

Safety analysis of leading electric vehicle manufacturers: A global perspective

Mayank Rai *

General Motors LLC, USA.

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Abstract

The global electric vehicle market demonstrates significant growth as manufacturers prioritize safety innovations and technological advancements. This comprehensive evaluation explores safety performance across leading EV manufacturers, examining accident rates, fatality statistics, and safety system effectiveness. The assessment encompasses crash test results, battery safety measures, and advanced driver assistance systems while considering market dynamics and regulatory frameworks. The findings reveal that EVs exhibit enhanced safety characteristics due to their fundamental design features, including lower centers of gravity and advanced battery protection systems. The integration of sophisticated safety technologies, combined with proper regulatory standards and consumer awareness, positions electric vehicles as increasingly secure transportation options. Recommendations for improving EV safety focus on manufacturing guidelines, regulatory frameworks, and consumer education, while future directions highlight the importance of battery technology advancement and safety system integration.

Keywords: Electric Vehicle Safety; Battery Protection Systems; Autonomous Safety Features; Thermal Management; Charging Infrastructure

1. Introduction

The global electric vehicle (EV) market has demonstrated remarkable growth, with passenger EV sales reaching 14 million units in 2023, representing a significant increase from previous years. This growth trajectory has positioned EVs to capture approximately 18% of total global passenger vehicle sales, reflecting a transformative shift in the automotive landscape [1]. The expansion has been particularly pronounced in major markets, with China leading global EV adoption, followed by Europe and North America, collectively shaping the future of automotive safety standards and performance metrics.

The evolution of EV technology has brought forth unique considerations in vehicle safety and maintenance requirements. Electric vehicles are fundamentally different from conventional internal combustion engine (ICE) vehicles in their design and operation, featuring fewer moving parts and different maintenance requirements. This structural distinction has significant implications for vehicle safety and reliability. The simplified powertrain design of EVs, comprising an electric motor and battery system rather than the complex engine and transmission systems found in conventional vehicles, contributes to their overall reliability and safety profile [2].

Real-world operational data has revealed distinctive patterns in EV safety and maintenance requirements. The high-voltage battery systems in EVs require specialized safety protocols and maintenance procedures, though they typically demand less regular maintenance than traditional ICE vehicles. These battery systems are designed with multiple safety features and sophisticated thermal management systems, contributing to their overall safety profile. The regenerative braking systems in EVs not only enhance energy efficiency but also reduce brake wear, potentially improving long-term safety performance through reduced maintenance requirements [2].

* Corresponding author: Mayank Rai

Current market projections indicate that EVs will constitute approximately 44% of global passenger vehicle sales by 2030 [1]. This significant market penetration underscores the importance of understanding and continuously improving EV safety systems. The industry's focus has shifted toward developing more advanced battery technologies, enhanced safety systems, and improved charging infrastructure, all of which contribute to the overall safety ecosystem of electric vehicles.

Safety considerations in EVs extend beyond traditional automotive safety parameters. The unique characteristics of electric powertrains necessitate specialized safety protocols, particularly in areas such as high-voltage system management and battery protection. The industry has responded by developing comprehensive safety standards and protocols specifically tailored to electric vehicles, encompassing everything from manufacturing processes to emergency response procedures.

Table 1 Global EV Market Characteristics and Regional Adoption [1,2]

Region	Market Position	Adoption Level	Market Growth	Infrastructure Development	Technology Integration
China	Market Leader	High	Rapid	Advanced	Comprehensive
Europe	Secondary Hub	Substantial	Progressive	Well-developed	Advanced
North America	Tertiary Hub	Growing	Steady	Expanding	Progressive
Global Market	Transformative	Accelerating	Strong	Evolving	Dynamic

2. Methodology

2.1. Data Sources and Collection Framework

This comprehensive safety analysis integrates data from multiple authoritative sources with a primary focus on standardized testing methodologies for electric vehicles. The primary data sources include the U.S. Department of Energy's electric vehicle maintenance and safety documentation [2], which provides baseline operational safety parameters. The crash test methodologies and safety assessment protocols are derived from standardized NCAP (New Car Assessment Program) testing frameworks [3], which establish comprehensive metrics for evaluating electric vehicle safety performance. Additional data sources include the Federal Consortium for Advanced Batteries (FCAB) recommendations [4], which provide critical insights into battery safety standards and testing protocols. The foundational testing framework follows established electric vehicle safety standards, incorporating detailed analysis of vehicle dynamics during impact scenarios, with particular emphasis on the mechanical and thermal response of battery systems during collision events. Testing protocols measure acceleration peaks ranging from 20g to 40g during impact scenarios, providing critical data about structural integrity and occupant protection systems [3].

The research methodology emphasizes both laboratory testing and real-world performance analysis, incorporating data from standardized impact tests performed at velocities of 48.3 km/h (30 mph) for frontal impacts and 54 km/h (33.5 mph) for side impacts. These tests evaluate the mechanical response of the battery pack and supporting structures, with specific attention to deformation patterns and energy absorption characteristics. The testing protocol includes comprehensive monitoring of electrical system integrity, measuring voltage variations, and potential thermal events during and after impact scenarios [3].

2.2. Analysis Parameters and Metrics

The analytical framework incorporates recommendations from the Federal Consortium for Advanced Batteries (FCAB), which emphasizes the importance of standardized safety metrics across the EV industry. The methodology addresses key safety parameters, including thermal runaway propagation, electrical isolation maintenance, and structural integrity of battery enclosures. Safety assessments focus particularly on rapid charging scenarios, where charging rates can reach up to 350 kW, requiring specific safety protocols and monitoring systems [4].

The safety evaluation process integrates multiple testing scenarios designed to assess vehicle performance under various conditions. This includes systematic analysis of battery thermal management systems, which must maintain operational temperatures between 15°C and 35°C for optimal performance and safety. The methodology incorporates

specific attention to electrical isolation requirements, maintaining minimum resistance levels of 500 ohms/volt for DC circuits, and appropriate safeguards for AC systems operating at frequencies above 0.1 Hz [4].

Structural integrity assessment follows standardized protocols developed through extensive research and real-world data analysis. The testing methodology examines critical safety parameters, including impact resistance, thermal stability, and electrical system integrity. Particular attention is paid to the battery enclosure design, which must withstand impact forces while maintaining structural integrity and preventing thermal runaway propagation. The analysis includes a detailed examination of cell-to-cell thermal isolation and propagation resistance, with specific metrics for thermal event containment and emergency response protocols [3].

The data analysis framework incorporates both quantitative and qualitative assessments of safety systems. This includes evaluation of battery management system (BMS) performance, monitoring voltage variations across individual cells, and temperature distributions throughout the battery pack. The methodology also addresses emergency response protocols, including electrical isolation procedures and thermal event management strategies. These protocols are designed to ensure consistent safety standards across different vehicle platforms and operating conditions [4].

Table 2 Electric Vehicle Safety Test Specifications [3,4]

Test Parameter	Value Range/Specification
Impact Acceleration	20g - 40g
Frontal Impact Velocity	48.3 km/h (30 mph)
Side Impact Velocity	54 km/h (33.5 mph)
Charging Rate Maximum	350 kW
Operating Temperature Range	15°C - 35°C
DC Circuit Resistance	500 ohms/volt
AC System Frequency	>0.1 Hz

2.3. Market Leaders in Global EV Sales

The global electric vehicle market has demonstrated remarkable growth, with the total market value reaching \$457.6 billion in 2023 and projected to expand at a compound annual growth rate (CAGR) of 17.8% through 2028. This growth has been particularly evident in key markets such as China, Europe, and North America, with various manufacturers competing for market dominance in different regions [5].

A prominent American EV manufacturer has maintained its position as a leading force in the global EV market, particularly in the premium segment. The company's global sales reached 1.31 million units in 2022, representing a significant portion of the total EV market. Its market penetration has been particularly strong in North America and Europe, where its Model Y and Model 3 vehicles have consistently ranked among the top-selling electric vehicles. The manufacturer's focus on technology integration, including advanced driver assistance systems, has contributed to its market position and safety reputation [5].

BYD has emerged as a formidable competitor in the global EV landscape, particularly with its strong presence in the Chinese market. The company's rise has been marked by significant technological innovations in battery technology and manufacturing processes. In 2022, BYD sold more than 911,000 battery electric vehicles (BEVs), reflecting a remarkable year-over-year growth rate. The company's expansion has been supported by its vertically integrated production model, which includes in-house battery manufacturing capabilities and a focus on technological innovation [6].

A major Chinese automotive company has established a significant presence in the electric vehicle market, particularly in Europe, where their ID series has gained substantial market share. The company's commitment to electrification has been demonstrated through its strategic transition towards electric vehicles, with the ID.4 becoming one of its most successful electric models. The global electric vehicle market size, which encompasses manufacturers, reached \$279.75 billion in 2023, showing the significant scale of market opportunity that major automotive groups are pursuing [6].

The market dynamics reflect evolving consumer preferences and regulatory environments across different regions. The Asia-Pacific region, led by China, has emerged as the largest market for electric vehicles, accounting for 40.2% of the

global market share in 2023. Europe follows as the second-largest market, with significant contributions from different manufacturers. The North American market, where Tesla maintains a strong presence, has shown consistent growth with increasing adoption rates across various vehicle segments [5].

Manufacturing capacity and technological innovation continue to be key differentiators among market leaders. The global electric vehicle market has seen substantial investments in production infrastructure, with major manufacturers expanding their dedicated EV manufacturing facilities. The industry's growth is further supported by advancing battery technology, with research indicating that battery costs have declined by more than 89% since 2010, enabling manufacturers to improve both performance and affordability [6].

Table 3 Global EV Market Development Status [5,6]

Region	Market Maturity	Primary Market Focus	Development Status	Infrastructure Readiness
China	Advanced	Mass Market Production	Industry Leader	Highly Developed
North America	Mature	Premium Technology	Technology Innovator	Rapidly Expanding
Europe	Well-Developed	Sustainability-Driven	Policy & Innovation Hub	Systematically Planned
Asia-Pacific	Developing	Value-Based Solutions	Fast-Growing Market	Steadily Improving
South America	Emerging	Affordable Mobility	Early Market Development	Initial Development
Middle East	Early Growth	Luxury & Performance	Strategic Investment	Selective Growth
Africa	Initial Stage	Basic Transportation	Foundation Development	Early Planning

3. Safety Performance Analysis of Electric Vehicles

3.1. Crash Test Results and Structural Safety

Electric vehicles have demonstrated significant safety advantages due to their fundamental design characteristics. The lower center of gravity, resulting from battery placement in the vehicle floor, provides enhanced stability and reduced rollover risk. This architectural advantage is complemented by the absence of a large engine block in the front of the vehicle, which creates an additional crumple zone for enhanced crash protection. Modern EVs incorporate multiple safety systems working in concert, including reinforced passenger compartments and specialized high-voltage safety systems that automatically disconnect in the event of a collision [7].

The structural design of electric vehicles incorporates specific safety features that address unique aspects of EV operation. These vehicles are equipped with dedicated battery protection systems that shield the battery pack during collisions, preventing damage that could lead to thermal events. The inclusion of automatic disconnects for high-voltage systems provides an additional layer of safety, activating within milliseconds of crash detection to prevent electrical hazards. This integration of safety systems has contributed to EVs achieving high ratings in standardized crash tests [7].

3.2. Statistical Safety Analysis and Performance Metrics

The statistical analysis framework employed descriptive statistics and comparative analysis methods to evaluate EV safety performance data. The methodology focused on frequency analysis of safety incidents and comparative risk assessment between electric and conventional vehicles. Key metrics included incident rates per 100,000 vehicles, with particular emphasis on fire safety statistics and collision avoidance effectiveness.

Safety performance data from extensive research indicates that electric vehicles demonstrate strong safety characteristics across various operational scenarios. According to a comprehensive analysis, electric vehicles have shown a significantly lower risk of fires compared to conventional vehicles, with EVs experiencing fire incidents at a rate of 25.1 per 100,000 vehicles compared to 1,529.9 per 100,000 for internal combustion vehicles. This substantial difference in fire risk can be attributed to the absence of flammable fuels and the robust safety systems inherent in EV design [8].

The research conducted on electric vehicle safety systems has revealed significant advancements in safety technology integration. Studies indicate that advanced driver assistance systems (ADAS) in electric vehicles have demonstrated effectiveness in preventing accidents. The combination of regenerative braking systems and traditional friction brakes

provides enhanced stopping capability, with testing showing that EVs can achieve deceleration rates comparable to or better than conventional vehicles. The integration of these systems with sophisticated control algorithms has contributed to improved overall vehicle safety performance [8].

3.3. Battery Safety Systems and Protection Measures

Battery safety represents a crucial aspect of electric vehicle design, with multiple systems working together to ensure safe operation. Modern electric vehicles incorporate sophisticated battery management systems that continuously monitor cell temperatures, voltage levels, and overall battery health. These systems can detect potential issues early and implement protective measures before they become critical. The battery packs are designed with multiple layers of protection, including structural reinforcement and thermal management systems that help maintain optimal operating temperatures [7].

The development of advanced battery protection strategies has been a key focus of electric vehicle safety engineering. Research has shown that modern battery management systems can effectively prevent thermal runaway events through early detection and intervention. These systems monitor multiple parameters simultaneously, including individual cell voltages and temperatures, allowing for rapid response to any anomalies. The implementation of these safety measures has contributed to the overall safety profile of electric vehicles, particularly in scenarios involving potential battery-related incidents [8].

3.4. Integrated Safety Features and Systems

The comprehensive safety approach in modern electric vehicles extends beyond basic crash protection to include advanced active safety features. These vehicles typically incorporate multiple layers of safety systems, from basic structural protection to sophisticated electronic safety measures. The integration of these systems is carefully designed to provide comprehensive protection while ensuring reliable vehicle operation. This systematic approach to safety has contributed to the strong safety performance of electric vehicles in both testing and real-world conditions [7].

Table 4 Comprehensive EV Safety Analysis [7,8]

Safety Category	Protection Type	Primary Function	System Integration
Structural Design	Passive Protection	Crash Energy Absorption	Foundational
Battery Protection	Active & Passive	Thermal Event Prevention	Core
High-Voltage Systems	Active Protection	Electrical Safety	Critical
Braking Systems	Active Safety	Vehicle Control	Operational
Monitoring Systems	Preventive Safety	Early Detection	Continuous
Conventional ICE	Traditional	Standard Protection	Baseline

4. Recommendations for EV Safety Enhancement

4.1. Manufacturing Sector Guidelines

The manufacturing sector must address critical safety considerations in electric vehicle production, particularly focusing on battery safety and electrical systems. Research indicates that lithium-ion batteries, which constitute the primary energy storage system in EVs, require specific safety protocols during manufacturing and operation. Manufacturers should implement enhanced safety measures for battery management systems that monitor voltage levels between 200V and 800V, typical in modern EVs. The development of more robust battery enclosures should focus on protecting against extreme temperature conditions, which can affect battery performance and safety during charging and operation [9].

Emergency response protocols require standardization across manufacturers to ensure consistent safety procedures. This includes the implementation of standardized high-voltage disconnection systems and clear marking of high-voltage components. Manufacturers should also focus on developing improved thermal management systems that can effectively maintain battery temperatures within safe operating ranges, particularly during fast-charging operations where thermal loads are highest [9].

4.2. Regulatory Framework Recommendations

The regulatory landscape for electric vehicles must evolve to address specific safety requirements through comprehensive standards. Key standards such as ISO 6469, which addresses safety specifications for electrically propelled road vehicles, should be universally adopted and enforced. Regulatory bodies should ensure compliance with standards like ECE R100, which specifically addresses battery electric vehicle safety, including requirements for protection against electric shock and safety requirements for rechargeable energy storage systems [10].

Data collection mechanisms should be enhanced to track EV-specific safety metrics effectively. This includes implementing standardized reporting protocols for incidents involving electric vehicles, particularly those related to battery thermal events or electrical system malfunctions. Regulators should establish clear guidelines for testing and certification of EV charging systems, ensuring compliance with standards such as IEC 61851 for electric vehicle conductive charging systems [10].

4.3. Consumer Safety Awareness

Consumer education plays a vital role in ensuring safe EV operation. Understanding proper charging protocols is essential, as research has identified charging-related incidents as a significant safety concern. Consumers should be educated about the importance of using certified charging equipment that complies with standards, such as SAE J1772 for AC charging and CHAdeMO or CCS for DC fast charging [9].

The importance of regular maintenance and inspection cannot be overstated in ensuring EV safety. Consumers should be aware of the specific maintenance requirements for electric vehicles, including regular inspection of high-voltage components and battery systems. Understanding warning indicators and proper response procedures for potential safety issues is crucial for safe vehicle operation [10].

4.4. Implementation Framework

The successful implementation of safety recommendations requires coordination between manufacturers, regulators, and consumers. Manufacturers must comply with international standards such as IEC 62660 for secondary lithium-ion cells for electric vehicle propulsion and IEC 61980 for electric vehicle wireless power transfer systems. These standards provide crucial guidelines for ensuring safety in both vehicle design and operation [10].

5. Future Research Directions in Electric Vehicle Safety

5.1. Emerging Research Priorities

The electric vehicle industry is experiencing significant transformation, with the Indian EV market projected to grow at a CAGR of 49% between 2022 and 2030. This rapid growth necessitates focused research across multiple domains of vehicle safety and performance. The evolving landscape of electric mobility, particularly in emerging markets, has highlighted the need for comprehensive research into safety systems that can adapt to diverse operating conditions and usage patterns [11].

5.2. Long-term Safety System Reliability

Research into the long-term reliability of EV safety systems must address the challenges presented by varying environmental conditions and usage patterns. The current focus includes studying the impact of fast charging on battery longevity, particularly as charging infrastructure expands to support growing EV adoption. With India's charging infrastructure projected to grow by 2.5x by 2030, understanding the relationship between charging patterns and safety system degradation becomes increasingly critical for sustained safe operation [11].

5.3. Battery Technology Advancement

The advancement of battery technology remains a central focus of future research directions. Current research indicates that lithium-ion batteries in EVs typically maintain operational safety within temperature ranges of 20-45°C. Future studies must address the challenges of maintaining these safety parameters while improving energy density and reducing costs. The development of enhanced thermal management systems is particularly crucial for regions experiencing extreme temperature variations [12].

5.4. Safety System Integration

The integration of multiple safety systems presents complex challenges that require continued research attention. Current studies focus on the development of comprehensive battery management systems that can monitor and control multiple safety parameters simultaneously. Research priorities include improving the response times of emergency shutdown systems and enhancing the accuracy of thermal event prediction algorithms. These developments are particularly crucial as EVs integrate more advanced autonomous features and higher-capacity battery systems [12].

5.5. Charging Infrastructure Safety

Future research must address the safety implications of expanding charging infrastructure. With rapid charging technologies becoming more prevalent, understanding the impact of high-power charging on battery safety and longevity becomes increasingly important. Research indicates that thermal management during fast charging remains a critical safety consideration, particularly as charging powers continue to increase beyond current levels [11].

5.6. Environmental Impact and Safety

Research into the environmental factors affecting EV safety systems has become increasingly important. Studies must address how varying climate conditions impact battery performance and safety systems, particularly in regions with extreme temperature variations. This includes understanding how humidity, temperature fluctuations, and atmospheric conditions affect both battery performance and the effectiveness of safety systems [12].

5.7. Advanced Material Research

Future research directions in EV safety must include the development of advanced materials for battery protection and thermal management. Current studies focus on materials that can enhance thermal conductivity while maintaining structural integrity under extreme conditions. This research is particularly relevant for improving battery enclosure designs and developing more effective thermal management systems [12]

6. Conclusion

Electric vehicles demonstrate compelling safety advantages through their inherent design characteristics and advanced protection systems. The lower center of gravity, enhanced crumple zones, and sophisticated battery management systems contribute to superior crash protection and reduced fire risk compared to conventional vehicles. Leading manufacturers continue to advance safety technologies while expanding production capacity and geographic reach. The regulatory landscape evolves to address EV-specific safety requirements, with standards development focusing on battery protection, charging safety, and emergency response protocols. Consumer education remains vital for maximizing safety benefits, particularly regarding proper charging procedures and maintenance requirements. The path forward emphasizes enhanced battery technologies, improved thermal management systems, and integrated safety features that adapt to diverse operating conditions. As the electric vehicle market expands globally, continued focus on safety innovations and standardization will further strengthen the position of EVs as secure and reliable transportation options.

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