Overview and Impact of Maintenance Process in 4th Industrial Revolution

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Abstract: This study offers a thorough analysis of maintenance procedures and how they affect society in the setting of the fourth industrial revolution which is defined by the use of digital technology across a range of sectors, has altered maintenance procedures and brought fresh ideas for enhancing asset management. The maintenance process, which is essential to guaranteeing the smooth operation of modern industrial systems, is an important facet of this transformation. For a better understanding of the process of maintenance in the Fourth Industrial Revolution and its tremendous effects on many industries, productivity together with operational effectiveness, this article first gave a general review of it. Organizations may use the power of digital technology to optimize maintenance procedures, reduce downtime, and increase asset dependability by taking a pro-active and data-driven strategy. The paper also analyse the development of maintenance procedures, considers how new technologies might improve maintenance effectiveness, and explains how these developments affect industrial productivity, dependability, and sustainability. In fourth industrial revolution context, difficulties alongside potential future advances in maintenance procedures are also covered.

1. Introduction

The Fourth Industrial Revolution, which merges digital technology with traditional industrial processes, has evolved as a great force in the consistently dynamic environment of technological breakthroughs. With the advent of technologies like artificial intelligence (AI), the Internet of Things (IoT), big data analytics, in addition to robotics, maintenance—traditionally seen as a reactive and expensive activity—has experienced substantial changes [1].
Additionally, the incorporation of intelligent systems enables condition-based and predictive maintenance, modernizing current maintenance procedures [2].

Beyond increased operational effectiveness, the Fourth Industrial Revolution's maintenance process has a significant influence. It might lead to considerable cost reductions, lessen the impact on the environment, and improve worker safety. Real-time equipment health monitoring, massive data collection, and the use of advanced analytics enable businesses to spend resources wisely, prioritize maintenance activities, and make educated decisions. As a result, there is improved asset utilization, longer machine life, and less unscheduled downtime. The Fourth Industrial Revolution presents problems for maintaining processes in addition to its enormous advantages. These include concerns with data security, the requirement for worker upskilling and reskilling to accommodate new technology, and the incorporation of antiquated systems with cutting-edge digital solutions. Harnessing the complete benefits of the Fourth Industrial Revolution in maintenance procedures involves cooperation between a variety of stakeholders, including maintenance professionals, technology providers, and organizational executives.

Having a thorough knowledge and understanding concerning these changes and their speed can it be guaranteed that all get and benefit the advancement of knowledge and technology [3].

1.1 Origin of Industrial Revolution

The first industrial revolution began with steam engine invention in 1760 which allowed the transition from farming to novel production techniques. In 1900, the second industrial revolution began with the internal combustion engine invention which resulted in speedy industrialization making use of electricity with oil for mass production power. In 1960, the third industrial revolution began and was identified with the integration of information technology and electronics for production automation. The fourth industrial revolution is characterized by 3D (three-dimensional) printing and computer-generated product design, that are capable of creating solid objects by constructing consecutive layers of materials. Compared with past industrial revolutions, the Fourth is emerging exponentially rather than linearly. However, it is interrupting almost every industry within every country. And the expanse of these changes signifies the complete change of the whole systems of production, governance as well as management.” [4]. Similarities exist between four industrial revolutions and the five ages of civilization: the industrial, the emerging age of wisdom, the hunter and gather age, the agricultural age including the information worker age. The opportunities of the fourth industrial revolution may be deduced through the features of these five ages of civilization as depicted by Steven Covey in his book, 8th Habit. [5] First, the productivity of each subsequent age increases 50 (fifty) times over the preceding age. Machines and capital were the major holdings and primary drivers of the industrial age. People were important but also replaceable. The issue/challenge now in the fourth industrial age is how companies can motivate their knowledgeable workers to bring forth their human potential [6].

There is argument by front line researchers that the fourth industrial revolution will frame the future through its effects on business and government. Though, the opportunities associated with fourth industrial revolution can be predicted: less obstacles between inventors and markets, more active role for the AI, robotics, internet as well as assimilation of different domains and techniques. There is prediction that the fourth industrial revolution will probably lower barriers between inventors and markets as a result of new technologies like 3D printing for prototyping [7]. Novel technologies, such as this three-dimensional (3D) printing, gives
room for entrepreneurs with new ideas to set up small companies with less start-up costs. Artificial systems that solve compound problems rationally, are threats to numerous job employments, although they also offer new channels to economy advancement. Half of the total existing work activities would undergo automation by technologies existing presently, this will enable companies to save dollars running into billions in addition to the creation of new jobs. [8]. Innovative technologies will incorporate varying technical and scientific disciplines. Key forces will combine in a merger of technologies that is shrouding the lines between digital, biological and physical spheres [9]. Robots are technically automated motorized tools. They play music, cook meals, record shows. [10]. Robots have the ability to enhance the quality of lives at work, home including several other places. Robots that are customized will necessitate the creation of new jobs, enhance the quality of the jobs in existence. Normally, the Internet of Things is likely to offer advanced devices connectivity, systems in addition to services that are beyond machine-to-machine (M2M) communications and extends over different protocols, applications and domains. [11]. The first ever data was transmitted over the Internet and connected two (2) main frame computers in the year 1969. Presently, the Internet is linking personal computers with mobile devices. The number of computers on the Internet had outnumbered the number of people on the planet earth by 2010." [12]. Challenges of the Fourth Industrial Revolution “We are standing on the brink of a technological revolution that will basically change how we relate to one another, live and work. The transformation and the response it will generate must be integrated and comprehensive, involving the stakeholders of the global polity including both private and public spheres to civil as well as academic society.” [13] [14]. The emergence of global industries in the fourth industrial revolution is scary and also exciting. The fourth industrial revolution will enhance the quality of life for a lot of people globally. [15] Consumers are also expected to benefit the most from the fourth industrial revolution. The cost of communication and Transportation will reduce, there will be more effective logistics and GSC (global supply chains) and in addition diminished cost of trade, all of these will open new markets and be enabling tools for economic advancement. [16]

1.2 The fourth Industrial Revolution Transformation

The fourth industrial revolution has transformed many sectors and brought about substantial changes in the maintenance process. It is defined by the integration of cutting-edge technology Nevertheless, despite the potential advantages brought about by these developments, a thorough grasp of the entire picture and impact of the maintenance process in the fourth industrial revolution is lacking [17].

The issue is paucity of information and study on the impact of the fourth industrial revolution on maintenance practices, particularly usage of automated maintenance processes, condition monitoring systems, and predictive maintenance tactics. Furthermore, it is yet unknown how these changes will affect the productivity, effectiveness, and dependability of maintenance efforts.

Explore the key features and characteristics of the maintenance process in the fourth industrial revolution. Analyze the consolidation of advanced technologies, like AI, IoT, robotics and big data analysis in the maintenance process [18].

Investigate the obstacles and opportunities involved in adopting maintenance process advancements in the fourth industrial revolution. Identify the possible barriers and hurdles in adopting and implementing advanced maintenance processes. Explore the opportunities and benefits that arise from leveraging cutting-edge technologies in maintenance practices [19].
2 Maintenance Processes: An Evolutionary Perspective

Maintenance processes have played a crucial role in ensuring the smooth operation and longevity of industrial assets throughout history. However, with the advent of the fourth industrial revolution, described by the adoption of digital technologies into different sectors/industries, maintenance processes have undergone a significant transformation. This evolution birthed novel opportunities with challenges, impacting the overall efficiency, productivity, and competitiveness of organizations. This paper will provide an overview of maintenance processes from an evolutionary perspective, focusing on their importance and impact in the fourth industrial revolution context [20].

2.1 Impact of Maintenance Process in the Fourth Industrial Revolution

The fourth industrial revolution, has had a profound impact on the maintenance process. Here are some key aspects: Data-Driven Decision Making: With its emergence of industrial IoT (Internet of Things), maintenance processes now generate vast amounts of data from sensors, connected devices, and equipment. Analyzing this data using advanced analytics techniques enables organizations to make data-driven decisions regarding maintenance activities, optimizing maintenance schedules, and improving overall equipment effectiveness. Condition Monitoring and Real-Time Insights: The fourth industrial revolution enables real-time monitoring of equipment condition and performance. Sensors and connected devices provide continuous data streams, allowing maintenance teams to detect anomalies, identify potential failures, and take proactive actions to prevent equipment breakdowns. Real-time insights improve maintenance planning and minimize downtime. Predictive Analytics and Machine Learning: Advanced analytics and machine learning algorithms help in predicting equipment failures by analyzing historical and real-time data. Predictive maintenance models can identify patterns, correlations, and early warning signs of failure, enabling organizations to schedule maintenance activities during planned downtime, optimize resource allocation [22].

2.2 Shift towards Proactive Maintenance

A considerable transition from preventive and reactive maintenance methods to proactive maintenance techniques has been triggered by the fourth industrial revolution. Utilizing cutting-edge technologies and data analytics, proactive maintenance is focused on anticipating and avoiding errors before they happen. This change is being made in order to reduce equipment downtime, reduce maintenance expenses, and boost overall equipment performance and dependability.

The adoption of proactive maintenance during the fourth industrial revolution has been influenced by a number of variables, including: advanced data analytics: The availability of large volumes of data and the advancements in data analytics techniques have enabled organizations to gain deeper insights into equipment performance. By leveraging predictive analytics algorithms, organizations can analyse historical and real-time data to pinpoint patterns, anomalies, together with early warning signs of failure, enabling proactive maintenance interventions. IoT (Internet of Things) and Sensor Technology: The propagation of Internet of Things devices and sensor technology have facilitated collection of real-time data on equipment condition, performance, and usage. These sensors provide continuous streams of data, allowing organizations to monitor equipment health in real-time.
and detect any deviations from normal operating conditions. This real-time data is crucial for implementing proactive maintenance strategies. Artificial Intelligence (AI) and Machine Learning (ML): By allowing predictive capabilities, AI and ML technologies have changed the maintenance process. Machine learning algorithms are highly accurate in analyzing data patterns, finding connections, and forecasting equipment breakdowns. Organizations can increase the lifespan of vital assets and improve maintenance plans by utilizing AI and ML [23].

2.3 Impact of Proactive Maintenance

In the fourth industrial revolution, proactive maintenance has numerous significant effects, such as: Reduced Downtime: By doing proactive maintenance, businesses can deal with possible issues before they arise. Predictive analytics and real-time monitoring enable maintenance personnel to see problems early and take proactive action to minimize unscheduled downtime and increase equipment availability. Cost reduction: Proactive maintenance solutions reduce wasteful maintenance procedures and allocate maintenance resources more efficiently. Organizations can lower maintenance expenses associated with reactive or irrational preventive maintenance by concentrating on preventative actions based on data-driven insights. Improved Equipment Reliability: Proactive maintenance improves the performance and reliability of equipment by anticipating future issues and fixing them before they occur. As a result, there is an improvement in product quality, a rise in manufacturing output, and a rise in client happiness [24].

2.4 Integration of Data and Analytics

The fourth industrial revolution has produced a massive influx of data from various sources within the maintenance process. The integration of data and analytics play a crucial part in harnessing the ability of the data to optimize maintenance strategies and enhance equipment reliability, these include: data collection, data management and storage, data analytics, predictive maintenance development, Prescriptive maintenance, data integration with analytics enable prescriptive maintenance in addition to predictive maintenance. Beyond only forecasting failures, prescriptive maintenance makes suggestions for the best maintenance procedures to follow. Prescriptive maintenance aids maintenance teams in decision-making and resource optimization by taking into account elements including equipment criticality, financial limits, and operational priorities [25]

2.5 Maintenance in the Fourth Industrial Revolution

The fourth industrial revolution, encompasses the consolidation they of digital technologies, automation, and data-driven processes into industrial operations. Maintenance plays a crucial role in this revolution by harnessing advanced technologies to optimize maintenance activities and improve overall equipment reliability and performance. They are: Digitalization and Connectivity, Maintenance Prediction and Prescription, AR, VR, AI and ML, Data-Driven Decision Making. In the fourth industrial revolution, choices on maintenance are more frequently informed by data. Organizations may obtain a comprehensive understanding of the performance, health, and upkeep needs of their assets by utilizing advanced analytics and visualization technologies. This enables maintenance teams to make knowledgeable judgments, efficiently allocate resources, and maximize maintenance tactics [26].
2.6 Impact of Maintenance Processes in the Fourth Industrial Revolution

The fourth industrial revolution, identified by the assimilation of digital technologies, automation, and data-driven processes, has revolutionized various aspects of industrial operations. One crucial area significantly affected by this revolution is maintenance processes. With the advent of advanced technologies and connectivity, maintenance has undergone a transformation, enabling organizations to optimize asset performance, reduce downtime, and enhance overall operational efficiency [27]. This overview explores the impact of maintenance processes in the fourth industrial revolution, highlighting the key advancements and their implications.

In the fourth industrial revolution context, maintenance processes have evolved from traditional reactive or preventive approaches to more proactive and data-driven strategies. The integration of digital technologies like the Industrial IoT, AI, machine learning, and predictive analytics has provided new avenues to enhance maintenance effectiveness and efficiency. By harnessing real-time data, organizations can now monitor equipment condition, predict failures, and make data-driven decisions to schedule maintenance activities at the optimal time [28].

Impact of these advancements in maintenance processes has been profound. By adopting predictive and prescriptive maintenance approaches, organizations can move away from costly and unplanned downtime caused by equipment failures. Instead, they can proactively identify potential issues, reduce cost of maintenance, and optimize availability with reliability of their assets. Furthermore, utilization of AR and VR technologies has enabled maintenance technicians to access digital overlays and virtual simulations, facilitating troubleshooting, remote assistance, and training [29].

This paper will delve into the specific advancements and their impact on maintenance processes in the fourth industrial revolution. Also, it will explore topics such as the digitalization and connectivity of assets, the implementation of predictive and prescriptive maintenance strategies, the utilization of AI and machine learning algorithms, and the role of data-driven decision making in optimizing maintenance activities [30].

2.7 Enhanced Predictability and Reduced Downtime

Different facets of industrial operations have undergone radical change as a result of the fourth industrial revolution, which is defined by digital technology integration, automation with data-driven processes. The maintenance procedure is one crucial area that has undergone tremendous change. Maintenance procedures have changed from reactive and time-based techniques to proactive and predictive tactics with the emergence of modern technology and analytics capabilities. With better predictability and less downtime as a result of this transition, equipment dependability, operational effectiveness, and cost optimization have all significantly increased [31].

In the fourth industrial revolution, organizations are leveraging the power of real-time data, machine learning algorithms, and connectivity to enable predictive maintenance, which is a paradigm shift from traditional reactive and preventive approaches. Predictive maintenance leverages data analytics and machine learning techniques to forecast equipment failures, allowing maintenance teams to proactively address issues before they result in unplanned
downtime. By continuously monitoring equipment condition, analyzing data patterns, and identifying early warning signs, organizations can optimize maintenance schedules, improve resource allocation, and minimize production interruptions.

The Industrial Internet of Things IoT-enabled condition monitoring's broad use is one of the main reasons promoting improved predictability and decreased downtime. Organizations may gather real-time data on numerous aspects including pressure, vibration temperature and energy usage by deploying sensors, linked devices, and smart equipment. Maintenance personnel may find abnormalities, follow performance variations, and pinpoint probable failure mechanisms thanks to this continual monitoring. Utilizing this plethora of data gives businesses insightful knowledge about the condition of their equipment, allowing them to take preventive steps and start maintenance procedures at the right moments to avoid expensive breakdowns and save downtime [32].

3.0 Sustainable Asset Management

In the fourth industrial revolution, consolidation of digital technologies, data-driven processes and automation has revolutionized asset management practices. Sustainable asset management has emerged as a key concept, focusing not only on optimizing the maintenance process but also on ensuring the long-term sustainability and resilience of assets. This approach acknowledges the importance of minimizing environmental impact, maximizing resource efficiency, and promoting social responsibility throughout the asset lifecycle. Sustainable asset management aims to strike a balance between operational efficiency, environmental stewardship, and social well-being [33], [34].

3.1 The Impact of the Fourth Industrial Revolution on Sustainable Asset Management

Enhanced Data Collection and Analysis: The fourth industrial revolution has made it feasible to gather enormous volumes of data from digital systems, networked devices, and sensors during the course of an asset's existence. This data-driven methodology offers insightful data on the performance, condition, and upkeep needs of assets. Organizations may examine this data to improve asset maintenance schedules, find abnormalities, and forecast failures by utilizing sophisticated analytics and machine learning approaches. This data-centric strategy improves the capacity to make decisions and makes proactive maintenance techniques possible, which results in increased asset dependability and less environmental impact [35].

Awareness of the Economy: The fourth industrial revolution has raised awareness of the circular economy idea, which emphasizes minimizing waste and optimizing resource efficiency. By taking into account the full asset lifespan, from design to disposal, sustainable asset management employs circular economy concepts and manufacturing to end-of-life disposal or recycling. Through strategies such as remanufacturing, refurbishment, and recycling, organizations can extend the useful life of assets, reduce material consumption, and minimize waste generation. This approach contributes to a more sustainable and resource-efficient asset management process [36].

3.2 Challenges as well as Opportunities in Maintenance Processes
The fourth industrial revolution has revolutionized maintenance processes by introducing advanced technologies and data-driven approaches. While it presents numerous opportunities for improving maintenance effectiveness, several challenges must be addressed. Here are key challenges and opportunities: Data Management and Integration, Skills and staff Readiness, Cybersecurity and Data Privacy, Interoperability and Standardization and Asset Complexity and Monitoring. The fourth industrial revolution has introduced highly complex and sophisticated assets with intricate components and subsystems. Monitoring and maintaining such assets require advanced techniques and specialized expertise. Organizations must invest in technologies like advanced sensors, condition monitoring systems, and artificial intelligence algorithms to effectively monitor, diagnose, and maintain complex assets, thereby maximizing their lifecycle and performance [37], [38].

3.3 Future Developments and Trends in Maintenance Processes

The fourth industrial revolution continues to drive advancements in maintenance processes, paving the way for future developments and trends that can further optimize equipment reliability, reduce downtime, and enhance operational efficiency. Here are some key areas of focus: AI and ML, Digital Twin Technology, Edge Computing and Real-Time Analytics, Advanced Robotics and Automation, PHM (Prognostics and Health Management) which involve the use of data-driven techniques to examine the condition of equipment so as to predict its remaining useful life. PHM leverages data analytics, AI, and machine learning algorithms to provide insights into equipment performance, reliability, and maintenance requirements. By predicting equipment failures and determining optimal maintenance actions, PHM can minimize downtime, extend asset lifecycles, and optimize maintenance costs [39], [40], [41].

3.4 Human-Machine Collaboration

The fourth industrial revolution has brought about an important transformation in the maintenance process by fostering human-machine collaboration. This collaboration involves the integration of human expertise and skills with advanced technologies and automation systems. By combining the strengths of humans and machines, organizations can enhance maintenance efficiency, improve decision-making, and optimize overall equipment reliability. The key aspects include: Augmented Intelligence which refers to the collaboration between humans and intelligent technologies, like data analytics, AI and ML. In maintenance, humans contribute their domain knowledge, experience, and intuition, while intelligent systems provide data-driven insights and decision support. This collaboration enables maintenance teams to make informed decisions, prioritize tasks, and allocate resources effectively, leading to optimized maintenance processes and reduced downtime [42]. Data-Driven Insights: The fourth industrial revolution has enabled the gathering of vast amounts of data from sensors, equipment and connected devices. By leveraging advanced analytics and machine learning algorithms, maintenance teams can extract valuable insights from this data. Humans play a crucial role in interpreting and contextualizing the insights generated by intelligent systems. They can combine data-driven insights with their domain knowledge to identify patterns, anomalies, and root causes of equipment failures. This collaboration facilitates more accurate diagnosis, prognosis, and decision-making, ultimately reducing downtime and enhancing maintenance effectiveness [43]. Remote Monitoring and Assistance, Collaborative Robotics as well as Continuous Learning and Skill Development: The fourth industrial revolution emphasizes the importance of continuous learning together with skill development for both humans and machines. As technology evolves, maintenance
teams need to acquire new skills and adapt to changing roles. Training programs and upskilling initiatives enable humans to develop competencies in areas such as data analysis, AI systems utilization, and collaborative problem-solving. This collaboration between humans and machines ensures that maintenance teams can effectively leverage advanced technologies and stay at the forefront of industry developments [44].

4 CONCLUSION

In conclusion, the Fourth Industrial Revolution has revolutionized the maintenance process, turning it from a reactive practice to a proactive and data-driven approach. By taking advantages of technologies IoT, AI, with robotics, organizations can optimize maintenance strategies, enhance asset reliability, and drive enhanced operational efficiency, improved reliability, and reduced downtime in industrial maintenance activities. Key aspects of the maintenance process in the fourth industrial revolution include: Predictive maintenance utilizes real-time and historical data to anticipate equipment problems. This technology was made possible by the combination of sensors, data analytics, and machine learning. Organizations may avoid unplanned downtime, improve maintenance schedules, and lower repair costs by taking a proactive approach. Condition Monitoring and the Industrial IoT: By deploying sensors and linked devices, the Industrial Internet of Things (IoT) has made it possible to continuously monitor the conditions of equipment. Real-time data gathering enables proactive maintenance techniques, enabling early detection of abnormalities and departures from typical operating conditions, resulting in prompt interventions and less downtime. Data-Driven Decision Making: The fourth industrial revolution has enabled data-driven decision making in maintenance processes.

The maintenance process in the fourth industrial revolution has evolved from reactive and time-based approaches to proactive and data-driven strategies. This transformation has resulted in enhanced predictability, reduced downtime, improved equipment reliability, and optimized maintenance costs, ultimately contributing to more efficient and productive industrial operations [45], [46].

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