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THE APPLICATIONS OF USAGE OF BUSINESS ANALYTICS IN INDUSTRY 4.0

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Purpose: The purpose of this publication is to present the applications of usage of business analytics in Industry 4.0.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: Specifically, the paper discussed how business analytics is employed in predictive maintenance, supply chain optimization, and quality control. Predictive maintenance allows organizations to proactively address equipment failures, thereby reducing downtime and maintenance costs. Supply chain optimization optimizes resource allocation, minimizes costs, and improves customer service through data-driven decision-making. Quality control relies on data analytics to monitor, assess, and enhance product and service quality, ultimately leading to cost reduction and customer satisfaction. It is evident that business analytics is not merely a tool but a strategic imperative for organizations in the era of Industry 4.0. It empowers them to continuously improve their operations, mitigate risks, and stay ahead in a rapidly evolving business landscape. As technology and data analytics capabilities continue to advance, businesses that effectively leverage these tools will be better positioned to thrive in the dynamic and competitive world of Industry 4.0.
Originality/value: Detailed analysis of all subjects related to the problems connected with the usage of business analytics in Industry 4.0.

Keywords: business analytics, Industry 4.0, digitalization, artificial intelligence, real-time monitoring.

Category of the paper: literature review.

1. Introduction

Business analytics plays a pivotal role in Industry 4.0, revolutionizing the way organizations operate and make informed decisions. In this era of advanced technology and data-driven insights, businesses across various industries harness the power of analytics to optimize processes, enhance efficiency, and drive growth (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021; Wolniak et al., 2023; Wolniak, Grebski, 2023; Wolniak, Skotnicka-Zasadzień, 2023; Jonek-Kowalska, Wolniak, 2023).

The purpose of this publication is to present the applications of usage of business analytics in Industry 4.0.

2. The juxtaposition of business analytics usage in business

The table 1 is summarizing examples of the usage of business analytics in Industry 4.0. These examples illustrate how business analytics is leveraged in Industry 4.0 to enhance efficiency, reduce costs, improve product quality, and provide a competitive edge by making data-driven decisions across various aspects of industrial and business operations making (Cam et al., 2021).

Industry 4.0 relies heavily on data, and business analytics facilitates the collection and integration of data from various sources (Jonek-Kowalska, Wolniak, 2021, 2022; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021; Orzeł, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Stecuła, Wolniak, 2022; Olkiewicz et al., 2021). This includes sensors, IoT devices, production equipment, and even external data sources. By aggregating this data, businesses gain a comprehensive view of their operations.

Table 1.
Examples of the usage of business analytics in Industry 4.0

Application of Business Analytics in Industry 4.0	Description
Predictive Maintenance	Analyzing historical and real-time data to predict when machinery or equipment needs maintenance, reducing downtime and costs.
Supply Chain Optimization	Using data to optimize supply chain operations, including demand forecasting, inventory management, and logistics, for efficiency and cost savings.
Quality Control	Real-time monitoring of production processes to detect defects and anomalies, ensuring consistent product quality and reducing waste.
Inventory Management	Accurate demand forecasting and real-time inventory tracking to minimize carrying costs while meeting customer demand.
Personalized Customer Experiences	Analyzing customer data and behavior to offer personalized products, services, and marketing, enhancing customer satisfaction and loyalty.
Process Optimization	Identifying inefficiencies and areas for improvement in manufacturing and operations, leading to increased productivity.
Cost Reduction	Data-driven decisions to identify and reduce operational costs, improving profitability and competitiveness.
Energy Management	Monitoring and optimizing energy consumption in manufacturing processes to reduce costs and promote sustainability.
Global Supply Chain Coordination	Coordinating global supply chains using data analytics to reduce disruptions and improve responsiveness.

Cont. table 1.

Environmental Sustainability	Using data analysis to identify areas for improvement in resource usage, waste reduction, and environmental impact.
Customization and Personalization	Tailoring products and services to individual customer preferences based on data insights.
Risk Mitigation	Identifying and mitigating risks through data analysis, enhancing overall operational resilience.
Maintenance Resource Allocation	Optimizing the allocation of maintenance resources based on equipment performance data.
Worker Safety and Health	Analyzing data from wearable devices and sensors to ensure worker safety and well-being in industrial settings.
Predictive Maintenance	Analyzing historical and real-time data to predict when machinery or equipment needs maintenance, reducing downtime and costs.

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 at al., 2015; Nourani, 2021; Peter et al., 2023).

3. The usage of business analytic in predictive maintenance

Business analytics employs predictive models to monitor equipment and machinery in real-time. By analyzing historical data and current performance metrics, organizations can predict when equipment is likely to fail, enabling proactive maintenance and reducing downtime (Scappini, 2016).

Predictive analytics plays a crucial role in predictive maintenance, a proactive approach to maintenance that aims to predict when equipment or machinery is likely to fail so that maintenance can be performed just in time to prevent costly breakdowns. The first step in predictive maintenance is collecting data from various sensors and monitoring devices installed on the equipment. These sensors capture real-time information such as temperature, pressure, vibration, and other relevant parameters. Predictive analytics relies on this continuous data feed.

Raw sensor data can be noisy and contain anomalies. Predictive analytics involves data preprocessing steps, such as cleaning, filtering, and normalization, to ensure that the data used for analysis is accurate and consistent (Greasley, 2019).

Predictive maintenance leverages historical data to build predictive models. These models analyze past equipment performance, failures, and maintenance records to identify patterns and trends. Machine learning algorithms are often used to extract meaningful insights from this historical data. Engineers and data scientists identify relevant features or variables from the data that are indicative of equipment health and potential failure. Feature engineering involves selecting, transforming, and creating new variables to improve the predictive accuracy of models (Charles et al., 2023).

Predictive analytics models are developed based on historical data and feature engineering. Commonly used models include regression analysis, time-series forecasting, machine learning algorithms (such as decision trees, random forests, or neural networks), and more advanced techniques like deep learning for complex data patterns. As new data streams in from sensors, the predictive maintenance system continuously analyzes this real-time data using the established models. The models compare the current equipment's performance metrics with the expected values to detect deviations or anomalies (Hurwitz et al., 2015).

Predictive analytics models establish thresholds or trigger points beyond which maintenance action is recommended. When sensor data breaches these thresholds or exhibits abnormal patterns, alerts are generated to notify maintenance teams or operators. Predictive maintenance systems provide actionable insights, including information about which components of the equipment are likely to fail and when. Maintenance teams can plan their schedules accordingly, ensuring that maintenance is performed only when necessary, reducing downtime, and minimizing maintenance costs (Peter et al., 2023).

By addressing maintenance needs precisely when they arise, organizations can significantly reduce unplanned downtime, avoid costly equipment failures, and extend the lifespan of their assets. This results in substantial cost savings and improved operational efficiency. Predictive maintenance is an ongoing process. Organizations continuously refine and improve their predictive analytics models as they gather more data and gain a deeper understanding of their equipment's behavior (Nourani, 2021).

Predictive analytics in predictive maintenance transforms equipment maintenance from a reactive, time-based approach to a proactive, data-driven strategy. It enhances equipment reliability, reduces operational costs, and maximizes the uptime and performance of critical assets in industries such as manufacturing, transportation, energy, and healthcare.

Table 2 is outlining examples of how business analytics is used in predictive maintenance. These examples showcase how business analytics is integrated into predictive maintenance to improve equipment reliability and reduce maintenance costs.

Table 2.
Examples of how business analytics is used in predictive maintenance

Use Case	**Description**
Data Collection	Gathering data from sensors, IoT devices, and equipment to monitor real-time performance and health.
Data Preprocessing	Cleaning, filtering, and normalizing raw sensor data to ensure accuracy and consistency for analysis.
Historical Data Analysis	Analyzing historical maintenance records and equipment performance data to identify patterns and failure trends.
Feature Engineering	Selecting and transforming relevant features from data to improve predictive model accuracy.
Predictive Model Development	Creating models using machine learning algorithms, regression analysis, or deep learning to predict equipment failures.

Cont. table 2.

Real-time Data Analysis	Continuously monitoring real-time sensor data and comparing it to predictive models to detect deviations or anomalies.
Threshold and Alert Generation	Establishing trigger points and generating alerts when sensor data breaches predetermined thresholds or exhibits abnormal patterns.
Condition-Based Maintenance Planning	Providing insights into which equipment components are likely to fail and when, enabling proactive maintenance planning.
Reduced Downtime and Cost Savings	Minimizing unplanned downtime, avoiding costly breakdowns, and extending equipment lifespan, resulting in significant cost savings.
Continuous Model Improvement	Continuously refining and enhancing predictive models as more data becomes available and the understanding of equipment behavior deepens.

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. The usage of business analytic in supply chain optimization

Analytics helps in optimizing the supply chain by providing insights into demand forecasting, inventory management, and logistics. This leads to more efficient resource allocation and cost savings.

Business analytics is a powerful tool used extensively in supply chain optimization to enhance efficiency, reduce costs, improve customer service, and make informed decisions. Business analytics leverages historical sales data, market trends, and other relevant factors to develop accurate demand forecasts. These forecasts help organizations align production, procurement, and inventory levels with expected demand, reducing the risk of overstocking or stockouts. Analytics assists in determining optimal inventory levels by analyzing factors such as demand variability, lead times, and carrying costs. By optimizing inventory, companies can free up capital, reduce storage costs, and minimize the risk of obsolescence (Adel, 2022).

Businesses use analytics to evaluate the performance of suppliers. Key metrics like on-time delivery, quality, and cost can be tracked and analyzed to make data-driven decisions regarding supplier relationships and contracts. For transportation and logistics, analytics helps in route optimization. It considers factors like traffic conditions, fuel costs, and vehicle capacity to determine the most efficient routes for deliveries, reducing transportation costs and delivery times. Analytics is used to optimize warehouse layout, picking routes, and storage allocation. This leads to reduced labor costs, improved order accuracy, and faster order fulfillment (Cillo et al., 2022).

By analyzing historical data, companies can gain insights into lead times for various suppliers and products. This information is vital for managing inventory levels effectively and meeting customer demand promptly. Business analytics can identify potential risks in the supply chain, such as disruptions due to natural disasters or geopolitical events. Companies can develop contingency plans and assess the impact of these risks on their operations. Analytics fosters collaboration with suppliers by sharing data and insights. This collaborative approach helps in aligning supply chain activities and improving overall performance (Sułkowski, Wolniak, 2015, 2016, 2018; Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Wolniak, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022; Gajdzik, Wolniak, 2023; Wolniak, 2013, 2016; Hys, Wolniak, 2018).

Businesses use analytics to segment customers based on purchasing behavior, preferences, and profitability. This information informs decisions about service levels, pricing strategies, and inventory allocation for different customer segments. Supply chain analytics provides real-time dashboards and reports that monitor key performance indicators (KPIs) such as inventory turnover, order fill rates, and transportation costs. This allows for quick identification of performance issues and opportunities for improvement (Di Marino et al., 2023).

Analytics is employed in production scheduling to balance demand and capacity. It helps in determining the most efficient production sequences, minimizing changeover times, and reducing production bottlenecks. Companies are increasingly using analytics to assess the environmental impact of their supply chain operations. This includes measuring carbon emissions, evaluating sustainable sourcing options, and identifying areas for eco-friendly improvements results (Wolniak, Sułkowski, 2015, 2016; Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022).

Analytics enables organizations to perform "what-if" scenarios to assess the impact of different decisions or external events on the supply chain. This helps in risk mitigation and strategic planning.

Table 3.
Examples of how business analytics is used in supply chain optimization.

Use Case	Description
Demand Forecasting	Utilizing historical data and market trends to forecast future demand accurately, helping in inventory planning and production scheduling.
Inventory Management	Analyzing demand variability, lead times, and carrying costs to determine optimal inventory levels, reducing excess stock and minimizing stockouts.
Supplier Performance Analysis	Evaluating supplier metrics like on-time delivery, quality, and cost to make data-driven decisions about supplier relationships and contracts.
Route Optimization	Using analytics to optimize transportation routes by considering factors such as traffic, fuel costs, and vehicle capacity, reducing transportation costs and delivery times.
Warehouse Optimization	Optimizing warehouse layout, picking routes, and storage allocation to reduce labor costs, improve order accuracy, and enhance order fulfillment efficiency.
Lead Time Analysis	Analyzing historical lead time data for suppliers and products to manage inventory effectively and meet customer demand promptly.
Risk Management	Identifying and mitigating potential supply chain risks using analytics, such as disruptions due to natural disasters or geopolitical events.
Supplier Collaboration	Collaborating with suppliers by sharing data and insights to align supply chain activities and improve overall performance.
Customer Segmentation	Segmenting customers based on purchasing behavior, preferences, and profitability to inform service levels, pricing strategies, and inventory allocation.

Cont. table 3.

Performance Metrics Monitoring	Monitoring key performance indicators (KPIs) like inventory turnover, order fill rates, and transportation costs in real-time through dashboards and reports for quick issue identification and improvement opportunities.
Production Scheduling Optimization	Using analytics to balance production capacity with demand, optimizing production sequences, minimizing changeover times, and reducing production bottlenecks.
Sustainability and Environmental Impact Assessment	Assessing the environmental impact of supply chain operations, measuring carbon emissions, evaluating sustainable sourcing options, and identifying areas for eco-friendly improvements.
Scenario Analysis	Performing "what-if" scenarios to assess the impact of different decisions or external events on the supply chain, aiding in risk mitigation and strategic planning.

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).

Business analytics in supply chain optimization empowers organizations to make data-driven decisions at every stage of the supply chain, from demand forecasting to logistics management. It leads to cost savings, improved customer satisfaction, reduced risks, and greater overall competitiveness in today's complex and dynamic business environment (Ghibakholl et al., 2022).

Table 3 is presenting examples of how business analytics is used in supply chain optimization. These examples demonstrate how business analytics is applied to various aspects of supply chain management to enhance efficiency, reduce costs, and improve overall performance.

5. The usage of business analytic in quality control

In manufacturing, analytics is used to ensure product quality. By analyzing data from sensors and cameras, companies can identify defects or anomalies in real-time, allowing for immediate corrective actions and reducing waste. Business analytics plays a critical role in quality control by providing organizations with data-driven insights and tools to monitor, assess, and improve the quality of products or services.

Business analytics in quality control begins with the collection and integration of data from various sources. This data includes information from production processes, customer feedback, supplier data, and quality inspection records. Integrating this data into a centralized system allows for comprehensive quality analysis. Analytics tools can continuously monitor production processes and quality parameters in real time. Sensors and IoT devices are often used to collect data on factors like temperature, pressure, and product dimensions. Any deviations from predetermined quality standards trigger alerts for immediate corrective action (Akundi et al, 2022).

Statistical techniques and control charts are employed to analyze process data and detect trends or variations that might indicate potential quality issues. SPC helps organizations maintain consistent quality and reduce defects by identifying when processes are out of control. When quality issues occur, analytics can assist in identifying the root causes behind defects or deviations. By analyzing historical data and process variables, organizations can pinpoint the factors contributing to quality problems and take corrective measures (Olsen, 2023).

Predictive analytics models use historical data to predict the likelihood of future quality issues. This allows for proactive quality control measures, such as adjusting production processes or identifying critical control points. Analytics helps assess the quality performance of suppliers by tracking key metrics like defect rates, on-time deliveries, and quality audits. This information guides decisions regarding supplier selection, improvement, or termination (Aslam et al., 2020).

Analytics tools can analyze customer feedback, including complaints and product reviews, to identify recurring quality issues or patterns. This information informs product improvement efforts and helps in addressing customer concerns. Analytics aids in the planning and execution of quality audits and inspections. It can prioritize inspection areas based on historical data and risk assessment, optimizing resource allocation (Bakir, Dahlan, 2022).

By analyzing quality data over time, organizations can identify long-term trends and patterns that impact quality. This information is crucial for making strategic decisions about process improvements and product development. Analytics can assess the financial impact of quality issues, including the cost of defects, rework, warranty claims, and customer returns. This data helps in cost reduction efforts and justifying investments in quality improvement initiatives (Javaid et al., 2020).

Business analytics supports the principles of continuous improvement by providing data-driven feedback loops. Organizations can set quality improvement goals, track progress, and adjust strategies based on analytical insights. In industries with stringent quality and safety regulations, analytics ensures compliance by monitoring processes and records to identify potential compliance risks (Javaid, Haleem, 2020).

Business analytics in quality control empowers organizations to proactively manage and enhance product and service quality. It enables them to reduce defects, minimize waste, lower costs, and maintain customer satisfaction by leveraging data-driven insights and process optimization techniques.

Table 4 provides examples of how business analytics can be used in quality control. These examples of how business analytics can be applied to quality control in various industries to enhance product quality, reduce costs, and improve overall operational efficiency.

Table 4.
Examples of how business analytics can be used in quality control

Use Case	Description
Defect Analysis	Analyzing production data to identify patterns and trends related to defects, helping organizations pinpoint root causes and reduce defects in products or processes.
Statistical Process Control (SPC)	Utilizing statistical techniques to monitor and control manufacturing processes, ensuring they remain within acceptable quality limits and identifying any variations or anomalies.
Predictive Maintenance	Using predictive analytics to anticipate equipment or machinery failures, enabling proactive maintenance to minimize downtime and ensure product quality.
Supplier Quality Management	Evaluating supplier performance through data analysis to ensure consistent quality of raw materials and components, reducing the risk of defects in the final product.
Six Sigma Analysis	Applying statistical analysis and data-driven methodologies like DMAIC (Define, Measure, Analyze, Improve, Control) to improve process efficiency and quality.
Root Cause Analysis	Investigating quality issues by analyzing data to identify the underlying causes, allowing for targeted corrective actions to be taken.
Customer Feedback Analysis	Analyzing customer feedback and complaints data to identify recurring issues, helping to improve product quality and customer satisfaction.
Process Optimization	Using data analytics to identify inefficiencies in manufacturing or service processes and making data-driven adjustments to enhance overall quality and efficiency.
Warranty and Returns Analysis	Analyzing warranty claims and product returns data to identify common problems and improve product design and manufacturing processes.
Data-driven Decision Making	Providing decision-makers with real-time quality data and insights, enabling them to make informed decisions that positively impact product quality and customer satisfaction.

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).

6. Conclusion

In conclusion, this paper has highlighted the significant role of business analytics in quality control and its broader applications in Industry 4.0. The examples presented in Tables 1, 2, 3, and 4 demonstrate the diverse ways in which business analytics is leveraged to enhance efficiency, reduce costs, improve product quality, and gain a competitive edge across various industrial and business operations. In the context of Industry 4.0, business analytics acts as a central pillar by enabling organizations to harness the power of data from multiple sources, including sensors, IoT devices, production equipment, and external data sources. This data aggregation empowers businesses with a comprehensive view of their operations, facilitating informed decision-making at every level.

Specifically, the paper discussed how business analytics is employed in predictive maintenance, supply chain optimization, and quality control. Predictive maintenance allows organizations to proactively address equipment failures, thereby reducing downtime and maintenance costs. Supply chain optimization optimizes resource allocation, minimizes costs, and improves customer service through data-driven decision-making. Quality control relies on data analytics to monitor, assess, and enhance product and service quality, ultimately leading to cost reduction and customer satisfaction. It is evident that business analytics is not merely a tool but a strategic imperative for organizations in the era of Industry 4.0. It empowers them to continuously improve their operations, mitigate risks, and stay ahead in a rapidly evolving business landscape. As technology and data analytics capabilities continue to advance, businesses that effectively leverage these tools will be better positioned to thrive in the dynamic and competitive world of Industry 4.0.

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