

Review Article

Advancing Predictive Failure Analytics in Automotive Safety: AI-Driven Approaches for School Buses and Commercial Trucks

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Abstract: The recent evidence on AI in automotive safety shows the potential to reduce crashes and improve efficiency. Studies used AI techniques like machine learning and predictive analytics models to develop predictive collision avoidance systems. The studies collected data from various sources, such as traffic collision data and shapefiles. They utilized deep learning neural networks and 3D visualization techniques to analyze the data. However, there needs to be more research on AI in school bus and commercial truck safety. This paper explores the importance of AI-driven predictive failure analytics in enhancing automotive safety for these vehicles. It will discuss challenges, required data, technologies involved in predictive failure analytics, and the potential benefits and implications for the future. The conclusion will summarize the findings and emphasize the significance of AI in improving driver safety. Overall, this paper contributes to the field of automotive safety and aims to attract more research in this area.

Keywords: AI, Predictive Analytics, School Bus Safety, Big data, Data Science, Smart Automation

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1. Introduction

1.1. Problem Statement

The concept of predictive failure analytics has been around since the 1990s, often in the arena of monitoring the health of complex systems and detecting anomalies. However, there have been few revolutionary strides in its overall development. Safety management in heavy vehicles is based on probabilities and assumptions, leaving little flexibility for innovation. Accidents in these areas are still common, with a significant number of fatalities. There is a pressing need to modernize the safety systems used in heavy vehicles. The market demand for services that adapt and respond to the modern world creates opportunities for companies to improve predictive failure systems. With the decreasing hardware and software costs, there is a promise that real-time predictive results will replace the old inefficient systems. These findings provide evidence and initiative for investment in these fields. Integrating artificial intelligence and advanced data techniques is the next step in having an effective and sophisticated predictive safety mechanism [1,7] (As shown in Figure 1).

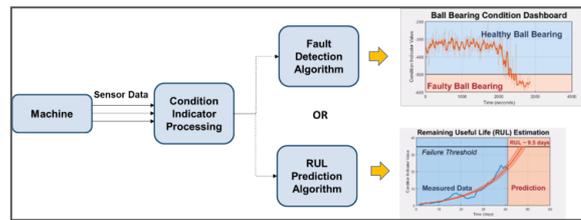


Figure 1. Prediction of Algorithms

1.2. Predictive Failure

The integration of modern technology and approaches is crucial. AI and Data Mining use in Predictive Failure Analysis has grown, with studies validating their advantages. However, it is a complex task involving various aspects and proper selection methods. This literature presents an add-on approach to introduce Predictive Failure Analytics, followed by details on using AI and Data Mining techniques. A real-life case study on Preventive Measures is included [1,5]. Continuous innovation and validation inform people through generated predictions. The outputs and conclusions of this chapter regenerate knowledge and document work done. The concept part provides fundamentals, and the section on AI and Data Mining techniques applies the concept in real life [3]. The Preventive Measures section may be ignored in the future, but currently, it is crucial in controlling machines and components (As shown in Figure 2).

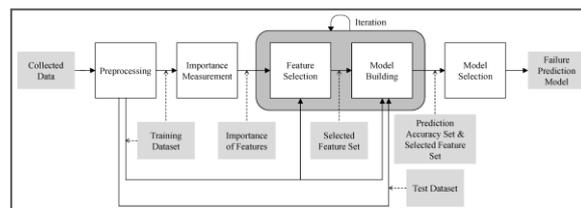


Figure 2. Flow chart of Data Collection

1.3. Role of AI in Automotive Safety

AI in automotive safety is experiencing substantial growth and expansion due to the availability of vast amounts of big data, constant advancements in deep learning techniques, and continuous improvements in hardware capabilities. This convergence of technological progress has paved the way for three prominent ways AI is utilized within the automotive industry: advanced driver assistance systems, conditional automation, and predictive and autonomous automation [3] (As shown in Figure 3).

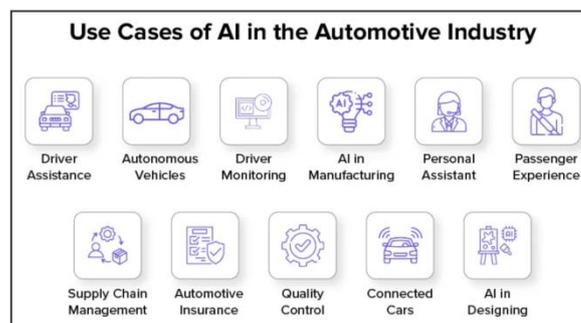


Figure 3. Use Case of AI in Automotive Industry

These applications of AI are revolutionizing the landscape of automotive safety by harnessing data-driven insights, enabling proactive decision-making, and ultimately

ensuring the well-being and security of drivers and passengers alike. Integrating AI into automotive safety is bound to shape a future where transportation is safer, smarter, and more efficient than ever before [4].

2. Current Challenges in School Bus and Commercial Truck Safety

One critical fact in traffic safety is the higher safety risks associated with larger vehicles like school buses and trucks. According to NHTSA, school-transportation-related crashes caused 281 fatalities between 2008 and 2017, with 72% being occupants of other vehicles. Two thousand eighteen large trucks caused 86% of fatal crashes involving passenger vehicles [2,6]. Improving the safety of these vehicles is challenging due to traditional safety measures and the need for new methods. Insufficient diagnostic methods and trial-and-error maintenance practices slow progress. Data analysis and predictive failure analytics can improve safety by providing insights and anticipating failures. IoT and cloud computing enable continuous monitoring and real-time warnings, making vehicles cost-effective and safer.

2.1. Risks and Accidents

School buses are a standard mode of transportation for students, but they also come with certain risks that should be noticed. One of the main concerns is the potential for traffic accidents, which can endanger the lives of passengers and other road users. Additionally, loading and unloading issues can cause further complications and increase the likelihood of accidents [4,7].

When it comes to commercial trucks, the risks are even more significant. These vehicles are involved in more accidents than school buses, and the economic costs associated with these incidents are substantial. Various factors contribute to truck accidents, with speeding, distraction, impairment, and fatigue being some of the most common. Addressing these issues and taking the necessary steps to mitigate their risks is essential (As shown in Figure 4).

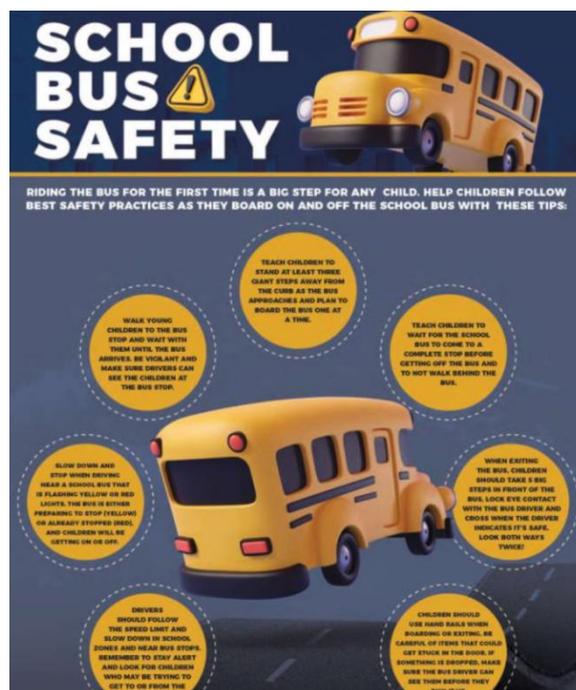


Figure 4. School Bus Safety

As the trucking industry grows the concern for crashes and accidents increases accordingly. This highlights the urgency of implementing effective safety measures and technologies. By doing so, we can improve the safety of trucking operations and minimize accidents [12].

To achieve this, a comprehensive examination of the current precautions is required. This analysis will help identify any shortcomings or areas that need improvement. Furthermore, predictive failure analysis can significantly contribute to better vehicle integrity and prevent travel hazards. By anticipating and addressing potential failures before they occur, we can enhance the safety of trucking operations and reduce the likelihood of accidents [2].

In conclusion, it is crucial to acknowledge the risks associated with school buses and commercial trucks. By developing and implementing appropriate safety measures and technologies, we can mitigate these risks and ensure the well-being of all individuals involved [8]. We can enhance vehicle integrity and prevent travel hazards by examining current precautions and utilizing predictive failure analysis. This, in turn, will contribute to a safer and more efficient transportation system [3].

2.2. Traditional Safety Limitations

Traditional safety methods must be replaced by predictive systems that use data analysis to identify potential failures. A computerized approach is necessary for trucking and bus industries to prevent accidents.

Inspections are visual, mechanical checks humans perform during scheduled maintenance or as part of a government safety inspection. There are two types: driver inspections and government inspections [9]. Driver inspections focus on obvious defects like worn brake pads or non-functional horns. These results are not stored electronically for cross-referencing or, more considerably, predictive analysis. Government inspections are basic visual checks, limited by time, resources, and human error. Inspectors ensure system functionality, check for burned-out dashboard lights, and scan for specific SAE-certified trouble codes. Standardization hinders program improvement (As shown in Figure 5).



Figure 5. Traditional Road Safety Practices Vs Safe System Approach

Traditional safety measures focus on preventive steps and mechanical repair to avoid accidents in the first place and mitigate damages or injuries. Well-known traditional truck and bus safety measures include regular maintenance, careful driver training and licensing, and standardized inspection programs. However, more than these measures are needed because the onus is on individual drivers and the conditions during his or her particular route [4,9].

2.3. Need for Advanced Predictive Failure Analytics

The current safety measures in school buses and commercial trucks need to be improved due to deterministic approaches and the increasing complexity of vehicles, which poses a significant risk. For instance, a sudden sensor failure in a school bus

equipped with automatic braking technology can cause severe injury to vulnerable children. In light of the shortcomings of traditional safety measures that rely on fault diagnostics after a failure has already occurred, there is an urgent requirement for more advanced and proactive solutions. Implementing predictive failure analytics is crucial to enhance automotive safety by continuously monitoring the vehicle's condition, accurately foreseeing potential system failures, and providing early warnings to circumvent accidents and their detrimental consequences. This proactive approach empowers authorities and drivers with invaluable insights, enabling them to take preventative measures and ensure the well-being of passengers and other road users. By embracing this transformative approach, transportation systems can prioritize the safety of all individuals and foster a future where accidents and injuries are significantly minimized [6,9].

3. AI-Driven Approaches for Predictive Failure Analytics

As mentioned in the introduction section, predictive failure analytics of automotive safety is essential for manufacturers and researchers of new automotive technologies and products. However, the validity and precision of the current failure predictive techniques use outdated and unrealistic models of component degradation or failures. Modern Artificial Intelligence (AI) and data-driven strategies can be applied as a more effective and efficient alternative to develop and validate new predictive techniques (As shown in Figure 6).

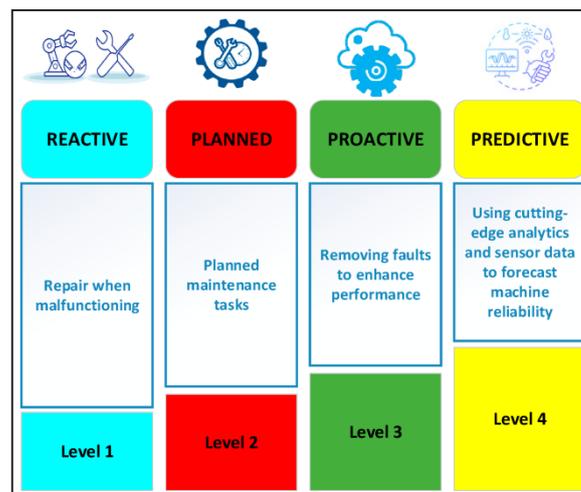


Figure 6. Levels of AI Predictive Analysis

In addition, AI can also be used to determine the dependency of the diagnostic precision on both the sensing parameter settings and the run-time parameter settings. This section focuses on AI and data-driven strategies for predictive failure analytics for automotive safety.

3.1. Data Collection and Analysis

The data collection system for the project is based on GNSS real-time monitoring of vehicle dynamics. Raw data is available in text and Matlab formats. The Vigilog system is a high-quality video solution for automotive applications. It uses a 4-channel digital video recorder with a video data format based on the H.264 standard. Several instrumentation modules can be controlled remotely in a software environment. A shaker test was used to measure the mechanical system in vehicle dynamics and find the natural frequency, damping ratio, and mode shape. ADAMS/Car simulation package was used for kinematic and dynamic analysis. It can simulate and visualize the dynamic behavior of components

and complete vehicles. MATLAB software was used to submit yaw rate and lateral acceleration data to the algorithm. This algorithm can be integrated into a commercial vehicle dynamic simulation model for safety prediction (As shown in Figure 7).



Figure 7. Using AI for predictive maintenance of manufacturing processes

3.2. Machine Learning Algorithms for Predictive Analytics

In machine learning, two types of techniques are supervised and unsupervised. Supervised learning uses "training data" to train the algorithm, relating inputs to outputs using patterns in the data. *Linear regression* is a simple supervised learning algorithm that finds correlations by fitting a straight line to the data. More complex algorithms like "black box" algorithms, like neural networks, are often preferred [7]. Neural networks are characterized by their depth, representing complex relationships in inputs. Stochastic gradient descent (SGD) is a training method for neural networks, updating parameters through shuffled data. This method of learning is why neural networks are a type of supervised learning algorithm known as "deep learning (As shown in Figure 8).

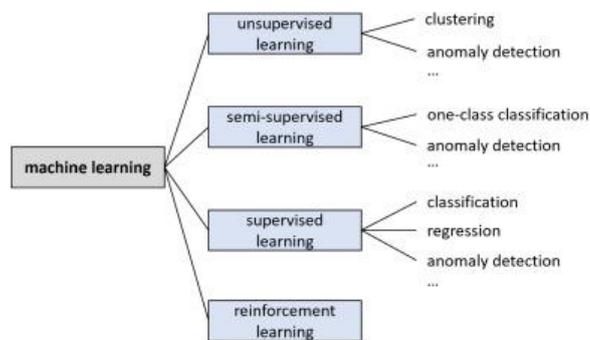


Figure 8. Classifications of ML

3.3. Integration of AI in Safety Systems

Integration of AI technology in automotive safety systems is crucial for predictive failure analytics and improving road safety. AI can assist drivers in making decisions and enforcing rules. Traffic accidents are a significant cause of workplace fatalities, with truck accidents being common. AI has immense potential in improving driving decisions and enforcing rules. AI can make real-time risk mitigation analyses when integrated with automotive safety systems. The rise of autonomous vehicles has also opened up new avenues for AI development in "closed-loop autonomous systems" that can make decisions and move the car with minimal driver input.

3.4. Real-Time Monitoring and Alerts

Real-time monitoring using predictive analytics is crucial for minimizing component failure. Node-RED is a user-friendly open-source tool for creating custom real-time

monitoring systems. For experienced coders, using languages like R, Python, and Julia is more achievable. Controllers and maintenance systems offer options for real-time monitoring and alert configuration. By constantly sampling and comparing parameters, potential failures can be caught, and appropriate actions can be taken. Guidelines from the Centre for Advancement of Trenchless Technology should be followed when implementing a monitoring system [5]. The adoption of AI in predictive analytics will likely change real-time monitoring setups. However, until standardized measures are in place, AI will coexist with more static monitoring programs like Node-RED (As shown in Figure 9).

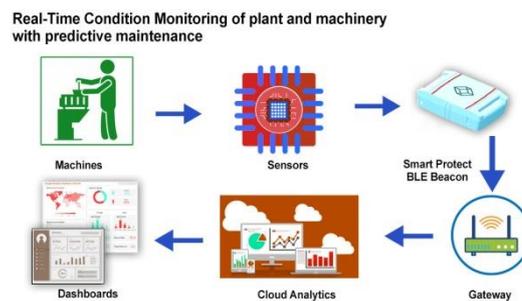


Figure 9. Real Time conditions monitoring of plant and machinery with predictive maintenance

4. Benefits and Future Implications

The progress of technology in automotive safety systems has surpassed traditional methods, especially in school buses and commercial trucks. AI-driven predictive failure analysis offers clear advantages in reducing safety risk and improving efficiency. With advancements in connectivity and sensor technology, AI has abundant opportunities in automotive safety. Harmonizing analytical methods and updating regulations are crucial for successful AI deployment. Continuous support from the industry and an understanding of academic research will help AI realize its potential in automotive safety (As shown in Figure 100).

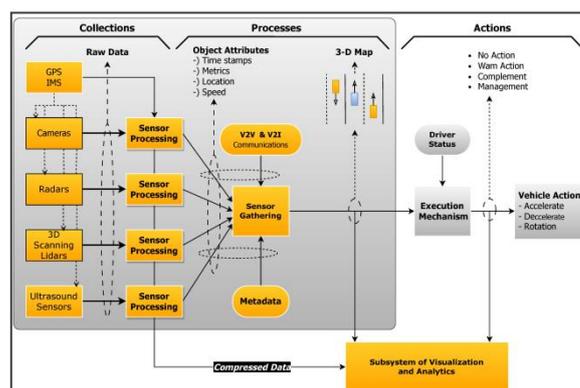


Figure 10. Analysis of Process

4.1. Improved Safety and Accident Prevention

Predictive maintenance analytics is a transformative solution that significantly enhances safety and accident prevention in the fast-evolving automotive industry. By leveraging the power of data-driven decision-making, it enables the adoption of customized and highly effective preventive techniques. This cutting-edge approach ensures that vehicles are constantly monitored for their health and facilitates pre-

determined checks and thorough reviews, thus alleviating safety concerns [12] (As shown in Figure 11).



Figure 11. Safety Guidelines for Accident Prevention

Implementing predictive maintenance analytics helps bolster regulatory compliance and enables the industry to stay at the forefront of advancements in data technologies. With a strong emphasis on objectivity, this revolutionary methodology minimizes the occurrence of accidents caused by human error, paving the way for increased autonomy and the proliferation of self-driven cars (As shown in Figure 12).

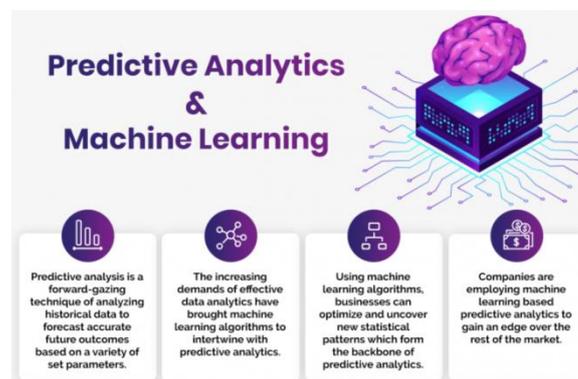


Figure 12. Predictive Analytics & Machine Learning

In addition to its immediate benefits, this groundbreaking maintenance method dramatically contributes to the overall safety and reliability of the transport network. Thanks to the industry's unwavering commitment to ensuring the utmost safety of commuters and motorists alike, it garners widespread acclaim and receives resounding legislative support [11].

By harnessing the potential of predictive maintenance analytics, the automotive industry witnesses a remarkable reduction in accidents and establishes itself as a trailblazer in safety innovation. With its unparalleled ability to analyze and interpret data, this approach catalyzes minimizing risks and optimizing overall operations, making every journey on the road safer and more secure.

4.2. Cost Reduction and Efficiency Enhancement

AI in automotive safety brings cost savings by maximizing the lifespan of components and reducing inspection frequency and labor costs. Roadside maintenance is five times more expensive than a shop visit, and breakdowns are ten times more expensive (As shown in Figure 133).

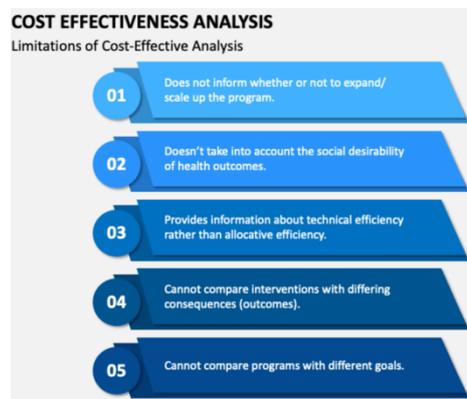


Figure 13. Cost Effectiveness Analysis

Predictive failure analytics can also save costs in bus fleets by minimizing timetable disruptions and allowing maintenance outside of operational hours. Remote service teams can work on buses when they return to the depot without wasting time waiting for maintenance personnel (As shown in Figure 144).

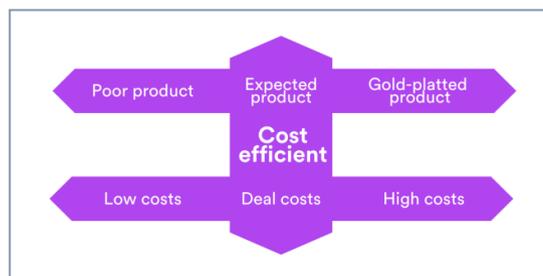


Figure 14. Cost Reduction and Efficiency Enhancement

4.3. Potential Applications in Other Industries

AI and predictive failure analytics have applications in various industries, such as manufacturing, healthcare, finance, and transportation. These cutting-edge technologies utilize advanced data analysis techniques to automate processes, detect anomalies, and make accurate predictions. In the healthcare sector, predictive tools greatly enhance diagnostics, enabling early detection of diseases and reducing the need for invasive procedures. They also facilitate personalized patient care by tailoring treatment plans based on individual characteristics and medical history (As shown in Figure 155).

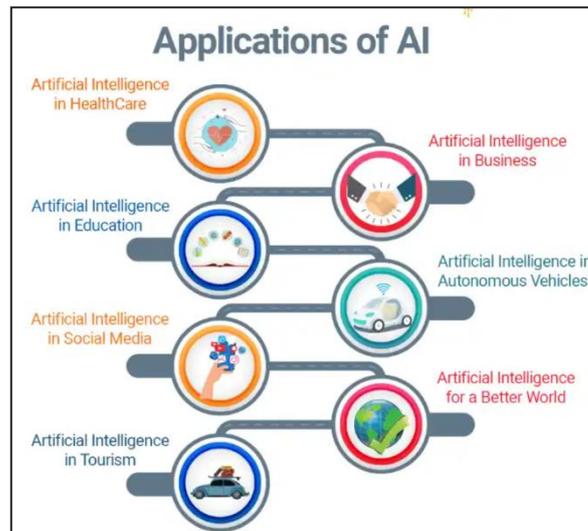


Figure 15. Applications of AI

AI and predictive analytics are crucial in preventing equipment failure and optimizing maintenance schedules in the manufacturing industry. By analyzing historical maintenance data and real-time sensor information, these technologies can predict when equipment will likely fail and alert maintenance teams to take proactive measures. This proactive approach minimizes unexpected downtime, reduces repair costs, and maximizes overall operational efficiency [9].

Moreover, the trucking industry benefits immensely from predictive failure analytics. AI can identify patterns and potential issues by analyzing data from various sources, such as vehicle sensors, historical maintenance records, and weather conditions. This enables trucking companies to optimize their maintenance schedules, ensuring that vehicles are serviced before major failures occur. In addition, predictive analytics can help optimize routes, improve fuel efficiency, and enhance driver safety through the identification of potential hazards on the road [8] (As shown in Figure 166).

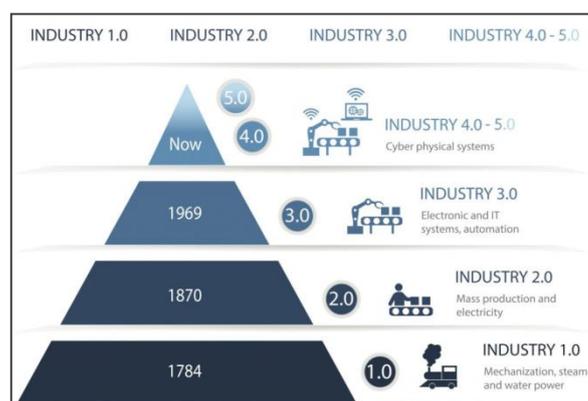


Figure 16. Potential Applications in Other Industries

While implementing AI and predictive analytics strategies requires an initial investment, the long-term benefits are substantial. Companies can save significantly by avoiding unexpected equipment breakdowns, reducing repair costs, and optimizing operational efficiency. Moreover, predictive analytics can provide valuable insights and recommendations for improving business processes and decision-making [10].

Effective communication, stakeholder involvement, and workforce training are essential for a successful transition to predictive analytics. Organizations need to educate

their employees about these technologies' capabilities and benefits. They should also develop strong data governance policies to ensure data quality, privacy, and security. Additionally, collaborations with technology partners and experts can facilitate the integration of AI and predictive analytics into existing systems and workflows.

Overall, AI and predictive failure analytics are revolutionizing multiple industries by harnessing the power of data analysis and machine learning. From healthcare to manufacturing to transportation, these technologies drive innovation, enable more intelligent decision-making, and enhance the efficiency and effectiveness of various processes. Embracing these advancements is crucial for organizations aiming to remain competitive in the increasingly data-driven business landscape [3].

5. Conclusion

In conclusion, it is clear that failure analytics is the ever-growing field of automotive safety that is of ever-increasing importance. The increased use of advanced technologies such as AI will ensure safer and more efficient vehicles shortly. Nonetheless, transitioning towards these technologies from the well-established methods used today will be gradual and assured. With cautious approaches, the more widespread use of predictive analytics and AI in the automotive safety industry will save more lives and avert countless accidents. Also, awareness of the risk of cybersecurity threats should increase as more vehicles connect to the internet so that predictive analytics can reach their full potential. There will be new challenges for cyber and data security in the future.

Last but not least, it is essential to distinguish the areas that require analytic approaches to automotive safety, each encompassing different aspects of vehicle technologies and applications, as discussed in the essay. Conventional diagnostic methodologies and their readings should be stressed less in the vehicle user safety aspect, as they are not designed to be predictive and rely on the user to recognize and act upon fault lights or messages. However, in the manufacturing and assembly process, the focus and industry advancement should be tilted toward diagnostic methods focusing on identifying intermittent faults and degrading parts. As for practicing industry professionals, continuous improvement in diagnostic and predictive technology should be at the forefront of development in the quest to revolutionize the future of automotive safety.

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