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Future of Industrial Asset Management: A Synergy of Digitalization, Digital Twins, Maintenance 5.0 / Quality 5.0, Industry 5.0 and ISO55000

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Abstract: The paper explores the future of industrial asset management, focusing on the profound transformations brought about by the integration of digital technologies. Specifically, it delves into the implications and potential of digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000. The research is based on the 2019-2023 sessions of the Cluster for Industrial Asset Management (CIAM). (CIAM 2023)

Paper begins by outlining how digitalization, chiefly driven by the Internet of Things (IoT), allows for real-time asset monitoring, predictive analytics, automated decision-making, and optimized asset usage. Then it expounds on the concept of digital twins and their utility in predicting and preventing equipment failures and optimizing asset performance.

The next section elucidates how Maintenance 5.0 and Quality 5.0 leverage AI, machine learning, and human factors to shift asset management towards proactive strategies, enhancing reliability and product quality. Industry 5.0's role in fostering human-machine collaboration for improved decision-making and productivity in asset management is also analyzed.

The paper also delves into ISO55000, a standardized approach to asset management, and its role in ensuring consistency, transparency, accountability, and continuous improvement in asset management practices. It further outlines the future role of ISO55000 in managing the influx of data from digital technologies and the integration of new technologies in asset management systems.

Finally, it elaborates on the integration, utilization, and implementation of these technologies and standards, which collectively herald a new era of industrial asset management characterized by optimized asset lifecycles, enhanced resilience, and operational excellence. The paper concludes that the future of industrial asset management will witness unprecedented efficiency, cost-effectiveness, and sustainability as organizations harness these advancements and navigate the challenges of the digital era. The industrial landscape is being transformed profoundly through emerging technologies and standards such as digitalization, digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000. These technologies offer novel possibilities in optimizing asset management, maintenance, and quality assurance, which in turn, could significantly enhance productivity, efficiency, and operational sustainability.

Keywords: Digitalization, Digital Twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, ISO55000, Industrial Asset Management.

I. Introduction

The advent of digital technologies has revolutionized industrial asset management, offering unprecedented opportunities to streamline processes, optimize assets, reduce costs, and improve productivity. With advancements like digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000, the future of asset management looks promisingly robust. Industrial asset management has been radically transformed by the integration of digital technologies, leveraging their capabilities to optimize the performance, lifecycle, and management of assets. The key advancements driving this transformation include digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000, each of which is discussed in detail below.

Digital Twins: This concept refers to the digital representation of a physical asset, allowing for real-time tracking, monitoring, and management of the asset. Digital twins leverage the power of IoT sensors and advanced analytics to create an accurate, real-time replica of the asset in a virtual space. This approach enables improved prediction and detection of issues, better planning of maintenance, and optimization of asset

utilization. The use of digital twins can lead to significant reductions in maintenance costs, improved asset performance, and increased overall productivity. (Jiang, Hsu and Zhu, 2022)

Maintenance 5.0 / Quality 5.0: Maintenance 5.0 focuses on predictive and preventive approaches to asset maintenance. It uses data collected from IoT sensors and leverages artificial intelligence (AI) and machine learning (ML) to predict failures before they occur, enabling organizations to take proactive steps and prevent downtime. (Chen et al 2021) Quality 5.0, on the other hand, merges digital technologies with human aspects to ensure better quality control. It encourages the use of digital tools and automation for quality assurance while emphasizing the importance of human intuition, creativity, and decision-making skills in the process. (Frick and Grudowski 2023)

Industry 5.0: This paradigm represents the latest phase in the evolution of industrial production, where human operators work in close collaboration with smart machines. It signifies a shift from automation to autonomy, where smart systems make informed decisions and carry out complex tasks. In the context of asset management, Industry 5.0 facilitates more effective collaboration between humans and machines, leading to more informed decision-making, increased flexibility, and improved productivity. (Leng et al 2022)

ISO55000: ISO55000 is an international standard that provides a framework for the effective management of physical assets. It offers guidance on how to achieve maximum value from assets while balancing financial, environmental, and social costs, risks, service quality, and performance-related considerations. This standard encourages organizations to adopt a comprehensive approach towards asset management, ensuring consistency, transparency, and accountability in their processes. (Woodhouse 2014, Parra 2021)

These technologies, when integrated, promise a future of asset management that is not only robust and efficient, but also sustainable. They enable companies to manage their assets more effectively, making data-driven decisions, predicting issues before they occur, and ensuring the longevity and performance of their assets. As such, the integration of digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000 will play a pivotal role in shaping the future of industrial asset management. This paper based on sessions 2019-2023 of Cluster for Industrial Asset Management elucidates the future of industrial asset management, integrating these modern advancements to achieve sustainable asset lifecycle management. (CIAM 2023)

II. Digitalization in Industrial Asset Management

Digitalization refers to the application of digital technologies to convert information into a digital format, leading to the transformation of business processes and models. This digital transformation enables organizations to access data more conveniently, analyze it more effectively, and make more informed decisions. It is shaping all aspects of business operations, and asset management is no exception. (Angelopoulos and Mourtzis 2022)

In the realm of industrial asset management, one of the key driving forces of digitalization is the Internet of Things (IoT). IoT consists of a network of physical devices, machines, and systems interconnected via the internet, enabling data exchange and interaction. The devices, or 'things' in IoT, are embedded with sensors, software, and other technologies to collect and exchange data.

Here's how IoT influences industrial asset management:

Real-time Monitoring: IoT devices, such as sensors attached to machinery, can collect a vast range of data in real-time. (Raju and Shenoy 2016) This includes parameters such as temperature, pressure, vibration, and more, depending on the nature of the asset. These devices can transmit data to a central system, enabling real-time tracking and monitoring of asset health and performance. This ongoing, real-time monitoring allows managers to promptly detect anomalies and respond to issues as they occur, minimizing potential downtime and repair costs.

Predictive Analytics: Data collected by IoT devices form the basis for predictive analytics. Advanced machine learning algorithms can analyze this data to identify patterns, trends, and correlations. This process facilitates predictive maintenance, a strategy that relies on data, statistics, machine learning, and artificial intelligence to predict equipment failure before it happens. This enables organizations to fix issues before they cause significant problems, thus reducing downtime and increasing productivity. (Kumar et al 2021)

Automated Decision-making: IoT can be combined with AI to facilitate automated decision-making. Data from IoT devices can be fed into AI systems, which can then analyze the data and make decisions based on predefined criteria. For example, an AI system could automatically order a replacement part when a machine part reaches a certain level of wear, based on data received from an IoT sensor. This automation reduces the time taken to respond to issues and can significantly increase the efficiency of asset management. (Araujo 2020)

Optimized Asset Usage: By providing detailed, real-time insights into asset performance, IoT enables better asset utilization. Companies can leverage these insights to optimize their asset usage, ensuring they get the most value from their assets while minimizing waste and inefficiency. (Chen 2022, Nordal and El-Thalji 2021)

In summary, IoT is a critical component of digitalization in industrial asset management. Its ability to collect and transmit real-time data, coupled with its integration with AI and advanced analytics, provides organizations

with the tools necessary for real-time monitoring, predictive maintenance, automated decision-making, and optimized asset usage. This digital shift allows for a more proactive, data-driven approach to asset management, significantly improving efficiency and productivity. (Angelopoulos and Mourtzis 2022)

III. Digital Twins for Real-time Asset Monitoring

Digital twins are a groundbreaking innovation in the field of industrial asset management. These digital replicas of physical assets leverage IoT, AI, and advanced analytics to provide real-time monitoring, simulation, and optimization. In essence, a digital twin is a bridge between the physical and digital world, allowing for advanced data analysis, scenario simulation, and real-time decision-making. (Gulewicz 2022) The use of digital twins can impact asset management and maintenance, including human factors, in several ways:

Real-time Monitoring and Predictive Maintenance: Digital twins allow for constant real-time monitoring of assets. Using sensors attached to the physical asset, data regarding its performance, environmental conditions, and wear and tear are continuously fed into the digital twin. This data can be analyzed to predict potential failures before they occur. In addition, based on the historical and real-time data, predictive models can be developed to forecast the lifecycle of the asset and optimize maintenance schedules. This can significantly reduce unexpected downtimes and the associated costs.

Optimization of Asset Performance: By analyzing the vast amount of data that the digital twin collects, operators can get valuable insights into how the asset is performing under various conditions. This can help in optimizing the operational parameters of the asset for maximum efficiency and productivity. It also allows for adjustments in response to changes in conditions, ensuring that the asset operates optimally at all times.

Simulation and Training: Digital twins can simulate the behavior of assets under different scenarios, which can be a valuable tool for operator training. By running simulations on the digital twin, operators can understand how to respond to different situations, enhancing their skills without risking the physical asset. This can significantly improve operator performance and safety.

Improving Human Factors: Digital twins not only provide a platform for better understanding and managing physical assets but also contribute to improving the human factors in asset management. By providing a digital platform for operators to interact with, digital twins can improve understanding of the assets and their behavior, reduce human error, and improve decision-making. Digital twins can also be used to study the impact of human factors on the performance of the asset, leading to the development of better training programs and operating procedures.

Enhancing Collaboration: Digital twins serve as a common platform where various stakeholders like design engineers, operators, and maintenance personnel can collaborate. Everyone can access the same data and insights, leading to better communication, faster problem resolution, and effective preventive strategies.

Digital twins represent a significant leap forward in asset management and maintenance. By providing a platform for real-time monitoring, prediction, and optimization, they enable organizations to significantly improve asset performance, reduce costs, and improve human factors related to asset management.

IV. Cost of Digital Twins

Implementing digital twins within an organization can entail several types of costs. However, these costs often represent an investment towards enhanced productivity, operational efficiency, and decreased downtime. It's crucial to note that the total cost can vary widely depending on the complexity of the assets, the extent of the digital twin deployment, and the organization's size.

Hardware Costs: These include the costs of IoT sensors and other devices required to collect data from physical assets. Depending on the type and number of assets that need to be monitored, this cost can vary. Additional costs may include network infrastructure to support data transmission from the IoT devices to the digital twin platform.

Software Costs: The creation of a digital twin involves complex software capable of modeling and simulating the behavior of the physical asset. This may involve using a pre-existing platform or developing custom software. The cost will depend on the complexity of the assets, the number of different types of assets, and the specific features required.

Data Storage and Processing Costs: Digital twins generate a massive amount of data that need to be stored and processed. Depending on the scale of operations, organizations may need to invest in cloud storage and processing capabilities or expand their existing IT infrastructure. This can also include costs related to data security and privacy measures.

Implementation and Integration Costs: This involves the cost of integrating the digital twin platform with the existing IT landscape of the organization. (Gulewicz 2022) Depending on the complexity of the existing IT infrastructure and the scale of the digital twin implementation, these costs can vary.

Training Costs: The successful operation of digital twins requires a workforce that understands the technology and can effectively interpret the data generated. This may involve the cost of training existing staff or hiring new employees with the necessary skills.
Maintenance Costs: Just like any other system, digital twins need ongoing maintenance. This can include regular software updates, hardware maintenance, and troubleshooting.
While the upfront cost might seem significant, it's important to consider the potential return on investment. The ability to predict failures, optimize maintenance schedules, reduce downtime, and improve overall asset performance can lead to substantial cost savings in the long run. These improvements can more than offset the initial and ongoing costs associated with implementing and maintaining a digital twin system.

V. Maintenance 5.0 / Quality 5.0: A Shift to Proactivity

Maintenance 5.0 and Quality 5.0 represent significant advancements in the field of industrial asset management. By integrating AI, machine learning, and human factors, organizations can significantly reduce costs and improve quality in their operations.
AI and Maintenance 5.0: AI and machine learning enable predictive maintenance, a proactive approach where potential issues are identified and addressed before they can cause failures. AI algorithms analyze data from sensors and other sources to predict when a piece of equipment is likely to fail. This allows organizations to schedule maintenance activities to prevent the failure, thereby reducing downtime and the associated costs. This not only saves the cost of emergency repairs but also extends the life of the equipment, resulting in significant cost savings over time.
Furthermore, AI can automate many routine maintenance tasks, such as monitoring equipment for signs of wear and tear, which can free up human workers for more complex tasks. This can reduce labor costs and improve efficiency.
Human Factors and Maintenance 5.0: While AI and machine learning provide the technology for predictive maintenance, human factors are essential in implementing and managing these systems. For instance, maintenance personnel need to understand how to use these systems effectively, make sense of the data and predictions they provide, and take appropriate actions. This requires proper training and education. Furthermore, maintenance personnel can provide valuable input that can be used to fine-tune the predictive models used by the AI, further improving their accuracy and effectiveness.
AI and Quality 5.0: AI can also be utilized in Quality 5.0 to improve quality control and process efficiency. Machine learning algorithms can analyze production data to identify patterns that indicate quality issues. This enables proactive quality control, where potential problems can be identified and addressed before they affect the final product. This can lead to significant improvements in product quality and customer satisfaction, while also reducing waste and rework costs.
Human Factors and Quality 5.0: In Quality 5.0, human factors play a crucial role. While AI can identify potential issues, human workers are needed to understand these insights, make informed decisions, and take appropriate actions. Furthermore, human creativity and problem-solving skills can be leveraged to continuously improve production processes and quality control procedures. This requires an organizational culture that values and encourages continuous learning and improvement. (Sun et al 2000)
By intelligently integrating AI and human factors, organizations can effectively implement Maintenance 5.0 and Quality 5.0, resulting in significant cost savings and improved quality. These approaches represent a paradigm shift in asset management, where proactive and predictive strategies replace reactive ones, and human skills are combined with advanced technology to optimize operations.5. Industry 5.0: Collaboration of Humans and Machines
Industry 5.0 emphasizes the collaboration of humans and machines. By integrating cognitive computing and AI with human intelligence, organizations can achieve greater flexibility, creativity, and decision-making capabilities, providing a new dimension to asset management.

VI. ISO55000: A Standardized Approach to Asset Management

ISO55000 provides a standardized approach to asset management. (Woodhouse 2014) With this standard, organizations can ensure consistency, transparency, and accountability in their asset management processes, driving continuous improvement and sustainable performance.
The ISO55000 series is a set of international standards that provides guidelines for asset management. These standards were developed by the International Organization for Standardization (ISO), with the aim of helping organizations effectively manage the lifecycle of their assets. The series includes three standards: ISO55000, ISO55001, and ISO55002.
ISO55000 provides an overview of asset management and the standard terms and definitions used.
ISO55001 specifies the requirements for a management system for assets.
ISO55002 gives practical guidance for the application of a management system for assets.

The ISO55000 series offers a universal framework for managing and optimizing physical assets, whether those assets are infrastructure (such as roads and bridges), machinery, equipment, or vehicles. It's important to note that these standards are applicable to assets of all types, sizes, and structures.

1. Consistency: The ISO55000 standards provide a consistent approach to asset management. They offer a universally recognized set of guidelines that ensure consistency in how assets are managed across different parts of an organization, and even between different organizations.

2. Transparency: The standards also encourage transparency. By promoting a standardized approach, they ensure that asset management practices are clear and transparent, which can improve stakeholder confidence and trust in an organization.

3. Accountability: The ISO55000 standards set clear guidelines for accountability in asset management. They specify the roles and responsibilities of different parties in the management of assets, ensuring that everyone knows what is expected of them.

4. Continuous Improvement: The ISO55000 standards encourage organizations to continuously improve their asset management practices. By providing a framework for regular reviews and audits, they help organizations identify areas of weakness and implement improvements.

6.1 ISO55000 Future Role in Digitalization

As industries become increasingly digital, the ISO55000 standards will play an important role in guiding how digital tools are used in asset management.

Data Management: With digitalization comes an influx of data from IoT devices, digital twins, AI, and more. The ISO55000 standards provide guidelines on how this data should be managed and used effectively in asset management.

Integration of New Technologies: As new technologies emerge, the ISO55000 standards will be crucial in guiding how they are incorporated into existing asset management systems. This could include technologies such as blockchain for data integrity, machine learning for predictive maintenance, or augmented reality for enhanced asset visualization.

Cybersecurity: As asset management becomes more digital, cybersecurity becomes increasingly important. The ISO55000 standards provide a framework that can help organizations manage the cybersecurity risks associated with their digital assets.

Sustainability: As organizations strive for more sustainable practices, digital technologies can play a crucial role. The ISO55000 standards provide a framework for managing assets in a way that balances cost, performance, and risk with sustainability goals.

In conclusion, as asset management evolves with the digital age, the ISO55000 standards will continue to provide a robust and adaptable framework that can accommodate new technologies and practices. This will help organizations manage their assets effectively, driving continuous improvement and sustainable performance.

VII. Integrating Digitalization, Digital Twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000

The convergence of these technologies and standards presents a new era of industrial asset management. By integrating these elements, organizations can optimize their asset lifecycle, enhance their resilience, and achieve operational excellence.

The integration, utilization, and implementation of digitalization, digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000 involve strategic planning and execution. (Angelopoulos and Mourtzis 2022) Here's an explanation of how this can be achieved:

Integration: The integration of these technologies and standards requires an understanding of how they complement and enhance each other. (Sun and Frick 1999)

- *Digitalization* is the underlying fabric of this integration, as it enables the transition of manual or analog processes to digital ones, leveraging the power of data and connectivity to enhance efficiency and effectiveness.
- *Digital Twins* offer the capability to replicate physical assets in a digital environment. This forms an integral part of the digitalization process, utilizing IoT data to create a real-time digital mirror of the physical asset.
- *Maintenance 5.0 / Quality 5.0* leverages AI and machine learning, underpinned by digitalization, to predict and proactively address maintenance needs and quality issues. This increases reliability, reduces downtime, and improves the overall quality of products or services.
- *Industry 5.0* underscores the collaboration between humans and intelligent machines, ensuring that the benefits of digitalization, digital twins, and Maintenance/Quality 5.0 are harnessed optimally, with human intuition, creativity, and decision-making at the core.

- *ISO55000* standardizes the approach to asset management, ensuring that the integration of these technologies and standards happens in a consistent, transparent, and accountable manner.

Utilization: After integration, it's crucial to ensure that these technologies and standards are utilized optimally.

- Leverage digitalization to drive operational efficiency, real-time monitoring, and data-driven decision-making.
- Utilize digital twins for predictive maintenance, process optimization, and efficient asset lifecycle management.
- Apply Maintenance 5.0 / Quality 5.0 principles to reduce downtime, improve quality, and boost customer satisfaction.
- Use Industry 5.0 principles to enhance human-machine collaboration, leveraging the power of AI and machine learning while capitalizing on human creativity and problem-solving skills.
- Use ISO55000 to ensure that asset management processes are standardized, transparent, accountable, and continuously improved.

Implementation: Finally, organizations must ensure effective implementation of these technologies and standards.

- Start with a well-defined strategy and roadmap, outlining how each technology and standard will be integrated and utilized.
- Ensure that necessary infrastructure (hardware, software, and network) is in place and that data security and privacy considerations are addressed.
- Prioritize training for employees to equip them with the necessary skills and knowledge.
- Roll out the technologies and standards incrementally, starting with pilot projects before scaling up.
- Continually monitor and measure the effectiveness of these technologies and standards, making adjustments as needed to optimize their benefits.

By integrating, utilizing, and implementing these technologies and standards, organizations can usher in a new era of industrial asset management. This approach can significantly optimize the asset lifecycle, enhance operational resilience, and drive operational excellence.

VIII. Conclusion

The future of industrial asset management is indeed exciting, marked by an impending revolution powered by cutting-edge technologies and advanced standards. The amalgamation of digitalization, digital twins, Maintenance 5.0 / Quality 5.0, Industry 5.0, and ISO55000 is poised to redefine the way assets are managed and maintained.

Digitalization forms the backbone of this revolution, fostering an environment where vast amounts of data can be harnessed in real-time to make informed decisions. With the Internet of Things (IoT) driving connectivity, each asset becomes a source of critical data that can be used to optimize performance and longevity.

Digital twins significantly augment this digital landscape, creating a virtual representation of physical assets that enables real-time monitoring, predictive maintenance, and sophisticated simulations. By mirroring the physical world in a digital context, businesses can preemptively address potential issues, thereby reducing downtime and improving productivity.

Maintenance 5.0 and Quality 5.0 bring a transformative shift towards proactive and predictive approaches in asset management. Powered by artificial intelligence and machine learning, these methodologies equip organizations to predict potential failures, optimize maintenance schedules, and enhance overall quality control processes. The integration of human factors in these technological advancements ensures that the inherent creativity, intuition, and problem-solving abilities of human personnel are not neglected, but rather fused with advanced systems for better outcomes.

Industry 5.0 emphasizes the collaboration between humans and smart machines, bringing the best of both worlds together. The synergy between human intelligence and machine precision can lead to unprecedented levels of efficiency, flexibility, and innovative problem-solving in asset management.

Lastly, ISO55000 provides a structured, standardized framework for effective asset management. It promotes consistency, transparency, and accountability, ensuring that the digital transformation in asset management aligns with recognized best practices and continuous improvement.

As organizations embrace these technologies and standards, they not only navigate the challenges of the digital era but also leverage them as opportunities for growth and innovation. Asset management's future will likely be characterized by enhanced operational efficiency, improved asset lifespan, cost-effectiveness, and sustainable performance. Companies that proactively adopt these practices stand to gain significant competitive advantage, emerging as leaders in industrial innovation and setting new benchmarks for asset management in the digital age.

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References

[1]. Angelopoulos J, Mourtzis D. An Intelligent Product Service System for Adaptive Maintenance of Engineered-to-Order Manufacturing Equipment Assisted by Augmented Reality. *Applied Sciences*. 2022; 12(11):5349. https://doi.org/10.3390/app12115349

[2]. Araujo, T., Helberger, N., Kruikemeier, S., & De Vreese, C. H. (2020). In AI we trust? Perceptions about automated decision-making by artificial intelligence. *AI & society*, *35*, 611-623.

[3]. Chen Y, Ma X, Wei F, Yang L, Qiu Q. Dynamic Scheduling of Intelligent Group Maintenance Planning under Usage Availability Constraint. *Mathematics*. 2022; 10(15):2730. https://doi.org/10.3390/math10152730

[4]. Chen X, Eder MA, Shihavuddin A, Zheng D. A Human-Cyber-Physical System toward Intelligent Wind Turbine Operation and Maintenance. *Sustainability*. 2021; 13(2):561. https://doi.org/10.3390/su13020561

[5]. CIAM 2023: Cluster for Industrial Asset Management, http://CIAM.uis.no

[6]. Frick, J. and Grudowski, P., 2023. Quality 5.0: A Paradigm Shift Towards Proactive Quality Control in Industry 5.0, DOI: https://doi.org/10.5430/ijba.v14n2p51, International Journal of Business Administration, ISSN 1923-4007(Print) ISSN 1923-4015(Online)

[7]. Gulewicz,M. (2022). Digital twin technology — awareness, implementation problems and benefits. Engineering Management in Production and Services,14(1) 63-77. https://doi.org/10.2478/emj-2022-0006

[8]. Jiang Z., Hsu C. and Zhu Y., 2022 "Ditto: Building Digital Twins of Articulated Objects from Interaction," *2022 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, New Orleans, LA, USA, 2022, pp. 5606-5616, doi: 10.1109/CVPR52688.2022.00553.

[9]. Kumar, M., Shenbagaraman, V. M., Shaw, R. N., & Ghosh, A. (2021). Predictive data analysis for energy management of a smart factory leading to sustainability. In *Innovations in Electrical and Electronic Engineering: Proceedings of ICEEE 2020* (pp. 765-773). Springer Singapore.

[10]. Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D. and Wang, L., 2022. Industry 5.0: Prospect and retrospect. *Journal of Manufacturing Systems*, *65*, pp.279-295.

[11]. Nordal, H., and El-Thalji, I. (2021). Modeling a predictive maintenance management architecture to meet industry 4.0 requirements: A case study. *Systems Engineering*, *24*(1), 34-50.

[12]. Parra, C., González-Prida, V., Candón, E., De la Fuente, A., Martínez-Galán, P., and Crespo, A. (2021). Integration of asset management standard ISO55000 with a maintenance management model. In *14th WCEAM Proceedings* (pp. 189-200). Springer International Publishing.

[13]. Raju, H. S., and Shenoy, S. (2016, December). Real-time remote monitoring and operation of industrial devices using IoT and cloud. In *2016 2nd International Conference on Contemporary Computing and Informatics (IC3I)* (pp. 324-329). IEEE.

[14]. Sun H. and Frick J. (1999) A shift from CIM to CHIM, International Journal of Computer Integrated Manufacturing, 12:5, 461-469, DOI: 10.1080/095119299130191

[15]. Sun, H., Kee Hui, I., Tam, A. Y., & Frick, J. (2000). Employee involvement and quality management. *The TQM Magazine*, *12*(5), 350-354.

[16]. Woodhouse, J. (2014). Briefing: Standards in asset management: PAS 55 to ISO 55000. *Infrastructure Asset Management*, *1*(3), 57-59.