Institute of Transport Economics
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ENGLISH **Summary**

Machine learning advancements for vehicle safety systems

Review of technical foundations and applications

TØI Report 2069/2024 • Authors: Anders Kielland, Anna Piterskaya, Christian Weber • Oslo • 25 pages

- Development in the Machine Learning (ML) field has transformed vehicle safety systems.
- ML relies on diverse data sources, including vehicle sensors, traffic flow and infrastructure data, weather conditions, and historical crash reports.
- Main ML applications in vehicle safety include:
    - Accident prediction analysis, leading to improved road condition.
    - Real-time adaptive traffic management, optimizing traffic flow.
    - In-vehicle advanced driver assistance systems that support safe vehicle operation.
    - Driver behaviour and fatigue monitoring, detecting drowsiness and distraction.
    - Identification of mechanical failures before they cause accidents.
- Autonomous vehicle systems, improving perception, planning, and decision-making.
- Challenges include the "black box" problem, bias in ML models, privacy concerns, and regulatory constraints, necessitating explainable AI and stronger cybersecurity measures.

As ML rapidly advances, its integration into modern vehicle safety applications has increased, shifting from traditional rule-based systems to more data-driven and adaptive technologies. With the growing adoption of ML in sensor-based technology, predictive analytics, real-time traffic control, driver behavior monitoring, and autonomous driving, these innovations are significantly enhancing road safety and mobility. Key findings show that ML improves accident prevention, optimizes traffic management, and advances driver assistance technologies.

This report provides an overview of the latest advancements in the use of ML in vehicle safety. It covers the methodological foundations, the integration of applications in vehicle safety, and the ethical and regulatory challenges associated with ML-driven systems.

ML is a data-driven process and often relies on high-quality and compressive datasets to function effectively. Data sources include in-vehicle sensor data from Light Detection and Ranging (LiDAR) technologies, radars, cameras, Global Navigation Satellite Systems (GNSSs), and accelerometers, as well as traffic and infrastructure data from surveillance cameras and smart city platforms. Environmental data are recorded via satellite imagery, weather stations, and internet-of-things sensors. Connected vehicle communication, known as Vehicle-to-Everything (V2X), further enable real-time information sharing between vehicles and infrastructure. Proper security and processing efficiency are essential to fully leverage the data sources in ML capabilities in vehicle safety systems.

ML applications in vehicle safety includes a broad spectrum of approaches and methodology, and are used in predictive modelling, anomaly detection, and adaptive decision-making. For example, real-time proactive accident prediction methods leverage ML to assess crash risks, road conditions, and traffic patterns, allowing dynamic speed limits, traffic signal adjustments, and lane direction changes, thus, optimize for a safer traffic flow. Advanced Driver Assistance Systems (ADAS) use ML for collision avoidance, lane-keeping, adaptive cruise control, and emergency braking. Predictive maintenance and vehicle status monitoring help detect mechanical failures, tire wear, and brake issues before they pose safety hazards. The advancement in Neural nets are fundamental in sensor fusion techniques, and object detection and perception in complex driving environments. Driver behaviour and fatigue monitoring rely on ML-based facial recognition, physiological sensors, and steering pattern analysis to detect distraction or drowsiness. Further, personalized safety recommendations analyse individual driving styles to provide tailored feedback, using gamification to encourage safer habits. Finaly, ML will be essential for autonomous vehicle safety, as self-driving cars must operate in a highly dynamic and complex environments, where ML approaches appear to be the only viable solution.

Despite the advancements, ML-driven vehicle safety faces numerous challenges such as data privacy, cybersecurity risks, lack of transparency, and regulatory barriers. The “black box” nature of ML models necessitates new methodologies for decision verification and trust. Bias in ML outcome can result in unjust evaluations of responsibility. Additionally, regulatory frameworks must evolve to align AI-based safety decisions with ethical principles and robust protection measures.