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Big data management, digital maintenance services and data analytics on intelligent operation: Basis for data management efficiency framework

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Abstract

Digital technology gradual maturity and widespread recognition of its application value has been widely applied in fields such as industrial development, public governance, and livelihood services, greatly changing people's lifestyles, triggering profound changes in multiple industries, and promoting the development of multiple industries and various aspects of society. The study aimed to analyze the relationships among big data management, digital maintenance services and data analytics as basis for developing data management efficiency framework. The paper utilized a descriptive method of research and self-made questionnaire as a data collection tool, with 406 employees from the Chinese manufacturing Industry participants. Non-parametric testing using Spearman's rho correlation coefficient is employed to test significant relationships. All analyses were conducted using SPSS version 28. The study revealed the respondents agreed that Big Data Management practices of wind farms with big data assisted decision making and maintenance management was commonly observed. Team member communication was highlighted by the respondents as they generally agreed on the assessment of digital maintenance services. Data analytics on intelligent operation was agreed by the respondents and noted the maintenance of data equipment with strong agreement. Big data assisted decision making was found to have high significance on team member communication and task evaluation and significant relationship with team member cooperation. Big Data Operation has high significant relationship with team member cooperation and task evaluation and Maintenance management has high significant relationship with team member communication. It was found that Big data assisted decision making and maintenance management to have high significant relationship with data analytics on intelligent operation. meanwhile, maintenance data equipment, and big data operation and maintenance decision has significant relationship with team member communication and task evaluation respectively. A Data Management Efficiency Framework was developed for wind power industry.

Keywords: data management, digital maintenance services, data analytics, intelligent operations, wind farms

Big data management, digital maintenance services and data analytics on intelligent operation: Basis for data management efficiency framework

1. Introduction

In the context of modern science and technology, new information technology and intelligent control protection technology are being actively promoted, and big data and digital twin construction are being actively promoted. Digital technology gradual maturity and widespread recognition of its application value has been widely applied in fields such as industrial development, public governance, and livelihood services, greatly changing people's lifestyles, triggering profound changes in multiple industries, and promoting the development of multiple industries and various aspects of society. The construction of big data and digital twins should draw inspiration from the thinking of the Internet, use data commercialization and comprehensive energy services as means, prioritize users and prioritize data, support the digital transformation of power grid enterprises, and promote the efficient development of the comprehensive energy industry.

The Chinese government attaches great importance to the role of science and technology in promoting the Chinese economy, especially in the areas of digitization and DIGITAL Maintenance Services. In 2015, the Chinese government issued important documents such as the "Action Plan for Promoting the Development of Big Data" and the "13th Five Year Plan Proposal" at the national level, marking the official elevation of the big data strategy to the national strategic level. The document proposes to attach importance to basic data and treat it as a national strategic resource. Furthermore, in 2016 the Big Data Industry Development Plan was issued by the Ministry of Industry and Information Technology, that pointed out the problem of insufficient application of big data in social governance and public services that needs to be strengthened. The construction of big data and digital twins is based on the full state information perception of grassroots equipment. It comprehensively collects and monitors basic data on the operation, status, and security of all equipment, facilities, resources, and other aspects. Through edge processing, it achieves on-site data analysis and improves the response sensitivity of equipment, management, energy, and other links. In recent years, with the continuous promotion and deepening of digital twin construction and its application, the amount of data in various links and businesses within N Wind Power Company has increased sharply compared to before. The types of data are becoming more diverse, the types of data are becoming more diverse, and the speed of data production is faster. The increase in the proportion of garbage data has led to a decrease in data value density, low data value, and low utilization rate. The government pointed out also that various institutions and enterprises, including the government, have not done enough in data sharing and integration, and need to put in effort in big data application and data integration to support innovative development and social governance of enterprises.

This situation and observation lead the researcher to conduct this study. As a management student, to understand how to effectively carry out data analytics work and maximize the development and utilization of these massive data. Also, as employee of N Wind Power Company, to help how to plan and implement data governance work in the process of gradual construction and achievement implementation in the digital twin and cooperate with the implementation of various strategies of the company, is a topic worth studying.

Objectives of the Study - The study aimed to analyze the relationships among big data management, digital maintenance services and data analytics as basis for developing data management efficiency framework. More specifically, it aimed to identify big data management practices as to big data assisted decision, big data operation maintenance management; assess digital maintenance services in terms of team member communication, team member cooperation and task evaluation; and evaluate data analytics on intelligent operation as to cognition of data value, maintenance of data equipment and big data operation and maintenance decision. It also tested the relationships among big data management, digital maintenance services and data analytics and proposed data management efficiency framework.

2. Methods

Research Design - This study used a descriptive research design to systematically record, analyze, and interpret the current status of big data management, digital maintenance service and data analytics on intelligent operation. It also explored the relationship among these variables. A descriptive design offers a clear illustration of the present situation in any circumstance. This is very important in looking at the current practices, issues, and prospects in the management of big data, digital-maintenance services, and analytics.

Participants of the Study - The participants of this study primarily included 406 employees from five wind power companies in China. They possessed extensive practical experience in big data management, digital maintenance services and data analytics. Wind energy company employees are very much exposed to the possible issues and prospects that come with big data management, digital maintenance service, and data science. They can therefore share useful information regarding the usage of such technologies in their field. As operational, maintenance and energy generation aspects of the business are characterized by a huge amount of data and information, the employees in organizations that install wind energy plants, are in a position to give knowledgeable opinions on the use of big data and analytics.

Data Gathering Instruments - In studies focusing on big data management, digital maintenance service, and data analytics on intelligent operation, self-made survey questionnaires prove helpful for data collection especially if it is designed for the purpose of the study and the study population. Researcher-designed questionnaires offered researcher the power to craft questions in accordance with the research purposes and characteristics of the target audience. This guarantees that the data obtained was useful and relevant. In addition, the researcher had total control over what is asked and how it is asked, allowing the researcher to eliminate concerns about the appropriateness of the questions. The survey questionnaire has three parts. The first part contains the indicators which assessed the big data management as to big data assisted decision making, big data operations and maintenance management. The second part described the digital maintenance service in terms of team member communication, team member cooperation and task evaluation. The third part evaluated the data analytics on intelligent operation as to cognition of data value, maintenance of data equipment and big data operation and maintenance decision. The questionnaire was pilot tested from small group of individuals in the same industry and the result is found below.

Table 1

Test of Reliability Result

Indicator	Cronbach Alpha	Remarks
Big Data Management		
Big Data Assisted Decision-making	0.855	Good
Big Data Operation	0.796	Acceptable
The Maintenance Management	0.943	Excellent
Digital Management Services		
Team Member Communication	0.778	Acceptable
Team Member Cooperation	0.771	Acceptable
Task Evaluation	0.868	Good
Data Analytics		
Cognition of Data Value	0.728	Acceptable
Maintenance of Data Equipment in the Wind Power Industry	0.859	Good
Big Data Operation and Maintenance Decisions	0.760	Acceptable

George and Malley (2003) provide the following rules of thumb ">0.90 – Excellent, >0.80 – Good, >0.7 – Acceptable, >0.60 – Questionable, >0.50 – Poor, and <0.50 – Unacceptable"

Data Gathering Procedure - First, an extensive literature review was initially conducted, focusing on identifying key issues and concepts related to the study variables and their corresponding dimensions. By carefully analyzing existing academic research, case studies, and industry reports, a list of questions concerning attitudes and behaviors of employees in Chinese manufacturing enterprises was summarized. This step ensured that our research design was closely linked to theoretical foundations while enhancing the relevance and comprehensiveness of our survey tool. Following this, based on the key issues summarized from the literature review, a detailed questionnaire was designed. The questionnaire underwent several rounds of review and revision after the content validation to ensure that the questions were clear, unbiased, and capable of effectively collecting data related to the research variables. This questionnaire was subjected to content validation with the expert in the field and subjected to reliability testing to test the coherence of the items for each construct. The data collection process involved distributing the questionnaire to selected wind power companies via email or online platforms and setting a reasonable deadline for responses. The collected questionnaire data were then organized, coded, and verified to ensure the accuracy and reliability of the data. All collected data were organized and entered a database, preparing for subsequent analysis work. This data collection process aimed to obtain high-quality data to support the accurate assessment of research hypotheses.

Ethical Considerations - In the process of cultivating company executives, only by emphasizing the improvement of information level can we fully leverage the functional advantages of executives and build a professional information management team. The comprehensive ability of executives is directly related to the management efficiency of wind power companies. To strengthen the attention of managers and improve through effective means, ultimately improving the company's information management level. The researcher considered the confidentiality of the information of the parties involved in their research. Including whether to disclose information and obtain informed consent with the consent of the parties involved. The researchers provided a letter to the employer requesting permission to participate in this study. In order to disclose the discussion situation, the individual's specific identity information is blank, and the respondent's information is highly confidential.

Data Analysis - This study assessed the performance of big data and data services by calculating the arithmetic mean, in which the weighted average algorithm is also adopted to assess the work quality while the correlation analysis and big data analysis are taken as the measures to collect data. The company's staff responded positively through a survey questionnaire. The distribution and retrieval of survey questionnaires were personally completed by researchers. Before conducting the correlation analysis, the Shapiro-Wilk test was used to check the normality of the data. The test results showed that the p-values for all variables were less than 0.05, indicating that the data set did not follow a normal distribution. Therefore, Spearman's rho was chosen as part of the non-parametric test to determine the significant relationships between variables. The data collected in this study were primarily analyzed using SPSS software version 28.

3. Results and discussion

Table 2

Summary Table on Big Data Management

Key Result Areas	Composite Mean	VI	Rank
Big Data Assisted Decision Making	3.19	Agree	1.5
Big Data Operation	3.03	Agree	3
Maintenance Management	3.19	Agree	1.5
Grand Composite Mean	3.14	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Table 2 summarizes the Big Data Management which have shown a composite mean of 3.14. The grand composite mean represents the overall average score across all key result areas related to big data management in wind farms indicating a generally positive perception of big data management practices among the employees. The effective management of data within a wind farm has many advantages, including the supporting of the respondents view on its usefulness in making decisions, operating, and maintaining such facilities. When deploying big data analytics, the effectiveness of operating a wind farm is increased, thus reducing down time, enhancing energy production and consequently leading to a reduction of operational costs and in turn the profitability growth. It is worth noting that the huge amount of data and information available to the operators of wind farms allows for more accurately and relevantly informed decision making which is likely to yield favorable results. Other possible applications of big data include helping in analyzing the components making up a wind farm and predicting where wear and tear, or damage, is most likely so that repairs can be made in advance (Guo, et al, 2022). Additionally, Wang, et al., (2021) showed that big data analytics has been applied to assess and diagnosed the condition of reactive wind farm assets thereby enhancing decision making and overall management of these assets. Thanks to big data, wind farm owners and operators gain operational efficiency, thereby reducing costs and increasing energy output that enables them to enhance their market competitiveness.

Among the indicators describing big data assisted decision making and maintenance management posted the highest weighted mean of 3.19. The findings confirm on the constructive role played by big data governance practices in the management of wind power plants, hence supporting the high ranking attributed to the big data assisted decision making and maintenance management. Wind farm operators can enhance the efficiency of their businesses and in turn the production of energy, lower expenses and gain skills from the use of big data. Guo, et al., (2022) confirmed that advanced analytics of big data can facilitate effective operational efficiency of wind farms, minimize idle time, and maximize energy generation in order to enhance cost efficiency and resultant profits. Further, according to Wang, et al., (2021) big data allows for an understanding of the performance and health of a wind farm’s assets leading to improved asset management and decision making.

The least in rank for big data management is big data operation (3.03). Organizations may face possible challenges and obstacles that could hinder the effective implementation of big data, probably explaining why big data operation was perceived to be ranked the least in the study. Development of management frameworks for integration and analysis of big data from several sources can be difficult and takes a long time. This may limit the utilization of big data for operational use in decision making. As revealed by Zhang et al. (2020), particularly in large-scale operations such as wind farms, ensuring data accuracy, reliability, and consistency can be challenging due to its complexity. Inaccurate data can impede the application of big data analytics to its fullest potential. Thus, in order to implement and harvest big data, changes within the organization are necessary especially with regards to investments in technology, training and in data governance systems. There are factors such as resistance to change or absence of resources inhibiting the use and acceptance of big data (Chen et al.,2019).

Table 3
Summary Table on Digital Maintenance Services

Key Result Areas	Composite Mean	VI	Rank
Team Member Communication	3.13	Agree	1
Team Member Cooperation	3.10	Agree	2
Task Evaluation	3.02	Agree	3
Grand Composite Mean	3.08	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

The summary table revealed the grand composite mean of 3.08 indicates that, overall, team members agree on the effectiveness of digital maintenance services across the key result areas. This positive perception underscores the importance of continuous improvement in communication, cooperation, and task evaluation to maintain high standards and achieve better outcomes in digital maintenance projects. Grant (2021) emphasizes the alignment of team efforts with organizational strategies underscores the overall need for effective communication, cooperation, and task evaluation practices. The grand composite mean reflects the general agreement on these practices, indicating a positive, though slightly needing improvement, alignment with strategic goals. By incorporating these practices, organizations can better achieve their strategic objectives and ensure successful outcomes in digital maintenance services.

The top item among the three was the Team Member Communication with 3.13 composite mean and verbally interpreted as agree. The high ranking for team member communication among the dimensions of digital maintenance services likely stems from the recognition of its critical importance in ensuring effective and efficient maintenance operations. Within a team setting, the ability to communicate effectively amongst the members is imperative to the carrying out of maintenance services, passing of information, as well as issues solving. Communication and collaboration can be supported by digital tools, which translates to enhanced efficiency and effectiveness. These platforms allow team members to utilize and transfer knowledge, share best practices and lessons learned making the workforce more knowledgeable and skillful (Al-Amoudi et al., 2023). Further, there are also digital communication tools which help to communicate much faster and more effectively thereby increasing the speed of the response rate to maintenance problems and so minimizing the duration of the breakdown (Al-Gahtani et al., 2022). However, the item task evaluation ranked third with 3.02 composite mean. Clearly defining and objectively assessing the standards for task performance in complex maintenance activities can be a difficult undertaking. This can in turn hinder the proper evaluation of digital maintenance services in terms of their efficacy. According to Huselid et al. (2018), the two major challenges associated with effective evaluation of performance with measures in place for a specific task are the lack of data and quality of the available data. In addition, the performance of maintenance activities in wind farm installations, for instance, is complex and is subject to a number of related factors, hence making it difficult to separate the effect of digital maintenance task services on the performance of a specific task (Boudreau et al.,2017).

Table 4

Summary Table on Data Analytics on Intelligent Operation

Key Result Areas	Composite Mean	VI	Rank
Cognition of Data Value	3.45	Agree	2
Maintenance of Data Equipment	3.51	Strongly Agree	1
Big Data Operation and Maintenance Decision	3.37	Agree	3
Grand Composite Mean	3.44	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Table 4 summarizes the Data Analytics on Intelligent Operation which have shown a composite mean of 3.44. This serves to demonstrate the importance of big data management in wind farm operations and substantiates the high rating ascribed to all three dimensions: cognition of data value, maintenance of data equipment, and big data operation and maintenance decision. The strong agreement among the respondents on all aspects of data analytics on intelligent operation, is probably owing to the large potential advantages that big data analytics is appreciated to bring. As revealed by Huselid et al. (2018), the application of big data analytics makes it possible to enhance the operation of wind farms, which in turn ensures the processes will be more operational and efficient. Thanks to data analysis, wind farm management is able to control the use of resources without waste, and even promote greater output. Big data can predict and mitigate risks before they cause equipment failures thereby decreasing the repairs and losses of operational hours caused by maintenance. According to Boudreau et al. (2017), big data can highlight specific factors that influence the operating costs like better scheduling of maintenance activities, or improved energy efficiency. In this way, by increasing productivity and saving on operational costs, big data is poised to raise the profit levels of wind farm owners.

Among the indicators describing Maintenance of Data Equipment posted the highest weighted mean of 3.51. The highest rating for maintenance of data equipment under data analytics on intelligent operation might be because of the great appreciation of the need for dependable and well-kept data infrastructure in promoting operations and decision making. This emphasized that wind farm operations do indeed benefit from big data analytics which has fueled the high rating for maintenance of data equipment. In analytics, ensuring accuracy, consistency, and integrity of data is critical to being able to extract any valuable information. Care and attention towards data facilities is important to uphold the quality of data and mitigate loss of data. Functioning data equipment is important for data collection, storage and processing and it minimizes the downtime during operations management (Chen et al.,2019). Further, Lee et al. (2018) disclosed that quality data is key in helping one arrive at objective and factual decisions. Reliable data equipment helps in the assurance of data fitness for use in decision-making.

Big data operation and maintenance decision (3.37) demonstrates the lowest score among the dimensions of data analytics on intelligent operation. This findings offer insight into potential challenges and obstacles that may hinder the application of big data in decision making in wind farm operations. This may, in turn, account for the low rating given to big data in operation and maintenance decisions. As shown, the data value, data equipment and big data operation have presented significant effect on the intelligent operation. Besides, Kim et al. (2024) interpreted that the maintenance of data equipment has provided solid foundations on the highly efficient, accurate operation of the intelligent industry. The findings of Chen et al. (2019) revealed that the process of integrating and analyzing large amounts of complex and diverse data from different sources can be difficult and very time consuming. This could impede the effective use of big data in making operational decisions. Overall, the data reflects a general agreement on the significance of these key result areas in intelligent operations.

Table 5
Relationship Between Big Data Management and Digital Maintenance Services

Variables	rho	p-value	Interpretation
Big Data Assisted Decision Making			
Team Member Communication	-0.283**	<.001	Highly Significant
Team Member Cooperation	0.166**	0.001	Significant
Task Evaluation	0.305**	<.001	Highly Significant
Big Data Operation			
Team Member Communication	-0.035	0.500	Not Significant
Team Member Cooperation	0.203**	<.001	Highly Significant
Task Evaluation	0.287**	<.001	Highly Significant
Maintenance Management			
Team Member Communication	0.217**	<.001	Highly Significant
Team Member Cooperation	-0.067	0.189	Not Significant
Task Evaluation	0.043	0.397	Not Significant

**. Correlation is significant at the 0.01 level

Table 5 shows the relationship between big data management and digital maintenance services. The computed rho-value of -0.283 indicates a weak indirect highly significant relationship between big data management and digital maintenance services in terms of team member communication. Also, the computed rho-values ranging from 0.166 to 0.305 indicates a very weak to weak direct relationship between big data assisted decision making and the sub variables of digital maintenance services namely team member cooperation and task evaluation. There was a statistically significant relationship between big data assisted decision making and digital maintenance services because the obtained p-values were less than 0.01. Usually, the provision of digital maintenance services entails the acquisition and retention of huge amounts of information from diverse channels such as sensors, equipment records, and climatic information. This data can then be made use of big data analytics for smart decision-making. Concurrently, the internet of things maintenance services usually permits the performance monitoring of the equipment to take place within the set time. This in turn allows one to collect data for analysis and even to foresee or diagnose problems instantly. This helps in making decisions in a quick and better way (Wu et al.,2024). Further, this is achieved by analyzing the past information and recognizing trends. Thus, large volumes of data can transform regular prescriptive methods to predictive maintenance scheduling of equipment with attendant shortfalls. This will minimize the time taken to complete scheduled tasks and hence increase the equipment availability (Zhang et al.,2023).

Meanwhile, big data operation has no significant relationship with team member communication with a computed rho-value of -0.035 and 0.500 p-value. Team member communication showed a significant negative correlation with big data-assisted decision-making and no significant impact on big data operation and maintenance management, suggesting it may not play a crucial role in these contexts. On the other hand, big data operation and team member cooperation and task evaluation has a significant relationship with computed rho-values ranging from 0.203 to 0.287 and <0.001 p-values. Furthermore, big data maintenance management and team communication has a highly significant relationship with a p-value of <0.001. Lastly, team member cooperation and task evaluation has no significant relationship with big data maintenance management as it provides a computed rho-values ranging from 0.043 to 0.217. There might be cases when the collaboration among team members and the assessment of their work performance is not significantly connected with big data maintenance management, however, this is not always the case. In most cases, team engagement and proper task assignments and assessments are necessary for the effective use of big data in maintenance activities. In certain circumstances, there are instances when the digital maintenance systems can be entirely automated. Thus, very little human interactions are required in such scenarios. In these cases, perhaps the cooperation between team members and the importance of evaluating tasks will not be so significant (Kim et al.,2023). Additionally, if organizations have well-defined processes and procedures for maintenance tasks, the need for extensive team collaboration and evaluation may be lessened (Huselid et al., 2018).

Strong correlations were found between task evaluation and big data-assisted decision-making, as well as between team member cooperation and both big data operation and maintenance management. These relationships emphasize the importance of task evaluation and cooperation in enhancing big data-related processes. While team member communication generally affects big data-assisted decision-making and maintenance management positively, its role in big data operation is negligible. These insights can guide strategic improvements in team dynamics and operational processes related to big data and maintenance management. Interestingly, the study of Al-Amoudi et al. (2023) analyzed that the large amounts of data has the potential to shed light on how well some elements performed, which allows for a more objective assessment. Evaluation of figures relating to the execution of various tasks will assist management in deciding how best to deploy resources, enhance processes, or train workers. Additionally, collaboration between the members of the team is one of the most important elements for the successful introduction and application of such technologies as big data into the maintenance management. When team members have a shared purpose and know how big data can be beneficial in the organization, there may be harmony and teamwork. (Liu et al.,2020).

Table 6
Relationship Between Big Data Management and Data Analytics on Intelligent Operations

Variables	rho	p-value	Interpretation
Big Data Assisted Decision Making			
Cognition of Data Value	-0.398**	<.001	Highly Significant
Maintenance of Data Equipment	-0.404**	<.001	Highly Significant
Big Data Operation and Maintenance Decision	-0.160**	0.002	Significant
Big Data Operation			
Cognition of Data Value	0.061	0.229	Not Significant
Maintenance of Data Equipment	-0.044	0.393	Not Significant
Big Data Operation and Maintenance Decision	-0.017	0.733	Not Significant
Maintenance Management			
Cognition of Data Value	-0.288**	< .001	Highly Significant
Maintenance of Data Equipment	-0.403**	< .001	Highly Significant
Big Data Operation and Maintenance Decision	-0.213**	< .001	Highly Significant

**. Correlation is significant at the 0.01 level

Table 6 revealed the relationship between big data management and data analytics on intelligent operations. There were highly significant relationship between big data assisted decision making and cognition of data value and maintenance of data equipment as it obtained p-values of <0.001. Strong negative correlations were found between cognition of data value, maintenance of data equipment, and big data-assisted decision-making, as well as between these factors and maintenance management. These relationships suggest that perceived data value and maintenance focus impact the effectiveness of big data utilization and maintenance management. Those companies that appreciate the importance of information will be more inclined to adopt big data analytics and use it effectively as a decision-making tool. When data value is recognized, it becomes possible to create constructive guides and Key Performance Indicators that will be useful in the process of making decisions. Companies that value the data are more likely to base their decisions on analytics, hence resulting in positive outcomes (Wu et al.,2024).

According to Zhang et al. (2023), organizations appreciate the importance of data, to adopt a data-driven approach in their decision making, and such decision making tends to produce better results. Meanwhile, there was a significant relationship between big data assisted decision making and big data operation maintenance with a p-value of 0.002. On the other hand, big data operations and data analytics has no significant relationship. In order to make sound decisions, the information being relied upon must be of high quality and accurate which is crucial for effective decision-making. With proper management of data equipment, it is possible to make sure that the data is present and ready for use, whenever required for the purposes of making decisions (Guo et al., 2022). Timely maintenance of data equipment is key to prevent downtime periods of inactivity that could disrupt and hinder an organization's decision-making process.

Sharma et al. (2022) presented that big data operation and maintenance decisions showed a significant negative correlation with big data-assisted decision-making, indicating a moderate trade-off. There were no significant correlations found between big data operation and aspects such as cognition of data value, maintenance of data equipment, and operational decisions. These insights suggest that while some aspects of big data management and maintenance practices have strong relationships with decision-making and maintenance management, others do not significantly impact these areas. Xie et al. (2016) explores the integration of big data with predictive maintenance strategies in industrial settings. It covers various aspects of how big data technologies are applied to enhance maintenance practices, including the role of data analytics in predicting equipment failures and optimizing maintenance schedules. The paper discusses how big data analytics contribute to more informed maintenance decisions by providing insights into equipment health and performance. It highlights the importance of maintaining data infrastructure to ensure accurate and reliable data collection, which is crucial for effective predictive maintenance. The review supports the observed relationships, where maintenance of data equipment has a significant impact on big data-assisted decision-making, and the effectiveness of big data operations.

Lastly, it showed a highly significant relationship between data management and data analytics with a p-values of <0.001 which has been depicted in the table 6. The strong significant relationship between data management and data analytics is primarily due to the interdependence between these two critical components of effective data utilization. Data management has a significant impact on data analytics. That is, if a management of data is properly adhered to, there will be quality data which is essential for efficient and correct data analysis. Low-quality data can give unpleasant and misleading results which will be a waste of resources. According to Chen et al. (2019), when you have organized data, it is more accessible which makes it easier for the analysts to reach out and analyze the data they want. The data governance policies and procedures ensure that the data is handled in an appropriate and ethical manner and this is very important so as to develop trust and confidence in the use of data in making decisions. Further, it is worth noting that data management techniques are also important in that they limit information or data to a certain group of people thus helping in controlling and maintaining the quality of such data. Another factor, which is important to point out, is that proper management of data consists of its integration from different sectors, which is very important for the whole process of analysis and making the necessary decisions (Lee et al.,2018).

Table 7

Relationship Between Digital Maintenance Services and Data Analytics on Intelligent Operations

Variables	rho	p-value	Interpretation
Team Member Communication			
Cognition of Data Value	0.005	0.922	Not Significant
Maintenance of Data Equipment	-0.223**	< .001	Highly Significant
Big Data Operation and Maintenance Decision	-0.012	0.820	Not Significant
Team Member Cooperation			
Cognition of Data Value	0.063	0.217	Not Significant
Maintenance of Data Equipment	0.023	0.651	Not Significant
Big Data Operation and Maintenance Decision	0.072	0.158	Not Significant
Task Evaluation			
Cognition of Data Value	0.052	0.310	Not Significant
Maintenance of Data Equipment	-0.119*	0.020	Significant
Big Data Operation and Maintenance Decision	0.152**	0.003	Significant

**. Correlation is significant at the 0.01 level/*. Correlation is significant at the 0.05 level

Table 7 presents the relationship between digital maintenance services and data analytics on intelligent operations. It showed that there was a highly significant relationship between maintenance of data equipment and team member communication with a p-value of <0.001. The condition of the data equipment guarantees the timely use of data for purposes of decision making and even sharing. This will foster effective interaction and relationship among group members. When the group members have confidence in the data's correctness and timely access, it helps in building trust and cooperative work amongst the members.

Zijun et al. (2022) has described roles of the team member communication, which has a significant negative correlation with the maintenance of data equipment, emphasizing a potential trade-off where communication priorities might impact equipment upkeep. On the other hand, there were no significant relationship between team member communication and cognition of data value and big data operation and maintenance decision. It suggest insights into how team communication can influence big data operation decisions, aligning with the findings where team member communication's impact on big data operation decisions was not significant. The study discusses challenges related to communication in big data environments and offers solutions for improving communication to enhance decision-making. Sharma et al., (2022) has interpreted the non-significant correlation by exploring both effective and ineffective communication strategies and their varying impacts on decision-making. In certain situations, as disclosed by Al-Amoudi et al. (2023) it is possible for digital maintenance systems to be extremely automated and therefore not require a great deal of human input. This may minimize the extent of teamwork, especially when it comes to issues concerning data, its value, and the subsequent actions, if any, which need to be taken. Further, well established processes and protocols for as data acquisition, data analysis and decision making may also favor less communication and teamwork among members of the team since there may be a routine in completing the activities.

The computed rho-values ranging from 0.023 to 0.072 indicate a very weak direct relationship between team member cooperation the sub variables of data analytics on intelligent operations. It shows that there was no statistically significant relationship between team member cooperation the sub variables of data analytics on intelligent operations because the obtained p-values were greater than 0.001. No significant correlations were found between team member communication, cooperation, or task evaluation and cognition of data value or big data operation and maintenance decisions, indicating that these aspects might not have a substantial impact on these variables. These insights provide an understanding of how digital maintenance services interact with data analytics in intelligent operations, emphasizing the importance of task evaluation in decision-making and the trade-offs involved in team communication and equipment maintenance. Lastly, the computed rho-values ranging from 0.052 to 0.152 indicate a very weak direct relationship between task evaluation and the sub variables of data analytics on intelligent operations namely cognition of data value and big data operation and maintenance decision while the computed -0.119 indicates a very weak direct relationship between task evaluation and maintenance of data equipment.

As revealed by the study of Kim et al. (2023) such digital maintenance systems can be very automated and require limited human involvement. This may in turn lessen the necessity for extensive team interactions and interactions especially for issues concerning task performance assessment. Additionally, clear-cut guidelines and operational steps regarding routine maintenance operations lessen the frequency of communication and teamwork as these operations tend to be more organized and repetitive in nature. In essence, according to Lee et al. (2018), in certain teams or organizations, perhaps the most important aspect is not the team work but rather the data in focus and the mechanisms of its analysis. This would decrease the relevance of teamwork communication and collaboration concerning evaluation of the performed tasks.

It shows that there was a statistically significant relationship between task evaluation and the sub variables of data analytics on intelligent operations namely maintenance of data equipment and big data operation and maintenance decision because the obtained p-values were less than 0.01/0.05. The high relationship characterizing the task evaluation and such sub-variables of data analytics on intelligent operation as maintenance of data equipment and big data operation and maintenance decision making is apparently due to the fact that these aspects are interrelated especially in the case of a wind farm system.

Johannes et al. (2021) confirmed that for task evaluation, the use of quality data is very important. Correct handling of data infrastructure ensures the precise and dependable state of data that is very critical in decision-making processes. Use of big data analytics helps in evaluation of the task making it more objective and accurate. The application of big data analytics offers a wealth of information regarding the effectiveness of maintenance work, thus enhancing the quality of choices made about resource utilization, process enhancement, and the growth of workers. Task evaluation can uncover shortcomings in the performance of the maintenance team, while big data analytics will be already existing data to address those limitations and ensure constant enhancement (Boudreau et al.,2017).

Data Management Efficiency Framework

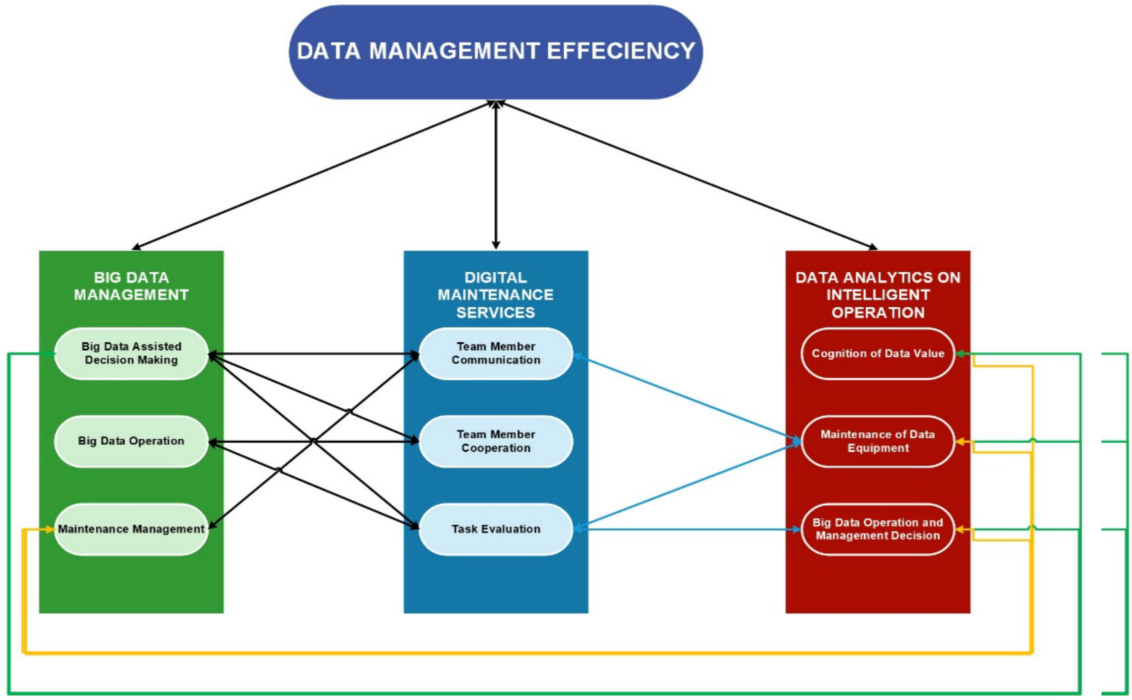

Figure 1. Data Management Efficiency Framework

The Data Management Efficiency Framework in the wind power sector takes a multidimensional approach in which big data management and digital maintenance services will be combined with intelligent operations data analytics to develop efficiency and effectiveness practices. The Data Management Efficiency Framework enables the optimal use of the available data with regard to wind farm operations, thereby enhancing efficiency and cost and performance management.

The high degree of interrelation between big data decision making, communication among team members and task evaluation as well as cooperation among team members is caused by how all these factors are connected within the operations of the wind farm. This relationship reinforces the need for such systems to be 'built' around team working and the use of management information in the operational processes of wind farms. Through the use of big-data analytics and efficient teamwork and communication, it is possible for organizations to make better decisions, become more efficient and be more effective overall. There exists a clear and positive association between big data operation and cooperation of team members and task evaluation for wind farm operations. This indicates that these factors have an impact on performance outcomes in wind farm operations. Improved big data analytics capabilities and teamwork culture designed around the data would assist in making the decisions faster and more efficiently and in turn achieve better results for the organization. Communication among the team is one of the most significant factors that guarantee maintenance management success. Proper and open communication is a very effective tool to promote efficiency, minimize wastage of time, and ultimately enhance performance of the organization.

The distinct relationship that exists between big data informed decision making, understanding the concept of data worth, decision making for the operation and upkeep of big data, and even the upkeep of data facilities is probably due to the fact that these elements are connected owing to the operations of the wind farm. All these aspects are related and complement each other. If an organization invests in data management, the data will be of higher quality and more accessible, making it easy to analyze and make decisions from that data. Such tends to improve operational efficiency and cut back on expenses, resulting in better performance.

The reasons why maintenance management practices closely related to big data operation and maintenance decision- making are the perception of the value of data maintenance, equipment, and systems, as well as wind farm systems themselves, is equally applicable to the operation of wind farms. These elements are related and support each other. While it's possible to manage maintenance without focusing on the value of data, no effective maintenance management practices can be implemented without insights facilitated by data. Data equipment must also be properly maintained in order to ensure the integrity and credibility of data generated for purposes of maintenance management decision making. Two-way communication among members in a team is critical in ensuring that every data equipment is effectively maintained. There is also the possibility of enhancing the performance and maintenance of data services in the organization by implementing transparency (Cascio, 2023).

For task evaluation or for making any decisions using big data analytics, the quality and trustworthiness of the data is important, and this is where the proper care of data equipment comes in. Focusing on all the three aspects helps the organization achieve better operating efficiency and effectiveness of wind farm management. The Data Management Efficiency Framework is a comprehensive approach that encompasses management of big data; provision of digital maintenance services; and data analysis for the improvement of wind farms. By ensuring correct information, reducing maintenance needs, defining threats and supporting leading management of the firm, the framework gives rise to several benefits (Robbins et. al.,2023). Such aspects comprise better decision making, improved maintenance and reduction of risks, better management of the assets, enhanced competitive edge and more. Finally, the framework offers a systematic approach towards the use of information, that is, the data available to improve how wind farms operations, resulting in efficiency, cost reduction and better output.

4. Conclusions and recommendations

Based on the findings of the study, the following conclusions were drawn: The respondents agreed that Big Data Management practices of wind farms with big data assisted decision making and maintenance management was commonly observed. Team member communication was highlighted by the respondents as they generally agreed on the assessment of digital maintenance services. Data analytics on intelligent operation was agreed by the respondents and noted the maintenance of data equipment with strong agreement. Big data assisted decision making was found to have high significance on team member communication and task evaluation and significant relationship with team member cooperation. Big Data Operation has high significant relationship with team member cooperation and task evaluation and Maintenance management has high significant relationship with team member communication. It was found that Big data assisted decision making and maintenance management to have high significant relationship with data analytics on intelligent operation. meanwhile, maintenance data equipment, and big data operation and maintenance decision has significant relationship with team member communication and task evaluation respectively. A Data Management Efficiency Framework was developed for wind power industry.

Company may improve its data analysis system from multiple dimensions such as organization, strategy, process, technology, and security, and develop data analysis measures. Wind Farms may adapt the development of the power industry, digital transformation, promote the improvement of management level, and assist in achieving the strategic goals of the new era company. The proposed framework for data management efficiency maybe utilized by the wind power companies for better results. Future researchers may conduct similar study using other variables of data management efficiency such as sustainability and shared value innovation.

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