various sectors, including the manufacturing industry. One of the innovations dominating the current industrial landscape is the concept of the "Digital Twin." This concept has become a foundation for the implementation of smart manufacturing, where physical devices in factories are digitally replicated in virtual environments. A digital twin is a real-time digital reproduction of physical entities, faithfully mapping physical objects, and not only describing them but also optimizing them based on models (He, 2021).

A digital twin is an accurate virtual representation of a physical system or real process, encompassing sensors, real-time data, and simulation models. In the context of smart manufacturing, digital twins play a crucial role in understanding, monitoring, and optimizing factory operations comprehensively. Recent technological advances, such as smart sensors, the Internet of Things (IoT), cloud computing, machine learning, and artificial intelligence (AI), have enabled digitalization and facilitated the development of digital twins in the manufacturing sector (Shao, 2020). The implementation of digital twin technology in manufacturing provides the ability to plan, manage, and predict factory performance more effectively.

The adoption of digital twin technology has become a primary focus for companies seeking to enhance efficiency and innovation in their production processes. Although there has been rapid growth in research related to digital twins in smart manufacturing, there remains a need for systematic literature reviews. The main challenge is the lack of comprehensive understanding of current research trends regarding the application of digital twins in smart manufacturing contexts. Therefore, this literature review aims to present a comprehensive perspective on recent developments in this field using VOS Viewer as the analytical tool. Through this study, we can identify existing knowledge gaps and formulate recommendations for future research. Consequently, this research can guide the direction of studies to advance the understanding and implementation of digital twins in the context of smart manufacturing, establishing a solid foundation for further industrial transformation.

II. METHOD

The data used in this study were obtained from publications indexed in Scopus. The dataset collection process was carried out using the “Publish or Perish” application with the keyword “Digital Twin Manufacturing” to achieve the research objectives.

The steps undertaken in dataset collection are as follows:

1. Searching and Collecting Publications

The search was conducted using the Publish or Perish application to identify and collect relevant publications on the topic of digital twin.

2. Bibliometric Data Processing

After obtaining the publications, bibliometric data were processed using Microsoft Excel. This involved compiling an accurate and structured dataset for further analysis.

3. Bibliometric Mapping with VOS Viewer

The next step was bibliometric mapping using VOS Viewer. The data downloaded from Publish or Perish in RIS format were processed in VOS Viewer to visualize inter-publication relationships and research trends.

4. Analysis of Bibliometric Mapping Results

The results of bibliometric mapping were analyzed in detail to explore trends, inter-publication relationships, and the contributions of each article.

5. Visual Representation in Three Form

The data processed in VOS Viewer were represented in three visualization formats: network visualization, overlay visualization, and density visualization. These visualizations provided a comprehensive overview of the interconnections among articles in the dataset.

Based on this methodology, a total of 621 articles related to digital twins in the manufacturing sector were retrieved from the Scopus database, covering the years 2016–2024. Subsequent analysis involved examining research trends through bibliometric mapping using VOS Viewer to gain in-depth insights into the research topic. After data collection and tabulation in Microsoft Excel, duplicate and irrelevant articles were filtered out. As a result, from the initial 621 articles, only 286 were deemed relevant and aligned with the research theme, and thus selected for further analysis.

III. RESULT AND DISCUSSION

The concept of the digital twin was first introduced by Dr. Michael Grieves in 2002. In this concept, Grieves transformed real-world objects into data within a virtual environment. This process involves data processing to generate value-added information, which can then be reapplied to the corresponding real-world objects. Research trends on digital twins in the manufacturing industry have shown significant growth over the past several years.

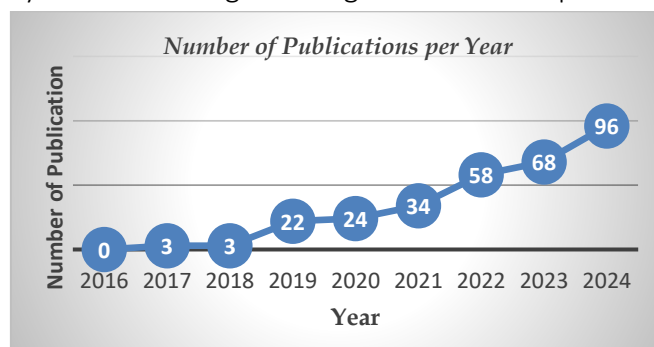


Figure 1. Number of Publications per Year
Source: Processed data by the author (2025)

Figure 1 shows that in 2016 there were no recorded publications, and even before 2015, no articles on digital twins were found in the Scopus database. This indicates a limited level of awareness and interest at that time. However, beginning in 2017, the number of publications gradually increased. In 2017 and 2018, there were three publications each year, reflecting the relatively small attention and exploration of the digital twin concept during this period. In 2019, the number of publications rose significantly to 22, signaling growing research interest and a deeper understanding of the application of digital twins in the manufacturing industry. This positive trend continued, with 24 publications in 2020. That year became a critical turning point, followed by another increase to 34 publications, marking broader adoption and a deeper comprehension of the benefits of digital twins in manufacturing processes. Exponential growth persisted in subsequent years: in 2022 the number of publications reached 58, followed by 68 in 2023. The peak occurred in 2024 with 96 publications. These findings indicate that digital twins have moved beyond being a research

trend to becoming a major subject of study aimed at enhancing efficiency, quality, and innovation in manufacturing.

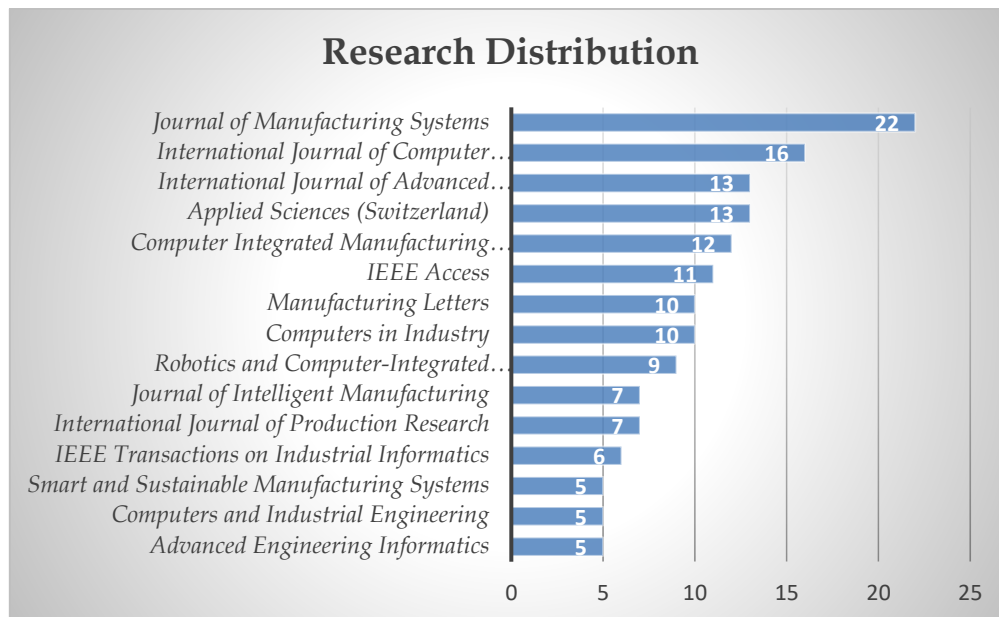


Figure 2. Distribution of Publications by Journal
Source: Processed data by the author (2025)

Figure 2 illustrates the contributions of various publishers in presenting recent studies on digital twins within the manufacturing sector. The varying number of publications demonstrates the level of interest and research focus among publishers, serving as an important indicator for identifying credible and relevant sources in this field. It is notable that the *Journal of Manufacturing Systems* recorded 22 publications between 2018 and 2023, making it one of the most preferred outlets for researchers publishing their work on digital twins.

A high number of citations reflects that these articles are considered influential and relevant sources of knowledge in the development of digital twin research. The article titled “Digital Twin-Driven Product Design, Manufacturing and Service With Big Data” by Tao (2018), published in the *International Journal of Advanced Manufacturing Technology*, has received significant attention from both academic and industrial communities. With 1,662 citations, it demonstrates a substantial impact and broad acceptance of Tao’s contribution, particularly in the areas of product design, manufacturing, and services through the utilization of big data. This study emphasized the transition toward a big data-driven era of manufacturing alongside the application of new-generation information technologies. Although big data can be collected throughout the product life cycle—including design, manufacturing, and services—Tao (2018) focused more on physical products rather than virtual models. The main challenges identified were isolation, fragmentation, and delays in product life cycle data, which resulted in inefficiency, reduced intelligence, and lower sustainability across design, manufacturing, and service stages. The study highlighted the importance of convergence between physical and virtual product data to support design, manufacturing, and services. Building on prior research

on big data in product life cycle management, Tao (2018) underscored how consolidated physical–virtual data can enhance efficiency, intelligence, and sustainability across product design, manufacturing, and service domains.

Table 1.
Most Cited Articles

Authors	Title	Source	Cites
Tao, 2018	<i>Digital Twin-Driven Product Design, Manufacturing and Service With Big Data</i>	<i>International Journal of Advanced Manufacturing Technology</i>	1662
Qi, 2018	<i>Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison</i>	<i>IEEE Access</i>	932
Tao, 2017	<i>Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing</i>	<i>IEEE Access</i>	832
Tao, 2019	<i>Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison</i>	<i>Engineering</i>	619
Cimino, 2019	<i>Review of Digital Twin Applications In Manufacturing</i>	<i>Computers in Industry</i>	422
Leng, 2021	<i>Digital Twin-Driven Manufacturing Cyber-Physical System For Parallel Controlling of Smart Workshop</i>	<i>Journal of Ambient Intelligence and Humanized Computing</i>	313
Wang, 2019	<i>Digital Twin for Rotating Machinery Fault Diagnosis in Smart Manufacturing</i>	<i>International Journal of Production Research</i>	303
Ding, 2019	<i>Defining a Digital Twin-based Cyber-Physical Production System for Autonomous Manufacturing in Smart Shop Floors</i>	<i>International Journal of Production Research</i>	293
Liu, 2019	<i>Digital Twin-Driven Rapid Individualised Designing of Automated Flow-Shop Manufacturing System</i>	<i>International Journal of Production Research</i>	265
He, 2021	<i>Digital Twin-Based Sustainable Intelligent Manufacturing: A Review</i>	<i>Advances in Manufacturing</i>	260
Mandolla, 2019	<i>Building a Digital Twin for Additive Manufacturing Through The Exploitation of Blockchain: A Case Analysis of The Aircraft Industry</i>	<i>Computers in Industry</i>	255
Knapp, 2017	<i>Building Blocks For A Digital Twin of Additive Manufacturing</i>	<i>Acta Materialia</i>	251
Leng, 2020	<i>Digital Twin-Driven Rapid Reconfiguration of The Automated Manufacturing System Via an Open Architecture Model</i>	<i>Robotics and Computer-Integrated Manufacturing</i>	219
Zhou, 2020	<i>Knowledge-Driven Digital Twin Manufacturing Cell Towards Intelligent Manufacturing</i>	<i>International Journal of Production Research</i>	205
Bao, 2019	<i>The Modelling and Operations For The Digital Twin in The Context of Manufacturing</i>	<i>Enterprise Information Systems</i>	199
Aivaliotis, 2019	<i>The Use of Digital Twin For Predictive Maintenance in Manufacturing</i>	<i>International Journal of Computer Integrated Manufacturing</i>	197
Coronado, 2018	<i>Part Data Integration in The Shop Floor Digital Twin: Mobile And Cloud Technologies to Enable A Manufacturing Execution System</i>	<i>Journal of Manufacturing Systems</i>	191
Liu, 2021	<i>Digital Twin-Based Designing of The Configuration, Motion, Control, And Optimization Model of A Flow-Type Smart Manufacturing System</i>	<i>Journal of Manufacturing Systems</i>	183
Li, 2022	<i>Digital Twin in Smart Manufacturing</i>	<i>Journal of Industrial Information Integration</i>	172
Redelinghuys, 2020	<i>A Six-Layer Architecture For The Digital Twin: A Manufacturing Case Study Implementation</i>	<i>Journal of Intelligent Manufacturing</i>	150

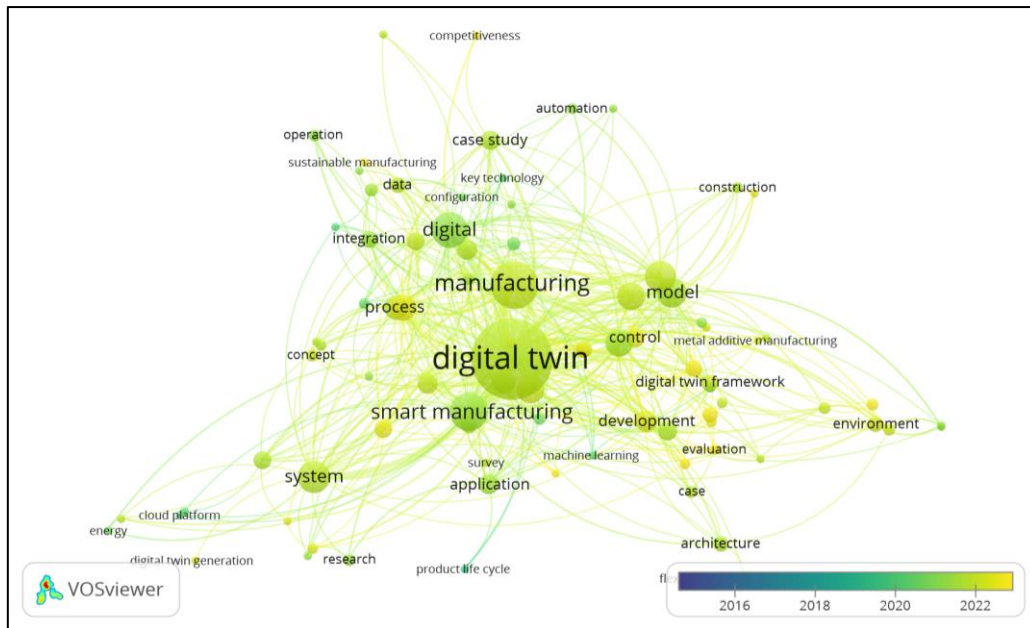


Figure 4. Overlay Visualization
Source: VOS Viewer Output (2024)

The overlay visualization from VOS Viewer provides a rich representation of the relationships and interactions among concepts in digital twin research. This type of visualization allows for a deeper understanding of the various aspects and dimensions associated with digital twins in the manufacturing sector. In the visualization, attributes such as color highlight the intensity or strength of relationships among terms. Some terms appear more prominent or strongly connected, while others appear with weaker intensity. This provides additional information on the degree to which certain concepts contribute to the research framework or broader understanding of the topic. Overlay visualization is a valuable tool for identifying patterns, trends, or relationships that may not be apparent through conventional analysis, making it particularly useful for addressing the complexity and structure of knowledge surrounding digital twin research.



Figure 5. Terms in Overlay Visualization
Source: VOS Viewer Output (2025)

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For example, the overlay visualization highlights the keywords “Human-Robot Collaboration”, “Optimization”, and “Intelligent Manufacturing System” as yellow nodes, indicating emerging research conducted between 2022 and 2023. The yellow coloring of these nodes reflects newer areas of study, providing insights into recent developments within these two concepts in the context of digital twin research in manufacturing. This suggests that research on digital twins in relation to “Human-Robot Collaboration”, “Optimization”, and “Intelligent Manufacturing Systems” remains limited. These findings can be used to identify and detect the state of the art for future digital twin research. Future studies may therefore focus on exploring the interactions between digital twins and these aspects, with an emphasis on optimization to enhance efficiency in manufacturing contexts.

Moreover, the identification of these emerging themes indicates a shifting research agenda in digital twin applications, moving beyond traditional system-level optimization toward more advanced, adaptive, and intelligent manufacturing paradigms. The integration of human-robot collaboration within digital twin frameworks, for example, could provide manufacturers with real-time insights to improve safety, productivity, and decision-making on the shop floor. Similarly, embedding optimization strategies into intelligent manufacturing systems can accelerate the adoption of autonomous operations, supporting flexible and sustainable production models. These directions not only reflect the evolving landscape of Industry 4.0 but also serve as strategic entry points for future investigations seeking to expand the role of digital twins in shaping next-generation manufacturing ecosystems.

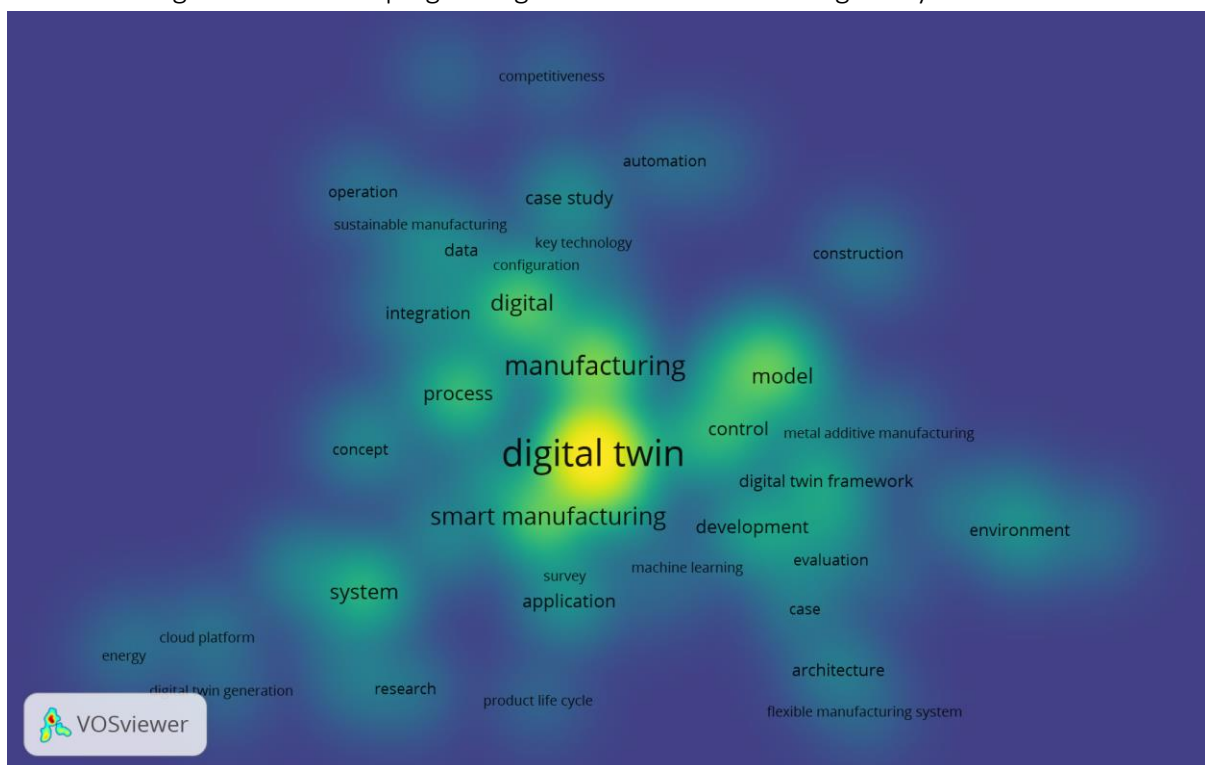


Figure 6. Density Visualization
Source: VOS Viewer Output (2025)

Bibliometric analysis using density visualization in VOS Viewer provides in-depth insights into the distribution and interconnections of bibliometric elements, such as keywords, topics, or research concepts. Density visualization highlights areas with high concentrations of elements, offering a visual understanding of the extent to which a topic or concept has become a research focus. In the density visualization shown, keywords with high concentrations represent concepts frequently co-occurring or closely related, whereas areas of low density indicate research gaps or underexplored topics.

For instance, keywords such as “Flexible Manufacturing”, “Competitiveness”, “Automation”, “Construction”, “Environment”, “Product Life Cycle”, “Energy”, “Cloud Platform”, “Operations”, and “Sustainable Manufacturing” appear with relatively low density, suggesting that studies connecting digital twins with these concepts remain scarce. Their distant positions in the visualization indicate limited direct linkages with the digital twin concept. This highlights a significant opportunity for further research to bridge these gaps and explore the integration of digital twins with aspects such as flexible manufacturing, competitiveness, automation, and sustainability. These limitations in current literature open avenues for future research, motivating scholars to investigate how digital twins can be expanded and applied across broader industrial contexts.

Future Research Recommendations

Based on the bibliometric analysis and visualization results, it is evident that while digital twin research in smart manufacturing has grown rapidly, several areas remain underexplored and present opportunities for further study. The identified gaps highlight the need for expanding the scope of digital twin applications, integrating emerging technologies, and strengthening their role in achieving efficiency, sustainability, and adaptability in manufacturing systems. In line with these findings, the following recommendations are proposed to guide future research directions:

1. Future research can focus on expanding the concept of digital twins to encompass more aspects of the manufacturing industry, such as Flexible Manufacturing, Competitiveness, Automation, and Sustainable Manufacturing.
2. Integrating emerging technologies such as the Internet of Things (IoT), machine learning, and artificial intelligence (AI) to enhance the capabilities of digital twins in understanding and optimizing factory operations.
3. Further studies may explore the relationship between digital twins and aspects of environment, energy, and sustainability in the manufacturing context.
4. Emphasis on the Optimization aspect of digital twins to improve operational efficiency, supply chain management, and resource utilization.
5. Deeper exploration of the interactions between digital twins, Human-Robot Collaboration, and Intelligent Manufacturing Systems to achieve higher efficiency and adaptability.
6. Future research can also delve into the understanding and application of digital twins across the product life cycle, including product design, operation, and maintenance.

Providing research recommendations is essential to ensure the continuity and relevance of digital twin studies within the broader context of smart manufacturing. While the current body of literature demonstrates rapid growth, there remain significant gaps in areas such as sustainability, competitiveness, and human-robot collaboration. Prior studies have emphasized the need to bridge these gaps, highlighting that digital twins must evolve beyond their current scope to fully support Industry 4.0 and future industrial ecosystems. For example, Tao (2018) stressed the importance of integrating big data with digital twin frameworks to overcome inefficiencies and data fragmentation in product life cycles. Similarly, Qi (2018) pointed out that the convergence of digital twins and big data is critical to advancing smart manufacturing and Industry 4.0. Other scholars, such as He (2021), also underlined the necessity of expanding digital twin applications toward sustainable and intelligent manufacturing practices.

In light of these findings, formulating future research recommendations is vital to guide scholars and practitioners in addressing existing limitations and exploring new opportunities. The following recommendations are proposed to direct future research and contribute to the advancement of digital twin implementation in manufacturing.

IV. CONCLUSION

To improve efficiency, quality, and innovation in the manufacturing industry, the concept of the Digital Twin has become a key element in the transformation toward smart manufacturing. This study conducted a systematic literature review using VOS Viewer to provide in-depth insights into the latest developments in the application of digital twins within the manufacturing sector. The bibliometric analysis revealed exponential growth in research since 2016, reaching its peak in 2023 with 96 publications. Several publishers have made significant contributions, and highly cited articles provide valuable knowledge on this topic.

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