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An Overview of Road Accident Analysis: A Data-Driven Approach for Enhanced Safety Solutions

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Abstract

This paper presents a focused analysis of the primary factors contributing to road accidents, encompassing human behavior, road conditions, and vehicle-related issues. To develop effective road safety strategies, it is crucial to identify key contributors to accident occurrence and severity. The study highlights that human factors, such as speeding, distraction, and impaired driving, play a central role in accidents. Additionally, environmental elements, including road and weather conditions, increase accident risks. The vehicle's role in ensuring safety is also emphasized as a critical aspect. This research contributes to the formulation of comprehensive road safety measures, offering an integrated framework that includes educational campaigns, infrastructural improvements, and technological advancements. These findings underscore the need for targeted interventions to mitigate high-frequency accidents and improve overall road safety.

Keywords: Road safety; accidents; human factors; vehicle factors.

1. Introduction

Nowadays, transport plays a very decisive role in the economic and social development of any country. The number of individuals died in traffic accidents worldwide ranks third among the primary causes of preventable deaths, according to data from the World Health Organization [1]. Understanding the key factors responsible for road accidents is so important, in order to develop effective strategies for the improvement of road safety. In response to the increasing concern over traffic incidents, this paper aims to identify and examine some of the primary causes contributing to road safety issues and a safer environment.

It is well known that the major from keys factors of road accidents is the human behaviour. Studies have shown that issues related directly to the driver, such as speeding, distraction, and impaired driving, are main causes of accidents. For example, a previous study with focus attention on driver behaviours, show that speed violations and loss of vehicle control, considerably impacts the accident severity [2]. Furthermore, most of dangerous driving practices that causes road traffic accidents can be preventable [3]. Another identified driver error includes over speeding and alcohol drinking, as dangerous

contributors to road accidents [4]. As a result, it is vital that human factors are manned through broad educational campaigns and law enforcement measures, in order to reduce accident level.

Another key factor that contributes to the accidents happening are the environmental conditions. Many studies show that factors such as road conditions, weather, day of the week and time of day are very important in determining the severity level of the accident. For example, [5] show that unfavourable and bad road conditions considerably correlate within the increase of accident severity on federal roads in Malaysia. Also, study of [6] has identified a number of environmental factors, such as temperature and humidity, as significant predictors of the severity of a traffic accident. The aforementioned findings suggest that improvements in road infrastructure and the implementation of more effective traffic management strategies can serve to reduce the impact of infrastructure and environmental factors on road safety.

New advances in information technology, especially in the areas of data analytics and machine learning, offer promising ways to improve road safety. The implementation of machine learning algorithms has been demonstrated to be an effective method for predicting the severity of accidents [7]. This is achieved by analysing historical accident data and identifying the key contributing factors. Furthermore, this approach can permit us to formulate the evidence-based strategies that are customized to specific road conditions and driver behaviours. Moreover, the integration of artificial intelligence into accident prediction can improve the early identification of risk factors, thereby allowing for the implementation of prompt interventions [8]. As stated by [9], machine learning can also assist in environmental resource management within the transportation sector, so it contributes to enhance the road safety.

In order to have a better increase on road safety, a good approach can be the management of road accidents through the implementation of systematic methodologies. In their study Makarova et al. propose such approach in order to identify the causes and severity of accidents, suggesting that data-driven and decision-making can reduce significantly the accident rates [10]. This perspective is aligned with the findings of [11], who emphasizes the importance of examining road traffic data to identify the critical factors contributing to accidents. By using the most elaborated data analysis techniques, authorities can prioritize interventions and allocate resources in a more effective way.

In summary, there is a need for an interdisciplinary solution that incorporates both human behaviours, the road and environmental conditions, benefiting from the use of the most advanced technologies.

2. Accident Factors

Traffic accidents are complex phenomena, with a variety of contributing factors that collectively give rise to their occurrence. Among these factors, human behaviour, vehicle

condition, and road infrastructure are the primary contributors to the occurrence and severity of accidents. the road infrastructure, see Figure 1.

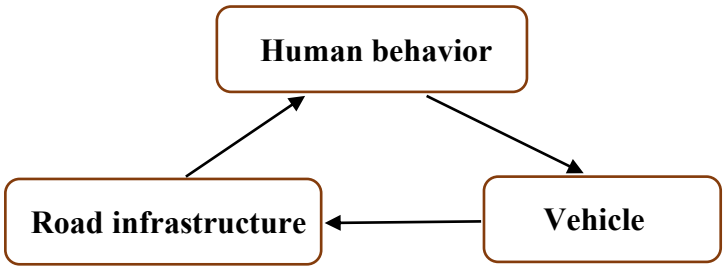

Figure 1. The primary contributing factors to road accidents

The probability of a road accident can be demonstrated by examining the state of the system in question, taking into account the aforementioned factors. In the context of road transport, it is possible to present the mechanical system, which concerns the connection between the vehicle and the road, as well as the biomechanical system, which pertains to the relationship between the human operator and both the vehicle and the road. The interdependence of these three factors in road safety can also be illustrated through the use of a Venn diagram in Figure 2, which represents the interrelationship between the three safety factors: man, vehicle, and road.

The environment in which we operate has a significant impact on our ability to ensure road safety. An examination of the figure below, which illustrates the interdependent relationship between the human operator, the vehicle, the road, the driver-vehicle subsystem, and the surrounding environment, reveals that the driving function is performed by the driver. The object being directed is the tool, while the environment provides the source of information that defines the state of the system. Figure 2 depicts the elementary connections between the three interactive subsystems.

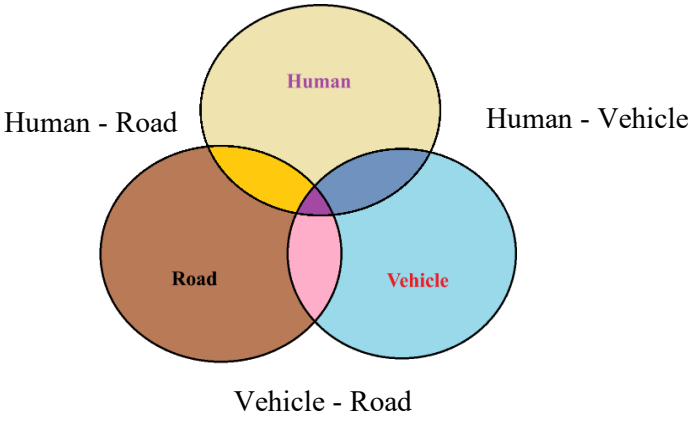

Figure 2. The elementary connections between the three interactive subsystems

In light of the aforementioned information regarding the road and the subjective assessment of external circumstances, the driver proceeds to operate the vehicle. As posited by Shala et al. (2021), the term "road factor" is understood to encompass a vast and largely unidentified array of elements [12]. These may include, but are not limited to,

the physical space occupied by the driver, the prevailing temperature, and the atmospheric conditions. Consequently, the road is regarded as a third factor in this context. The human-vehicle-road factor does not encompass all potential elements that could influence road safety, such as traffic regulations, traffic management, and control measures. Consequently, it is essential to consider a fourth traffic factor. While certain rules govern these factors, unsystematic factors also influence road safety. These include atmospheric conditions and obstacles on the road, such as stones and animals. In light of the aforementioned factors, it is imperative to identify a factor that encompasses all the elements. This factor is also known as the "incident factor," which can be defined as a road safety factor presented as a chance factor.

The human-vehicle-road system and road traffic operate under a set of predictable rules. However, these rules do not account for atmospheric conditions or other elements like oil spills, dirt, or the presence of wild animals, which can obstruct safe vehicle movement. Therefore, it is essential to introduce the concept of an "incident factor," which includes all unexpected safety hazards that may arise in road traffic.

2.1 Human Behaviour Factor

Human behaviour represents a primary causal factor in road accidents on a global scale. Notwithstanding the contribution of advances in vehicle safety technology and road infrastructure to a reduction in accidents, human error remains a significant factor. Risky driving behaviours have been recognized as major contributors to road accidents, including speeding, distracted driving, and driving under the influence of alcohol. Additionally, transgressive behaviours, particularly during holiday periods, significantly increase accident risks. In their study [13] found that a lack of awareness of traffic regulations and impulsive actions further elevate the likelihood of crashes. Risky behaviours such as texting while driving is a growing concern for road safety, with studies suggesting they may account for up to one-third of all accidents [14]. Therefore, raising awareness is critical for improving road safety. This can be achieved through education, stricter enforcement of traffic laws, and targeted awareness campaigns.

Driving is seen by behavioural researchers as a very complex task, which requires continuous adaptation to meet the needs and requirements to survive traffic situations. According to statistics, based on data from EU countries (see Table 1), the average manager is responsible for approximately 30 errors per hour, resulting from approximately 7,200 observations, 2,400 decisions, and 1,800 actions [15]. If these statistics are taken accurately, it can be suggested that only one in every 60 mistakes on average is likely to result in a dangerous situation and similarly that every accident is preceded by almost 75,000 mistakes.

In discussing the role of human factors in road accidents, it is important to consider a number of contributing elements, including:

- Personal characteristics of the driver
- Psychophysical properties
- Education and culture

The state of the leader may vary considerably depending on a number of factors, including level of education, health condition, age, temperament, morality, and intelligence. The probability of collisions is significantly elevated when individuals engage in risky behaviours such as distracted driving (e.g., texting), speeding, driving under the influence (alcohol/drugs), and aggressive driving. Additionally, fatigue and inexperience have been identified as significant contributing factors, impairing reaction times and judgment. The performance of drivers plays a pivotal role in ensuring road safety, as it directly influences the likelihood of errors that could potentially result in accidents.

Table 1: Events of an average driver, based on an average speed of 60 km/h and annual mileage of 200,000 km [15].

Events	**Frequency in time unit**	**Frequency per kilometre**
Part of the traffic information	5 in 1 sec	300 per km
Driver reviews	2 in 1 sec	120 per km
Driver decisions	40 in 1 min	40 per km
Driver actions	30 in 1 min	30 per km
Driver errors	1 to 2 min	1 per 2 km
Dangerous situations	1 to 2 hours	1 per 120 km
Almost accidents	1 per month	1 per 2 000 km
Accidents	1 in 7.5 years	1 per 1 500 km
Accidents with consequences	1 in 100 years	1 per 2 million km
Fatal accidents	1 in 2,000 years	1 per 40 million km

The effectiveness of a driver is contingent upon a multitude of factors, including their personal abilities, psychological and physical conditions, and the surrounding environment. These factors encompass the following:

- The skills and experience of the driver,
- Attention and concentration,
- Psychological and emotional conditions,
- Physical and health condition.

The classification of driving mistakes is a multifaceted one, encompassing a spectrum of infractions that can result in a spectrum of consequences, from minor to serious accidents. The most prevalent categories of errors include:

- Inappropriate decision-making
- Technical errors
- Delayed reaction time

The quality of a driver's performance is inextricably linked to the frequency of errors they make. Education and culture are very important factors in road safety performance. A driver who has acquired a certain education, traffic, road safety, respects traffic signs and rules and behaves seriously towards other traffic participants. It is a simple fact that drivers who perform poorly are more likely to make errors, thereby increasing the probability of accidents.

It is important to improve the driver's performance in order to reduce the possibility of errors. Continuous training and educational programs related to road safety are an effective method for increasing driver awareness and competencies. By enhancing their preparation and abilities in managing dangerous situations, the occurrence of errors can be decreased significantly.

Alcohol reduces the ability to assess critical situations and prolongs reaction time. The small amount of alcohol reduces caution and such drivers are more frequent causes of traffic accidents. Drivers under the influence of alcohol are not aware of reduced driving skills, but overestimate personal skills. During the concentration of alcohol in the blood of 0.2 %, the ability to drive progressively drops up to 1.4 %, when it can be assessed that the driver is not capable of driving. During the concentration of alcohol in the blood of 0.2 - 0.5 %, the critical condition decreases. The driver drives his vehicle faster, irregularly overtakes and does not respect traffic rules and priorities. It takes 10 - 15 minutes for alcohol to penetrate the blood, until the maximum concentration is reached after 40 - 60 minutes. It takes 6 hours for the body to get rid of the influence of alcohol. Table 2 depict the amount of alcohol in the blood during different hours.

Table 2. Alcohol amount in the blood during different hours

Type of drink	**Volume**	**Blood alcohol percentage (%)**				
		1/2 hour	**1 hour**	**2 hours**	**3 hours**	**4 hours**
beers	0.5 *l*	0.25-0.4	0.4-0.6	0.3-0.5	0.2-0.4	0.1-0.3
wine	0.5 *l*	0.6-0.8	0.8-1.4	0.7-1.3	0.6-1.2	0.5-1.1
alcohol	0.04 *l*	0.3	0.45	0.35	0.2	0.2

2.2 Road Factor

Roads, in a broad sense, consist of many technical elements with a function and a sense of meaning, which directly or indirectly realize elementary goals, such as unhindered communication in all atmospheric conditions, including all types of people and road user comfort. According to statistical data, 8-10% of the total number of road accidents is thought to be caused by road factors [16].

Beside human behaviour road condition is another key factor impacting significantly road accidents, through quality, design, and maintenance of roads. By this analysis we want to explores how road conditions, design flaws, and inadequate maintenance contribute to road accidents and provides clear knowledge to possible solutions. These elements are designed to achieve a set of fundamental objectives, including facilitating traffic flow and ensuring road users' safety and comfort. Road accidents are caused due to deficiencies during the design, construction and maintenance of roads, profiles and wear of the road surface, namely due to deformations along the road. From the perspective of vehicle vibrations, the road profile can be:

- Micro-profile.
- Macro-profile.
- Rudeness.

Such a road profile has a negative impact on the pneumatics and especially on its performance. Contemporary road surfaces, namely the upper layer of the road through which vehicles move, is constructed of asphalt, concrete asphalt and concrete.

If roads are poorly designed or not well maintained, there will be more accidents. Poor signage, potholes, a lack of crossings, and poor lighting can all make it harder for drivers to be aware of what's around them and to control their vehicles. It is evident that deficiencies in the design, construction, and maintenance of roads, particularly the deterioration of the surface and profile, are the primary causes of these incidents. A major contributing element to a lot of traffic accidents is poor road design. The probability of collisions on roads with insufficient planning, visibility, or safety elements may be considerably increased. Good roads with clear markings, good lighting and safe intersections help to decrease the number of accidents. Furthermore, regarding this issue is important to invest in better roads in order to prevent accidents. Figure 3 depicts an illustrative photo of road surface defects in the highway Tirana-Durres.

Figure 3. Illustrative photo of road surface defects, highway Tirana-Durres in Albania

The surface of the asphalted road is very sensitive to temperature changes, for high temperatures the upper layer of the road softens, while at low temperatures it hardens. During the year, temperatures on the surface of the asphalted road reach up to 80º Celsius in the summer season, while in the winter up to -15º Celsius where it is difficult to have an asphalt road surface that has the properties of roughness both during the summer season and during the winter season. It is difficult to maintain the proper roughness on the road surface because of these extreme temperatures, especially in the summer and winter. The condition of the road surface greatly affects road safety. Many accidents occur due to the dirty and wet road surface, which reduces the grip coefficient between the tire and the road surface, especially potholes. For a safe circulation, a good grip between the vehicle's tires and the road surface is necessary, which prevents the vehicle from sliding during its movement.

Geographical and environmental factors also have an impact on road safety; potential risks can become higher by insufficient adaptation to local conditions and bad road infrastructure. Numerous geographical factors, such as hilly and mountainous terrain, climate and weather patterns, and small roadways, increase the probability of accidents. Geographical and environmental factors can increase the dangers associated with road

safety, especially when local characteristics are not taken into account while designing infrastructure. To reduce accidents in roads exposed to environmental risks, investment must be made in customized road design that takes into account local constraints.

Road accidents are also on increase as a result of the phenomenon of fast urbanization and the congestion that follows. Advanced road designs and traffic control systems must be implemented in urban areas with large traffic volumes to maintain safety, however the infrastructure frequently cannot keep up with population expansion. Two important issues are lacking facilities for pedestrians and congested traffic. As a result, it is critical that urban road infrastructure develops in step with increasing traffic and population. To reduce accidents in urban areas, it is critical to improve traffic flow management, expand and modernize road networks, and incorporate pedestrian-friendly design elements.

2.3 Vehicle Factor

Road infrastructure and human behavior are frequently cited as the main causes of traffic accidents, but a vehicle's condition and features are also key factors in determining road safety. A vehicle's technology, maintenance, and design can either reduce or increase the chance of an accident. This investigation looks at how cars play a part in road accidents as well as the possible benefits and limitations of new vehicle developments in technology for road safety.

The vehicle, with its construction and the way it is used, affects to a large extent the safety of traffic on the road. According to road safety statistics in the EU, a substantial proportion of road accidents, estimated to be between 3 and 5% of the total number of accidents, are attributed to vehicle-related factors. However, this percentage may be underestimated, as post-accident inspections may not reveal all potential causes.

The elements of a vehicle that affect road safety can be classified as either active or passive. Active safety elements may also include technical solutions designed to reduce the likelihood of accidents. These may include, for example, the braking system, steering system, tires, lighting and signalling devices, and so forth. In contrast, passive elements can be defined as solutions that are designed to mitigate the consequences of an accident. The following elements are included in this category: doors, safety belts, headrests, windshields, engine position, and airbags.

One of the most direct ways that vehicles contribute to road accidents is through mechanical failures. Inadequate maintenance or inherent mechanical defects in vehicles pose a considerable risk to drivers, passengers, and other road users. Common mechanical issues that precipitate accidents include brake failure, tire blowouts and wear, steering and suspension system malfunctions, and lighting and signalling failures. Mechanical failures and substandard maintenance are pivotal contributors to road accidents. Routine vehicle inspections, proper maintenance, and adherence to manufacturer-recommended service intervals are indispensable for preventing accidents caused by vehicle defects, see Figure 4.

Figure 4. Illustrative photos of the Albanian official vehicle technical control centre, located in Tirana.

The design of a vehicle, including its dimensions, mass, and safety features, is of paramount importance with regard to road safety. While modern vehicles are equipped with advanced safety technologies, certain design elements can both increase and decrease the risk of accidents. To limit the impact of accidents and decrease their frequency, it is important that vehicles be provided with modern safety systems and that design standards be increased as well. A car's safety performance is significantly influenced by its age and condition. Older cars are more probable to be involved in accidents because they may not have the latest safety measures or have old parts. Older cars are more likely to be involved in collisions because they lack contemporary safety systems and have components that are damaged. The kind of vehicle also has a big impact on how likely an accident is to occur. It is necessary to establish legislative measures, educational programs, and infrastructure improvements to meet the safety problems presented by electric vehicles, motorcycles, and commercial vehicles.

3. Summary and Conclusion

The analysis reveals that human factors are the leading cause of road crashes, with distractions, excessive speed, aggressive driving, and impaired driving significantly increasing the risk of accidents. To mitigate these behaviours, targeted countermeasures such as public awareness campaigns, stricter law enforcement, the application of advanced technology, and driver education are essential. These measures can save lives by reducing both the frequency and severity of accidents caused by human error. Continuous driver training and education are crucial to improving awareness and driving skills, contributing to overall road safety.

Equally important is the role of road design in accident prevention. Poorly designed roads can substantially raise the likelihood of crashes, emphasizing the need for infrastructure improvements that prioritize safety. Vehicle conditions also play a critical role, with mechanical failures, outdated or poorly designed vehicles, and over-reliance on technology contributing to accidents. The integration of advanced safety technologies, such as reliable driver-assistance systems, along with regular vehicle maintenance, can significantly reduce these risks.

In conclusion, road accidents result from the complex interaction of human behaviour, vehicle conditions, and road infrastructure. Addressing these factors through a holistic approach—incorporating better infrastructure, education, and technology—can enhance road safety. By focusing on the primary causes of accidents, we can develop targeted strategies to not only reduce accident rates but also improve overall safety on our roads. Continued research is essential to discovering new solutions and interventions that can be implemented at the policy and road management levels

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Conflict of interests

The authors would like to confirm that there is no conflict of interests associated with this publication.

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