Sensor Technology in Intelligent Transportation Systems - Lane Departure Warnings

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ABSTRACT

This study offers a thorough analysis of the vital role that mobility plays in economic growth, especially in emerging nations where the proliferation of vehicles and the deterioration of infrastructure coexist. In order to synthesise previous research on the topic and determine if Lane Departure Technology is beneficial in reducing traffic accidents, the study used a scoping review methodology. In order to analyse the significance of the technology adoption in the reduction of detrimental effects that transportation activities have on the environment and society, the study emphasises the necessity of Smart Transportation Systems (STS), sometimes referred to as Intelligent Transportation Systems (ITS). According to the study, a variety of sensors—including infrastructure-, vehicle-, and device-based sensors—are critical to the efficiency of ITS. These sensors gather data in real time for traffic control and safety enhancements. A key component of this system is Lane Departure Warning Systems (LDWS), which use sensors like cameras, Lidar, or radar to track lane locations and issue alarms, greatly enhancing road safety. However, the result points out a number of obstacles to the broad use of ITS and LDWS, including sensor limitations, environmental considerations, high prices, and privacy issues, especially in poor nations. Notwithstanding these difficulties, LDWS has been demonstrated to improve overall vehicle performance and traffic flow by raising driver awareness and lowering accident rates. Promising improvements in lane recognition accuracy and driver behaviour prediction are possible with the incorporation of AI and machine learning into LDWS. In order to create safer and more effective transport systems, this study emphasises the significance of ongoing investment and innovation in ITS and LDWS.

Keywords: Intelligent Transportation System (ITS), Sensor, Artificial Intelligence (AI), Smart Transportation System (STS), Transportation

INTRODUCTION

According to Osoja et al. (2022), transportation is the movement of products, services, or people from one place (the origin) to another (the destination). This can be done by air, rail, sea, or road. Any economy needs transport, which is also a typical tool for socioeconomic development (Oyeyemi et al., 2025). This is significant in a global economy as the flow of people and things, including information and communication technology, is related to economic possibilities (Olasokan and Toki, 2021). Vehicles are becoming increasingly common in both urban and rural regions as emerging countries' populations grow rapidly and living conditions improve.

The number of vehicles per capita (VpC) is a well-known metric used to track the progress of this phenomenon. The development of transport networks has been critical to the economic growth of all countries. This exceptional growth in Vehicles Per Capita (VpC), which is common in cities in developing nations throughout the world and is linked to infrastructure decline in those countries, is out of date, and investment in its renewal lags far behind VpC. This problem is exacerbated by geopolitical factors because 10 of the 15 most populous landlocked countries are in Africa; thus, they lack access to the sea, and with a total population of 300 million, the countries rely heavily on land and air transport to sustain economic growth (Casal and Selamé, 2015).

In today's linked world, the Smart Transportation System (STS) is critical for addressing the environmental issues related to transportation operations. The STS is the standard for developing next-generation technologies. Qureshi and Abdullah (2020) describe the STS as a distinct discipline that works in a variety of fields, including the transportation industry, which encompasses operations, policy, control techniques, control systems, and transportation management strategies. The remuneration paid for STS missions varies substantially. The introduction of STS has the potential to drastically reduce risks linked with high accident rates, traffic congestion, carbon emissions, and air pollution.

An Intelligent Transportation System (ITS) is one component of Smart City Transportation development. In contrast, many developed economies throughout the world have used ITS to increase safety and dependability, traffic flow, travel speeds, and passenger happiness across all forms of transportation. An intelligent transport system is now widely employed in industrialised nations to avoid and decrease traffic accidents, thanks to several research projects and efforts. In recent decades, as global urbanisation has progressed, an increasing number of people have moved to cities. The expansion in city population has undoubtedly caused a number of internal challenges, including land usage and supply-demand mismatch. In response to these concerns, smart cities have received a lot of attention to explore sustainable development using sophisticated technology and environmental principles to alleviate recognised issues.

Smart city development thus entails integrating Intelligent Transportation Systems (ITS) into the city transportation system, to apply information, communication, and sensor technologies to vehicles and transportation infrastructure in order to provide real-time information to road users and transportation system operators to help them make better decisions (Meneguette et al., 2018). ITS utilises electronic information technology to optimise traffic concerns. The notion of intelligent transport systems was initially proposed in 1991 (Bazzan & Klügl, 2022). Over ITS has grown rapidly over the last decade as a result of advances in computer speed, mixed with sensors that capture a wide range of data from transportation infrastructure.

ITS enables the precise, real-time estimate of present and future traffic conditions, allowing for traffic forecasting and prediction. ITS enhances transportation system mobility and efficiency by reducing congestion while also boosting traveller information and convenience. Furthermore, ITS enhances public transit and promotes sustainable development. ITS also increases road safety and security. The development of ITS surely improves citizens' travel experiences while highlighting the advantages of smart travel.

A STS is made up of three major components: the transportation management system, which includes regulatory bodies and traffic rules; the primary transportation infrastructure, which includes cars, buses, and road networks; and, most importantly, the integration of information and communication technology (ICT), which includes the Internet, cellular networks (4G/5G), cloud/edge computing, and the Global Positioning System (GPS). These proposals all have one thing in common: they incorporate ICT into transportation networks. The Internet of Things (IoT) enables the combination of data from roads, traffic controllers, and cameras with real-time traffic movement information from various modes of transportation, including vehicles, buses, boats, trains, and aeroplanes (Hilmani,2020).

In ITS, the use of numerous sensors is the most fundamental instrument for building the overall framework. The first phase in information collection is frequently to detect and analyse continuous or discrete data using sensor recognition, followed by additional management and decision-making utilising communication technology, electronic control technology, and so on. Designing and placing multiple sensors reasonably can increase data collection accuracy while also lowering energy and maintenance expenses.

Scholars have used computer technology to enhance sensor safety and accuracy. Cao et al. (2021) were the first to employ machine learning to investigate the safety of self-driving cars based on LiDAR perception. However, the variety of in-vehicle sensors results in constantly rising data gathering, necessitating increasingly powerful computers and data processing technology. Furthermore, diverse sensor manufacturers' production and application standards provide substantial challenges to sensor development; this requires close communication and collaboration between investors and traffic administrators.

ITS coverage is determined by the deployment of sensors on roadways. Cameras and laser speed sensors can be put in urban traffic networks to collect real-time road conditions for specific sections, allowing traffic management to learn about traffic flow features and trends over time. In parking lots, numerous types of sensors can monitor car identifying information and outwardly show the utilisation status. Road sensors can be classified as environmental sensors or data sensors based on the type of data collected. Environmental sensors are generally used to monitor road conditions such as weather, ice, and damage. They assist in cutting road maintenance expenses and human resource usage.

Data sensors offer direct information about the traffic network to transportation management departments and users, laying the groundwork for the development of intelligent transportation systems. Odat et al. (2017) suggested a novel sensing device that combines passive infrared (PIR) sensors with ultrasonic rangefinders to monitor vehicles, estimate speeds, and identify vehicle types. Researchers have significantly improved sensor accuracy while substantially reducing mistakes. ITS still has a fundamental challenge, though, which includes the effective integration of data from a variety of sensor types. Additionally, this study is important and will likely necessitate future advances.

The hectic pace of many cities throughout the world makes people look for solutions to problems relating to transportation. Intelligent transport systems have been put in place by a number of developed nations, including the US, UK, Germany, and Singapore, to improve the speed and convenience of transit within their borders. Nevertheless, STS is not widely accepted in underdeveloped nations, as the majority of them have not yet completely embraced the idea. Only in their big cities have a few nations, like Nigeria and a few other African nations, started to use this approach.

A range of technologies is used by Intelligent Transportation Systems (ITS) to enhance traffic efficiency, lessen congestion, and improve road safety. Lane departure warning (LDW) systems are one of these technologies that are essential for lowering accidents brought on by sleepiness or inattention on the part of drivers. Thus, the purpose of this study is to investigate sensor technologies in intelligent transportation systems, specifically focusing on Lane Departure Warning. To achieve the aim, underlisted objectives were adopted:

1. To examine the type of sensors, technologies used in the Lane Departure Warning System (LDWS)

2. The effectiveness of the sensors, technologies in the mitigation of Road accidents

LITERATURE REVIEW

Evolution of Intelligent Transportation System (ITS)

The development of Intelligent Transportation Systems (ITS) is a reflection of technological breakthroughs and a growing emphasis on enhancing the sustainability, safety, and efficiency of transportation. As a result, the 1960s and 1980s are when this transformation began. Controlling traffic signals and a simple monitoring system using timers and sensors were the main goals of the first attempt. Data challenges during the initial acceptance period prompted the integration of electronics in the 1980s and 1990s, which in turn led to the automated collection of traffic data, the development of computerised systems for incident management and traffic signal control, and the installation of electronic signs to inform drivers in real time about road closures and traffic conditions.

In order to enable automobiles to connect with traffic signals and other infrastructure, communication technologies were integrated during the 1990s and 2000s as a result of the heavy traffic in Europe and the USA at this time. This system employs GPS and mobile technologies to provide drivers with access to real-time traffic information through applications and navigation systems. Advanced technology was introduced between the 2000s-2010s, popularly known as the Intelligent Transportation System (ITS), which integrates information, communication, control, computer technology, and other modern technologies to deploy a real-time, flexible, and efficient transportation management system. The concept was introduced by the United States and Europe in the 20th century. However, the technology was confronted by some challenges in its implementation, like integration of heterogeneous data from various sources, implementation cost, unavailability of expertise in this area, and also the dissemination problem.

Nowadays, the technology has been globally accepted, and it has spread to other countries such as Japan, Singapore, Korea, and some European countries. From 2010 to the present, the technology attention is now more on sustainability and safety, which involves the integration with environmental monitoring to reduce emissions and promote eco-friendly transportation. Autonomous Vehicle (AV) has also been introduced, which allows the development of self-driving technology and its integration into existing transportation systems. It promoted a shift towards integrating various transportation modes into a single accessible service platform, enhancing user convenience. The growing use of cloud computing and next-generation cellular networks, such as fifth generation (5G) or beyond 5G, have made this possible. These technologies are used differently in different networks.

Sensors used by the Intelligent Transportation System

The relationship between the sensing capabilities of Intelligent Transportation Systems (ITS) and the range and depth of services they offer is crucial for creating a comprehensive and effective transportation ecosystem. The categorisations from the sensor level are as follows:

1. Vehicle-based sensors,
2. Infrastructure-based sensors, and
3. Device-based sensors.

Vehicle-based sensors: According to Guerrero-Ibanez, Zeadally, and Contreras-Castillo (2018), vehicle-based sensors are a broad category of devices integrated into automobiles to gather and analyse different types of data. These provide information on the environment around the vehicle, road conditions, and other environmental factors. Examples of these include LiDAR, cameras, temperature, humidity, and air quality sensors. They make it possible for functions like pollution tracking, weather monitoring, lane departure alarms, and object detection. Speed, braking, engine, fuel consumption, pollution sensors, energy meters, cameras, and LiDAR are examples of vehicle-specific sensors that track performance, energy efficiency, emissions, and energy consumption. By enabling energy management, environmental compliance, fuel efficiency assessments, and vehicle diagnostics, these sensors increase the uptake of zero-emission vehicles and lessen dependency on fossil fuels.

Infrastructure-based sensors: An Intelligent Transportation System (ITS) uses infrastructure-based sensors, which are a group of gadgets positioned inside the infrastructure to carry out certain tasks (Soga and Schooling, 2016). These sensors may monitor road conditions; for example, pavement quality analysers and surface temperature sensors are put immediately on the road to constantly analyse pavement conditions, detect cracks and potholes, and track temperature swings. To gather vital vehicle data like identity, classification, speed, and weight, vehicle presence and behaviour sensors—including weigh-in-motion systems, LiDAR, and license plate recognition cameras—are positioned at traffic signals, overhead structures, or roadside gantries. These sensors enable autonomous vehicle (AV) technology and enhance traffic enforcement and control.

Device-based sensors: Personal electronics like smartphones, wearables, and connected gadgets are equipped with device-based sensors. These sensors gather a range of information, such as position from GPS sensors, motion from gyroscopes and accelerometers, light and proximity data, and environmental data like humidity and temperature. Visual data may be gathered using cameras and other image sensors. Real-time traffic monitoring, travel analysis, personalised navigation, crowd sensing for road conditions, and incident reporting are just a few of the applications for the data collected by these sensors in Intelligent Transportation Systems (ITS). Device-based sensors can also record user-specific information, such as biometrics, for health and driving monitoring. They make real-time data collection and personalised services possible.

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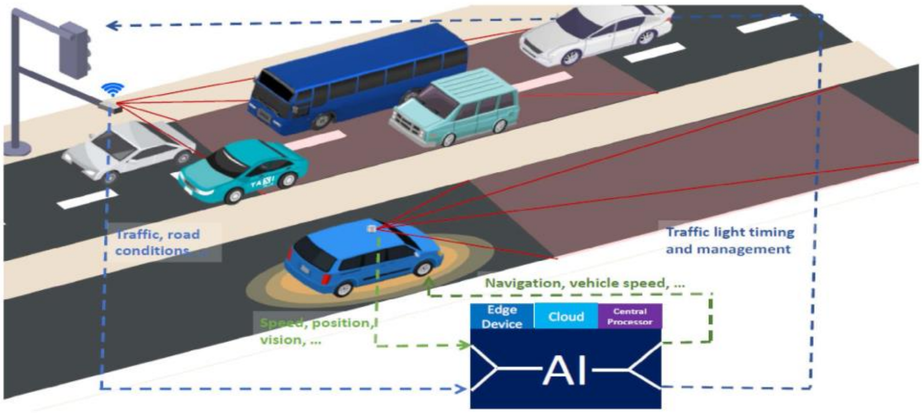
Role of Data in Intelligent Transportation Systems

Travel behaviour patterns may be analysed using location data to improve transportation services, promote shared mobility choices, and minimise the number of individual car journeys. Furthermore, through feedback and recommendations, these sensors can encourage user involvement and behavioural change, resulting in more energy-efficient transportation choices. An algorithm on an edge device, the cloud, or a central processor, which might be a deterministic algorithm or artificial intelligence, examines the supplied data and returns navigation suggestions for each car, while traffic lights get timing and management directives. Such a situation might immediately pave the way for sophisticated traffic management tactics like cooperative adaptive cruise control (CACC) and smart junction management, resulting in a large increase in EER.

Furthermore, intelligently changing traffic signal timings and vehicle routing recommendations can decrease idle time at crossings (as seen in Figure 1). Reduced idle time results in lower fuel use and hence lower pollution levels. Excessive braking and acceleration may be avoided with appropriate vehicle speed and following distance adjustments based on current and anticipated traffic conditions. This improves traffic flow and lowers fuel consumption. Emissions are quickly reduced when less gasoline is used. Additionally, by removing the need for abrupt acceleration and stopping, which wastes fuel and worsens vehicle wear and tear, these systems encourage more comfortable driving habits. By promoting smoother driving and more constant speeds, these gadgets increase energy efficiency and reduce pollution.

Figure 1: Hybrid sensing collaboration.



Source: Omar Rinchi, Ahmad Alsharoa1 and Ibrahem Shatnawi, and Anvita Arora, 2024

Overview of Lane Departure Warning Systems

Lane Departure Warning Systems (LDWS) are cutting-edge safety features that notify drivers when their cars inadvertently stray from their assigned lanes. This is especially critical to preventing accidents caused by inattentive or sleepy drivers. LDWS usually alerts the driver by means of tactile, visual, or audible input. Sensors, including lidar, radar, and cameras, are the main tools used by LDWS to keep an eye on road lane markers. The system examines how the car is positioned in relation to these lane markers.

The evolution of LDWS over time is a reflection of improvements in safety regulations, driver aid systems, and automotive technology. These developments initially surfaced in academic and research contexts in the early 1980s, with an emphasis on the potential to improve vehicle safety. Its early usage is distinguished by the use of basic image processing methods for lane marker recognition. The first commercial systems were introduced in the 1990s as a result of additional technology advancements, mostly in luxury automobiles. For the purpose of monitoring lane markers, these devices employed crude camera technology. In order to give the driver input, it also resulted in the integration with the Anti-Braking System (ABS).

The 2000s saw more advancements, including better image processing algorithms that increased lane recognition accuracy and enabled greater performance across a range of driving circumstances. Additionally, there was a greater emphasis on car safety, which prompted regulatory agencies to look at lane departure warning systems and encourage automakers to use them. By the 2010s, Lane Departure Warning (LDWS) had become a commonplace feature in many new cars, especially luxury and mid-range models. As the systems developed, they added new features like lane keeping assistance, which helped drivers navigate their cars back into their lanes while also warning them. Other advanced driving assistance systems (ADAS), such as adaptive cruise control and collision avoidance systems, were further integrated with the LDWS.

Since the 2020s, LDWS has changed to include AI and machine learning. LDWS's capacity to precisely identify lane markings and forecast driver behaviour is being improved by the application of AI and machine learning. LDWS technologies are being included in autonomous driving systems as cars become more fully automated, enabling smooth operation on both urban and interstate roadways. Putting more emphasis on usability and driver experience while making sure that notifications are clear and unobtrusive.

Functionality of Lane Departure Warning Systems

LDWS has played a pivotal role in transportation management. The technology is often integrated with other safety features, such as lane keeping provides comprehensive support to drivers in the following ways:

1. **Accident Prevention**: LDWS significantly reduces the risk of accidents caused by unintentional lane departures. Research indicates that LDWS significantly reduces the likelihood of lane departure-related accidents. Studies have shown that vehicles equipped with LDWS technology experience lower accident rates compared to those without.
2. **Increased Driver Awareness**: The alerts encourage drivers to stay attentive and focused on the road.
3. **Enhanced Safety for Vulnerable Road Users**: By preventing lane drift, these systems help protect pedestrians and cyclists.

Operational Mechanism of LDW Systems

The operational mechanism of LDWS typically involves the following steps:

1. **Data Acquisition**: Data plays a significant role in the operation of LDWS; Sensors gather data about the vehicle's position, speed, and the surrounding environment, which are then used for reference.
2. **Lane Detection**: The vehicles have sensors installed on them. The sensor processes available data to identify lane markings and assess whether the vehicle is staying within its lane.
3. **Driver Alert**: The system detects an unintended lane departure; therefore, it activates an alert mechanism on the vehicle, such as a visual warning on the dashboard, auditory signals, or steering wheel vibrations.

Types of Sensors in Lane Departure Warning System

Lidar Sensors

An alternative to camera-based detection in LDWS is the use of radar and Light Detection and Ranging (Lidar) sensors. While the Radar Sensors can measure the distance and speed of adjacent cars and help detect lane departures by studying vehicle movement patterns, the Lidar technology employs laser pulses to produce a 3D image of the surroundings, providing great precision in lane boundary identification.

Camera-based systems

Camera-based sensors are one of the most common technologies used in LDW systems. Camera-based sensors in LDWS are essential components that help monitor a vehicle's position relative to lane markings on the road. Camera-based sensors in an LDWS use a front-mounted video camera to detect lane markings on the road. Algorithms then analyse the camera's continuous video feed to monitor the vehicle's position within its lane. If the system detects the vehicle drifting out of its lane unintentionally (without a turn signal), it provides a warning to the driver, which can be visual, auditory, or a steering wheel vibration, prompting the driver to steer back into the lane.

Radar Sensors

Radar uses radio waves to detect the proximity of the vehicle and the speed of the object. The system is less common for LDWS; they can complement other sensor types in providing a more comprehensive detection system.

Sensor Modalities for Lane Detection

1. **Camera-Based Sensors:** The camera-based sensor utilises optical imaging to capture road conditions and lane markings. It works best under good weather conditions, as it enables it to capture high-resolution images and provide detailed information about lane markings and the surrounding environment, and it is cost-effective and widely available in consumer vehicles. However, one of the limitations of the sensor is performance can degrade in low-light conditions, adverse weather (e.g., rain, fog), or when lane markings are worn or obscured.

2. **LIDAR (Light Detection and Ranging):** LIDAR creates a three-dimensional map of the surroundings by measuring the distances between objects using laser pulses. Because it can identify lane borders even in situations when markers are not evident, it is incredibly precise, thorough, and efficient in a variety of weather conditions. However, its usage is restricted due to its high cost and the complexity of integration into automobiles.

3. **Radar:** Radar is more effective in low visibility situations (such as fog or rain) and is less impacted by illumination than cameras since it employs radio waves to determine an object's position and speed. The sensor's poorer resolution in comparison to cameras and LIDAR is its limitation. As a result, it is more frequently employed for speed and distance measurements than for lane markers.

Lane Detection Methods

1. **Convolutional Neural Networks (CNNs):** A class of deep learning models specifically designed for processing grid-like data, such as images. It can automatically learn features from raw pixel data, improving accuracy in diverse conditions. It is effective for detecting complex lane shapes and occlusions. Its limitation is that it requires large amounts of labelled data for training, and is computationally intensive and may necessitate specialised hardware (e.g., GPUs).

2. **Semantic Segmentation Networks (e.g., U-Net, SegNet):** networks built for pixel-by-pixel classification tasks, which provide a thorough comprehension of the picture. Distinguishes between various road elements and offers accurate lane marker division. It works well in a range of weather and lighting settings. Its training needs a variety of datasets and can be resource-intensive.
3. **Recurrent Neural Networks (RNNs):** Networks that are helpful for temporal analysis and can analyse data sequences. It can improve tracking over time by taking temporal information into account for lane detection. However, compared to feed-forward networks, it is longer to train and more complicated.

Current Lane Detection Methods

Recently, with the help of technological advancement and modelling, LDWS has evolved to include the underlisted, just to mention a few:

1. **Semantic Segmentation:** i. The method allows for accurate lane marker recognition by giving each pixel in an image a class label. U-Net is the name of the algorithm that is employed. Its design, which records both spatial and contextual information, makes it useful for lane detection even though its primary use is biological picture segmentation. Additionally, Deep Lab was released; it improves segmentation accuracy by capturing multi-scale context using atrous convolution. The segmentation approach can distinguish between lanes and other road characteristics because of its great accuracy in recognising lane markers, including intricate curves and forms. The technique is computationally demanding and requires a sizable dataset for training to maximise efficiency.

2. **Anchor-Based Detection:** i. This method recognises lane lines in photos by using pre-established anchor boxes. In order to forecast lane lines using the characteristics that are derived from the picture, the approach necessitates dividing the images into a grid and placing anchors at certain locations. This approach adapts quicker R-CNN algorithms for lane identification. The system can adjust to various lane arrangements and is effective at recognising numerous lanes in a single pass. The approach may have trouble with uneven lane shapes or missing markers since it heavily relies on the quality of anchor box placement.
3. **Curve-Based Line Models:** i. These models represent lane borders as curves rather than straight lines by using mathematical functions. Polynomial or spline functions are used to depict lane markers. To accommodate different road geometries, the road curvature is computed. In comparison to linear models, the approach may give smoother lane prediction and is hence more appropriate for curving roads and complicated lane designs. When compared to a linear model, it can offer a smoother lane prediction. However, for the model to work well, an accurate initial estimate of lane location is necessary. Higher-order polynomials may become more computationally difficult.
4. **Hough Transform:** A traditional image processing method for identifying straight lines in pictures is the Hough transform. These methods convert the image into a parameter space in which lines may be recognised according to their distances and angles. The method has a minimal computing cost and is straightforward and efficient for identifying distinct lane markers. The method is less successful for curving lanes and has trouble detecting straight lines due to noise and abnormalities in lane markers.
5. **Optical Flow:** ii. This technique tracks lane markers by analysing object motion between successive frames. It is capable of estimating lane continuity by computing the displacement of lane characteristics over time. The technique improves resilience to occlusions and transient impediments and works well in dynamic contexts where lane markers may be altered. The technique needs favourable starting circumstances and is sensitive to changes in illumination. In situations where speed is high, performance may suffer.
6. **Machine Learning Approaches:** To categorise pixels or picture areas as lane or non-lane, the method uses conventional machine learning techniques, including Support Vector Machines (SVM) and Random Forests. Compared to deep learning techniques, it may be learnt on fewer datasets and is frequently simpler to use and comprehend. In complicated contexts, the method is less precise than deep learning techniques, and feature engineering—which can be labour-intensive—is necessary.

Lane Detection Algorithm

Classical vs. Deep Learning

1. **Performance:** Deep learning algorithms generally outperform classical methods in complex environments, particularly in varied lighting and weather conditions.
2. **Data Requirements:** Classical algorithms require less data and are easier to implement, while deep learning methods require large datasets for effective training.
3. **Robustness:** Deep learning models show greater robustness to variations in lane markings and environmental conditions.
4. **Computational Resources:** Classical algorithms are less resource-intensive, while deep learning models typically require significant computational power.

LDWS Integration Approaches

LDWS can be integrated into a vehicle safety system to enhance overall safety and driving experience, adopting the following approaches:

1. **Lane Keeping Assist (LKA):** This method improves lane-keeping reliability by sharing data from the same sensor (camera), resulting in a smooth experience. When the car veers out of its lane, it alerts the driver. By automatically guiding the car back into place (the lane) if the driver does not react, LKA goes one step further.

2. **Adaptive Cruise Control (ACC):** When LDWS is combined with ACC, the system may automatically adapt to the speed of the car in front of it while modifying the speed based on traffic flow and lane position. This keeps the car in its lane and at a safe distance.
3. **Collision Avoidance Systems (CAS):** CAS integrates collision avoidance with LDWS data. The car can react quickly and more accurately in circumstances where veering out of the lane may result in an accident. When the system detects possible crashes, it applies the brakes or sounds a warning as a preventative measure.
4. **Blind Spot Monitoring (BSM):** BSM improves lane change safety by warning drivers of cars in their blind areas when they try to change lanes while LDWS is engaged. In order to stop dangerous moves, it may also send out extra alerts if a car is in the blind spot.
5. **Traffic Jam Assist (TJA):** In traffic bottlenecks, LDWS can help by making sure the car stays in its lane. By automatically regulating direction and speed, the device assists drivers in navigating through heavy traffic.
6. **Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) Communication:** Vehicles may connect with infrastructure (such as traffic lights) and with each other thanks to V2V and V2I technologies. By offering data about impending road conditions, lane closures, or traffic patterns, the technological integration can improve LDWS's efficacy.
7. **Driver Monitoring Systems:** These systems keep an eye on drivers' conduct and attentiveness, warning if they exhibit any indications of inattention or tiredness. The driver monitoring system can take control by triggering additional safety features or sending out more intense warnings if the driver is not responding to LDWS notifications.

Impact on overall vehicle performance and safety

Lane Departure Warning Systems (LDWS) have a significant impact on overall vehicle performance and safety. Here’s an overview of their effects:

1. **Improved Driver Awareness:** By giving drivers visual and audio warnings when they inadvertently stray from their lane, LDWS improves driver visual awareness and helps them maintain concentration on the road, which makes our roadways safer. It also helps minimise distraction; LDWS enables the driver to concentrate better on driving responsibilities, particularly during lengthy trips or in boring situations.
   Accident Prevention: Lane-Drift Accidents are less common because of LDWS. According to studies, lane-departure accidents—which are frequently brought on by driver weariness or distraction—can be considerably decreased by LDWS (Riexinger et al., 2019).
2. **Complementing Other Safety Systems:** LDWS can offer a multi-layered safety strategy, significantly reducing the chance of accidents when combined with other safety features like blind spot monitoring and collision avoidance.
   Better Vehicle Control: LDWS aids in maintaining vehicle stability and control, particularly in inclement weather, and it helps notify drivers of lane deviations. The car may actively direct itself back into the lane when equipped with desired technology, such as Lane Keeping Assist (LKA), improving control and lowering the chance of losing it.
3. **Greater Driving Confidence:** LDWS also boosts driving confidence, which can help novice and inexperienced drivers by giving them more encouragement and certainty when they're behind the wheel. Therefore, knowing that the technology may help maintain lane position increases driver confidence while doing longer trips.
4. **Data Collection and Analysis:** Manufacturers and researchers may evaluate driver behaviour and enhance future safety systems by using LDWS to gather data on driving trends. The input from LDWS may be used to improve algorithms and the system's efficacy, which will support continued advancements in car safety technology.
5. **Notable Decrease in Traffic Congestion:** Lane departure incidents are less common due to LDWS. This can help improve traffic flow and lessen accident-related congestion. Consequently, traffic efficiency and safety will increase, and there will be less downtime on the roads.

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METHODOLOGY

Framework for Data Gathering and Scope

The study used Arkey and O'Malley's scoping review methodological framework, which served as a guide for creating protocols for scoping reviews and meta-analyses. Examining articles and other resources that are suitable for the study project requires a methodical approach. Relevant potential sources were looked up between 2010 and 2025. The researchers created a thorough search strategy in order to simplify and streamline the search procedure. The following keywords were incorporated into the search strategy: lane departure technology, transportation, intelligent transportation system, and sensor technology.

Framework for the Analysis

Using Arksey and O'Malley's Framework, the researchers conducted a scoping assessment of sensor technologies in intelligent transportation systems (ITS), with a special emphasis on lane departure warnings (LDWs). The framework offers a methodical way to carry out scoping evaluations. There are four phases to this study. Below is a breakdown of the stages:

1. **Identifying the Research Question:** Clearly define what you want to explore regarding sensor technology and LDWs. The purpose of this research is the analyse the effectiveness and adoption of the technology.
2. **Identifying Relevant Literature:** Use databases to gather a comprehensive range of literature on the topic.
3. **Charting the Data:** The data collected was later charted into the following categories: Types of sensors, technologies used in LDWs, and the effectiveness in mitigating accidents.
4. **Collating, Summarising, and Reporting Results:** The analysis and summation of the findings, highlighting trends and gaps in the literature.

Data Charting Process

According to the JBI Manual for Evidence Synthesis, charting the results is an iterative process in which the charting table is constantly updated using a template designed for ease of reference and tracking. The important information graphic in each source comprises the following, as taken from JBI and revised by the researcher:

- Authors and year of publication
- Type of sensor technology used
- Study design/ methodology
- Effectiveness of the technology
- Limitations mentioned by the authors
- Recommendations

Synthesis of Results

A scoping review study is not considered complete until all materials have been effectively synthesised and presented in an understandable format. Thus, results synthesis is the act of arranging and summarising the findings from the included research. The study mapped existing literature and identified essential themes, ideas, and knowledge gaps. The synthesis process entails repetitive study of the literature and continuous refining of themes and concepts as new articles are evaluated. The method gives a wide overview and comprehension of the available literature, which may be used to drive future research, policy formation, and practice.

Presentation of Findings

The researcher synthesises the various sample data using the JBI Manual for Evidence Synthesis, focusing on the topic of "Sensor Technology in Intelligent Transportation Systems - Lane Departure Warnings." This synthesis summarises the findings from hypothetical studies and organises them into a structured format presented below:

S/No	Author(s)	Study Design	Sensor Tech.	Effectiveness	Limitation	Recommendations
1.	Tochukwu et al, 2024	Systematic Review	Camera-based sensor	It was effective for traffic management, driving assistance, and safety improvements at 65%	Challenges of implementing the technology in poor nations	There is a need for legislative frameworks and infrastructure investment.
2.	Guerrero-Ibáñez et al., 2018	Field survey/ Quantitative survey	Camera-based sensor	Ability to detect lane departure on a road with good lane marking	Inability to detect damaged infrastructure, such as blurry or erased transit lines Inadequate or, in some cases, inexistent traffic signals, fast object detection	There is a need to integrate other technologies and devices, such as data analytics, automated operation tools, decision-making tools, and social and mobile networks
3.	**Orie, 2022**	Quantitative approach	LIDAR	Effective in monitoring lane departure at 75% effectiveness	Inability to monitor or sense devices' ranges located on roads, vehicles, and transportation infrastructures.	Recommend the possible creation of numerous next-generation smart applications to enhance traffic management and safety in both current and future transportation systems.
4.	Balashanmugam et al., 2015	Observation study	LIDAR	Ability to detect lane marking under well-illuminated conditions at 85% effectiveness	Their performance strongly depends on illumination conditions.	In areas proposed for adoption, there should be proper illumination.
5.	Ankit Singh et al., 2025	Quantitative approach	Camera Based	Effective when the driver is not distracted, enabling a swift response into	The efficiency of these systems under critical distracted	The findings from the study highlight the positive influence of lane departure warning

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				action	driving conditions is a matter of concern.	systems on driver behaviour under distracted driving conditions. The study supported the idea of installing LDW systems in vehicles to enhance road safety.
6.	Scanlon et al., 2016	Field Survey	LIDAR	Effective at 70%	The effectiveness of these systems is highly dependent on roadway characteristics, such as lane markings and shoulder width.	The results suggest that modifying all roadway infrastructures to include lane markings and expanding roadway shoulder width.
7.	Sultana et al., 2016	Simulation study	Camera-based/ Radar	The system, an accuracy of lane detection is almost 96% in different environments.	This system is robust against noise and a high-speed algorithm. The driver assist system, which is used, is very efficient, low-cost cost and robust against noise.	Proposes a video-based driver assist system that alerts the driver with an audio alarm and visual message about lane departure, as well as tracks the specific vehicle using license plate extraction.

Source: Researchers' Output, 2025

A study by Tochukwu et al, 2024, a study on the integration of Advanced Sensors in Smart Transportation Systems: Enhancing Efficiency and Safety. The study involves a systematic review of various literature. The study examined the effectiveness of camera-based sensors on the efficiency and safety of motorists. The study adjudged that the technology was effective for traffic management assistance, and it helped to improve safety by 65%. The researchers identified the challenges of implementing the technology in poor nations because of their financial constraints. The research recommends a legislative framework and infrastructural investment in the technology for its effectiveness. Guerrero-Ibáñez et al. (2018) examined Sensor Technologies for intelligent transportation Systems. The study involves a field survey and a quantitative approach, where camera camera-based sensor was used. The authors acknowledged the ability of the camera to detect lane departure on roads with good lane marking, but have difficulty in detecting damaged infrastructure, such as blurry or erased transit lines. It also has challenges in cases where there are nonexistent traffic signals, fast object detection. The researchers recommend the need to integrate the technology with other devices such as data analytics, automated operation tools, decision-making tools, and social and mobile networks to aid effectiveness.

A study by Orie (2022) examined Sensor Technologies Perception for Intelligent Vehicle Movement Systems on the Nigerian Road Network. The researcher adopted a quantitative approach in his study using LIDAR. The study established the effectiveness of the technology in monitoring lane departure at 75% effectiveness. The researcher identified the inability of the technology to monitor or sense devices located on roads, vehicles, and transportation. The researcher recommends the possible creation of numerous next-generation smart applications to enhance traffic management and safety in both current and future transportation systems. In the same vein, Balashanmugam et al. (2015) studied the development of a lane departure warning traffic system using an observation study, and camera camera-based sensor. The study established the ability of the technology to detect lane marking under well-illuminated conditions, effective of 85%. The study identifies its inability to perform under poor lighting conditions. The study, therefore, recommends better illumination in proposed areas of installation.

Ankit Singh et al. (2025) researched improving power quality in electric cars and battery energy storage systems with multiple inverter topologies. The study took a quantitative approach, utilising a camera-based sensor. The study demonstrated the usefulness of the technology while the driver is fully active, allowing for a quick swing into action, since the system's efficiency during crucial distracted driving conditions is a source of worry. Therefore, the data demonstrated a favourable impact of lane departure warning systems on driver conduct under distracted driving situations, but care is advised. The study supports the notion of putting an LDW system in automobiles to improve road safety.

Furthermore, Scanlon et al. (2016) investigated the impact of roadway characteristics on the potential safety benefits of lane departure warning and prevention systems in the United States vehicle fleet. Field surveys were conducted using LIDAR technology and were found to be 70% successful. The study found that the efficacy is greatly dependent on route parameters such as lane markers and shoulder width. As a result, it advises that the highway infrastructure be modified to incorporate lane markings and an increase in roadway shoulder width. Finally, Sultana et al. (2016) investigated LDW using message and alarm systems, as well as vehicle position tracking. The study includes a field survey, which necessitates the use of a camera-based sensor. In various environments, the system detects lanes with an accuracy of over 96%. The research suggests a video-based driving assistance system that would inform the driver with an aural alarm and a visual message regarding lane deviation, as well as the capacity to follow car license plate extraction.

Types of Sensor Technologies

- **Camera-based Systems**: The study reveals that camera-based sensor is widely embraced by most of the studies and found to be effective but sensitive to environmental conditions like fog and rain.
- **LIDAR Systems**: The various studies reveal LIDAR possesses a high accuracy and reliability reported, though cost remains a hurdle for widespread adoption, and its effectiveness greatly depends on the road characteristics.
- **Radar Systems**: Effective in various weather conditions but with fewer studies by the studied by the various researchers.

Effectiveness

- Studies indicate a range of accuracy from 80% to 92% depending on the technology and environmental factors.
- Multi-sensor systems tend to outperform single-sensor solutions.

LIMITATIONS

High prices, system complexity, and performance problems in low-visibility situations are all examples of the technology's drawbacks. Additionally, because its efficacy is dependent on lighting, it is unable to identify damaged infrastructure, such as transportation lines that are obscured or indistinct. Numerous studies emphasise the necessity for further long-term dependability data.

SUMMARY, RECOMMENDATIONS, AND CONCLUSION

Summary

The study offers a thorough examination of how transportation contributes to economic growth, highlighting the development and importance of lane departure warning systems (LDWS) and intelligent transportation systems (ITS). Economic growth depends heavily on transportation, particularly in emerging nations with inadequate infrastructure. Although it makes it easier for people, products, and services to move about, it also presents social issues that call for the use of Smart Transportation Systems (STS) in order to lessen adverse effects. From simple traffic control to complex systems combining control, communication, and sensor technologies, STS has come a long way. For real-time data gathering necessary for traffic management and safety enhancements, effective STS depends on a variety of sensors, including infrastructure-, vehicle-, and device-based sensors. In order to reduce accidents brought on by inadvertent lane exits, LDWS is essential. These systems improve road safety by raising driver awareness and warning them of lane positioning by using sensors like cameras and LIDAR. Environmental restrictions, high expenses, integration difficulties, and privacy issues are some of the difficulties that both ITS and LDWS must overcome, especially in developing nations. These elements impede efficacy and broad adoption.

Sensor Technologies Effectiveness

Camera-based Systems: Widely used and effective, but sensitive to environmental conditions like fog and rain.

LIDAR Systems: High accuracy and reliability noted, though costly. Effectiveness is influenced by road characteristics.

Radar Systems: Effective across various weather conditions but less frequently studied.

Effectiveness Metrics: Studies report effectiveness ranging from 80% to 92%, with multi-sensor systems generally outperforming single-sensor solutions.

Limitations Identified: Common limitations include performance issues in low visibility, high costs, and complexity. Specific challenges were noted in detecting damaged infrastructure and reliance on illumination conditions for accurate functioning.

Recommendation

Based on the findings of the study regarding the evolution and impact of Intelligent Transportation Systems (ITS) and Lane Departure Warning Systems (LDWS), the following recommendations are proposed:

1. **Legislative Framework:** Legislative frameworks and infrastructural investments are necessary to enhance the effectiveness of sensor technologies.
2. **Integration with other technology:** Integration with data analytics and automated tools is recommended to improve overall system performance.
3. **Enhance Infrastructure Investment**: Governments should prioritise investment in transportation infrastructure to support the integration of ITS. This includes upgrading existing roads, signals, and communication networks to accommodate advanced technologies.
4. **Promote Smart Transportation Systems (STS)**: Encourage the adoption of STS by providing incentives for municipalities and the private sector to invest in intelligent transportation solutions. This could include subsidies for technology implementation and training programs for staff.
5. **Strengthen Sensor Integration**: Develop standardised protocols for the integration of various sensor types (vehicle-based, infrastructure-based, and device-based) to ensure seamless communication and data sharing. This will enhance the effectiveness of ITS and LDWS.

6. **Address Environmental Challenges**: Invest in research to improve sensor reliability under adverse weather conditions. Implementing robust algorithms that can compensate for environmental factors will enhance the performance of LDWS.
7. **Focus on Affordability and Accessibility**: To facilitate wider adoption, develop cost-effective ITS and LDWS solutions tailored for developing countries. This may involve partnerships with technology providers to lower implementation costs.
8. **Enhance Public Awareness and Education**: Conduct public awareness campaigns to educate drivers about the benefits of ITS and LDWS. Understanding these systems will encourage acceptance and proper usage.
9. **Implement Data Privacy Measures**: Establish clear regulations and guidelines to protect user privacy while collecting data for ITS and LDWS. Transparency in data handling will build public trust and encourage participation.
10. **Leverage Artificial Intelligence (AI)**: Invest in advancements in AI and machine learning to continuously improve the capabilities of LDWS. Enhanced algorithms can provide better lane detection and predict driver behaviour, further reducing accident risks.
11. **Encourage Collaborative Efforts**: Foster collaboration among government agencies, private companies, and academic institutions to share knowledge and resources. Collaborative efforts can lead to innovative solutions and a more effective implementation of ITS.
12. **Monitor and Evaluate Progress**: Establish monitoring frameworks to evaluate the performance of ITS and LDWS continuously. This will help in identifying areas for improvement and ensuring that systems are meeting safety and efficiency goals.
13. Further exploration: Future research should focus on developing next-generation smart applications to enhance traffic management and safety.

Conclusion

According to the study, transportation plays a crucial role in economic development by facilitating the movement of people, goods, and services, especially in developing countries with limited infrastructure. The development of Intelligent Transportation Systems (ITS) and Lane Departure Warning Systems (LDWS) is a major step towards mitigating the adverse effects of transportation activities on the environment and society. ITS improves operational efficiency, safety, and sustainability by integrating many technologies, whereas LDWS is essential for preventing accidents by improving driver awareness and providing real-time notifications. In the end, improving traffic flow, promoting sustainable urban growth, and improving road safety all depend on the effective deployment of Smart Transportation Systems and Lane Departure Warning Systems. In order to remove current obstacles and optimise the advantages of these cutting-edge transportation technologies, sustained investment, cooperation, and innovation will be essential.

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