CIEG 504: Intelligent Transportation Systems

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A Study of Seatbelt Usage Behavior in Commercial Motor Vehicles Using Sensor-Based Technology

Abstract

Intelligent transportation systems (ITS) have a substantial impact on enhancing safety, improving travel efficiency, and reducing traffic congestion as a result of the constant development of new technologies in different functional areas. Despite the advancement in ITS technologies, the technology related to seatbelt compliance in commercial motor vehicles is lagging. The improvement of seatbelt compliance in CMVs requires increased attention to ensure better user safety and convenience. The focus of this study is on CMV safety enhancement through the development of a new ITS technology. The proposal of this study is to develop a sensor-based ITS technology where a sensor will be used in the seatbelt to detect chest circumference and heartbeat to monitor and track the seatbelt compliance of drivers and passengers of CMVs. A control center will monitor the real-time information on seatbelt compliance and will report any inconveniences to law enforcement to take appropriate action. The development of this proposed technology can be beneficial to enhance seatbelt compliance among the drivers and passengers of CMVs.

1. Introduction

A livable city must have a solid transportation infrastructure since it may provide employment possibilities and promote urban development. Transport, whether for people or goods, is critical to every economy. As the population rises, so does the desire for faster and more convenient transportation, resulting in increased traffic congestion, accidents, and environmental deterioration [1,2]. So, the environmental impacts of these emerging modes of transportation should also be considered. To overcome these challenges, intelligent transport systems (ITS) were introduced through various modes of transport. The purpose of ITS was to maximize transportation efficiency and safety by analyzing, controlling, or improving transportation systems by combining existing and emerging information [3,4].

The concept of ITS has been around since the 1930s, initially in the preparation phase, followed by two other phases: feasibility study (1980-1995) and product development (1995–present). The breakthrough came in the early 1980s with the Japanese, who back then referred to it as the Japanese Intelligent Vehicle System (IVS) [5,6]. In Europe, with the help of companies, governments, and universities from 19 different countries, several developments were made in ITS under the PROMETHEUS (Program for European Traffic with Efficiency and Unprecedented Safety) establishment. Americans were working on something similar, known to them as Intelligent Vehicle Highway Systems (IVHS) [7,8]. The USDOT (United States Department of Transportation) later changed IVHS to the Intelligent Transportation Society of America (ITS America) and has produced several projects in over eighty locations across the country [9].

The Intelligent Vehicle Initiative (IVI), Advanced Rural Transportation Systems (ARTS), and Commercial Vehicle Operations (CVO) are the three key components of an ITS. The IVI effort intends to hasten the development, availability, and adoption of integrated in-vehicle technology that assists drivers of automobiles, buses, and trucks in operating their vehicles more safely and efficiently during different climatic conditions [10]. The CVO facilitates simple and cost-effective data sharing for safety and commercial purposes; carriers, along with state and national information networks, are integral parts of it. The purpose of ARTS is to solve challenges that develop in rural regions (where the residents of the communities or areas are less than 50,000). Rural roads have steep slopes, blind turns, curves, inadequate directional markings, a mix of users, and few alternative routes [11].

2. Functional Areas of ITS

There are five functional areas of Intelligent Transportation Systems (ITS). They are briefly described below:

2.1 Advanced Traffic Management System (ATMS)

It is a type of ITS that uses real-time traffic data, communication networks, and algorithms, along with other advanced technologies, to improve traffic flow and reduce congestion. A traffic systems management center (TMC) monitors and processes this data to take the necessary action to improve the traffic flow. ATMS supports state transportation departments and local agencies involved in traffic management systems. The system replaces outdated traffic controllers and wirelessly connects signals to allow for remote monitoring of the traffic system [12]. Listed below are examples of ATMS:

A Road Weather Information System (RWIS) is comprised of Automatic Weather Stations (AWS) (also technically known as Environmental Sensor Stations (ESS)) that continuously monitor atmospheric parameters, pavement conditions, water levels, visibility, and other factors. To process ESS observations, create nowcasts or forecasts, and display or distribute road weather data, central RWIS hardware and software are utilized. RWIS data is often incorporated into the primary numerical weather forecast models and is utilized by road operators and maintainers to help with decision-making. However, with all the benefits of this technology, there are some drawbacks. The inadequate life span of the pavement sensors and the location of the RWIS sensors being stationary are some of them, as they limit their overall effectiveness and coverage [13].

A ramp meter is a device that is used to regulate the flow of traffic entering freeways. Ramp metering systems have proven to be significantly effective in increasing the speeds of freeways, decreasing travel time by 20–48%, reducing congestion, and improving driver safety by decreasing demand and breaking up platoons of cars. Some ramp meters are designed to operate at peak travel demand; during off-peak, they are either shown as steady green or flashy yellow (Maryland); others are designed for continuous operation; the only exception is maintenance or repairs. It was revealed in a survey by FHWA, which was conducted on seven ramp meters, that after the installation of the ramp metering system, the average speed increased by 29%. Despite these benefits of the ramp metering system, one of the major issues with this system is diversion, which increases ramp delays as well as spillback [14].

2.2 Advanced Traveler Information Systems (ATIS)

It is an ITS technology that provides real-time information to travelers about traffic conditions, travel times, incidents, weather, and other relevant data. This information can be accessed through various channels, such as mobile apps, websites, electronic message signs, and social media. Listed below are examples of ATIS:

In July 2000, 511 was officially recognized by the Federal Communications Commission (FCC) as the only travel information hotline available to states and municipal governments across the United States. As there are no federal laws mandating its adoption, the implementation of this service falls primarily on state and municipal organizations and telecommunications providers. 511 is a three-digit telephone number that provides travelers with current information about travel conditions, allowing them to make informed decisions on time, mode of transportation, and route. 511 systems require precise and timely data from multiple sources, including traffic sensors and incident reports, to deliver current information to the public. However, any data reporting delays or inaccuracies can reduce the effectiveness of these systems [12].

Variable message signs (VMS) provide drivers with information about expected travel times and alerts on incidents, weather conditions, and other events. VMS are usually installed on freeways near major interchanges and provide options for selecting alternate routes. In addition to being used to provide information in the case of major incidents, work zones, or special events, portable VMS signs are also used by transit agencies to provide real-time information on transit vehicles and their routes to travelers at different transit stations. Even though the signs help people travel better, they are very expensive, and sometimes they may be contradictory as information is given to the vehicles through radio as well as navigation systems [12].

2.3 Commercial vehicle operations (CVO)

CVO refers to the operations involved with the movements of freight and passengers in commercial vehicles, as well as the activities related to their regulations of these operations, as well as safety assurance, vehicle operations, fleet management, and freight management. To do these operations and manage commercial vehicles, monitoring and coordination should be at their best. To do that, ITS plays a big role. One of the key components of commercial vehicle operations is the use of advanced technologies such as GPS tracking, electronic logging devices, and telematics systems. These technologies enable fleet managers to monitor the location, speed, and driving behavior of their vehicles in real-time, allowing them to optimize routing and minimize fuel consumption. In addition, these systems can also provide important data on vehicle maintenance needs, enabling managers to schedule repairs and maintenance proactively, reducing downtime and increasing vehicle uptime. CVO also aims to improve safety and efficiency by utilizing technology to monitor and manage commercial vehicles. Listed below are examples of CVO:

Sensors for cargo and freight conditions have been used by the freight transportation industry for a long time. In addition to pressure and poisonous chemical sensors that boost the safety of hazardous material shipments, these sensors also contain temperature sensors and recorders that enhance the quality and accountability of perishable shipments. In order to monitor hits and shocks on roadways, identify those responsible for issues, and map problem patterns, accelerometers connected to GPS are also employed. Some truck fleet operators track vehicle operational metrics, such as engine RPM, highway speed, tire pressure, and brake wear, using sensor data. Managers can use this information to forecast maintenance problems and promote prudent and effective driving behavior. However, the reliability and accuracy of sensor data may impact the effectiveness of this system [12].

Electronic logging devices (ELD) are used to track the hours of service of commercial drivers, ensuring that they are not exceeding their allotted driving time and thereby reducing the risk of driver fatigue and accidents. It records engine data, location, speed, and miles driven, and the reporting can be done using a cell phone. However, ELDs capture a substantial amount of information about a driver's location, driving patterns, and work hours, which some drivers and carriers find intrusive.

2.4 Advanced Public Transportation Systems (APTS)

APTS refers to the application of advanced and innovative navigation and communication technologies in public transportation systems. These modern technologies are responsible for providing passengers with real-time arrival information and enhancing the safety, convenience, and dependability of public transit networks. APTS helps optimize transit operations by delivering real-time information to passengers and operators, enabling better route planning, scheduling, and dispatching. Listed below are examples of APTS:

Automatic vehicle location (AVL) system is a vehicle tracking system that is computer-based. AVL is used to track the real-time location of different transit vehicles (bus, van, train, or boat) using a GPS receiver and mobile data communication technologies, which then transmit the information to a transit operation center. While AVL, GPS, and dispatching software are not identical, they function in tandem to allow transit agencies to have an estimation of the arrival time of the transit vehicle, which can be shared through various applications and VMS at transit stops, monitor transit driver performance, and assist in operations and planning. However, inaccuracy, poor signaling, and battery life concerns are some of the disadvantages of AVL [12].

Transit signal priority systems allow authorized transit vehicles to adjust traffic signals automatically, often by prolonging the green cycle. This is conditional on elements such as passenger load, service type, and adherence to the timetable. TSP helps improve the efficiency of the transit road network by reducing transit travel time. It was demonstrated in a LA County Metro Bus project that TSP helped improve travel time savings by 25%. However, implementation of TSP in locations that have frequent stops or heavy congestion may not be successful [15].

2.5 Advanced vehicle control systems (AVCS)

AVCS are technologies that combine components such as brakes, steering, and engine management to increase vehicle safety and control. AVCS are designed to work in tandem with advanced driver assistance systems (ADAS) to improve driving and reduce the probability of collisions. Listed below are examples of AVCS:

Electronic Stability Control (ESC) is a computer-based system that stops a vehicle from skidding by recognizing when it loses traction and stopping it. Whenever it detects a loss of steering control, it applies the brakes and decreases engine power until control is reestablished. According to estimates from the Insurance Institute for Highway Safety and the U.S. NHTSA in 2004 and 2006, anti-skid devices may avoid one-third of fatal incidents. Since 2011, 2012, and 2014, it has been mandatory for new cars to have this technology in Canada, the United States, and the European Union, respectively. It has saved an estimated 15,000 lives in Europe. 82% of all new passenger automobiles on the planet are fitted with anti-skid technology. This safety feature is, however, exclusive to certain models and is not an option. In addition, the ESC cannot take full control of the vehicle [16].

Adaptive cruise control (ACC), also known as "dynamic cruise control", is an advanced driver assistance system that helps to automatically adjust the vehicle speed so that a safe distance is maintained with the vehicle in front of it. It is a sensor-based technology that detects the proximity and speed of other vehicles using radar, lasers, or a camera and enables the vehicle to brake or accelerate appropriately. This technology not only improves passenger comfort and safety but also expands the capacity of the road by maintaining a safe distance between vehicles and minimizing driver mistakes. However, in bad weather conditions such as heavy rain, fog, etc., some sensors may not work well [12].

3. Proposed ITS Area of Interest

The area of interest of this study is related to commercial vehicle operations (CVO), more specifically, commercial motor vehicle safety. The Federal Motor Carrier Safety Administration (FMCSA) is diligently striving to prevent collisions between CMVs. The FMCSA and National Highway Traffic Safety Administration (NHTSA) estimate that in 2012, at least 34% of CMV occupant fatalities from crashes occurred when drivers and passengers were not wearing seatbelts. In 2014, this increased to 39% and remained the same in 2016 [17]. According to earlier observational research, the use of seatbelts by CMV drivers and passengers lags substantially behind that of passenger vehicles. In a survey, it was found that just 48% of CMV passengers buckle their seatbelts [16,17]. Despite the benefits of seatbelt use for safety, many drivers and passengers in CMVs do not wear seatbelts consistently. Consequently, one of the main factors contributing to fatalities in crashes involving CMVs is not wearing a seatbelt. Due to the economic significance of commercial vehicles, ensuring the safety and resiliency of freight transportation is a top issue, as the safe and efficient movement of freight is essential to a nation's economic development. According to the Federal Highway Administration (FHWA, 2017), fatal CMV collisions have an annual economic impact of more than $20 billion. According to a final rule issued by the FMCSA, all CMV occupants must wear seatbelts while the vehicle is in motion (FMCSA, 2016) [18,19].

The current basic seatbelt reminder produces a warning light and auditory warnings when the vehicle is started for a few seconds, as well as a visual alert that lasts at least 60 seconds anytime the occupant's seatbelt is unlocked. These existing technologies can be tracked and monitored. Drivers and passengers have, however, discovered ways to disable the seatbelt safety reminder. This research aims to investigate the use of sensors that will detect the chest circumference and heartbeats of an occupant as a means of tracking and monitoring seatbelt compliance in CMVs and using that data as real-time information for law enforcement to take the appropriate actions.

Numerous studies have examined the occurrence and severity of crashes involving CMVs in addition to potential impacts due to human behavior [20-28]. However, there are not many studies focusing on developing methods to increase seatbelt compliance for CMV occupants.

4. Goals and Objectives

This proposal focused on developing an ITS sensor-based technology that will improve the seatbelt compliance in CMVs. The objectives of the proposed research are:

- To develop a sensor-based system for tracking and monitoring seatbelt usage in CMVs,
- To determine the effectiveness of using a sensor to track chest circumference and heartbeat as a means of tracking seatbelt compliance,
- To make recommendations to policymakers on how to improve seatbelt compliance in CMVs.

5. Proposed ITS Technology

The aim of this proposal is to develop the use of chest circumference and heartbeat-sensing technology to track and monitor seatbelt compliance in CMVs. The workflow of the proposed ITS technology has been delineated with the help of a flowchart in Figure 1.

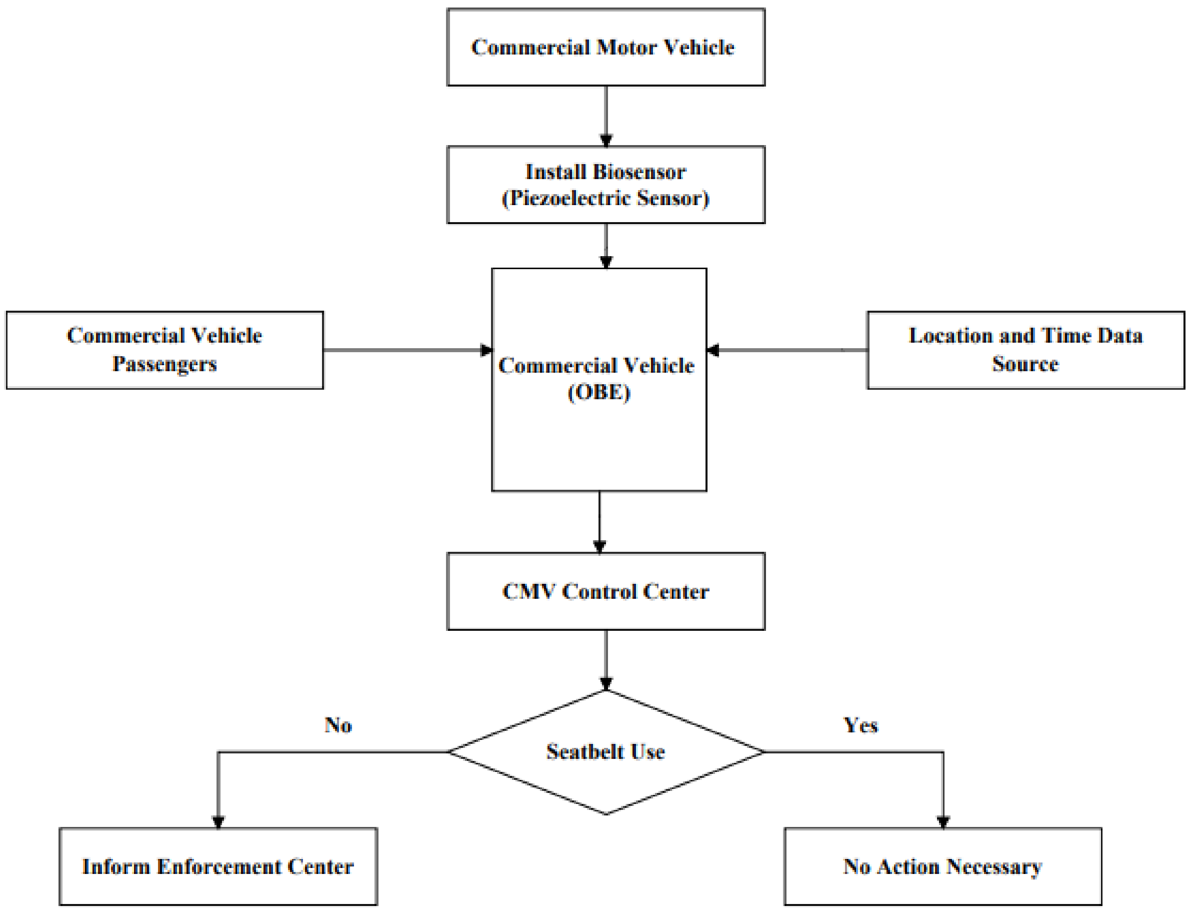

Figure 1: Workflow of the Proposed ITS Technology

Commercial Motor Vehicles (CMVs): Commercial Motor Vehicles (CMVs) are vehicles that are used to transport goods and passengers for individuals or agencies. The commercial vehicle is typically operated by a professional driver and managed as part of a larger fleet.

Sensor Installation: A biosensor, more specifically a piezoelectric sensor, will be installed in the seatbelts, which will detect chest circumference and heartbeat, hence the use of the seatbelt. Piezoelectric sensors can detect cardiac activity, and they can easily be sent through a Bluetooth-based system [29].

Commercial Vehicle On-Board Equipment (OBE): This will reside in the commercial vehicle and have sensory, processing, and storage functions. It will have information about the vehicle, driver, and passengers of the CMVs, the location and time of the vehicle, and seatbelt compliance information.

CMV Control Center: The CMV control center will have access to real-time routing information and will be able to access databases containing vehicle location, driver, and passenger information. They will also have real-time information about the seatbelt compliance of the driver and passengers.

Law Enforcement: If any passenger is not wearing the seatbelt for more than 60 seconds while the vehicle is moving, the control center will inform law enforcement about the vehicle's location, and law enforcement will take appropriate action.

6. Limitation of the Proposed ITS Technology

Limitations of this proposal may include the potential for data collection errors because of the accuracy of the sensor data, the limited sample size, and privacy concerns from the passengers of the vehicle.

7. Recommendation

The recommendation of this project is to develop a small-scale deployment and test a sensor-based system to improve seatbelt compliance in CMVs. To begin with, 20 CMVs will be selected as the sample size for the deployment of this technology. Then biosensors (piezoelectric) will be installed in the seatbelts of the CMVs for drivers and passengers and tested and calibrated if necessary for the accuracy of the data. The on-board equipment of a CMV will have real-time seatbelt compliance information along with other related information. A control center will be responsible for monitoring and tracking the real-time information of CMVs. If a driver or passenger of a particular CMV does not wear a seatbelt, the control center will receive a notification, and it will share the real-time information of the CMV with law enforcement so that they can take the appropriate action.

The result of this proposed technology may have significant implications for the safety of drivers and passengers by highlighting the importance of seatbelt use and reducing the risk of injury and fatalities in CMV collisions. Through the development of the proposed ITS technology, insights might be gained into the factors that influence seatbelt compliance, and effective strategies for promoting seatbelt compliance in the commercial motor vehicle industry might be proposed.

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