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THE APPLICATION OF DRIVING FATIGUE DETECTION AND MONITORING TECHNOLOGIES IN TRANSPORTATION SECTOR: A REVIEW

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Abstract: *Driving fatigue is the leading cause of traffic accidents in many countries, prompting the development of a number of fatigue detection devices. This paper concisely reviews the existing fatigue detection system for transportation sectors. A rigorous systematic literature review (SLR) was utilized to find robust and high-potential material related to the research issue. According to the available literature research, many fatigue detection devices have been developed and commercialized, categorized into three groups based on the detection target's features: vehicle-based parameters, behaviour-based parameters and physiological-based parameters. However, currently available driver fatigue detection systems are divided into two categories: (i) very expensive systems that are limited to specific high-end automobile models and (ii) affordable alternatives for old and cheap vehicles that are not robust. Regardless of the physiological-based parameters' great accuracy in identifying driving fatigue, practically all available fatigue detection devices are classified as vehicle and driver behaviour-based parameters. As a result, this study looked into the use of physiological method in the future fatigue detection studies. The study's findings will help researchers, politicians, and practitioners create a system to significantly reduce road accidents and improve road safety.*

Keywords: driving fatigue, fatigue detection, transportation, road accidents.

1. Introduction

Malaysia is now one of the most urbanized nations in the East Asia. The urban population in Malaysia has rapidly increased from 70% in 2010 to 77% in 2020 (O'Neill, 2022). This is expected to reach more than 80% in year 2030 (Malaysia, 2019). As a consequence of urban sprawl, the human population has become more reliant on the transportation system. Recently, the number of registered vehicles in Malaysia have skyrocketed from 3,447,712 units in 1996 to 17,486,589 units in 2020 (CEIC, 2021).

The expansion of transportation systems is a significant contributor to economic growth, nevertheless, the rapid growth of mobility in metropolitan areas causes substantial economic losses in road safety. According to Malaysia Institute of Road Safety Research (MIROS), the number of road crashes in Malaysia has climbed drastically, from 462,426 cases in 2012 to 567,516 cases in 2019 (Caprioli & Coleman, 2010).

Driver inattention and distraction due to fatigue are the top causes of traffic collisions in developed and developing nations including Malaysia (Li et al., 2020) and have been termed a "silent killer." Driving fatigue is a sensation of tiredness or weakness caused by excessive physical and mental impairment while driving (Ibrahim et al., 2022). Driving fatigue impairs judgement and eyesight, deteriorates cognitive functions such as attention and reasoning and reduces the capacity to detect incoming risks (Jiang et al., 2017). Driving fatigue is responsible for around 20% of all traffic accidents globally (MacLean et al., 2003). Under these conditions, it is critical to reduce road accident rates by employing a system that detects and monitors driving fatigue.

In the past few years, many studies have proposed various measures to detect and monitor driving fatigue. Therefore, in this study, a comprehensive review of the existing fatigue detection and monitoring technologies was presented. The mechanism, application and contribution of the current fatigue detection and monitoring technologies in the transportation sector were discussed to determine the literature gap in existing knowledge.

2. Review Method

To identify robust and high potential literatures related to the research in transportation sector, a highly rigorous method, known as a systematic literature review (SLR) was utilized. A SLR determines, chooses and critically appraises research to answer a clearly formulated question (Dewey, 2016). This method focuses on finding novelty and research gap as well as provides research direction by showing what work has already been conducted in the subject area and what research approaches and theories being used. Pertinent keywords were first listed out such as “driving fatigue,” “driving fatigue detection system,” “vehicle-based parameters,” “behavior-based parameters,” and “physiological-based parameters”.

To obtain productive results, three basic Boolean operators: AND, OR and NOT were then utilized to connect the keywords in a logical way that the database will understand. The command AND joins two or more search terms by telling the database that all these keywords must present in the resulting records, for example searching on “decision support system” AND “urban transportation”. If one key word contained in the item is returned and the other is not, a very limited results will be obtained as the item will not appear in the search result list. The command OR connects two or more synonym concepts, where any of the search terms can be included in the returned document, for example “urban” OR “city”. Meanwhile, NOT command narrows a search by excluding the search results that contain the search terms following it, for example "decision support system in transportation NOT decision support system in agriculture". The system will only determine documents that only contain the key phrase "decision support system in transportation" and will ignore all results that include the keyword NOT "decision support system in agriculture" However, it is advisable to take high precaution when narrowing the search as good records might be eliminated. It is recommended to place double quotes (<<>>) around the key words, for example a search on "Melaka NOT city" includes results as follows: "the nation of Melaka"; "Melaka trade"; but does not return "Melaka City" or "This city's trade relationship with Melaka". Three frequently utilized academic databases by researches across various fields are Scopus, Google Scholar and Web Science, which were used in this study.

The screening process is visually summarized in the PRISMA flow diagram in Figure 1. The initial electronic searches identified 1235 documents. The documents were then subjected to a de-duplication process in which duplicates were determined and discarded. The de-duplication process yielded 847 documents. The next step involved two-step process, (i) titles and abstract screening to find those related to DSS in transportation realms and (ii) selection of full-text document for inclusion in the review. Through an examination of the title and abstracts of this batch, 135 eligible documents were extracted. During the full-text screening, 712 documents were considered. Out of the potentially relevant batch of 586 documents, 126 documents were chosen as relevant to the research topic.

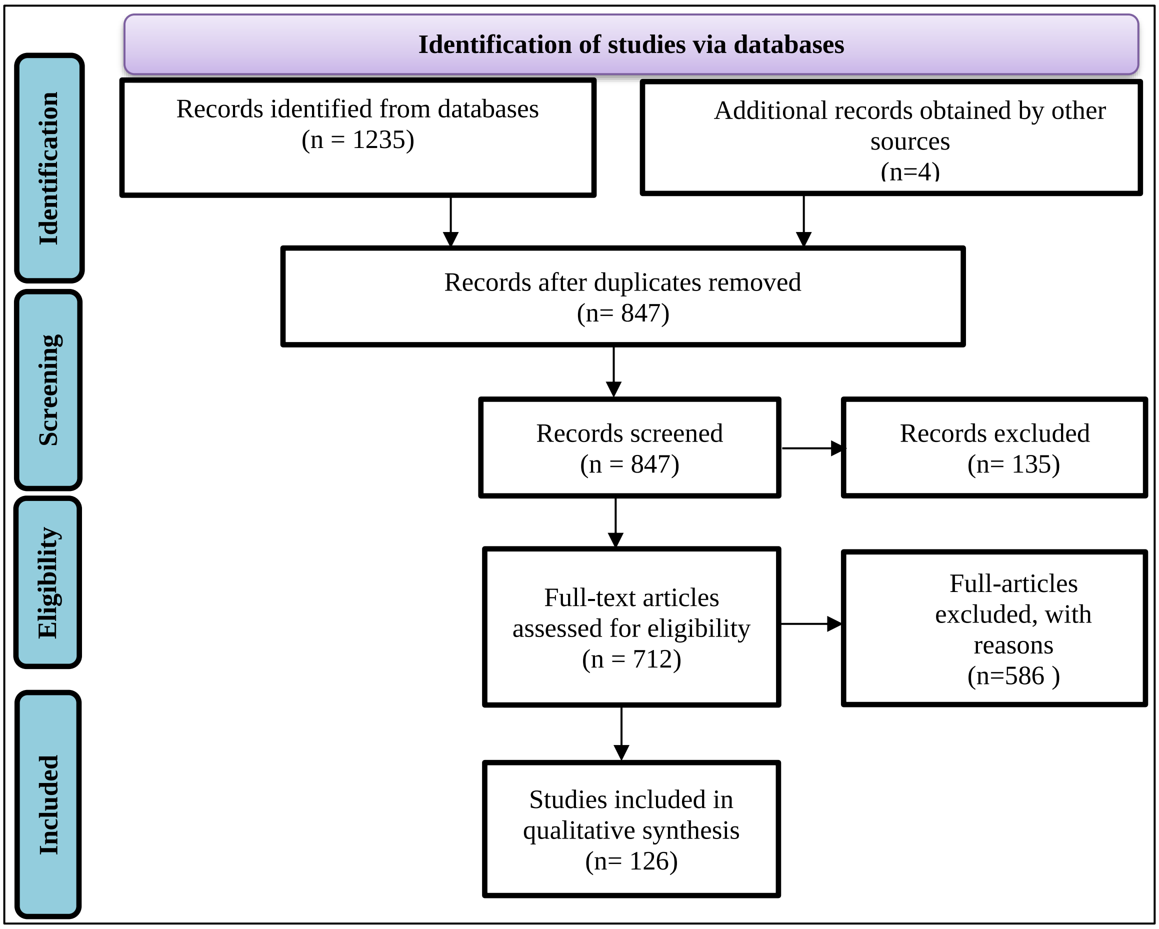

Figure 1: PRISMA Flow Diagram Illustrating Selection of Articles

3. Category of Fatigue Detection and Monitoring Technologies

Fatigued driving has the features of high concealment and difficulty quantifying, making it difficult to identify and measure the driver's fatigue level. Today, there are numerous detection technologies that have been developed and divided into three groups based on the detection target's features, namely vehicle-based parameters, behavior-based parameters and physiological-based parameters.

3.1 Vehicle-Based Parameters

The driver's capacity to comprehend the surrounding environment, assess the situation and control the vehicle will deteriorate as fatigue sets in. This modification diminishes the accuracy of the driver's control, which can be seen in the unusual fluctuation of vehicle driving parameters. Current vehicles are outfitted with a variety of sensors that collect real-time parameters such as vehicle speed, fuel usage and engine speed (Peppes et al., 2021). The modelling of these data allows for the indirect detection of the driver's fatigue level. As a result, methods for detecting fatigue driving based on vehicle driving parameters are receiving a great deal of attention in the research field.

3.2 Behavior- Based Parameter

Driver behavior-based parameters are based on recognizing different behavioral clues displayed by a fatigued driver. A common focus is on facial expressions that convey characteristics like eye tracking system, rapid blinking (Junaedi & Akbar, 2018), head nodding or swinging (Ghourabi et al., 2020) or regular yawning (Jie et al., 2018). All of these symptoms indicate that a person is sleep deprived and/or fatigued. Generally, systems based on this approach use a video camera to capture images and depend on a combination of computer vision and machine learning methods to detect, measure, and determine whether the driver is fatigued or not. If the sequence of captured images and measured parameters, for example, nodding pattern or time lapsed in a closed eye state, indicates that the driver is fatigued, an action like sounding an audible alarm may be justified (Peng et al., 2021).

3.3 Physiological-Based Parameters

Physiological-based parameters are dependable and accurate in fatigue detection as this technique is concerned with what is happening physiologically with the driver. According to related research, when a driver is fatigued, human's physiological systems like breathing rate (Yang et al., 2020), heart rate (Du et al., 2020), body temperature (Dong et al., 2019), galvanic skin response (Manikandan et al., 2021), muscular system (Rampichini et al., 2020), eye behaviours (Mehta et al., 2019), oxygen saturation level (SpO_2) and brain activities (Tuncer et al., 2021) can be negatively affected. As a result, the physiological reaction slows, the body's response to stimulation looks delayed and physiological signs diverge from the usual state (Zhou et al., 2020). This type of detection system recognizes these changes and alerts the driver if he is in a fatigue state. The benefit of this method is that it warns the driver to take a break before the physical symptoms of tiredness occur (Ramzan et al., 2019), making this approach as the ideal tool in defining drivers' fatigue compared to vehicle-based parameter and behavior – based parameter. As a result, physiological characteristics recorded by physiological sensors can be utilized to identify whether a driver is fatigued, eventually prevent traffic accidents.

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4. Existing Commercial Fatigue Detection Technologies

The existing fatigue detection and monitoring system are divided into two categories. First, a number of car manufacturers have made significant investments in the development of systems aimed at detecting driver fatigue in high-end automobile models. Second, independent companies have developed solutions with comparable ambitions for old and cheaper vehicles.

4.1 Built-in System for High-End Automobile Models

Table 1: Built-In System for High-End Automobile Models

Information	Detection Mechanism
Device's Name: Driver Alert System Year Release: 2012 Developer: Ford Device Category: Vehicle-based parameter	Driver Alert System works by attaching a camera to the rearview mirror. When the system is turned on and the vehicle is travelling faster than 40 miles per hour, it detects straying toward one of the lane's margins. If the turn signal is turned off, the system assumes the drift was unintentional and sends a warning vibration to the steering wheel. The vehicle's instrument cluster will display a "Rest Suggested" visual message. If the car continues to drift, a more severe "Rest Now" message (complete with a red light and chime sound) will be delivered and displayed until the driver specifically dismisses it. Users can also utilize the technology to check their current estimated level of concentration at any time (Ford, 2023).  **Figure 2: Driver Alert System (Ford, 2023)**
Device's Name: Driver Monitoring System Year Release: 2006 Developer: Toyota Device Category: Behavior-based parameter	Driver Monitoring System works in tandem with the pre-collision system (PCS). Infrared sensors are used by the system to monitor the driver's attention. The driver monitoring system features a charge-coupled device CCD camera mounted on the steering column that tracks the driver's face using infrared LED detectors. Six built-in near-infrared LED sensors allow the system to function correctly both day and night. The system estimates the position of the driver's facial characteristics and calculates the width and center line of the face during startup. This data is used as a reference to track the driver's head movement when gazing from side to side. If the driver is not concentrating on the road ahead and a potentially dangerous scenario is recognized, the system will alert the driver with flashing lights and warning sounds. The vehicle will apply the brakes if no action is taken (a warning alarm will sound followed by a brief automatic application of the braking system) (Toyota, 2005).

	 **Figure 3: Driver Monitoring System (Toyota, 2005)**
Device's Name: Attention Assist Year Release: 2009 Developer: Mercedes-Benz Device Category: Vehicle-based parameter	To detect driver fatigue, an algorithm and a specialized sensor are used. During the first few minutes of driving, the system analyses the driver's specific driving characteristics by utilizing over 70 different types of parameters. The device activates at speeds ranging from 80 to 180 km/h since it has been demonstrated that driving at these speeds for an extended period of time makes the driver significantly more prone to become tired than driving in the city. The sensor's ability to capture steering actions and steering speed is a key feature. Mercedes-Benz engineers did extensive research and discovered that fatigued drivers make modest steering errors and slightly change their steering behavior. The system will offer the audible and visual prompt, "Take a break" after assessing the responses and settings. Most Mercedes-Benz vehicles will have a coffee cup emblem on the dashboard (Benz, 2023).  **Figure 4: Attention Assist (Benz, 2023)**
Device's Name: Driver Alert Control (DAC) Year Release: 2007 Developer: Volvo Device Category: Vehicle-based parameter	The DAC function detects deteriorating driving ability and is intended primarily for large highways. The feature is not intended for use in busy areas. When the speed exceeds 65 km/h (40 mph), the function is activated and remains active until the speed exceeds 60 km/h (37 mph). A camera recognizes the painted carriageway boundary markers and compares the road alignment to the driver's steering wheel movements. If the driver's driving becomes clearly irregular, a coffee cup icon in the driver's display, accompanied by an audible signal and the text message "Time for a break," alerts the driver. Suggestions for a good rest stop are also displayed if the car is equipped with senses navigation and the "Rest Stop Guidance" function is active. If the driver's behavior does not improve after a set amount of time, the warning is issued again (Volvo, 2020).  **Figure 5: Driver Alert Control (Volvo, 2020)**

Device's Name: Lane Departure Warning (LDW) Year Release: 2007 Developer: Volvo Device Category: Vehicle-based parameter	The LDW lowers the risk of a crash by alerting drivers when the car passes a clear line marker or the road's center middle line, depending on the camera's ability to distinguish the lines. Users can enable or deactivate this feature by clicking the button on the center console or in the "MY CAR" menu. When the button is pressed, the light on it glows and displays on the instrument panel. The LDW system, according to Volvo Cars researchers, might avert 30–40% of these types of incidents at speeds ranging from 70 to 100 km/h. The technology also employs a camera to monitor the car's position between the road lines. At 65 km/h, the LDW engages and remains active until the speed hits 60 km/h (Volvo, 2018).
Device's Name: Driver Alert System Year Release: 2005 Developer: Volkswagen Device Category: Vehicle-based parameter	The Driver Alert System monitors driver behavior by detecting irregular steering wheel movements and lane deviations. When vehicles exceed 40 mph, the mechanism goes into action. A "Take a break" visual message and a warning sound will be displayed upon that dashboard if the system notices that the driver is losing concentration. If the driver does not take a break within 15 minutes, the warning will be repeated (Volkswagen, 2023).  **Figure 6: Driver Alert System (Volkswagen, 2023)**

4.2 Independent Product for Old and Cheaper Vehicle

Table 2: Independent Product for Old and Cheaper Vehicle

Information	Detection Mechanism
Device's Name: Life by Smart Cap Year Release: 2009 Developer: SmartCap Technologies Device Category: Physiological-based parameter	Life by SmartCap is a sensor band that can be worn as a headband or under a hat (SmartCap, 2023). The Lifeband measures brainwaves to assess sleep resistance. The technology provides real-time feedback to the user and vocally and graphically informs the user before micro sleeps occur via a display or an app on a mobile phone or tablet. (Rajaratnam & Howard, 2011) conducted the Osler (Oxford Sleep Resistance Test) test to evaluate the SmartCap. The Osler is a sleep-latency behavioural test in which four consecutive misses indicate having brief intervals of EEG-defined sleep. The researchers discovered that an average SmartCap score of 4 (extremely fatigued) exhibited a high sensitivity (94.75%), correctly detecting the majority of the 1-minute periods when severe fatigue was present. A SmartCap score of 4 has a specificity range of 81.9% to 82.1%. As a result, it has a low to moderate false-positive rate. Limitations: There are no defined and clear environmental limits, such as day vs. night or rain vs. sun. To be effective, drivers must wear the cap (or, at the very least, the band) at all times while driving. Drivers must be at ease while wearing the device; otherwise, detection accuracy may be low. Furthermore, the cap tends to grow dusty owing to the humidity when wearing it, therefore, drivers should clean the hat or band every three months for best performance (SmartCap, 2023). Drivers with sensitive skin may become infected if the device is not thoroughly cleaned.

	 **Figure 7: Life by Smart Cap (SmartCap, 2023)**
Device's Name: Optalert Eagle Year Release: 2017 Developer: Optalert Device Category: Driver-based parameter	The Optalert Eagle are tracking glasses for eye and eyelid movement (Optalert, 2023). The system calculates numerous factors with each blink based on the neuromuscular function of muscles in the eyelids and their reflex-controlled movements. The spectacles are equipped with infrared (IR) reflectance oscillography, which enables continuous fatigue assessment using the validated Johns Drowsiness Scale (JDS). The JDS is transmitted to the user in real time every minute as a value between 0.0 and 9.9. Because of the consistent input, the driver may self-manage fatigue. Drivers are warned 15 to 20 minutes before falling asleep. When a high level of weariness is detected, an audible alert is issued. Managers may see all of their drivers' drowsiness levels in real time and choose whether to get an email or text alert when a driver receives a "high risk" warning. The system's data can be analyzed and used to help organizations reduce fatigue. Homeostatic and circadian shifts were used to confirm the JDS scores (Anderson et al., 2010). Fourteen people wore the Eagle glasses for 30 hours while taking bi-hourly neurobehavioral tests such as the Karolinska Sleepiness Scale (KSS) and the Psychomotor Vigilance Test (PVT). Researchers discovered that average JDS scores above the warning level were associated with delayed response times and subjective fatigue when compared to average JDS scores below the cautionary level. Limitations: The main issue with this technology is that drivers must wear the glasses in order for the system to function. Some people may find the lenses unpleasant or believe they make driving more difficult.  **Figure 8: Optalert Eagle (Optalert, 2023)**
Device's Name: DFM-HV PRO Driver Fatigue Monitor Year Release: Not found Developer: Geobox Pth Ltd Device Category: Driver-based parameter	The DFM-HV PRO Driver Fatigue Monitor is a camera mounted on the dashboard that monitors driver fatigue and distraction based on PERCLOS and looks away from the forward path (Geobox, 2019). When the technology senses that the driver is tired, it emits an audible beep. When a driver's eyes are shut for a specified sensitivity time (approximately 1 second) or when the motorist looks more than 30 degrees away from the forward roadway, the alert sounds. Another alarm notifies the motorist if the drowsiness persists for 1 second after the first alarm and the driver does not open his or her eyes. A different alert will sound if a driver is distracted (as indicated by a glance diversion from looking forward). When unsafe levels of fatigue are detected, the alarm volume and frequency rise. The system also includes an output port that may be used to activate external warning devices and telematics systems, allowing fleet personnel to monitor alarms. This system operates in car cabs from -20℃ to +70℃. At night and in tunnels, infrared LEDs illuminate the driver. With the exception of mirror-coated glasses, eye detection is achievable even when an individual is wearing glasses or shades.

	Limitations: The technology is compatible with any skin or eye color. However, people with white or no brows, rough scars, deep wrinkles surrounding the eyes, or only one eye may not be recognized by the system. If the driver's hair blocks the eye in any manner, the system may fail to register eye movements.  **Figure 9: DFM-HV PRO Driver Fatigue Monitor (Geobox, 2019)**
Device's Name: Seeing Machines Guardian Backup- Driver Monitoring System Year Release: Not information Developer: Guardian Device Category: Driver-based parameter	The Seeing Machines Guardian Backup- Driver Monitoring System consists of two cameras (Machines, 2023). One camera records the forward roadway, while the other records the driver. In the case of an incident, the forward-facing camera captures footage using a wide-angle lens. The in-vehicle technology detects weariness and distraction using infrared sensors and unique face- and eye-tracking algorithms that assess eyelid closure, blink rate, and the driver's head position. When these sensors identify microsleeps or the driver's lack of concentration, an audible tone and vibrating seat inform the driver. The 24/7 SafeGuard Center protects the fleet around the clock through live data analysis and human action. A study of three long-haul trucking companies in South Africa found a 93.2% decrement in fatigue incidents per hour during the intervention period (incidence rate ratio [IRR]: 0.068, 95% confidence interval [CI]: 0.059-0.078, p 0.001) compared to the baseline period when the trucks were installed with Guardian but no feedback was given to the driver. When fatigue-related incidents were compared per distance travelled, there was a 90.9% decrease in fatigue-related incidents (IRR: 0.091, 95% CI: 0.080-0.105, p 0.001) (Lenné & Fitzharris, 2016). Guardian runs and maintains tracking fidelity in a variety of lighting conditions, from direct sunlight to complete darkness. It also works with most glasses, including sunglasses, because the system uses head posture to evaluate fatigue levels. Management is alerted and can intervene if a driver receives a fatigue alarm. They can also use system data to examine the entire fleet and discover ways to reduce fatigue. Furthermore, if an incident occurs, the video from the forward-facing camera provides the organization with additional security. Drivers may appreciate the camera's privacy feature, which records only if it detects fatigue (Machines, 2023).  **Figure 10: Seeing Machines Guardian Backup- Driver Monitoring System (Machines, 2023)**
Device's Name: Smart Eye's AntiSleep Year Release: 2001 Developer: Smart Eye	Smart Eye's AntiSleep device tracks various fatigue factors with a single camera, focusing on gaze direction, eyelid closure and head posture and orientation (Eye, 2023). AntiSleep derives real-time data output from 3-D mapping and an algorithm. The system employs a single standard VGA camera in conjunction with IR flash illuminators tuned to frequencies that receive minimal interference from outside light, making the device resistant to all natural lighting situations in automobile applications (Ahlstrom & Dukic, 2010). It is currently an extendable system, while it does not provide specific alarms or feedback to the driver

Device Category: Driver-based parameter	following fatigue detection, such features can be implemented as desired by manufacturers. As opposed to multi-camera systems, which are more accurate and readily available, Smart Eye AntiSleep is less expensive, easier to operate, and easier to install in a car. Also, because the AntiSleep makes its own light, it can be used in all kinds of natural light and with almost any kind of eyeglasses. (Ahlstrom & Dukic, 2010). Limitations:  **Figure 11: Smart Eye's AntiSleep**
Device's Name: ASTiD® Year Release: No information Developer: Fatigue Management International Device Category: Physiological-based parameter	ASTiD®, which stands for "Advisory System for Tired Drivers," employs a predictive, non-invasive approximation model to detect the onset of dangerous driving fatigue. ASTiD® is not a device that can be installed in the vehicle. It is an early warning system designed to help drivers become more aware of their own limitations and empower them to monitor and control their fatigue risk before they become too impaired to drive safely. ASTID® continuously analyses the recognized factors contributing to driver sleepiness, such as the time of day, the monotony of the drivingand the driver's past sleep quality. ASTiD® is made up of two interconnected systems that evaluate the factors in real time. The evaluation of these factors is then utilized to generate a fatigue index (fatigue score) that is displayed every minute. This fatigue index rises and falls throughout the shift in response to the peaks and valleys of the circadian effect (human body clock). At some point, an early warning signal may be created, alerting the driver to the fact that they may be becoming weary before they are completely aware of it (FMI, 2022).  **Figure 12: ASTiD®** Limitations: There was no information about how well the ASTiD could work in many different environments. This technology displays the driver's fatigue level in real time, which is computed every minute. It is unknown how much data is recorded and made available to managers. Further products that can be connected with ASTiD include fatigue self-assessment tools, as well as e-learning and training tools to aid individuals and fleets in fatigue management. There are no video recording devices, which some drivers may find bothersome.

5. Conclusion and Recommendation

This study gives a thorough evaluation of the literature on the application and contribution of existing fatigue detection and monitoring system for transportation sectors. A highly rigorous process known as a systematic literature review (SLR) was used to discover resilient and high-potential literature linked to research topic. According to the survey, currently available driver fatigue detection systems are classified into two categories: (i) very expensive systems that are limited to specific high-end automobile models and (ii) economical alternatives for old and cheap vehicles that are not robust. Most recent fatigue detecting devices are intended for high-end, branded vehicles. Yet, there are substantially less expensive fatigue detecting systems on the market. Nonetheless, the effectiveness and robustness of the systems are frequently called into doubt. Regardless of the physiological-based parameters' great accuracy in identifying driving fatigue, practically all available fatigue detection devices are classified as vehicle and driver behavior-based parameters. This review paper focuses on finding a research gap in fatigue detection system that attempts to bridge the gap by balancing affordability and availability with functionality. As a result, this study looked into the use of physiological method in the future fatigue detection studies. The study's findings will assist researchers, policymakers, and practitioners in developing a system that will substantially reduce fatigue-related road accidents, ultimately improving road safety.

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