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MAINTENANCE RESOURCE ALLOCATION – THE BUSINESS ANALYTICS USAGE IN INDUSTRY 4.0 CONDITIONS

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Purpose: The purpose of this publication is to present the applications of usage of business analytics in maintenance resources allocation.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The integration of business analytics with condition monitoring technologies heralds a transformative shift in maintenance resource allocation. Through the utilization of real-time data from sensors and monitoring devices, organizations can craft dynamic and adaptive maintenance strategies. These strategies, grounded in the current equipment condition, strike a nuanced balance between preventive and corrective actions. Business analytics enriches decision-making by factoring in critical elements such as equipment importance, operational impact, resource availability, and budget constraints. This integration instigates a paradigm shift, fostering proactive, adaptive, and efficient resource allocation, resulting in heightened asset reliability, diminished downtime, and amplified operational performance. The evolving synergy between business analytics and maintenance practices is becoming integral to the future of asset management and industrial operations. The diverse applications of business analytics in maintenance, as outlined in Table 1, underscore its versatility, encompassing predictive maintenance, condition monitoring, asset performance management, work order prioritization, resource optimization, cost-benefit analysis, inventory management, and performance metrics monitoring. Concurrently, the adoption of advanced software solutions in Industry 4.0 conditions, exemplified by IBM Maximo Asset Management, SAP Intelligent Asset Management, and Fiix CMMS, reflects a commitment to efficiency and innovation in maintenance resource allocation. Despite the substantial advantages, addressing challenges outlined in Table 4, including data quality, integration complexities, implementation costs, and skill development, is crucial. These challenges underscore the necessity for a strategic and holistic implementation approach that considers technology, personnel training, and organizational readiness. In essence, the evolution of maintenance resource allocation through business analytics signifies a data-driven revolution poised to optimize current operations and position organizations for sustained success amid rapid technological advancements and the transformations of Industry 4.0.

Originality/value: Detailed analysis of business analytics in the case of maintenance resource allocation.

Keywords: business analytics, Industry 4.0, digitalization, artificial intelligence, real-time monitoring; maintenance resource allocation.

Category of the paper: literature review.

1. Introduction

The integration of business analytics with condition monitoring technologies enhances the accuracy of maintenance resource allocation. Sensors and monitoring devices can collect real-time data on the health and performance of assets, feeding this information into analytical models. The result is a dynamic and adaptive maintenance strategy that allocates resources based on the current condition of equipment, optimizing the balance between preventive and corrective maintenance actions. Moreover, business analytics facilitates a more informed decision-making process by considering various factors that influence maintenance resource allocation. These factors may include equipment criticality, the impact of failures on overall operations, resource availability, and budget constraints. By analyzing a comprehensive set of variables, organizations can prioritize maintenance activities and allocate resources in a way that aligns with broader business objectives (Zeng et al., 2022; Pech, Vrchota, 2022).

Integration of business analytics into maintenance resource allocation brings about a paradigm shift in how organizations approach asset management. The ability to harness data-driven insights enables a proactive, adaptive, and efficient allocation of resources, leading to improved asset reliability, reduced downtime, and ultimately, enhanced operational performance. As technology continues to advance, the synergy between business analytics and maintenance practices will likely play an increasingly vital role in shaping the future of asset management and industrial operations (Bakir, Dahlan, 2022).

The purpose of this publication is to present the applications of usage of business analytics in maintenance resource allocation.

2. The selected aspects of business analytics usage in maintenance resource allocation

Maintenance resource allocation is a critical aspect of ensuring the optimal functioning and longevity of equipment, facilities, and infrastructure. It involves strategically assigning resources such as manpower, time, and budget to effectively address maintenance needs and

uphold operational efficiency. By carefully planning resource allocation, organizations can minimize downtime, reduce the risk of equipment failures, and extend the lifespan of assets.

Efficient maintenance resource allocation requires a comprehensive understanding of the maintenance requirements of different assets. This includes routine inspections, preventive maintenance tasks, and the ability to respond promptly to unexpected breakdowns. Prioritizing resources based on the criticality of assets and the potential impact of their failure is essential for maximizing the overall reliability and availability of the systems. In addition to manpower, technology and tools are also integral components of maintenance resource allocation. Investing in advanced diagnostic equipment and predictive maintenance technologies can enhance the effectiveness of resource utilization by enabling proactive identification of potential issues before they escalate. This proactive approach not only reduces the frequency of unplanned downtime but also contributes to cost savings in the long run. Furthermore, a well-structured maintenance resource allocation plan considers factors such as the skill sets of maintenance personnel, training requirements, and the availability of spare parts. Continuous evaluation and adjustment of resource allocation strategies based on performance metrics and feedback are crucial for optimizing the overall maintenance process (Ghibakholl et al., 2022).

Maintenance resource allocation is a strategic practice that involves judiciously assigning human, financial, and technological resources to ensure the reliable and efficient operation of assets. By adopting a proactive and data-driven approach, organizations can minimize disruptions, control costs, and ultimately enhance the overall performance and lifespan of their critical systems (Cillo et al., 2022).

Business analytics has emerged as a powerful tool in the realm of maintenance resource allocation, revolutionizing the way organizations manage and optimize their assets. In the context of maintenance, business analytics involves the use of data-driven insights to inform decision-making processes, enabling more efficient allocation of resources such as manpower, time, and budget (Gajdzik, Wolniak, 2022; Gajdzik et al., 2023). One of the key advantages of leveraging business analytics in maintenance resource allocation is the ability to move from a reactive to a proactive maintenance approach. Through the analysis of historical maintenance data, organizations can identify patterns and trends that highlight potential issues before they escalate into critical failures. This foresight allows for a more strategic deployment of resources, focusing efforts on preventive maintenance tasks that address underlying issues and minimize the risk of unplanned downtime (Akundi et al., 2022).

Predictive analytics, a subset of business analytics, plays a crucial role in enhancing maintenance resource allocation. By utilizing predictive modeling and machine learning algorithms, organizations can forecast equipment failures and determine optimal maintenance schedules. This enables a more precise allocation of resources, ensuring that maintenance activities are performed when needed, rather than on a fixed schedule, leading to cost savings and increased asset reliability (Jonek-Kowalska, Wolniak, 2021).

Furthermore, business analytics provides insights into the performance of maintenance strategies and the effectiveness of resource allocation decisions. Key performance indicators (KPIs) such as mean time between failures (MTBF) and mean time to repair (MTTR) can be monitored and analyzed to assess the impact of maintenance interventions. This data-driven evaluation allows organizations to continuously refine their resource allocation strategies, adapting to changing conditions and improving overall operational efficiency (Scappini, 2016).

Table 1 contains descriptions of how business analytics is used in the case of maintenance resource allocation. This table provides an overview of various applications of business analytics in maintenance resource allocation along with brief descriptions of each application.

Table 1.
The usage of business analytics in maintenance resource allocation

Application	Description
Predictive Maintenance	Utilizes historical data and machine learning algorithms to predict when equipment is likely to fail, optimizing resource allocation by focusing on preventive measures.
Condition Monitoring	Monitors real-time data from equipment sensors to assess their current state, enabling proactive maintenance and efficient allocation of resources to address potential issues before they escalate.
Asset Performance Management (APM)	Analyzes the performance of assets over time, identifying areas for improvement and helping allocate resources to enhance the overall reliability and efficiency of critical assets.
Work Order Prioritization	Uses analytics to prioritize maintenance tasks based on factors such as criticality, cost, and potential impact on operations, ensuring that resources are allocated to the most urgent and impactful activities.
Resource Optimization	Analyzes historical maintenance data to identify patterns and trends, optimizing the allocation of resources by adjusting staffing levels, scheduling maintenance activities, and minimizing downtime.
Cost-Benefit Analysis	Evaluates the cost-effectiveness of different maintenance strategies and resource allocation scenarios, helping organizations make informed decisions about where to allocate resources for maximum impact.
Inventory Management	Applies analytics to track and manage spare parts inventory, minimizing stockouts and excess inventory, thus ensuring that the right resources are available when needed without unnecessary costs.
Performance Metrics Monitoring	Utilizes key performance indicators (KPIs) to monitor the effectiveness of maintenance activities, guiding resource allocation decisions based on the actual impact on equipment reliability and overall business goals.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz et al., 2015; Nourani, 2021; Peter et al., 2023).

3. Software used in maintenance resource allocation in Industry 4.0 conditions

In the context of Industry 4.0, the integration of advanced technologies has revolutionized the landscape of maintenance resource allocation, allowing organizations to enhance efficiency, reduce downtime, and optimize overall operational performance. Several cutting-edge software

solutions play a pivotal role in this domain, leveraging the power of Industry 4.0 technologies to transform traditional maintenance practices (Adel., 2022).

IBM Maximo Asset Management is a leading software solution that embodies the principles of Industry 4.0 for maintenance resource allocation. It integrates seamlessly with IoT devices and employs predictive analytics to forecast equipment failures. This enables proactive maintenance strategies, optimizing the allocation of resources for preventive actions and minimizing disruptions (Nourani, 2021).

SAP Intelligent Asset Management is designed to empower organizations with smart maintenance practices. By harnessing the capabilities of the Industrial Internet of Things (IIoT), it provides real-time insights into asset conditions, allowing for data-driven decision-making in maintenance resource allocation. The software emphasizes a holistic approach to asset management, incorporating predictive and preventive maintenance strategies.

Fiix CMMS is a cloud-based Computerized Maintenance Management System that aligns with Industry 4.0 principles, offering a modern approach to maintenance resource allocation. It leverages data analytics to optimize asset performance, streamline work order processes, and improve overall maintenance efficiency. With its user-friendly interface and customizable features, Fiix CMMS facilitates agile decision-making in dynamic Industry 4.0 environments (Du et al., 2023; Fjellström, Osarenkhoe, 2023; Castro et al., 2014; Wang et al., 2023).

Table 2 highlighting examples of software and applications used in maintenance resource allocation, along with descriptions of their usage. This table provides an overview of various business analytics software and applications used in maintenance resource allocation, along with descriptions and key features of each.

Table 2.
The usage of business analytics software in maintenance resource allocation

Software/Application	Description	Key Features
IBM Maximo Asset Management	Comprehensive asset management software that utilizes analytics to optimize maintenance resource allocation.	- Predictive maintenance capabilities - Work order management and prioritization - Inventory optimization
SAP Intelligent Asset Management	SAP's solution for intelligent asset management leverages analytics for effective maintenance resource allocation.	- Real-time condition monitoring - Predictive and preventive maintenance - Integration with IoT devices for data collection
Microsoft Dynamics 365 for Field Service	A field service management application with analytics features to enhance maintenance resource allocation.	- Schedule optimization and routing - Asset performance monitoring - Mobile accessibility for field teams
Infor EAM	Infor's Enterprise Asset Management system that incorporates analytics to streamline maintenance resource allocation.	- Reliability-centered maintenance - Asset performance analytics - Integration with IoT and other data sources
Oracle Maintenance Cloud	Oracle's cloud-based maintenance management solution with analytics for efficient resource allocation.	- Condition-based and predictive maintenance - Work order and task management - Asset lifecycle management

Cont. table 2.

Fiix CMMS	Cloud-based Computerized Maintenance Management System (CMMS) that uses analytics for maintenance resource allocation.	- Asset tracking and management - Customizable dashboards and reporting - Integrations with other business systems
Smartenance by Festo	A cloud-based maintenance management solution that incorporates analytics for intelligent resource allocation.	- Condition monitoring and anomaly detection - Automated work order generation - Collaboration features for teams

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz et al., 2015; Nourani, 2021; Peter et al., 2023).

4. Advantages and problems of business analytics usage in maintenance resource allocation

Business analytics plays a crucial role in optimizing maintenance resource allocation, offering a myriad of advantages that contribute to enhanced efficiency, reduced downtime, and improved overall operational performance. Here are several key advantages of leveraging business analytics in maintenance resource allocation:

Business analytics enables organizations to move from reactive to proactive maintenance strategies. By analyzing historical data and employing advanced algorithms, predictive maintenance identifies potential equipment failures before they occur. This foresight allows for timely intervention, reducing unplanned. Through data analysis, business analytics helps organizations allocate maintenance resources more effectively. It considers factors such as equipment criticality, historical performance, and real-time conditions to prioritize tasks. This ensures that resources are directed to the most critical areas, maximizing their impact on overall operational reliability (Nourani, 2021).

Analytics provides insights into asset performance, allowing organizations to identify patterns and trends. This knowledge enables targeted maintenance efforts that address specific issues, leading to improved equipment reliability. Regular analysis helps in fine-tuning maintenance strategies for optimal performance. Business analytics aids in identifying cost-effective maintenance strategies. By analyzing historical maintenance data, organizations can optimize spending, reduce unnecessary expenses, and implement strategies that provide the best return on investment. This cost-conscious approach contributes to overall financial efficiency.

Proactive maintenance, facilitated by business analytics, minimizes unexpected equipment failures and, consequently, reduces downtime. By addressing potential issues before they escalate, organizations can ensure continuous operations, meeting production schedules and enhancing overall business continuity. Business analytics continuously monitors and analyzes asset performance data. This leads to the identification of opportunities for improvement and

optimization. By acting on these insights, organizations can enhance asset performance, maximizing operational efficiency and the overall value derived from their assets.

Business analytics provides actionable insights derived from data analysis. This empowers decision-makers to make informed choices regarding maintenance resource allocation. Data-driven decision-making ensures that strategies align with organizational goals and contribute to long-term success. Optimized maintenance processes, guided by business analytics, reduce manual intervention and streamline workflows. This increased efficiency translates into higher productivity, as maintenance teams can focus on critical tasks, respond to issues promptly, and perform tasks more effectively (Charles et al., 2023).

Business analytics assists in prioritizing maintenance tasks based on criticality, historical performance, and potential operational impact. This ensures that resources are allocated to the most urgent and impactful activities, optimizing the use of available manpower and time. By providing feedback on the effectiveness of maintenance strategies, business analytics facilitates a continuous improvement cycle. Organizations can learn from past performance, refine their approaches, and implement changes that lead to ongoing optimization and excellence in maintenance resource allocation (Greasley, 2019).

Table 3 contains the advantages of using business analytics in maintenance resource allocation within Industry 4.0 conditions, along with descriptions for each advantage. These advantages underscore the transformative impact of business analytics on maintenance resource allocation, contributing to improved efficiency, cost-effectiveness, and overall operational excellence.

Table 3.
The advantages of using business analytics in maintenance resource allocation

Advantage	Description
Predictive Maintenance	Anticipates equipment failures based on data analysis, enabling proactive maintenance and reducing unplanned downtime.
Optimal Resource Allocation	Analyzes historical and real-time data to allocate resources efficiently, ensuring that tasks are prioritized based on criticality.
Improved Equipment Reliability	Identifies patterns and trends in asset performance, allowing for targeted maintenance efforts that enhance overall equipment reliability.
Cost Savings	Enables organizations to optimize maintenance spending by identifying cost-effective strategies and minimizing unnecessary expenses.
Reduced Downtime	Proactively addresses potential issues, minimizing equipment downtime through timely and targeted maintenance interventions.
Enhanced Asset Performance	Utilizes analytics to monitor and improve asset performance, extending the lifespan of equipment and maximizing its operational efficiency.
Data-Driven Decision-Making	Provides actionable insights through data analysis, empowering decision-makers to make informed choices regarding resource allocation.
Increased Productivity	Optimizes maintenance processes, reducing manual intervention and streamlining workflows, leading to increased overall productivity.
Improved Work Order Prioritization	Utilizes data to prioritize maintenance tasks based on criticality and potential impact on operations, ensuring efficient resource utilization.
Enhanced Planning and Scheduling	Facilitates better planning by using historical data, allowing organizations to schedule maintenance activities more effectively and minimize disruptions.
Inventory Optimization	Analyzes spare parts usage and demand patterns, optimizing inventory levels to ensure that the right parts are available without excess stock.

Cont. table 3.

Compliance Management	Helps organizations adhere to regulatory and compliance standards by providing visibility into maintenance activities and documentation.
Continuous Improvement	Facilitates a continuous improvement cycle by providing feedback on the effectiveness of maintenance strategies, leading to ongoing optimization.
Adaptability to Changing Conditions	Allows organizations to adapt quickly to changing conditions by analyzing data and adjusting resource allocation strategies accordingly.
Integration with IoT and Emerging Tech	Integrates with IoT devices and emerging technologies, providing a foundation for advanced maintenance strategies in the era of Industry 4.0.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz et al., 2015; Nourani, 2021; Peter et al., 2023).

Table 4 contains the problems of using business analytics in maintenance resource allocation within Industry 4.0 conditions, along with descriptions for each advantage. While the benefits of using business analytics in maintenance resource allocation are significant, addressing these challenges is essential to ensure successful implementation and maximize the value derived from analytics-driven strategies.

Table 4.
The problems of using business analytics in maintenance resource allocation

Problem	Description
Data Quality Issues	Incomplete or inaccurate data can compromise the effectiveness of analytics. Poor data quality may lead to incorrect insights and decisions, impacting the overall maintenance strategy.
Integration Challenges	Integrating analytics tools with existing systems and data sources can be complex. Incompatibility issues may arise, hindering the seamless flow of information for informed decision-making.
Implementation Costs	The initial costs associated with implementing robust analytics solutions, including software, hardware, and training, can be substantial. Organizations may face financial constraints in adopting such systems.
Skill Gaps and Training	Organizations may lack personnel with the necessary skills to effectively use and interpret analytics tools. Training staff to understand and leverage these tools is crucial for success.
Complexity of Analytics Tools	Advanced analytics tools can be complex, requiring a high level of expertise to navigate and interpret. This complexity may pose challenges for non-technical users in the maintenance team.
Resistance to Change	Employees may resist adopting new processes driven by analytics. There might be a cultural shift required within the organization to embrace data-driven decision-making in maintenance.
Lack of Standardization	Inconsistencies in data formats and maintenance processes across different departments or sites can impede the standardization needed for effective analytics.
Scalability Issues	Some analytics solutions may face challenges when scaling up to handle larger datasets or increasing numbers of connected devices, limiting their scalability.
Security and Privacy Concerns	As maintenance data becomes more interconnected, ensuring the security and privacy of sensitive information is critical. Concerns may arise regarding data breaches or unauthorized access.
Overemphasis on Technology	Organizations may focus too much on implementing advanced analytics technology without considering the importance of aligning analytics efforts with strategic business goals.
Lack of Historical Data	For new systems or organizations without sufficient historical data, predictive analytics may be less accurate, limiting the ability to forecast future maintenance needs effectively.
Unforeseen External Factors	External factors such as sudden changes in market conditions, regulations, or technology advancements may impact the relevance and effectiveness of established analytics models.

Cont. table 4.

Limited Understanding of Analytics	Stakeholders may not fully comprehend the insights generated by analytics tools, leading to misinterpretation or underutilization of valuable information.
Difficulty in Measuring ROI	Determining the return on investment (ROI) for analytics initiatives in maintenance can be challenging, making it harder to justify the upfront costs.
Maintenance Process Complexity	Maintenance processes can be intricate, involving various variables. Capturing the full complexity of these processes in analytics models may be challenging, affecting accuracy.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz et al., 2015; Nourani, 2021; Peter et al., 2023).

5. Conclusion

The integration of business analytics with condition monitoring technologies represents a transformative approach to maintenance resource allocation. By harnessing real-time data from sensors and monitoring devices, organizations can create dynamic and adaptive maintenance strategies. These strategies prioritize resource allocation based on the current condition of equipment, striking a balance between preventive and corrective actions. Business analytics further enhances decision-making by considering factors such as equipment criticality, operational impact, resource availability, and budget constraints. The paradigm shift brought about by the integration of business analytics into maintenance resource allocation is evident. This approach enables a proactive, adaptive, and efficient allocation of resources, leading to improved asset reliability, reduced downtime, and enhanced operational performance. As technology continues to advance, the synergy between business analytics and maintenance practices is poised to play a vital role in shaping the future of asset management and industrial operations.

The applications of business analytics in maintenance resource allocation, as highlighted in Table 1, demonstrate its versatility across various facets of maintenance, including predictive maintenance, condition monitoring, asset performance management, work order prioritization, resource optimization, cost-benefit analysis, inventory management, and performance metrics monitoring. Moreover, the integration of advanced software solutions in Industry 4.0 conditions exemplifies the commitment to efficiency and innovation in maintenance resource allocation. Examples such as IBM Maximo Asset Management, SAP Intelligent Asset Management, and Fiix CMMS showcase the power of analytics, IoT integration, and cloud-based solutions in optimizing maintenance processes.

While the advantages of using business analytics in maintenance resource allocation are substantial, it is essential to acknowledge and address challenges. Table 4 outlines potential issues such as data quality, integration complexities, implementation costs, and the need for skill development. These challenges underline the importance of a strategic and holistic

approach to implementation, encompassing technology, personnel training, and organizational readiness.

The evolution of maintenance resource allocation through business analytics signifies a data-driven revolution in the industrial landscape. By leveraging these technologies, organizations can not only optimize their current operations but also position themselves for continued success in an era of rapid technological advancement and Industry 4.0 transformations.

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