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Assessing Vehicle Safety Technologies in Preventing Crashes and Mitigating Their Severity Within the Oil and Gas Sector

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Abstract

The Oil and gas sector involves the transportation of substantial volumes of highly flammable substances. Crashes/accidents during transit pose substantial risks, potentially leading to considerable harm to people and property. It is crucial to guarantee the safety of vehicles employed in operations. This study examines vehicle safety technologies within the oil and gas sector, specifically focusing on their role in preventing crashes and mitigating their severity. The assessment encompasses active and passive safety features, utilizing a comprehensive literature review. By synthesizing findings from the literature, the study aims to provide insights into the current state of vehicle safety within this critical sector. It is worth mentioning that using safer vehicles represents a move toward achieving the vision of zero incidents (fatalities and serious injuries).

Keywords: *Vehicle safety, Technologies, Prevent, Mitigate, Crashes, Accidents*

1. Introduction

Roadways undeniably contribute to a consistent occurrence of fatalities and injuries resulting from various crashes and accidents that take place during transportation. From a global standpoint, the annual toll of road traffic deaths averages around 1.35 million, positioning road traffic deaths as the eighth leading cause of mortality worldwide [29; 3]. These statistics encompass all categories of road users, like pedestrians, cyclists, motorcyclists, and motorists, regardless of gender and age groups [3]. Road traffic fatalities and injuries involve various road users, with motorists being the most prominent, as illustrated in Figure 1 [28].

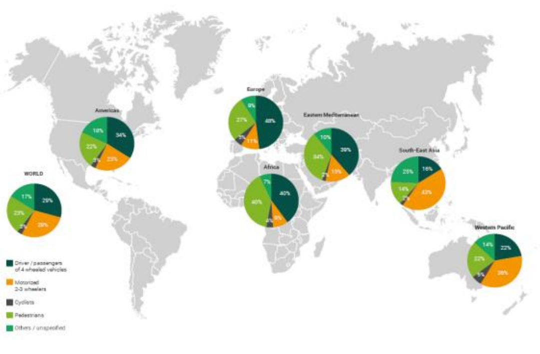

Figure 1: Distribution of deaths by road user type by WHO Region [28].

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According to Figure 1, the most considerable portion (29%) of global road fatalities includes motor vehicle occupants [20]. It is important to note that various factors contribute to the incidence and severity of road accidents. Among these factors, the safety of vehicles stands out as a crucial aspect. This underscores the importance of enhancing vehicle safety to offer optimal occupant protection. Consequently, concerted efforts are being made to reduce the number and the rates of road-related fatalities in different sectors, including the oil and gas industry.

1.1. The Problem

Accidents involving vehicles are a recurrent issue within the oil and gas sector, carrying the potential for grave repercussions. The Oil and gas sector involves the transportation of substantial volumes of highly flammable substances. Any collisions during transit carry significant risks, potentially leading to considerable harm to individuals and property. Such incidents pose substantial threats, including injuries, loss of life, environmental damage, disruptions in operations, and adverse effects on nearby communities [16; 6]. The demanding conditions prevalent in road transportation within the oil and gas industry, including adverse weather conditions with extremely high/low temperatures, heavy rains, and snow, impacting visibility and road surfaces, pose a heightened risk of accidents. Moreover, long driving hours and transporting hazardous flammable materials contribute to additional risk. In this context, vehicle safety technologies must operate efficiently and effectively. These technologies play a crucial role in averting accidents and minimizing the extent of injuries should accidents occur. It is imperative for the oil and gas industry to give paramount importance to the evaluation and improvement of safety measures and technological advancements aimed at alleviating the potentially serious outcomes associated with transportation in this sector [6].

The World Health Organization [29] holds that a comprehensive approach can prevent traffic fatalities and serious injuries. Governments must take proactive measures to address road safety, involving various sectors such as transportation, law enforcement, healthcare, and education, and by implementing strategies to enhance the safety of roads, road users, and vehicles [29]. WHO collaborates across multiple sectors within countries and partners with national and international stakeholders to work in a coordinated manner. Their primary goal is to assist Member States in the development, execution, and assessment of road safety policies to save lives and achieve the road safety target of reducing global fatalities and injuries from road traffic accidents by half by 2030. Among the essential interventions is enhancing vehicle safety [29]. This paper seeks to assess vehicle safety technologies in preventing crashes and mitigating their severity within the oil and gas sector to propose suggestions for improvement.

2. Literature review

The International Association of Oil and Gas Producers has reported that incidents related to land transportation have historically been the leading cause of fatalities in its member companies' operations. According to NIOSH (2023), the sector's primary cause of land transportation fatalities is motor vehicle accidents, constituting 29% of all industry-related deaths. This has placed motor vehicle fatalities in the oil and gas extraction industry among the highest of any private industry [20]. A significant portion of these incidents involve employees of well-servicing companies who undertake extensive travel on rural highways to reach well sites. These journeys often occur on substandard roads lacking secure shoulders and other essential safety features.

Since the year 2000, such incidents have accounted for 22% of all work-related fatalities reported by these members [2]. In 2001, an estimated 27.700 car occupant fatalities were recorded. As per information from United States Energy Media in 2020, the transportation of gas and oil is a complex undertaking that demands specialized equipment, rigorous safety procedures, and strict compliance with regulations.

Thanks to improvements in car safety design and operating systems, a substantial reduction of approximately 55% was achieved by 2012, resulting in 12.345 car occupant deaths. While this progress cannot be attributed to a single factor, the contribution of vehicle safety improvements cannot be understated [8]. This progress underscores the increasing demand for maximum occupant protection in the event of accidents or crashes, considering the varying severity of injuries and fatalities resulting from different types of collisions, such as car-car or stationary object collisions, frontal impacts, side impacts, or rollovers, as indicated by the Abbreviated Injury Scale (AIS) [8].

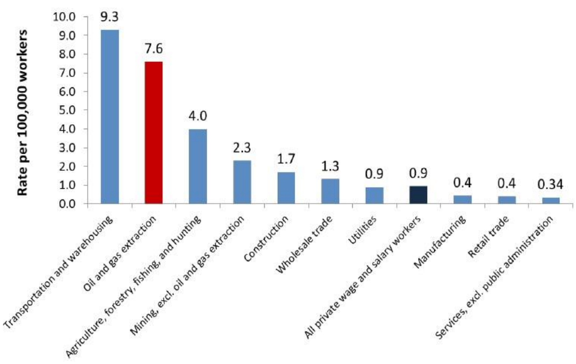

Figure 2: Motor Vehicle Fatality Rate, Oil and Gas Extraction vs. Other Private Industries, 2003–2009 [20].

NIOSH (2023) explains that 38% (2.88 out of 7.6) of fatalities in the oil and gas industry in Figure 2 occurred to workers who were not wearing their seatbelts, and 24 more fatalities were ejected from the vehicle, indicating that their seatbelts were most likely not worn [15].

Since the occurrence of the first motor vehicle fatality in New York City in 1889, the focus on occupant protection has remained a central concern in the field of transportation. Manufacturers have shouldered the responsibility of demonstrating the design of safer vehicles used across different industries, and this aspect has undergone significant evolution in vehicle design principles and operational processes, particularly in the context of collisions [7]. Early vehicle safety measures included reducing tire blowouts to enhance vehicle control, incorporating laminated glass to reduce facial lacerations, and adopting all-steel car body structures for improved occupant protection. Subsequently, safety enhancements, such as introducing seat belts during the intermediate safety period, made notable strides. Today, vehicle design incorporates more advanced safety measures, including dummies and electronic devices to regulate crashworthiness and crash avoidance performance, aiming to achieve maximum occupant protection and safety [7].

Enforcing thorough motor vehicle safety initiatives can avert worker fatalities. One such initiative involves using in-vehicle monitoring systems (IVMS), electronic devices that capture information regarding a driver's behavior and vehicle utilization, including details like date, time, speed, acceleration, deceleration, and safety belt usage. According to reports from oil and gas companies, these systems are proving effective in lowering the incidence of crashes and injuries among their workforces [15]. The oil and gas sector employs Internet of Things (IoT) sensors and a handful of safety devices in machinery, fleets, and pipelines to identify issues such as corrosion, leaks, fleet operations monitoring, and other types of damage that can result in accidents. Additionally, remote-operated vehicles (ROVs) have land and deep-water inspection and exploration applications for oil and gas companies. Certain ROVs can perform minor maintenance tasks beneath the water's surface [22].

According to the National Highway Traffic Safety Administration (2023), vehicle safety has introduced various technologies to enhance safety across different eras. This data is shown in Table 1.

Table 1: Eras and vehicle safety technologies introduced.

Eras	Safety focus	Technologies Introduced
1950-2000	Safety and convenience	Cruise Control, Seat Belts, and Antilock Brakes
2000-2010	Advanced Safety	Electronic Stability Control, Blind Spot Detection, Forward Collision Warning, and Lane Departure Warning
2010-2016	Advanced Driver Assistance	Rearview Video Systems, Automatic Emergency Braking, Pedestrian Automatic Emergency Braking, Rear Automatic Emergency Braking, and Lane Centering Assist
2016-2025	Partially Automated Safety	Lane Keeping Assist, Adaptive Cruise Control, and Traffic Jam Assist

Source: National Highway Traffic Safety Administration (2023).

Between 1950 and 2000, safety and convenience features such as Cruise Control, Seat Belts, and Antilock Brakes were developed. From 2000 to 2010, the focus shifted to Advanced Safety Features like Electronic Stability Control, Blind Spot Detection, Forward Collision Warning, and Lane Departure Warning. From 2010 to 2016, Advanced Driver Assistance Features emerged, including Rearview Video Systems, Automatic Emergency Braking, Pedestrian Automatic Emergency Braking, Rear Automatic Emergency Braking, and Lane Centering Assist. In the period spanning from 2016 to 2025, there is ongoing development of Partially Automated Safety Features like Lane Keeping Assist, Adaptive Cruise Control, and Traffic Jam Assist. It is anticipated that fully automated safety features will be developed from 2025 onward.

The European New Car Assessment Program (Euro NCAP) is a benchmark for developing vehicle safety technologies, contributing to improved safety performance in Europe and globally. Euro NCAP adjusts its vehicle safety protocols to align with changing technology and shifts in societal mobility trends. These technologies, which have evolved, apply to various vehicles, including passenger cars and trucks, for use in different sectors, one being the oil and gas industry. The updated safety assessment procedures go beyond incorporating dummies and electronic devices in vehicle design to regulate crashworthiness and crash avoidance performance. The goal is to ensure maximum occupant protection and safety by implementing more advanced safety measures. These measures include new elements like child presence detection systems, vehicle submergence standards, and technologies designed to detect and respond to motorcycles and vulnerable road users. This evolution begins in 2023. Manufacturers striving for Euro NCAP's coveted five-star rating must meet the stringent requirements outlined by this enhanced test protocol. Furthermore, these safety technologies have applications in various industries, including oil and gas [10].

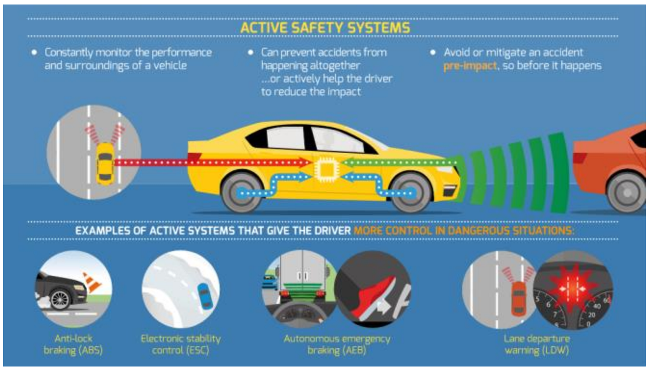

Figure 3: Active safety systems [11].

In the realm of oil and gas corporations, Sentinel Transportation LLC, headquartered in Delaware and engaged in the transportation of crude oil and petroleum products throughout the United States, exemplifies the integration of advanced driver assistance systems within the commercial fleet sector. The company incorporates a range of vehicle safety technologies, encompassing radar, video and braking sensors, in-cab cameras, both rear and forward-facing cameras, speed limiters, lane departure warnings, tire monitoring systems, and automatic emergency braking systems, among other technologies, to enhance overall vehicle safety [21]. According to Netradyne, in 2023, vehicles within the oil and gas sector are utilizing in-cab audio alerts to deliver immediate feedback, prompting corrective action. This feedback is an active method to promote adopting safe driving habits.

3. Objective

Safe vehicles are pivotal in preventing accidents and minimizing the risk of severe injuries. Several United Nations (UN) regulations on vehicle safety exist that, if adopted as part of a country's manufacturing and production standards, can save more lives. Without these fundamental standards, the risk of traffic injuries, both for those inside the vehicle and those outside of it, significantly increases [29]. This document examines vehicle safety technologies to minimize road fatalities and injuries within the oil and gas industry.

4. Methodology

This research is grounded in thoroughly examining the current state of vehicle safety technologies through a comprehensive literature review. This method entails critically examining and synthesizing scholarly information from diverse sources, such as articles, books, and websites. The primary aim is to develop a comprehensive understanding of the research topic, serving as a crucial foundation to inform and direct new research initiatives. This approach is instrumental in identifying existing gaps, offering insights to guide further studies, and proposing recommendations for enhancement on the topic [14].

5. Vehicle Safety Technologies

Like many other industries, the current vehicle safety technologies in the oil and gas industry can be broadly categorized into two groups. Active safety technologies, aimed at preventing crashes and accidents, are designed to forgive and correct driver errors. On the other hand, passive safety technologies focus on minimizing the severity of injuries sustained in a crash or accident [12].

5.1. Active Safety Technologies

The Anti-lock Braking System (ABS) originated in the 1920s for aircraft and was subsequently applied to automobiles. Its prevalence increased in the 1970s and 1980s. ABS is designed to avert wheel lock-up during intense braking by regulating pressure. It uses sensors to identify potential wheel locks and adjusts the brake pressure, enabling the driver to retain steering control. In emergency braking scenarios or slippery road conditions, ABS effectively prevents skidding and maintains traction during operations in the oil and gas industry [10].

Autonomous Emergency Braking (AEB) was introduced in 2014. AEB systems utilize various sensors such as cameras, radars, and lidars. These sensors may operate individually or in combination (referred to as sensor fusion) to fulfill the specifications established by the vehicle manufacturer. Typically, these systems integrate autonomous braking with a forward collision warning, notifying the driver of potential danger with enough time for corrective measures. The system only intervenes to initiate emergency braking if the driver fails to respond promptly. To sum up, AEB identifies potential hazards, and if the driver does not act promptly, the system engages emergency braking to prevent or reduce the severity of a collision. The system is used in many sectors, including the oil and gas industry [10].

Electronic Stability Control (ESC) was implemented in the mid-1990s, initially appearing in luxury vehicles and gaining broader adoption in the 2000s. ESC employs sensors to observe the vehicle's speed, steering input, and lateral acceleration. Its function is to enhance the vehicle's stability by identifying and mitigating instances of traction loss, preventing skidding, and maintaining control by selectively applying brakes to individual wheels and, in certain instances, adjusting engine power, aiding the driver in retaining control of the vehicle, especially in demanding road conditions like those prevalent in most oil and gas environments [10].

Adaptive Cruise Control (ACC): Initially introduced in the late 1990s and widely adopted in the 2000s. ACC is a safety feature that utilizes radar and laser scanners to detect a vehicle's proximity to others in traffic, aiding the driver in partially controlling the vehicle to maintain a safe distance from surrounding vehicles. The system's primary focus is on the pre-crash condition, considering the speed at which a vehicle approaches others and the spacing between them. In response to potential hazards, the system adjusts the vehicle's speed, maintaining a safe distance until conditions allow the vehicle to proceed. ACC is particularly effective in rectifying driver errors, enhancing safety and convenience, and optimizing vehicle separation to increase road capacity. It is also called autonomous and dynamic cruise control and is utilized by vehicles involved in oil and gas operations [27].

Lane Departure Warning and Lane-Keeping Assist: Lane departure warning systems emerged in the mid-2000s. A lane departure warning alerts the driver when the vehicle drifts out of its lane. Lane-keeping assist operates after the lane departure warning is passed to the driver. When no proper action is taken, the LKA may intervene by applying steering input (torque to the car's steering wheel) to keep the vehicle within its lane. This operates without the driver's control, preventing side crashes with other vehicles and frontal crashes for vehicles that move in opposite directions. It functions mainly on arterial routes and freeways and manifests differently. For instance, the system may warn a driver using audible audio-visual signals, and others may vibrate the car's steering wheel for the driver to act. The technology is found in vehicles across different industries, including oil and gas [27].

Speed Limit Information (SLI) is a technology designed to identify and communicate the recommended driving speed based on road speed signs. This system utilizes built-in vehicle cameras to recognize road signs or obtain speed-limit data from the road navigation system. The information is then displayed on the car's dashboard or navigation system, ensuring the driver knows the appropriate speed for each road segment. This functionality reduces the risk of rollover accidents caused by excessive speeding and helps prevent collisions with stationary or moving objects [11].

Cross-traffic alert systems started appearing in the mid-2010s and are now widely used in the oil and gas sector. It warns drivers of approaching traffic from the side, typically when backing out of parking spaces. It uses sensors to detect cross-traffic behind the vehicle. [27].

360-degree cameras: It is a sophisticated technology equipped with four intelligent cameras that offer drivers a comprehensive view of their vehicle in a single image. Its purpose is to eradicate blind spots in vehicles and aid in maneuvering. By seamlessly integrating images from four ultra-wide-angle cameras, the system presents a real-time, bird's-eye-view of the vehicle and its surroundings on the driver's monitor, ensuring no blind spots are overlooked. 360-degree cameras are equipped in most vehicles involved in oil and gas operations [1].

Radar Obstacle Detection is an advanced technology designed to identify stationary and moving objects, even in challenging environmental conditions like petroleum. This system gives drivers audible and visible warnings when objects approach a specified distance. The customizable distance settings accommodate various vehicle sizes and applications, ranging from 2m to 10m in width and 3m to 30m in length. Whether used on-road or off-road, such as in specialized petroleum equipment, radar obstacle detection ensures top-tier protection by averting collisions, thus saving lives [1].

Also, vehicle camera systems are used in the oil and gas industry to enhance the safety of drivers and operators during maneuvering and driving. CCTV cameras mounted on vehicles eliminate blind spots and assist in reversing by providing a live feed on the monitor, displaying everything within the camera's field of view. In challenging conditions, such as when visibility is compromised due to accumulated grit and dirt from roads or work sites, shutter cameras are an option. These cameras have an automatic cover that protects the lens when not used. Camera monitor systems exhibit exceptional durability in various environmental conditions and can function as low as -40 °C, making them particularly well-suited for industries like oil and gas [1].

5.2. Passive Safety Technologies

Airbags, initially introduced in the 1970s and widely adopted in the 1980s and equipped in all newly manufactured vehicles including those used in the oil and gas industry. Airbags rapidly deploy upon impact to provide a protective cushion, reducing the risk of injury for vehicle occupants. According to the National Highway Traffic Safety Administration (2023), airbags deploy within a remarkably short time frame of 10-20 milliseconds from the moment of collision. Sensors connected to the airbag system detect the impact and send signals to an inflator module, initiating deployment. The igniter within the airbag releases harmless gas, inflating the airbag with nitrogenous gas generated through the reaction of potassium nitrate (KNO3) and sodium azide (NaN3), as outlined by the United States Department of Transport (2022).

Seatbelts: Seatbelts were initially introduced in the 1950s and played a crucial role in collision safety. They secure occupants during a collision, preventing them from striking the vehicle's interior or being thrown out. These safety belts significantly decrease the likelihood of fatal or severe injuries in the event of a crash or sudden vehicle stop. Doing so diminishes the force of secondary impacts with interior hazards, ensuring occupants are correctly positioned for optimal effectiveness of airbags. The restraint provided by seatbelts keeps front seat occupants from the car's interior or windshield, as passengers move at the same speed as the car and maintain that speed when the vehicle abruptly stops, as the Centers for Disease Control (2015) explains. Seatbelts are found in all vehicles used for oil and gas operations today, as the importance is demonstrated by NIOSH (2023), which explains that 38% of fatalities in Figure 2 occurred to workers not wearing their seatbelts.

In the 1990s, Whiplash Protection Systems (WHIPS) were introduced to enhance safety during rear-end collisions. These systems incorporate adjustable headrests and specially designed seats to minimize the risk of whiplash injuries. WHIPS is specifically designed to mitigate injuries resulting from rear-end collisions, focusing on protecting the heads of front-seat passengers. During a rear-end collision, WHIPS responds to factors such as vehicle speed, collision nature, and angle, adjusting the position of front seat occupants. This adjustment involves lowering the front seat backrests and moving the seat cushions downward, absorbing energy and reducing the potential for whiplash injuries. Vehicles carrying out oil and gas operations are equipped with WHIPS [12; 26].

Crumple Zones: Crumple zones were introduced in the 1950s and became more prevalent in the 1970s. they deform and absorb energy during a collision, reducing the force transferred to the occupants. This helps minimize injury by slowing down the deceleration of the vehicle. An example is an energy-absorbing or collapsible steering column. It minimizes injuries to the driver's head, chest, ribcage, and abdomen during a frontal collision by redirecting the motion of the steering wheel to the vehicle's ground wheels. This design helps mitigate potential injuries to the driver in a significant frontal crash by preventing impact transmission through the steering gearbox and linkages. Constructed with collapsible tubes, the steering column collapses upon encountering a severe frontal impact, absorbing a larger portion of the energy, and decreasing the impact on the driver. Some vehicles oil and gas companies use are manufactured with crumple zones [12].

Side-Impact Beams: Side-impact beams started appearing in the 1960s and became more widespread in the 1980s. Side-impact beams are reinforcements in the doors that enhance the vehicle's structural integrity, providing additional protection during side-impact collisions. This innovation has been adopted by most, if not all, vehicle manufacturing companies [12; 10].

Safety Cages: A safety cage is a vehicle's structural framework to maintain its integrity during a crash. It protects occupants by preventing the collapse of the passenger compartment [12].

Pedestrian Protection Systems: Pedestrian protection systems became prevalent in the 2010s. These systems include design elements such as external airbags or energy-absorbing materials to reduce the severity of pedestrian injuries in the event of a collision. Vehicle manufacturers today are increasingly incorporating pedestrian protection systems into newly manufactured vehicles utilized by different industries, including oil and gas [12].

Also, warning system devices that provide early warnings to the car occupants, including drivers and passengers, have been developed. Occupants receive an auditory signal, and a corresponding symbol is sometimes displayed on the car's dashboard to indicate the need for proper behaviors. These systems and devices do not prevent accidents but warn occupants about the potential risks. They include speed limit information, seat belt reminders, lane departure warning devices, alcohol interlockers, tire pressure monitors, and attention detection and drowsiness devices. They are also found in vehicles involved in oil and gas operations [27].

6. Limitations

A limitation might be the study's failure to clarify whether the technologies are exclusively utilized in the oil and gas sector. Nevertheless, it is important to note that these technologies are employed across diverse sectors, including but not limited to the oil and gas industry.

Another constraint is the absence of data regarding the specific vehicle safety technologies that individual oil and gas companies employ. Nevertheless, information from a few companies, like Sentinel Transportation LLC, provides insights into the status of vehicle safety technologies within the global oil and gas industry.

One potential limitation of this research could be its omission of a comprehensive review of all vehicle safety systems and devices, lacking in-depth explanations of the operational mechanisms of each technology. Nevertheless, the study extensively delves into well-established technologies associated with active and passive safety measures.

7. Conclusion

In conclusion, the vehicle safety technologies presented in this document are widely used in the oil and gas industry. Preventing crashes and minimizing injury severity when accidents occur involves integrating various systems and devices for vehicle safety. It is crucial to acknowledge that the implementation of these technologies differs among manufacturers and models, and the provided timeline offers a general perspective.

Ongoing research and development in the automotive sector continually introduces new safety technologies and improves existing ones. This study recommends that the oil and gas industry regularly update vehicle safety technologies due to the ever-evolving landscape.

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