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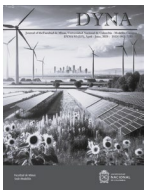

UNIVERSIDAD NACIONAL DE COLOMBIA

Enhancing road safety: a comprehensive examination of critical factors

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Abstract
The global road traffic safety situation is alarming, with millions of fatalities and injuries annually, underscoring the urgent need for improved safety measures. This study examines factors influencing highway safety, prioritizing them using the Relative Importance Index (RII). Through case evaluations, expert interviews, and a 29-criteria questionnaire grouped into road, vehicle, driver, and environmental factors, key issues were identified. The most critical factors include poorly designed roads (84.2%), malfunctioning brakes (83.4%), distracted driving (82.8%), and adverse weather (80.6%). These findings highlight the necessity of addressing fundamental road safety challenges to reduce accidents and their economic impacts. Proactive measures targeting infrastructure, vehicle maintenance, driver behavior, and environmental adaptability are essential for enhancing traffic safety worldwide.

Keywords: road safety; traffic accidents; human factors; highway design; vehicle maintenance; environmental factors; safety management; risk assessment.

Mejorar la seguridad vial: un análisis exhaustivo de los factores críticos

Resumen
La situación global de seguridad vial es alarmante, con millones de muertes y lesiones anuales, lo que subraya la necesidad urgente de mejorar las medidas de seguridad. Este estudio analiza los factores que influyen en la seguridad vial, priorizándolos mediante el Índice de Importancia Relativa (RII). Mediante evaluaciones de casos, entrevistas a expertos y un cuestionario de 29 criterios—agrupados en factores viales, vehiculares, humanos y ambientales—se identificaron problemas clave. Los factores más críticos incluyen diseño inadecuado de carreteras (84.2%), fallas en los frenos (83.4%), conducción distraída (82.8%) y condiciones climáticas adversas (80.6%). Estos hallazgos resaltan la necesidad de abordar desafíos fundamentales en seguridad vial para reducir accidentes y sus impactos económicos. Medidas proactivas enfocadas en infraestructura, mantenimiento vehicular, comportamiento del conductor y adaptación ambiental son esenciales para mejorar la seguridad vial a nivel global.

Palabras clave: seguridad vial; accidentes de tráfico; factores humanos; diseño de carreteras; mantenimiento de vehículos; factores ambientales; gestión de la seguridad; evaluación de riesgos

1. Introduction

Every year, approximately one million people lose their lives in automobile accidents, with up to fifty million sustaining injuries. The global economic impact is estimated at $518 billion, representing 1% to 3% of the world's GDP [1]. Traffic accidents continue to increase annually, causing severe injuries and property damage [2]. Consequently, numerous researchers have studied the factors contributing to different types of road traffic accidents to enhance safety. However, road collisions are primarily caused by interactions involving motorized and non-motorized vehicles, pedestrians, and passengers, excluding incidents solely between individuals. Current research often focuses on specific accident types while neglecting others, underscoring the urgent need for a comprehensive analysis of contributing

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factors. According to findings, for children and individuals aged 5 to 29, road traffic accidents rank as the ninth leading cause of death across all age groups. In the United States, recent reports highlight similar concerns [3].

The highway traffic system primarily consists of individuals, vehicles, roads, and traffic environments. For this dynamic system to operate effectively, all components must work in harmony.

The current study identifies human-related factors like driver behavior, age, and experience as major contributors to accidents, with research showing that distractions, impaired driving, and speeding significantly increase crash risks. Vehicle-related factors such as tire blowouts, brake failures, and mechanical defects, particularly in commercial trucks, contribute to accidents, while poor road design, including sharp curves and inadequate markings, further elevates risks. Additionally, adverse weather conditions like rain, fog, and snow heighten accident severity, emphasizing the need for comprehensive safety measures addressing human, vehicle, road, and environmental factors. While other studies. The response mechanism of drivers to warnings was studied by Shao et al. [4] by taking into account the characteristics of the driver along with the real-time risk level of driving, so as to compare normal and conservative drivers with impulsive drivers who tend to follow another car much closer ahead of them with a lower probability to slow down. And Haq et al [5]. studied severity regarding crashes and injuries pertaining to brake failure in steep mountainous roads in Wyoming. Some scholars have thus described the impact of vehicle safety hazards on traffic accidents. Excessive speed is the leading cause of traffic accidents. Uddin et al. [6] indicated that on rainy days, variable speed limit signs should be placed in order to restrain the speed of trucks. The studies Any imbalance or inconsistency can disrupt the system, leading to accidents. Factors contributing to such issues include:

- Human-Related Factors: Driver behavior significantly affects accidents. Inadequate driving skills and driver age are major contributors [4,5]Inexperienced drivers are more likely to be involved in crashes, emphasizing the need for additional training and education. Risky driving behaviors remain one of the leading causes of fatal accidents [6-8].
- Vehicle-Related Factors: Research has examined the effects of vehicle defects, including tire blowouts, steering malfunctions, and brake failures, on traffic accidents [9]These flaws, particularly tire blowouts and braking failures, are significant contributors to accidents [10]. Speed is another major factor influencing road accidents [11-13].
- Road-Related Factors: Research has examined how certain road features, like steep climbs, sweeping curves, and points of intersection, affect auto accidents. Reducing accidents requires careful consideration of roadway geometry. For instance, the likelihood of collisions increases when the radius of horizontal curves is less than 200 meters [14].
- Environment-Related Factors: Beyond human and vehicular components, environmental conditions significantly impact highway safety. Poor weather and high traffic volume are closely associated with accident rates. Adverse weather, such as rain, fog, snow, and wind, poses serious [15,16]. In such conditions, limited visibility, impaired judgment, and slippery roads increase the likelihood of errors and accidents [17]. This paper aims to identify the factors influencing highway safety and their overall impact.

2. Methodology

The initial step comprises a questionnaire and how the author gathers and prepares the questionnaire from the ministry of transportation in Iraq which spate into open and closed questionnaires. The second step consists of two steps including the selection of the use of case studies for road.

projects. Then, list the elements that influence roadway safety. Finally, the research ranks these aspects using the Relative Importance Index (RII). Fig. 1

2.1 The first part: general information

The following part contains general information about the participant as well as information on the people who completed the questionnaire from the study's target community (specialty, educational background, current field, and years of experience).

2.2 Part two: the factors affecting on highway safety

This section of the questionnaire contains a list of variables that are likely to have a negative influence on highway safety in (Appendix (A).

2.2.1 Design questionnaire

Based on the study's goals, a questionnaire survey was created to assess the causes and impacts of building delays. The questionnaire was divided into two sections. The first segment collected essential data regarding the people who participated. The second section contained a list of identified significant failure variables impacting highway safety.

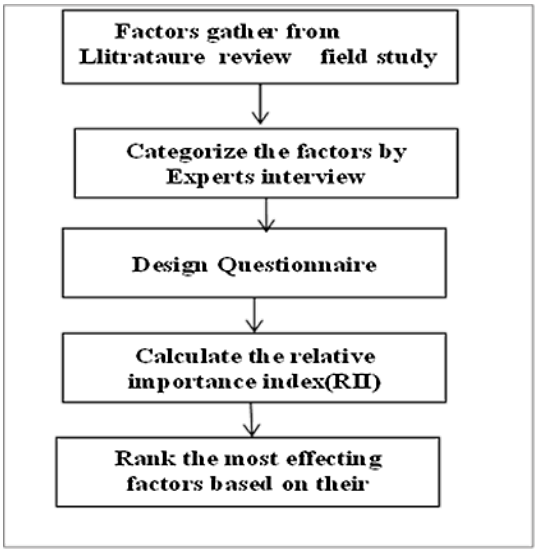

Figure 1. Research Methodology
Source: own work

The factors were divided into four categories: driver, road, vehicle, and environment. The significance of each element was assessed on a five-point scale: strongly agree, agree, neutral, disagree, and strongly disagree (scoring from five to one). This section contains 29 closed questions geared up with a five-point Likert scale [18]**.** this study aims to enhance road safety using relative important index

2.2.2 Questionnaire distribution

The questionnaire was delivered to the 82 persons who comprised who intended sample. Professionals working on Iraqi construction projects in Diyala province (Architects, Civil Engineers, Mechanical Engineers, Electrical Engineers, and any other professional with associated specialty) are included in the research population Using this strategy, the researcher presented a clear summary of the research project's aims and provided any further clarifications that were required.

This approach ensures higher levels of precision and realism since it allows for direct engagement and follow-up with participants. Direct meetings enabled the involvement of seventy people.

Only 75 surveys have been received by participants. Fig. 1 presents a summary of the research sample, containing the total quantity of surveys that were sent and received. Additionally, it displays the distribution process and response rate.

The findings show that 91% of respondents are happy, indicating a high level of engagement according to the size of the sample (72 ÷ 82 =91%)

2.2.3 Reliability of Questionnaires

One of among the most important methods for determining dependability is the Alpha Cronbach constant, which has a value between 0 and 1; the closer to 1, the better the degree of reliability [20].

The degree of reliability is categorized in Table1.

The process of assessing whether questionnaire findings remain consistent by delivering the same responses while applying again (twice) to the same group of people at different periods. It refers to the degree to which a measuring process produces comparable findings when repeated.

Cranach's Alpha is used to assess reliability, and it has to be at least 0.7 representing the values of Alpha Cronbach.

Table 1.
Reliability Cutoff Values

Cronbach's alpha	Degree of Reliability
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Source: Adapted from P. N. Vijayamohanan and A. Rjumohan, 2020.

3. Results and Discussion

3.1 Statistical analysis

Part one: General Information

The characteristics of the target sample for the survey are shown in the following figures.

The x-axis represents the (Experience Years, Academic Degree, Working Sector, and Field of Specialization

The y-axis represents the percentage of respondents

Experience Years

Fig. 2 shows the years of experience in the sample where the percentages are as follows: (0-5) equal to 26%, (5-10) equal to 40%, (10-25) equal to 18%, and 25-30 equal to 12%

Academic Degree

Fig.3, represented the distribution of academic degrees. The findings show that 50% of those surveyed hold a bachelor's degree; 22% have a master's degree and 23% a PhD.

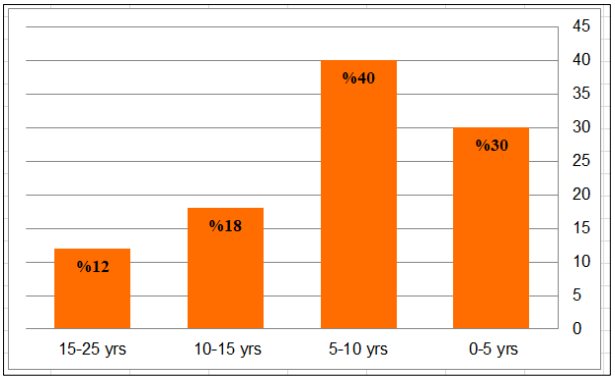

Figure 2. Experience years of responding
Source: own work

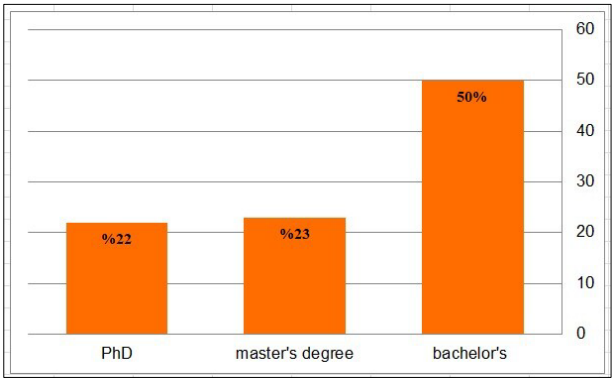

Figure 3. Academic Degree
Source: own work

Working Sector

As shown in Fig. 4, this part focuses on the working sectors of the respondents. According to the data in the figure, 67% of participants are from the public sector, and 33% are from the private sector.

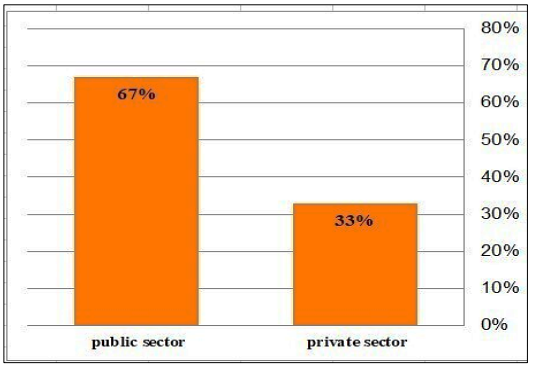

Figure 4. Working Sector
Source: own work

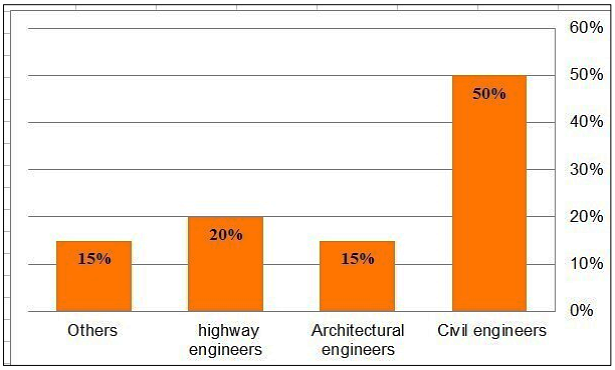

Figure 5. Field of Specialization
Source: own work

Field of Specialization

With 40% going to civil engineers, 17% to architects, 20% to mechanical engineers, and 8% to electrical engineers, there is a notable diversity of specializations. According to Fig. 5, 15% of responders have a variety of expertise.

3.2 Descriptive statistics

The numerical, graphical, and tabular approaches for organizing, analyzing, and presenting data are known as descriptive statistics and the most significant benefit of descriptive statistics is that they make a large amount of study material easier to 'read.' The results of the study can be conveyed clearly and concisely by condensing a big set of data into a few statistics or a graphic such as a graph or table (Argyrous, 2011). The following descriptive statistics were used.

Data Analysis The forms were gathered and organized in tables to compute the statistical analysis by using the statistical program SPSS version 26

3.2.1 Relative Importance Index (RII)

The relative importance index (RII) approach was used to calculate responders' rankings of items/variables. RII is determined using a specific equation [19]

$$RII = \frac{\sum W}{(A * N)} \quad (1)$$

When:
W: The weight given by respondents for each component (ranging from 1 to 5)
A: Represents the highest weight (which equals 5)
N: Represents the total number of respondents

3.2.2 Mean score ranking technique

One of the most important indicators of central tendency is the mean. The following formula was used to determine the mean score for each element or option. [20].

$$Ms = \sum_{K=1}^{K=N} \frac{X_1 * S_1 + X_2 * S_2 + X_3 * S_3 + X_4 * S_4 + X_5 * S_5}{N} \quad (2)$$

Were
Ms= mean score (1≤Ms≤5)

3.2.3 Measure of variation

The most important measure of variation is the standard deviation. It is quantitative measurement, which indicates the variability among the numbers in any distribution; and tells as to whether it is centered or dispersed-about-the-mean (SD) (Gravetter and Wallnau, 2016).

The standard deviation(SD) for respondents based on the equation given below is: [20]:

$$SD = \sqrt{\sum_{k=0}^{n} (xi - x)^2 * \frac{fi}{\sum_{k=0}^{n} fi}} \quad (3)$$

Were
SD = standard deviation
x= mean score
xi= degree of the criterion importance
fi= frequency

4. Results and discussion

The primary goal of employing a closed questionnaire is to evaluate the relative relevance of the elements influencing highway safety. The tables of information below present the data evaluation for the twenty-nine factors.

Table 2 highlights key factors related to vehicle influencing highway safety, assessed through their mean, relative importance index, and rank. The analysis reveals that Poorly Designed Roads (RII: 84.2%) are the most critical factor, significantly contributing to unsafe driving conditions. Roadway Design Flaws (RII: 80.6%) also rank highly, underscoring the impact of improper alignment and

Table 2
Factors related to Vehicle[21]

No.	Factors	Mean	Std. Deviation	RII	Rank
1	Poor Vehicle Maintenance	3.24	1.662	0.648	7
2	Malfunctioning brake systems	4.17	1.167	0.834	1
3	Defective Lights	3.83	1.537	0.766	3
4	Improperly Adjusted Mirrors	3.66	1.61	0.732	6
5	Missing Safety Features	3.72	1.486	0.744	5
6	Overloaded Vehicles	4.07	1.557	0.814	2
7	Vehicle Design Flaws	3.79	1.521	0.758	4

Source: Adapted from R. A. Rahman, A. R. Radzi, M. S. H. Saad, and S. I. Doh, 2020

Table 3.
Factors related to roads[22]

No.	Factor	Mean	Std. Deviation	RII	Rank
1	Poorly Design Roads	4.21	1.236	0.842	1
2	Inadequate Road Signage	3.69	1.339	0.738	6
3	Inadequate Lighting	3.9	1.472	0.78	3
4	Roadway Design Flaws	4.03	1.375	0.806	2
5	Lack of Cycling Infrastructure	3.1	1.633	0.62	9
6	Road Hazards	3.79	1.449	0.758	4
7	Obsolete Infrastructure	3.61	1.721	0.722	8
8	Inadequate Road Maintenance	3.69	1.514	0.738	5
9	Inadequate Road Markings	3.66	1.565	0.732	7

Source: Adapted from S. Deep, S. Banerjee, S. Dixit, and N. I. Vatin,2022

design elements on accident rates. Inadequate Lighting (RII: 78%) is equally significant, as insufficient visibility, particularly at night, increases the likelihood of traffic accidents.

These high RII values emphasize the need for immediate interventions to address these pressing safety issues[21].

Table 3 identifies critical road-related factors significantly affecting traffic safety, as reflected by their high relative importance index values and top rankings. Malfunctioning brake systems rank as the most impactful factor with RII (88%), highlighting their essential role in preventing accidents. Overloaded Vehicles follow closely with RII (87.6%), as excessive

weight compromises vehicle stability and control. Defective Lights with RII (80.2%) are another key concern, as poor lighting reduces visibility and increases the risk of collisions. Addressing these issues through regular maintenance, strict weight regulations, and proper vehicle inspections is crucial for enhancing road safety[22]

Table 4 highlights critical driver-related factors that significantly impact traffic safety. Distracted Driving ranks as the most influential factor (RII: 87.2%), emphasizing the dangers of losing focus while driving. Exceeding speed limits (RII: 86.6%) is equally critical, as it increases the likelihood and severity of accidents.

Aggressive Driving (RII: 82.6%) also poses a significant risk, as it often leads to reckless behavior and reduced reaction times. Addressing these behaviors through awareness campaigns, strict enforcement of traffic laws, and driver education programs is essential to improving road safety[23].

Table 4.
Factors related to Driver[23].

No.	Factors	Mean	Std. Deviation	RII	Rank
1	Distracted Driving.	4.14	1.407	0.828	1
2	exceeding speed limits	4.1	1.472	0.82	2
3	Aggressive Driving	3.72	1.437	0.744	3
4	Lack of driving knowledge and skills	3.66	1.653	0.732	5
5	Failure to follow traffic rules	3.66	1.696	0.732	4
6	Lack of Proper Training	3.28	1.623	0.656	7
7	Misinterpretation of Road Signs and Signals	3.31	1.442	0.662	6
8	Failure to Adapt to Changing Conditions	3.24	1.573	0.648	8

Source: Adapted from N. Maelissa, M. Arif Rohman, and I. Putu Artama Wiguna,, 2023.

Table 5:
Factors related to Environment [24]

No.	Factors	Mean	Std. Deviation	RII	Rank
1	Adverse Weather Conditions	4.03	1.239	0.806	1
2	Poor Visibility	3.97	1.451	0.794	2
3	Wildlife Crossings	3.55	1.549	0.71	4
4	Pollution	3.38	1.59	0.676	5
5	Natural Disasters	3.93	1.646	0.786	3

Source: Adapted from Z. Zhou, Y. Su, Z. Zheng, and Y. Wang,2023

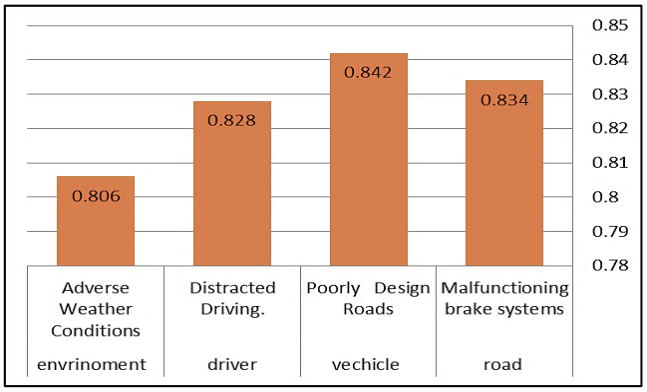

Figure 6. Factors affecting on highway safety
Source: on work

Table 5 emphasizes key environmental factors that significantly impact traffic safety. Adverse Weather Conditions rank as the most critical factor with RII(80.6%), highlighting the risks posed by rain, snow, and fog, which reduce visibility and increase the likelihood of accidents. Poor Visibility with RII (79.4%) further compounds these dangers, especially during nighttime or in areas with inadequate lighting.

Natural Disasters with RII (78.6%) also play a notable role, as events like floods and earthquakes disrupt road conditions and driver safety.

Addressing these factors requires improved infrastructure, such as better drainage systems and lighting, and robust emergency response strategies to mitigate risks during extreme conditions [24].

This Fig. 6 represents the relative importance of four factors contributing to certain outcomes (likely road safety or accident-related issues).

The x-axis lists the factors categorized into groups (environment, driver, vehicle, and road), while the y-axis shows their importance score, likely based on a normalized value ranging from 0.78 to 0.85.

1. Conclusion

This research focuses on assessing the essential role aspects in highway safety. Twenty-nine indicators were identified through cases and interviews with experts. These variables were divided into four major categories: road factors, vehicle-related concerns, driving factors, and environmental factors. Seventy-five of the eighty questionnaire forms were returned.

The outcomes demonstrated a high level of consistency amongst responders when rating the criteria. Cronbach's alpha test has a high coefficient and is valid, demonstrating this. These variables are ranked using the relative significance index. Additionally, the results showed that the factors' RIIs varied from 62% to 84%.

and these factors Driver-related RII was (0.828) from Distracted Driving. Malfunctioning brake systems from Road related factors the RII was (0.834),.while Vehicle-related issues, the problem the Poorly Design Roads the RII was (0.842). Adverse Weather Conditions from Environmental factors the RII was 0.806. Addressing these issues requires a multidisciplinary approach involving enhanced training, better road and vehicle design, and improved management of environmental risks.

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Appendix (A) questionnaire

Part I: general information

Name (Optional):	
Name of Ministry	
Age :	
Gender:	**Field of Specialization**
Male	Architect
Female	Civil Engineer
	Electrical Engineer
	Mechanical engineer
	Other (specify Please)
Academic Degree:	
Bachelor	
Master	
Ph.D.	
Experience Years:	
From 0 to 5 years	**Work sector:**
From 5 to 10 years	Public
From 10to 15 years	Private
More than 20 years	

Part 2: The factors affecting on highway safety

Number	Item	Strongly Agree	Agree	Moderate	Disagree	Strongly Disagree
	Factors related to roads					
1	Poor Vehicle Maintenance					
2	Malfunctioning brake systems					
3	Defective Lights					
4	Improperly Adjusted Mirrors					
5	Missing Safety Features					
6	Overloaded Vehicles					
7	Vehicle Design Flaws					
	Factors related to Vehicle					
8	Poorly Design Roads					
9	Inadequate Road Signage					
10	Inadequate Lighting					
11	Roadway Design Flaws					
12	Lack of Cycling Infrastructure					
13	Road Hazards					
14	Obsolete Infrastructure					
15	Inadequate Road Maintenance					
16	Inadequate Road Markings					
	Factors related to Driver					
17	Distracted Driving.					
18	exceeding speed limits					
19	Aggressive Driving					
20	Lack of driving knowledge and skills					
21	Failure to follow traffic rules					
22	Lack of Proper Training					
23	Misinterpretation of Road Signs and Signals					
24	Failure to Adapt to Changing Conditions					
	Factors related to Environment					
25	Adverse Weather Conditions					
26	Poor Visibility					
27	Wildlife Crossings					
28	Pollution					
29	Natural Disasters					

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