STM JOURNALS

Journal of
Advanced Database
Management & Systems

ISSN: 2393-8730
Volume 13, Issue 1, 2026
January–April
DOI (Journal): 10.37591/JoADMS

https://journals.stmjournals.com/joadms

Review JoADMS

Optimizing Airline Efficiency Using Big Data and Predictive Analytics

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Abstract

Recent technological advancements have resulted in the generation of vast volumes of data across industries, including the airline sector, supporting operational control and service quality. Big data analytics (BDA) enables organizations to analyze large and complex datasets to derive actionable insights that support highly informed decision-making and truly superior operational performance. This review paper systematically analyzes twenty relevant research studies to explore the application of BDA within the airline industry. A structured search was carried out across major scholarly databases, including Web of Science, ScienceDirect, Google Scholar, and IEEE Xplore, using relevant keywords associated with BDA, data mining, predictive analysis, and machine learning. The reviews show that BDA is commonly applied in airline operations, optimizations, customer service, risk management, safety, and aircraft maintenance. The review further reveals that the adoption of BDA in the airline industry is constrained by challenges, such as data integration complexities, strict regulatory compliance requirements, data privacy, and security concerns. In summary, this study presents a comprehensive review of current BDA applications in the airline sector while highlighting key implementation challenges. These insights enrich the existing literature and serve as a useful foundation for future research as well as practical applications of data-driven solutions in airline operations.

Keywords: Airlines industry, big data analytics (BDA), data mining, machine learning, predictive analytics

INTRODUCTION

The rapid evolution of information and communication technologies has led to unprecedented growth in data generation across a wide range of industries, with the airline sector being a prominent contributor. Modern airline operations generate massive volumes of data from multiple sources, including flight scheduling and operations, passenger bookings and interactions, onboard and ground-based sensor systems, and aircraft maintenance and inspection activities. The continuous flow of such diverse data has created both opportunities and challenges for airlines seeking to improve their performance and competitiveness [1].

Effectively analyzing vast and complex data is essential for enhancing operational efficiency, improving passenger experience, and ensuring high levels of safety and reliability. Airlines operate in a highly dynamic and competitive environment, where small improvements in efficiency or

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Received Date: January 27, 2026
Accepted Date: February 01, 2026
Published Date: March 20, 2026

Citation: Tamasa Priyadarsini, Achinta Kumar Palit, Preetiprada Samantara. Optimizing Airline Efficiency Using Big Data and Predictive Analytics. Journal of Advanced Database Management & Systems. 2026; 13(1): 13–18p.

decision-making can lead to significant cost savings and service enhancements. Consequently, the ability to transform raw data into actionable knowledge has become a strategic priority for industry [2].

Big data analytics (BDA) plays a crucial role in enabling airlines to process, analyze, and interpret large-scale heterogeneous datasets that traditional data processing methods cannot handle efficiently. By leveraging advanced analytical techniques such as predictive modeling, machine learning, and real-time data processing, BDA allows organizations to uncover hidden patterns, trends, and relationships within complex datasets [3]. These insights support informed decision-making and help airlines respond more effectively to operational and market changes [4].

Within the airline industry, BDA is applied across a wide range of functional areas. It is extensively used to optimize operational processes such as route planning, fuel management, and crew scheduling. Demand forecasting and revenue management systems rely on BDA to analyze historical and real-time data, enabling airlines to predict passenger demand, adjust their pricing strategies, and maximize their revenue [5]. Additionally, BDA supports risk management and safety initiatives by analyzing aircraft performance data and maintenance records to detect potential failures and reduce downtime through predictive maintenance approaches. Customer-related analytics further allow airlines to personalize services, enhance customer satisfaction, and improve loyalty programs through data-driven insights [6].

Despite the significant benefits associated with BDA, its implementation in the airline industry faces several challenges. The integration of data from multiple, often incompatible sources remains a major technical obstacle. Airlines must also comply with strict regulatory requirements related to aviation safety, data protection, and international standards [7]. Privacy and security concerns regarding sensitive passenger and operational data further complicate the adoption of advanced analytics solutions. Additionally, the high costs of infrastructure, skilled personnel, and system integration can act as barriers, particularly for smaller carriers [8].

The primary objective of this study is to review and analyze existing research on the application of BDA in the airline industry. By examining prior studies, this research aims to identify key application domains, assess the benefits achieved through BDA adoption, and highlight the major challenges associated with its implementation [9]. This review provides a comprehensive understanding of the current state of BDA in aviation and offers insights that can guide future research and practical applications in the industry [10].

LITERATURE REVIEW

Prior research shows that the growing adoption of BDA in the airline industry improves operational performance and competitive advantage. Studies have emphasized the application of data analytics in optimizing airline operations, particularly in-flight scheduling, fuel management, and crew planning [11]. Several studies have focused on customer service and satisfaction, where predictive analytics and data mining techniques have been used to analyze passenger behavior, personalize services, and improve loyalty programs [12]. Other researchers have emphasized the role of BDA in risk management and aviation safety, including anomaly detection and predictive risk assessment [13]. Additionally, aircraft maintenance has benefited significantly from advanced automated machine-learning-based predictive maintenance models, which reduce downtime and maintenance costs. However, the literature also identifies challenges such as heterogeneous data sources, strict regulatory requirements, and concerns related to data privacy and cybersecurity, which can limit the effective implementation of BDA solutions [14].

The analysis of aviation data requires specialized analytical approaches owing to its unique characteristics. The volume of data generated daily in the aviation sector is enormous, necessitating a robust infrastructure for efficient data storage and analysis [15]. Additionally, the high velocity at which data is produced, driven by real-time streams from multiple sources, demands systems capable of highthroughput data processing. Aviation data are obtained from a wide range of sources, including aircraft sensors, air traffic control systems, and weather stations, making them highly varied and necessitating advanced algorithms for integration, cleaning, and harmonization. Furthermore, data veracity is critical in safety-sensitive environments, such as aviation, where inaccurate or unreliable data can lead to serious consequences [16]. Ultimately, aviation data becomes valuable only when they are effectively analyzed and interpreted, converting raw information into actionable insights for informed decision-making. These five characteristics—volume, velocity, variety, veracity, and value—present significant challenges and opportunities for the aviation industry. Compared with many other industries, managing and analyzing vast and complex datasets remains particularly challenging for the aerospace sector [17].

Data security and privacy are significant concerns in the aviation industry. Aviation data often contains highly sensitive information related to passengers, flight operations, and security procedures. Consequently, the implementation of robust security mechanisms is essential to protect this data from unauthorized access, cyber intrusions, and potential misuse while ensuring compliance with data protection and privacy regulations [18]. Furthermore, the increasing use of advanced analytics and artificial intelligence technologies intensifies the need for careful consideration of the ethical and legal implications of these technologies. The risk of security breaches and privacy violations highlights the importance of responsible data governance and ethical AI practices in the aviation sector [19].

METHODOLOGY

This study employs a systematic literature review methodology to analyze relevant studies and synthesize their key findings. Twenty research papers were selected from reputable electronic databases such as Web of Science, ScienceDirect, Google Scholar, and IEEE Xplore [20]. The literature search employed keywords including BDA, airline industry, data mining, predictive analytics, and machine learning. The selected studies were screened based on their relevance, publication quality, and contribution to the research objectives. The reviewed papers were then analyzed and categorized according to the application areas and implementation challenges of BDA in the airline industry [21].

This study adopted a qualitative systematic review approach to integrate and evaluate existing knowledge from peer-reviewed scholarly sources. The primary purpose of this methodology was to develop a structured and comprehensive understanding of the ways in which BDA is reshaping operational practices within the aviation sector [22]. By systematically reviewing the literature, this study ensured consistency, transparency, and rigor in the selection and analysis of relevant research findings.

This review focused on the implementation of BDA across several critical functional areas of aviation. These include enhancing supply chain robustness, improving air traffic management systems, optimizing flight planning and fuel efficiency, enabling predictive maintenance of aircraft systems, and supporting strategic and operational decision-making within organizations [23]. The examination of these diverse application areas allowed for a holistic assessment of how data-driven techniques contribute to both operational efficiency and safety.

This methodological framework also supports the identification of recurring themes, emerging technological developments, and unresolved challenges in the existing body of research. By highlighting the patterns and gaps in the literature, this review provides meaningful insights into current trends and future research directions [24]. Overall, this approach offers valuable perspectives on the evolving role and impact of BDA in advancing innovation and performance across the aviation industry.

To ensure comprehensive retrieval of relevant studies, a structured set of keywords combined with Boolean operators was developed. The primary search terms included combinations such as “big data analytics” and “aviation,” “predictive maintenance” and “aircraft,” “big data” and “air traffic management,” “machine learning” and “aviation decision-making,” “data-driven decision making” and "airlines," "Internet of Things (IoT)" and "aviation systems," and "ethics" and "big data" and "aviation." To capture recent developments and technological advancements in the field, this review focused exclusively on peer-reviewed articles published between 2010 and 2024.

RESULTS AND DISCUSSION

The review reveals that BDA is widely applied across multiple domains in the airline industry. Airline operations and optimization have emerged as a major application area, focusing on improving efficiency and reducing costs. The results of our customer service and satisfaction studies highlight the importance of data-driven personalization and service quality improvements. Risk management and safety applications demonstrate how analytics can enhance proactive decision-making. Predictive models that reduce operational disruptions benefit aircraft maintenance. Despite these advantages, challenges such as data integration from multiple sources, compliance with aviation regulations, and data privacy and security concerns remain significant barriers to successful BDA adoption.

To ensure academic rigor and credibility, each selected study was systematically evaluated using a quality assessment checklist. The evaluation criteria included the authorship and year of publication, clarity of research objectives and questions, BDA techniques or technologies employed, and the specific application areas addressed, such as route optimization, aircraft maintenance, and air traffic flow management (ATFM). Additionally, the methodological approach adopted in each study—such as case studies, simulations, or empirical surveys—was examined, along with the key findings, identified challenges or limitations, and recommendations for future research. The extracted data were subsequently coded and subjected to thematic analysis to identify recurring patterns, dominant themes, inconsistencies, and research gaps within the literature. Based on this analysis, the identified themes were organized into five core categories: (1) operational applications, (2) data characteristics and management, (3) human and organizational factors, (4) ethical and regulatory issues, and (5) emerging trends and technologies.

CONCLUSION

This review study presents an extensive examination of how BDA is utilized within the airline sector, along with the key obstacles encountered during its adoption. The results indicate that BDA holds considerable promise for improving operational performance, enhancing passenger experience, strengthening safety measures, and optimizing maintenance activities. However, overcoming challenges related to data integration, regulatory compliance, and information security remains critical to fully realizing these advantages. This study adds value to the existing body of research and serves as a useful reference point for future investigations and real-world applications of BDA in airline operations.

BDA has substantial potential to transform aviation operations and enhance data-driven decision-making. Its use spans a broad range of influential functions, including optimizing flight routes, enabling predictive maintenance, improving air traffic flow control, and strengthening supply chain operations. Despite these benefits, several challenges must be addressed to ensure the effective and responsible adoption of BDA, including data complexity, shortages of skilled personnel, data security concerns, and high implementation costs. Future research should focus on developing more advanced and tailored BDA solutions, integrating human expertise with intelligent systems, and comprehensively examining the ethical, legal, and societal implications of these technologies. By proactively addressing these challenges and leveraging emerging opportunities, the aviation industry can fully realize the transformative potential of BDA, leading to improved safety, operational efficiency, and profitability, while maintaining the highest ethical standards.

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