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Microsleep and Fatigue Behind the Wheel: The Unrecognized Danger on the Road

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Abstract
Driver fatigue is a state of physical and mental depletion that drastically reduces concentration, reaction time, and alertness. From this scientific research, interested readers can learn about: speed, the distances traveled by a motor vehicle as a function of speed, and braking distance—theoretical and practical calculation methods; the distance traveled by a motor vehicle during driver fatigue or microsleep; advanced technologies for detecting and preventing driver fatigue or microsleep and others; a driver fatigue monitoring system using infrared cameras and AI for eye tracking; the influence of fatigue and microsleep on defensive driving; microsleep while driving near the destination (the end point of the trip); an analysis of traffic accidents caused by fatigue and microsleep while driving in Romania; a case study on the influence of tire type on braking distance. The data presented in this paper represent the authors' own views. Conclusions regarding the topic are drawn at the end of the paper.

Keywords: Fatigue, Microsleep, Motor Vehicle, Speed, Distance, Time

1. Introduction

Driver fatigue is widely recognized as a major risk factor that reduces road safety and represents a threat not only to drivers but to all other road users. Driver fatigue manifests in two forms: chronic fatigue and acute fatigue, which often occurs after a long day of work or prolonged driving, leading to a sleep deficit. It reduces the ability to anticipate hazards and increases the risk of accidents and microsleep, during which drivers often do not realize when they are falling asleep. A 5 to 10 second episode of microsleep while driving at 100 km/h means that the car travels approximately 140 to 280 meters completely *"blindly"*, with the driver having no control over the steering or brakes. However, there is little research on driver fatigue in commercial transport, and there have been no comprehensive EU-wide studies or reports on this topic in the last 15 years. Fatigue and sleepiness drastically reduce a driver's reaction time. The phenomenon of *"microsleep"* (a loss of consciousness lasting a few seconds) can occur unexpectedly. In addition, issues such as sleep apnea and driving safety, which fatigue and sleepiness drastically reduce a driver's reaction time. The phenomenon of *"microsleep"* (a loss of consciousness lasting a few seconds) can occur unexpectedly [1]. Fatigue while driving drastically reduces a driver's ability to concentrate and slows reaction time; experts consider it just as dangerous as driving under the influence of alcohol. It alters the way a driver perceives their environment and reacts in traffic [1]. In Romania, one in eight serious accidents is caused by a driver who has fallen asleep at the wheel. Experts who have studied this phenomenon say that, in reality, a driver in this situation enters a state known as microsleep. That is, they doze off for a few seconds, during which time their eyes are open, but they drive "on autopilot," without being aware of what they are doing. 64% of drivers admit that they have gotten behind the wheel at least once after not sleeping a full night, according to data from a Romanian Police campaign dedicated to road safety consciousness [2]. To prevent such dangerous incidents, experts recommend stopping at the first signs of drowsiness and avoiding driving during the hours when the sleep cycle is at its peak (2:00 a.m. – 4:00 a.m. and 2:00 p.m. – 4:00 p.m.).

2. Literature review and legislation

2.1 Literature Review

Fatigue is a state of general physical or mental weakness. According to dictionaries, it is defined as a loss of strength or exhaustion caused by intense and prolonged exertion [3].

Here are the main characteristics and synonyms as explained in dictionaries:

- General definition: A condition of the body caused by excessive exertion, resulting in a loss of physical or mental strength;
- Main synonyms: Fatigue, exhaustion, toil, lethargy, or weariness.

Microsleep is a brief period of sleep or dozing off that usually lasts between a few seconds and 30 seconds (on average, 5–10 seconds). It often occurs suddenly and involuntarily, even when the person believes they are awake, and is the brain's response to a state of severe exhaustion.

The most important aspects of this phenomenon include:

- The mechanism: It occurs when the brain suddenly shifts from the waking state (with brain waves specific to wakefulness) to the brain waves characteristic of deep sleep. The person does not always realize when they have fallen asleep;
- Major dangers: Microsleep is extremely dangerous during activities that require continuous attention. While driving, a 5-second microsleep at a speed of 100 km/h means the car travels nearly 140 meters completely out of control;
- Main causes: Sleep deprivation (insufficient or poor quality sleep), chronic fatigue, and sleep disorders such as narcolepsy [4].

2.2 Legislation

European traffic laws combat driver fatigue by imposing maximum driving times and minimum rest periods (EU Regulation 561/2006) [5]. For professional drivers, compliance with these limits is strictly monitored using a tachograph, and the use of tachographs has also become mandatory for smaller commercial vehicles.

European standards set forth the following essential safety rules:

- Continuous driving time: You may not drive for more than 4 hours and 30 minutes without a break;
- Mandatory break: After driving for 4 hours and 30 minutes, you must take a break of at least 45 minutes. This break may be divided into two parts: the first lasting at least 15 minutes, followed by a 30-minute break;
- Daily limit: The maximum driving time in a day is 9 hours, which may be extended to 10 hours no more than twice a week;
- Daily rest: Drivers must have a rest period of at least 11 hours within each 24-hour period (this may be reduced to 9 hours no more than three times a week);
- Accommodations: For long term stays, weekly rest periods exceeding 45 hours must not be taken in the truck cab, but in adequate accommodations.

Romanian traffic laws do not explicitly penalize general fatigue, but the Romanian Highway Code prohibits driving a vehicle when the driver's physical or mental condition is impaired. Drivers are required to drive defensively and not to endanger the safety of other road users.

Measures and legal provisions:

- Indirect penalties: Although there is no direct fine for *"fatigue"* if a traffic officer determines that a driver is not in a fit condition to drive and poses a danger (e.g., repeatedly dozing off at the wheel), the traffic police may request a medical or psychological evaluation, or even the collection of biological samples, to rule out other medical conditions or the use of prohibited substances (alcohol or drugs);
- Prohibition on driving: Article 44 of the Traffic Regulations [6], stipulates that drivers must follow special rules and avoid situations that could dangerously distract them;

Regulations for professional drivers: the laws governing the road transport of goods and passengers are strict. With the alignment of Romania's traffic laws with European traffic laws, professional drivers are required by law to comply with driving times and rest periods (EU Regulation 561/2006) to prevent accidents caused by fatigue.

Recommendations from the Romanian Traffic Police for drivers.

To prevent tragedies caused by falling asleep at the wheel, the romanian police recommends:

- Planning breaks: Stopping the vehicle every 100–150 km or after no more than 2 hours of continuous driving;
- Rest: Taking a break of at least 15–20 minutes, during which the driver can rest or move around;
- Avoiding night driving: Avoid the hours when the body is biologically programmed to sleep (e.g., 2:00 a.m. – 6:00 a.m.);

3. Speed, distances traveled by a motor vehicle as a function of speed, and braking distance—theoretical and practical calculation concepts

The speeds taken into account when a vehicle travels a certain distance while the driver is fatigued or experiencing microsleep are the ***average speed*** and the ***instantaneous speed***. They directly influence the braking distance required to bring the vehicle to a complete stop in the event of danger, as well as "blind driving" when the driver falls asleep at the wheel.

A. *Average speed* directly influences fatigue levels through cognitive load and reaction time. Both high and very low speeds significantly increase the risk of accidents.

Here's how average speed affects driver fatigue:

- *High average speed:* Requires intense concentration on the part of the driver. The brain processes more information per second, which leads to rapid mental fatigue. It also reduces reaction time in the event of danger;
- *Low (or fluctuating) average speed:* This often occurs due to heavy traffic, problematic national roads, or adverse weather conditions. It causes frustration and stress, rapidly increasing fatigue levels;
- *Monotony and lack of stimuli:* At constant legal speeds on highways (long, straight roads), monotony can induce a state of *"driver hypnosis"*, which reduces vigilance and causes sleepiness.

Additional factors that contribute to fatigue are:

- Driving at night or during peak hours (2:00 a.m. – 4:00 a.m. and 2:00 p.m. – 4:00 p.m.);
- Prolonged exposure to noise, vibrations, and inappropriate temperatures inside the vehicle.

Average speed does not directly cause microsleep (caused by fatigue), but it exponentially amplifies its consequences. A period of unconsciousness lasting just a few seconds can turn into a tragedy on the road because of the enormous distance traveled without control.

Here is the impact of speed during a microsleep episode:

- *Distance traveled "blindly"*: During a 5-second microsleep (the average duration of an episode), a car traveling at an average speed of 50 km/h covers

approximately 70 meters. At a speed of 130 km/h, the car travels 180 meters completely out of control;
- *Loss of control and reaction time:* High speed reduces the time needed to notice an obstacle. When suddenly startled, the driver needs those precious extra seconds to realize what is happening and take evasive action—time during which the car may change trajectory.
- *Severity of the accident:* In the event of a collision, kinetic energy increases in proportion to the square of the speed. A higher average speed turns almost any run outside of the road incident or collision caused by microsleep into a fatal or extremely serious accident.

The relationship between driving and fatigue is as follows:
- *Monotony and speed:* Constant, high speeds on highways or national roads induce a state of hypnotic monotony, accelerating the onset of microsleep;
- *The body's trap:* Psychologists warn that the body does not always send clear warning signals, and drivers may fall asleep without realizing it.

B. Instantaneous speed (at a given moment) is the speed of an object at a precise moment in time, in a specific direction and sense. It is a vector quantity and is mathematically defined as the derivative of position with respect to time, precisely indicating how fast and in which direction the car is moving.

How we visualize it: it is exactly what the speedometer on the vehicle's dashboard shows at any given moment.

Key concepts and mathematical formulas:
- *Physical definition:* Instantaneous speed is the limit toward which the average speed tends as the time interval tends to zero:

$$(\Delta t \rightarrow 0) \quad (1)$$

- *Vector formula:* It is expressed as the derivative of the position vector r ⃗ with respect to time t, given by the mathematical relation:

$$\vec{v} = \frac{d\vec{r}}{dt} \quad (2)$$

- *Trajectory:* The instantaneous speed vector is always tangent to the trajectory of the material point at that point;
- *Unit of measurement:* The official unit in the International System is the meter per second (m/s).

Instantaneous speed significantly influences fatigue through the level of brain stimulation and the demand on attention.

Beyond safety risks, there is a direct link between speed and fatigue, as follows:
- *High speeds on monotonous roads (highways):* Maintaining a constant, high speed in a monotonous environment induces a state of hypnosis and passive fatigue, as the brain receives few visual stimuli. However, the risk of an accident becomes extremely serious because the driver can no longer brake in time in the event of danger;
- *Slow speeds frequent changes in speed:* To combat microsleep, drivers sometimes tend to change speed and accelerate or decelerate, stimulating their senses to stay alert. However, fatigue itself often leads to erratic speed fluctuations, as drivers are no longer able to maintain a constant speed;

Roads with sharp turns or heavy traffic: constantly adjusting speed to curves or heavy traffic requires a high level of cognitive effort, causing active fatigue by overtaxing reflexes and coordination.

The relationship between speed ***(v)***, distance ***(d)***, and time ***(t)*** is fundamentally calculated using the physical formula ***v = d/t*** (speed is equal to distance divided by time). For a motor vehicle, these values are influenced by the type of road, the driver's reaction, and the laws governing traffic restrictions on a given road.

Distance ***(d)*** or displacement ***(s)*** as a function of velocity ***(v)*** and time ***(t)*** is calculated by multiplying velocity by time. The fundamental relationship is ***(d = v * t)***. Depending on the type of mechanical motion, specific equations are used to determine the distance.

We can categorize the main calculations for determining the distance traveled by a vehicle in road traffic into three situations:

A. When the motion is rectilinear and uniform.

When a body moves in a straight line at a ***constant speed*** (it does not accelerate or decelerate):

$$d = v * t \quad (3)$$

Where,
d is the distance driven;
v - the vehicle's speed;
t - time (the duration of the trip or travel).

B. When the motiont is varied (performed at a average speed).

When the vehicle's speed varies along the route (as it accelerates or decelerates), the average speed is used:

$$d = v_{med} * \Delta t \quad (4)$$

Where,
v_{med} is the average speed, calculated as the ratio of the total distance to the total time of the motion.

C. When the motion is uniformly accelerated.

If a vehicle starts from a stationary position and increases its speed constantly:

$$d = \frac{a * t^2}{2} \quad (5)$$

Where,
a represents the vehicle's acceleration.

The following example illustrates how quickly, on average, we cover a certain distance in a given period of time:

The basic mathematical relationship is:

$$v_{medie} = \Delta s / \Delta t \quad (6)$$

Where,
v_{medie} is the average speed;
Δt - total time (usually in seconds, minutes, or hours);
Δs - distance traveled (usually in meters or kilometers).

Therefore, *average speed = distance traveled / total time.*

A simple example of a calculation:

We'll be driving from 10:00 to 11:00 and covering 60 km:
- Distance: $\Delta s = 60$ km

- Time: Δt = 1 hour.

$$v_{medie} = 60\ km/1\ h\ = 60\ km/h \tag{7}$$

3.1 Example of calculating the average speed for two road segments

Example with two different speeds.
We'll be traveling along two sections of road:

- 30 km with 60 km/h;
- 30 km with 90 km/h.

What is the average speed for the entire route?
We calculate the time for each segment:

- Segment 1:

$$t_1 = 30\ km/60\ km/h = 0{,}5\ h; \tag{8}$$

- Segment 2:

$$t_2 = 30\ km/90\ km/h = 1/3\ h \approx 0{,}33\ h; \tag{9}$$

A. Total time:

$$t_{total} = t_1 + t_2 = 0{,}5 + 0{,}33 \approx 0{,}83\ h. \tag{10}$$

B. Total distance:

$$s_{total} = 30 + 30 = 60\ \text{km}. \tag{11}$$

C. Average speed:

$$v_{average} = 60\ km/0{,}83\ h \approx 72\ km/h. \tag{12}$$

We note that it is neither 60 nor 90, nor is it simply the average (60+90)/2 = 75). It is **≈ 72 km/h**, because we spent more time driving at a slower speed.

3.2 Sample calculation for average speed on a round trip

A classic example is when you travel the same distance there and back, but at different speeds.
Example: We travel a route from City A to City B at 60 km/h and return along the same route at 40 km/h. The distance between the cities is 100 km. What is the average speed for the entire trip?

A. Total distace:

$$s_{total} = 100 + 100 = 200\ km; \tag{13}$$

B. Time out:

$$t_{out} = 100/60\ h \approx 1{,}67\ h; \tag{14}$$

C. Time back:

$$t_{back} = 100/40\ h = 2{,}5\ h; \tag{15}$$

D. Total time: $t_{total} = 1{,}67 + 2{,}5 \approx 4{,}17\ h;$

E. Average speed:

$$\text{v}_{\text{average}} = 200\ \text{km}/4{,}17\ \text{h} \approx 48\ \text{km/h}. \tag{16}$$

So the average speed is **≈ 48 km/h**, not 50 km/h. Why? Because we spent more time riding more slowly (at 40 km/h).
Note: For an equal round-trip distance, with two speeds *v1* and *v2*, the average speed is the harmonic average:

$$v_{medie} = 2v_1v_2/(v_1 + v_2) \tag{17}$$

3.3 The difference between average speed and instantaneous speed

The main difference lies in the time interval: average speed measures how fast we move over a long distance (over a longer period of time), while instantaneous speed tells us exactly how fast we are moving at a specific moment (as the motion occurs).
Average speed is calculated over a longer period of time (minutes, hours) and uses the following mathematical formula [7, p. 52]:

$$V_{average} = \Delta d/\Delta t \tag{18}$$

Where,
Δd is total distance;
Δt – total time.

Example: if we drive 100 kilometers in 2 hours, our average speed is 50 km/h, regardless of whether we drove at 80 or 90 km/h on certain stretches or stopped at traffic lights.
General steps for troubleshooting average speed issues:

A. Identify the distance (or distances) traveled. If there are multiple segments, add them together using the following mathematical formula:

$$s_{total} = s_1 + s_2 + s_3 \ldots + s_n \tag{19}$$

B. Identify the correct tense(s):
   - If we are given the speed on a segment and the distance, we calculate the time using the following mathematical formula:

$$t_i = s_i/v_i \tag{20}$$

   - then:

$$t_{total} = t_1 + t_2 + t_3 \ldots + \text{t}_\text{n} \tag{21}$$

C. We calculate the average speed using the following mathematical formula:

$$V_{average} = s_{total}/t_{total} \tag{22}$$

D. We check the units (all distances are in the same unit, as are the times).

In vector form, we have [8, pp. 21-41]:

$$\vec{v}_m = \frac{\Delta\vec{r}}{\Delta t} = \frac{\vec{r}(t+\Delta t)-\vec{r}(t)}{\Delta t} \tag{23}$$

Where,
$\vec{r}(t)$ is the position vector of the vehicle at time *t*;
$t\vec{r}(t + \Delta t)$ - its position vector at the time $t + \Delta t$.

3.4 The vehicle's braking distance

When a vehicle brakes, its total stopping distance consists of the distance traveled during the reaction time (the time the vehicle continues to move before the brake pedal is pressed) and the actual braking distance (deceleration), until the vehicle comes to a complete stop. This distance increases exponentially with speed, even on dry pavement (Fig 1).

Fig 1: Graphical representation of the total stopping distance [21]

The general formula for the calculation is as follows:

Total stopping distance = Reaction distance + Braking distance.

A. *Reaction distance:* it is the distance traveled during the time interval between noticing the obstacle and pressing the brake pedal. The average reaction time of an experienced driver is approximately 0.75–1 second.

Quick calculation rule: Multiply the first number of the speed by 3.

Example at 50 km/h: 5 * 3 = 15 meters.

B. *Braking distance:* represents the distance traveled from the moment we pressed the brake pedal until the vehicle came to a stop.

To calculate it, a detailed physical formula is used, as follows:

$$Braking\ distance = \frac{v^2}{2 * f * g} \tag{24}$$

Where,

v is the speed in meters per second;

f - coefficient of friction (e.g., 0.8 on dry asphalt; 0.4 on wet asphalt);

g - gravitational acceleration (9.81 m/s²).

Fatigue significantly increases reaction time, affecting the brain's ability to process information and make quick decisions. This causes drowsiness, which slows down physical movements and reduces the ability to anticipate dangers in traffic or in everyday life.

A tired driver may have a reaction time of up to 2–3 seconds, compared to the normal reaction time of about 0.75–1 second.

The mechanisms by which fatigue affects reaction time include:

- *Slow cognitive processing:* Your ability to concentrate decreases, which means it takes you longer to notice an obstacle and realize that you need to react;
- *Decreased vigilance:* Fatigue can lead to microsleeps (brief lapses in consciousness). During these moments, reaction time becomes virtually zero, as the brain does not register stimuli from the surroundings;
- *Reduced motor coordination:* The transmission of signals from the brain to the muscles is slowed, resulting in movements that are more sluggish and less precise.

A. Factors that negatively affect a driver's reaction time when braking are [9]:

- Fatigue;
- Use of contraindicated medications (sedatives, antiallergics, sleeping pills, tranquilizers);
- Consumption of alcoholic drinks;
- Drugs use.

B. Factors that negatively affect a vehicle's (mechanical) braking time are [9]:

- Brake system malfunctions;
- Severe tire wear;
- Road category and condition;
- Weather conditions;
- Uneven load distribution.

Table 1 shows the relationship between speed (km/h), the distance traveled during the reaction phase (m/s), the distance traveled during the (mechanical) braking phase (m/s) and the total distance until the vehicle comes to a stop, in meters.

Table 1: The relationship between speed (km/h), the distance traveled during the reaction phase (m/s), the distance traveled during the (mechanical) braking phase (m/s) and the total distance until the vehicle comes to a stop (m) [9]

Speed (Km/h)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**
Speed (m/s)	2.7	5.5	8.3	11.1	13.8	16.6	19.4	22.22	25	27.8	30.55	33.33	36.11	38.88
Distance traveled during the driver's reaction (m/s)	2.7	5.55	8.32	11.11	13.88	16.65	19.4	22.22	25	27.8	30.55	33.33	36.11	38.88
Distance traveled during (mechanical) braking (m/s)	1.50	3	7	12	19	27	37	48	61	78	90	108	130	147.
Total Stopping Distance (m)	4.27	8.55	15.32	23.11	32.88	43.65	56.4	70.22	86	105.8	120.55	141.33	166.11	185.88

Note: The values in Table 1 are calculated under ideal conditions (dry pavement, tires in good condition, average reaction time of 0.7–1 second for driver) for an experienced driver who is not fatigued and is not tired.

4. The distance traveled by a motor vehicle while the driver is fatigued or experiencing microsleep

Driver fatigue is a major risk factor that profoundly affects road safety. It impairs cognitive abilities and reduces alertness, and is often compared by experts to drunkenness.

The consequences for the driver are direct and dangerous:

- *Increased reaction time:* The brain processes visual and auditory stimuli more slowly (e.g., the appearance of an unexpected obstacle or the brake lights of the car ahead coming on);
- *Delayed decision to brake:* Concentration is reduced, meaning it takes the driver longer to choose the correct evasive maneuver;

- *Prolonged reaction time:* The ability to brake or avoid an obstacle decreases considerably, as reflexes are delayed;
- *Impaired attention and judgment:* Caution decreases, and the driver becomes less able to correctly assess traffic risks (e.g., risky passing maneuvers);
- *Impaired visual acuity:* Difficulty focusing the eyes may occur, vision may become blurred, and recognizing road signs becomes more difficult;
- *Falling asleep at the wheel:* In advanced stages, brief, involuntary episodes of sleep (microsleep) may occur, which can lead to a complete loss of control over the vehicle.

Fatigue or sleepiness at the wheel dramatically reduces the ability to make sound decisions. There are several stages of fatigue while driving—ranging from mild fatigue to severe fatigue, drowsiness, and, finally, falling asleep.

According to expert analyses, the risk of accidents increases significantly, especially when rest regulations are not followed. To prevent these dangers, it is essential to take breaks while driving.

Sleepiness at the wheel is a dangerous combination, as the effects of fatigue are very often compared to those of driving under the influence of alcohol. Just like alcohol, sleepiness slows reaction time, reduces awareness of the surrounding environment, impairs judgment, and increases the risk of being involved in a car accident. However, it is nearly impossible to determine with certainty whether an accident was caused by driver fatigue, since there are no objective tests or evidence to establish just how tired the guilty driver was.

Causes of sleepiness or fatigue while driving include:

- Insufficient sleep;
- Interrupted or fragmented sleep;
- Accumulated fatigue over time / accumulated lost sleep hours over time;
- Circadian factors associated with work or driving routines. A circadian factor (often associated with the circadian rhythm) is a trigger or environmental factor that influences and regulates the body's internal "biological clock"—that is, the natural 24-hour cycle that controls sleep and wakefulness, hormone secretion, and metabolism.;
- Untreated or undiagnosed sleep disorders;
- Use of sedative medications;
- Alcohol consumption when a person is already tired;

Sleepiness or fatigue while driving causes the following problems:

- Impaired reaction time, impaired vision, impaired judgment;
- Problems with information processing and short-term memory;
- Decreased performance, alertness, and motivation;
- More irritable and aggressive behavior.

When falling asleep at the wheel or experiencing a microsleep, every second of inattention results in huge distances traveled *"blindly"*. At a constant speed, the distance traveled is calculated by multiplying speed by time traveled.

To calculate the distance (space) traveled based on speed and time, use the basic physics formula: distance *(d)* = speed *(v)* × time *(t)*. To get the result in meters, the time must be expressed in seconds.

Practical calculation examples [10]:

- 1 m/s: in one second, we travel 1 meter;
- 50 km/h (approximately 13.89 m/s): in 3 seconds, we travel 41.67 meters;
- 90 km/h (25 m/s): in 3 seconds, we travel 75 meters;
- 130 km/h (approximately 36.11 m/s): in 3 seconds, we travel 108.33 meters.

Therefore, the distance traveled in meters per second, calculated based on speed, is as follows:

- **50 km/h** (in urban areas): **~13.89 meters** traveled per second;
- **70 km/h: ~19.4 meters** traveled per second;
- **90 km/h** (national highway): **~25 meters** traveled per second;
- **110 km/h** (expressway): **~30.5 meters** traveled per second;
- **130 km/h** (highway): **~36.11 meters** traveled per second;

On wet or icy roads, tire traction decreases dramatically, which causes the total stopping distance to increase considerably.

To drive safely, we must take the following changes in braking distance into account:

- Wet road surface: braking distance increases by about 2 times (doubles) compared to a dry road surface, while maintaining the same speed;
- Icy road surface (snow/ice): braking distance can increase up to 10 times, as traction is nearly zero and the risk of skidding is very high.

Warning! To the distances traveled in m/s by a motor vehicle, specific to each speed listed above, add the braking distance, in meters, as shown in Table 1, and sum them. Together, these represent the total stopping distance until the vehicle—whose driver is fatigued or falls asleep at the wheel—comes to a complete stop. The distance at which the vehicle comes to a complete stop increases exponentially (2–10 times) if the event occurs on a wet road surface or one covered with frost, ice, or snow.

If we set out on a long drive without taking a break every two hours (after driving 200–300 km), fatigue or microsleep sets in, often without the driver even realizing it. Consequently, long distances exponentially increase the risk of fatigue while driving due to the accumulation of physical and psychological factors, leading to a dramatic decrease in attention and reaction time.

To effectively manage this risk factor during our travels, below we explain how distance (long routes without taking a break from driving) affects the driver and outline some practical measures:

- *Exposure time:* Driving long distances (over 200 km) keeps the brain in a state of constant tension, which gradually leads to exhaustion;
- *Decreased alertness:* After hours behind the wheel, the ability to anticipate dangers decreases, and reflexes slow down significantly;
- *Monotony of the route:* On long, straight roads, the lack of visual and auditory stimulation induces a state of road hypnosis and boredom, accelerating the onset of sleep.

The "golden" rules for long-distance driving are:

- *The 2 hour rule:* Psychologists and road safety experts recommend taking a break every 2 hours of driving or after every 200 kilometers traveled;
- *Active rest stops:* During rest stops, don't just sit in the car to recover. Take a few steps, stretch your muscles,

stay hydrated, and have a cup of coffee;
- *Avoid driving at night:* Fatigue is most intense during the hours when the body is accustomed to sleeping (especially between 2:00 a.m. and 6:00 a.m.).

5. Advanced technologies for detecting and preventing fatigue or microsleep at the wheel and others

The automotive industry has integrated advanced technologies to prevent driver fatigue and microsleep, which have become mandatory safety standards. These systems use artificial intelligence and biometrics to detect inattention and issue audible, visual, or tactile alerts before the driver falls asleep.

The first commercial system was launched in 2007 by Volvo under the name Driver Alert Control. Later, in 2012, Bosch introduced a system that monitors steering wheel movements. Currently, these systems also analyze fatigue using interior video cameras.

Here are the most important milestones in the evolution of technology:
- Volvo (2007): Launched the world's first system that assessed how the car was being driven. It monitored deviations from lane markings and erratic steering, alerting the driver with an audible signal and an icon depicting a cup of coffee;
- Bosch (2012): Introduced a drowsiness detection system based on the analysis of steering movements (steering angle and steering wheel actions). The algorithm records driving behavior from the start of the trip and identifies the less frequent micro-corrections characteristic of fatigue;
- Modern Artificial Intelligence Systems: Today, vehicles use cameras pointed at the driver's face to measure eyelid movements, blink rate, and facial expressions, triggering alerts when drowsiness is detected.

The latest technologies used include:
- *Infrared and AI-powered cameras for eye monitoring:* Cameras facing the driver analyze eyelid movements (blink rate), gaze direction, and eye closure duration in real time. They also detect microsleep and frequent yawning;
- *Steering behavior analysis:* The systems continuously record how you handle the steering wheel, the accelerator, and the brakes. If irregular or sudden steering corrections specific to fatigue are detected, the car recommends taking a break;
- *Vital signs monitoring:* Some innovations in the automotive industry measure heart rate and breathing using sensors integrated into the seatbelt or steering wheel, signaling a decline in alertness;
- *Emergency Assist systems:* If the driver does not respond to repeated warnings (or if the car detects that the driver has fallen asleep), the system can gradually reduce speed, keep the car in its lane, and bring it to a safe stop while activating the hazard lights;
- *Wearable anti-drowsiness devices:* For older vehicles, there are devices that are worn like a ring on the finger and monitor your pulse or hand position, vibrating to wake you up.

In EU countries, as well as in Romania, new European regulations regarding the registration of new motor vehicles entered into force on July 7, 2026. These regulations stipulate that any newly registered motor vehicle must be equipped with advanced safety features. These technologies use cameras and sensors to monitor the driver's eye movements and head position, so they can detect if the driver is distracted while driving and in other situations as well. Newly registered vehicles must be equipped with intelligent speed assistance, emergency braking assistance, lane departure warning systems, fatigue and attention warnings, factory installed backup cameras, parking sensors, and sensors that detect if the driver has consumed alcohol.

This package of safety measures and devices was designed from the outset to increase passenger safety and, of course, to improve traffic safety. These include advanced electronic technologies, driver monitoring cameras, and driver assistance systems that help drivers better control their vehicles and avoid dangerous situations. Vehicles recently manufactured in European factories have rolled off the assembly line equipped with alcohol detection sensors, though these are currently inactive. European politicians must decide how this sensor will function and what action it will take if it detects that a driver has consumed alcohol and is driving. Should it immobilize the vehicle, or should it call the police directly?

Newly approved motor vehicles, particularly public transit buses, will be equipped with event data recorders — a type of black box for motor vehicles. These black boxes will record speed, acceleration, braking, steering angle, seat belt status, the moment the airbag was deployed, and even a few seconds before impact.

However, the black box will not infringe on the right to privacy; that is, it will not record the vehicle's route, will not transmit data in real time, and will not continuously monitor the driver. All of these technologies cost money and will be included in the vehicle's price at the time of purchase. Due to emissions-reduction and safety technologies, the price of vehicles has increased by up to 10,000 euros for the same model over the past decade, and prices will continue to rise for buyers.

By 2030, the European Periodic Technical Inspection must also be implemented, and vehicle safety systems will be inspected. For this reason, any work we perform on a vehicle—from a simple repair or repainting of a bumper to replacing a windshield, etc.—must be followed by an ADAS calibration, which will be performed exclusively at certain service centers, as the equipment required for this process is extremely expensive.

ADAS (Advanced Driver Assistance System) calibration is the process of electronically aligning and adjusting a vehicle's cameras, sensors, and radars. This is performed using specialized diagnostic equipment (such as that developed by Bosch or Texa) and ensures that the safety systems function properly.

The systems most commonly controlled by ADAS technology include:
- Autonomous Emergency Braking (AEBS);
- Lane Assist;
- Traffic Sign Recognition;
- Adaptive Cruise Control.

For example: a single windshield replacement can affect how the front camera is calibrated.

Works to replace or repair the bumper may affect the AEB (Autonomous Emergency Braking) radar—an active vehicle safety system that scans the road and automatically applies the brakes to prevent or reduce the severity of a collision, intervening if the driver does not react in time— and modifications to the vehicle's wheel alignment or suspension can affect the existing and implemented technologies on the vehicle, which prevent accidental lane departure. At the same time, ADAS systems cannot be calibrated at unauthorized service shops due to the very expensive equipment required, so we will be required to take our vehicle for repairs or for its Periodic Technical Inspection only to service shops that issue an invoice for the services provided.

6. Driver fatigue monitoring system using infrared cameras and AI to monitor the driver's eyes and behavior while driving

Driver fatigue monitoring systems are an important part of modern vehicle safety technology. These systems are designed to detect when a driver shows signs of sleepiness or fatigue and to issue an alert, helping to prevent accidents caused by driving under the influence of alcohol. Modern fatigue detection systems prevent traffic accidents by continuously monitoring the driver's behavior and driving style. These systems either use cameras pointed at the driver (visual monitoring) or analyze the vehicle's dynamic parameters (driving behavior monitoring) to trigger audible and visual alerts. As technology advances, these systems are becoming more sophisticated, incorporating features such as driver eyes an face tracking to enable real-time monitoring and recording (Fig 2). In this article, we explore the importance of driver fatigue monitoring systems and how they can improve road safety [11].

Fig 2: Driver eyes and face detection technology [11]

The driver fatigue monitoring system, also known as a driver sleep alarm or driver assistance system, is a device that uses various sensors and algorithms to analyze the driver's behavior and physiological state (Fig 3). The main purpose of these systems is to detect signs of drowsiness or fatigue and provide drivers with timely warnings, allowing them to take the necessary measures to avoid potential accidents.

Fig 3: Driver behavior detection technology [11]

One of the key features of modern driver fatigue monitoring systems is the use of eye tracking technology. By tracking the driver's eye movements and behavior, these systems can assess alertness and detect signs of drowsiness. Real time monitoring of the driver's eyes allows the system to issue warnings when it detects prolonged eye closure or irregular eye movements (indicating potential fatigue).

In addition to real time monitoring, some driver fatigue monitoring systems are also equipped with recording capabilities. These systems can capture and store data related to driver behavior including eye movements, head position, and other relevant parameters which is valuable for post-accident analysis and identifying patterns of driver fatigue over time.

The importance of driver fatigue monitoring systems cannot be overstated, especially when it comes to road safety. Fatigue related accidents are a major concern, particularly for over long distances truck drivers, shift workers, and people who drive for long periods of time. According to the National Highway Traffic Safety Administration (NHTSA), drowsiness behind the wheel causes thousands of accidents and deaths each year. Driver fatigue monitoring systems play a vital role in mitigating this risk, providing additional protection for drivers and other road users [11].

Fig 4 shows how the camera is positioned inside the vehicle's passenger compartment for the driver fatigue monitoring system.

Fig 4: Positioning of the driver monitoring system camera inside the vehicle [11]

Systems that monitor driver fatigue and drowsiness (Driver Sleepiness and Attention Warning) are already mandatory in the European Union for all new vehicles entering production as of July 2022, and as of July 2024, the requirement will apply to absolutely all new passenger cars sold. These safety technologies were made mandatory by EU Regulation 2144/2019 [12] of the European Union, and new road vehicles are equipped with this technologies as standard from the factory.

So, in short, as a brief overview, these technologies use three main methods of intervention (correction), or a combination of them:

A. It visually monitors the driver's gestures (using infrared cameras and AI)

They use a camera focused on the driver's face often built into the back of the steering wheel or mounted on the dashboard to detect signs of fatigue, which:

- *Monitors the driver's eyelid activity:* The system measures blink rate, the duration that the eyes remain closed (risk of microsleep), and the direction of look;
- *Performs a facial analysis of the driver:* Detects head movements (inclination forward) and yawning frequency;
- *Uses the latest technology:* Infrared waves enable effective operation even at night or through the lenses of sunglasses.

B. Analysis of the driver's conduct regarding the operation of the motor vehicle (Vehicle-Based)

The system analyzes the vehicle's motion parameters and the driver's reactions at the wheel by:

- *Steering corrections:* Instead of driving in a straight line, a tired driver tends to hold the steering wheel steady, followed by sudden movements to keep the car

in the lane, and the system intervenes if it detects deviations;
- *Related factors:* Other parameters are constantly monitored, such as the use of turn signals, total trip duration, and deviation from the center of the lane. The system intervenes if it detects deviations.

C. Vehicle warnings and feedback
- *Issuing progressive alerts in the first phase:* When the fatigue level exceeds a safety threshold, a message appears on the dashboard (e.g., an icon in the shape of a coffee cup or the message *"Fatigue alert: take a break!"),* accompanied by an audible signal;
- *Active interventions in phase 2:* In the case of highly advanced systems (such as those installed by most European passenger vehicle manufacturers), the vehicle may apply brief braking to wake the driver or increase the frequency of vibrations in the steering wheel.

7. The Influence of fatigue and microsleep on preventive-defensive driving

Fatigue while driving drastically reduces reaction time and the ability to concentrate, making it a major risk factor. For effective preventive and defensive driving, recognize the signs of sleepiness (heavy eyed lids, frequent yawning, loss of attention) early on and pull over immediately to rest.

Here are some strategies for preventing and combating fatigue and microsleep while driving, as part of a preventive and defensive driving approach:
- *Respect rest stops and stops during your trip*: Stop every 2 hours or 150–200 km to stretch your legs and breathe some fresh air;
- *Stay hydrated and eat properly*: Drink water and avoid heavy meals before setting out, as they can make you drowsy;
- *Take active rest breaks*: Don't try to "fight" sleep while driving. If you feel yourself falling asleep, pull over to a safe spot and sleep for 15–20 minutes;
- *Maintain a comfortable temperature inside the vehicle*: Keep the cabin well-ventilated and at a moderate temperature. Air that's too hot can contribute to fatigue.

Risks and studies:
- *Determining factors:* This condition can be caused by prolonged physical or mental exertion, insufficient rest before departure, or driving at night;
- *Nighttime driving:* At night, the body's natural circadian rhythm is disrupted, and the risk of falling asleep at the wheel increases significantly, requiring adaptation strategies*;*
- *Specialized resources:* you can learn more about this by consulting recommendations on fatigue as a risk factor or strategies for preventing drowsiness while driving from driving schools or law enforcement agencies.

Microsleep completely eliminates a driver's ability to drive preventively and defensively, turning the driver into a mere passenger. It is a brief episode of loss of consciousness (lasting from a few seconds to 10 seconds) that affects the driver in the following ways:
- *Loss of control over steering and speed:* During the 10 seconds you fall asleep at the wheel, your brain stops processing visual and auditory information, making it impossible to anticipate hazards or stay in your lane;
- *Inability to react in time:* Preventive and defensive driving relies on observation and quick action. During microsleep, reaction time drops to zero, and the driver cannot brake or avoid a sudden obstacle;
- *Inability to accurately judge distances:* A driver experiencing episodes of microsleep can no longer maintain a safe following distance or adjust their speed to traffic conditions.

In the case of microsleep, warning signs that the body is failing include:
- To maintain a preventive and defensive driving style, we must recognize the symptoms of fatigue and drowsiness while driving early on;

Heavy eyes and frequent blinking: The need to blink frequently or the inability to keep your eyes open;
- *Loss of concentration: "looking into empty"* space and your mind wandering elsewhere instead of focusing on driving;
- *Sudden jerks:* Sudden, involuntary physical reactions of the body or muscles just as you fall asleep briefly;
- *Excessive yawning* or a feeling of intense drowsiness.

To prevent this dangerous phenomenon, technical documents recommend immediately pulling over to rest and combating microsleep by taking regular breaks during the trip. As we mentioned earlier, a single bout of microsleep on the highway at a speed of 130 km/h means we travel hundreds of meters completely "blindly".

8. Falling asleep at the wheel near your destination (the end of your trip)

Falling asleep at the wheel when you're close to your destination is caused by the ***relaxation effect***, the ***monotony of the drive***, and a ***decrease in cognitive effort***. When you know you're close to your destination, your brain receives a signal that the task is complete, your blood pressure drops suddenly, and your body succumbs to accumulated fatigue.

This dangerous phenomenon which can affect the relaxing effect of falling asleep at the wheel can occur and is caused by several factors, such as:
- *Decreased alertness (the relaxation effect):* During the trip, the brain remains "on alert" due to the novelty of the situation and the need to concentrate. When you recognize the area or get close to home, your adrenaline levels drop, and the accumulated drowsiness sets in;
- *Monotony on long stretches:* Long, straight roads induce a trance-like state and intense monotony for the driver. The lack of visual and auditory stimulation can cause you to fall asleep without realizing it;
- *Physical and mental fatigue:* Prolonged driving depletes your energy reserves. If you haven't taken regular breaks every 2 hours, your body gives out precisely when the pressure on it eases;
- *Heart rate fluctuations:* This sleep often occurs during the hours when the body is biologically programmed to sleep (early afternoon or late at night).

Next, we will explain in detail how the three main factors cause the human body to become fatigued as we approach our destination.

A. The relaxing effect it eliminates the state of alertness required for driving. Against a backdrop of accumulated fatigue, the body interprets sudden relaxation as a signal that it is time to sleep. Drowsiness sets in rapidly, slowing reaction time and causing a loss of concentration.

The mechanism by which sleep sets in during relaxation manifests itself through:

- *Monotony and lack of stimulation:* A long drive, a comfortable seat, and a pleasant temperature in the car create a comfort zone that reduces brain activity;
- *Physiological transition:* Muscular and mental relaxation lowers the heart and respiratory rates. If you're already tired, this transition tricks the brain, causing it to enter a sleep state;
- *Decreased alertness:* Reflexes become delayed, and the ability to anticipate traffic hazards drops dramatically, leading to a loss of steering control;

Factors that exacerbate the relaxing effect while driving include:

- *Monotonous music or voices*: Listening to certain radio stations or slow songs induces a trance-like state. A trance is an altered state of consciousness characterized by detachment from the surrounding reality, intense mental focus, and increased receptivity to suggestions. It is not a form of sleep, but rather a threshold between wakefulness and deep sleep;
- *Smoking while driving:* Certain substances, such as the nicotine in cigarettes, can initially induce a state of calm, which later turns into sleepiness;
- *Engine vibrations:* The rocking motion of the car can accelerate the onset of sleep, especially during the body's critical hours, such as between 3:00 and 5:00 a.m. Be mindful of electric vehicles. The quiet environment devoid of the noise or vibrations produced by an internal combustion engine, which are absent in this type of vehicle can amplify and induce feelings of boredom and, consequently, sleepiness.

How to prevent falling asleep at the wheel when experiencing the relaxation effect:

- *Take regular breaks from driving:* Stop the vehicle every 2 hours or 200 kilometers to stretch your legs (exercise) and stay hydrated;
- *Ventilate the vehicle's interior and regulate the cabin temperature:* Keep the cabin cooler to prevent sleepiness;
- *Avoid sedatives (herbal or prescription):* Do not take medications that cause muscle relaxation or sleepiness before driving.

B. The monotony of the road it induces sleepiness by reducing visual and auditory stimuli (lack of curves, monotonous scenery, constant engine noise). The lack of brain activity and "driver hypnosis" cause reaction times to increase, promoting the onset of microsleep—an extremely dangerous condition comparable to driving after consuming alcohol.

To prevent falling asleep, the following is recommended in this case:

- *Take regular breaks:* Stop every 2 hours or every 150–200 km make physical exercise and walk for relaxion your legs;
- *Hydration and ventilation:* Drink water and maintain a moderate temperature inside the vehicle (excessive heat can make you drowsy);
- *Vary your activities:* Change the radio station, have a conversation, or chew gum.

C. Reduced cognitive effort it is caused by the monotony of the road, the lack of new visual stimuli, or driving on familiar stretches of road—all of which lead to a state of hypovigilance. This phenomenon promotes sleepiness, reducing the brain's ability to process information and exponentially increasing the risk of falling asleep at the wheel.

We illustrate how a decrease in cognitive effort affects the brain, the mechanism by which this occurs, and how we can prevent it, as follows:

- *Monotony and "self hypnosis"*: When driving on highways or straight, uneventful roads, the brain is no longer challenged to make complex decisions. Brain activity slows down, and the lack of stimulation triggers the transition from a state of waking to sleepiness;
- *Decreased alertness:* Studies show that drivers' alertness decreases significantly, and fatigue accumulated in just a few hours of driving affects their reaction time, putting their own safety and that of other road users at risk;
- *Delayed reactions:* Lack of concentration causes the driver to have a longer reaction time when faced with an unexpected obstacle, because the brain must first switch from a *"standby"* state to one of maximum activity.

Strategies for staying alert:

- *Take regular breaks:* Prolonged driving is your biggest enemy. Experts recommend stopping the car every 2 hours or after every 100–200 kilometers driven;
- *Change of pace:* Stop occasionally to get some physical activity, drink water, open the car windows for fresh air, or take turns driving if there are people in the car with a driver's license valid for the category of vehicle you're in;
- *Avoid passive activities:* Avoid listening to monotonous music or radio stations, or setting the cabin temperature too high, as heat and a lack of mental activity can make you sleepy.

9. An analysis of traffic accidents caused by fatigue and microsleep while driving in Romania

As a result of the authors' research in newspapers, magazines, and specialized websites, we found that there are no official statistics from the Romanian Police indicating an exact number of accidents caused exclusively by fatigue and microsleep in 2025 and 2026, as these are often broadly classified under the categories of *"driver error"* or *"failure to adjust speed to road conditions"* when control of the vehicle is lost.

However, in 2025, a total of 3,950 serious traffic accidents were recorded nationwide, according to the official report published by the Romanian Police. Unfortunately, these incidents resulted in [13]:

- **1,293** people died;
- **3,125** people were seriously injured.

These incidents were also caused by driver fatigue or microsleep.

Although the overall figures showed a 6.7% decrease in serious accidents compared to 2024, sleepiness at the wheel remains an underreported factor, though experts recognize it as a major cause of accidents on long distance roads and at night.

We found a comprehensive analysis of traffic accidents caused by fatigue and falling asleep at the wheel in the Road Safety Bulletin—Annual Report 2024 [14], issued by the Romanian Police at the end of 2025.

According to this document, we found that road traffic accidents worldwide cause 1.19 million deaths annually, and millions of people are seriously injured or left with permanent disabilities.

Over the past 10 years, the number of road traffic fatalities in the EU has decreased by 17%, while in Romania these incidents have decreased by over 18.8%; Lithuania is the only EU country that has managed to significantly reduce the number of road traffic fatalities by over 50% between 2014 and 2024.

In the EU, 20,017 people died in traffic accidents in 2024, representing a 2.2% decrease compared to 2023.

In Romania, traffic accidents resulted in 4.3% fewer deaths in 2024 compared to 2023, representing a sharper decline than the European average. For this reason, Romania is among the 21 countries monitored by the PIN (Road Safety Performance Index) [15], in which the number of deaths decreased in 2024 [14, p. 7].

In 2024, the road fatality rate across the EU was 45 deaths per million inhabitants, compared to 46 in 2023, while in Romania the fatality rate fell from 81 deaths per million inhabitants in 2023 to 77 deaths per million inhabitants in 2024. However, despite this decline, Romania ranked first in the EU in terms of road traffic fatalities. The safest countries in the EU in this regard were Norway, with 16 deaths per million inhabitants, and Sweden, with 20 deaths per million inhabitants, in 2024 [14, p. 7].

Here are some more detailed statistics on traffic accidents that occurred in Romania in 2024, taken from this document; in most cases, fatigue or falling asleep at the wheel (microsleep) was also a contributing factor [14, pp. 9-10]:

- Total number of serious traffic accidents: 4,235, indicating that there were 12 serious accidents per day;
- Fatality rate: 34.9%, compared to 34.1% in 2023;
- Highest number of serious traffic accidents: 1,645 in rural areas, accounting for 28.8% of the annual total:
- Rural fatality rate: 37.1%, compared to the urban fatality rate, which was 20.6% (the fatality rate on roads outside urban areas was much higher, at 55.8%);
- Outside urban areas, there were 33 (-3.4%) fewer serious traffic accidents compared to 2023;
- As in previous years, streets accounted for the road sector with the highest number and most significant serious traffic accidents (38.6%);
- National Roads (DN) are the second category of road infrastructure with the highest number of serious traffic accidents (32.8%);
- Although streets rank first in terms of the number of serious accidents, they recorded the lowest fatality rate (19.1%);
- There were: 738 serious accidents at intersections and 607 serious accidents on curves;
- 92.1% of serious traffic accidents occurred under normal weather conditions;
- 83.8% of serious traffic accidents occurred on dry road surfaces, 13% on wet road surfaces, and 3.2% on road surfaces covered with snow, ice, or sleet;
- 29.6% of serious traffic accidents resulted in a pedestrian being struck, a decrease of 128 people compared to 2023;
- The highest figures of the day are recorded between 5:00 p.m. and 6:00 p.m., when fatigue, stress, and exhaustion after work cause drowsiness and microsleep, and impair the reflexes, attention, and senses of drivers. During this time period, 347 serious traffic accidents occurred (Fig 5);

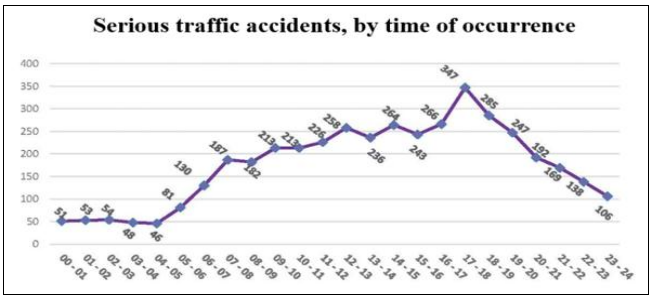

Fig 5: Serious traffic accidents, by time of occurrence [14, p. 53]

- Serious traffic accidents occurring between 3:00 p.m. and 4:00 p.m. are characterized by a lower fatality rate (20.6%) compared to the 12:00 a.m. to 1:00 a.m. time slot, when the fatality rate is highest (58.8%). We attribute this to fatigue and microsleep while driving;
- An analysis of the causes of serious accidents shows that falling asleep at the wheel ranks 14th out of 37, with 90 serious accidents occurring (Source: Table in [14, pp. 44-45]);
- Falling asleep at the wheel is one of the main causes, ranking third out of 10 factors in the mortality index. As a result, 55 people died in the 90 serious accidents, resulting in a mortality rate of 61.1% (Source: Table in [14, p. 46]);
- Here are some differences that highlight the number of serious accidents caused by favorable or unfavorable weather conditions. In this context, falling asleep at the wheel ranks 13th out of 37 causes of serious accidents, with 84 accidents on dry roads, 4 on wet roads, and 2 during winter driving conditions (Source: Table in [14, pp. 47-48]);
- With regard to the fatality rate by time of day for serious traffic accidents, our research shows that the highest rate is recorded between midnight and 1:00 a.m. (30 deaths out of 51 accidents, with a fatality rate of 58.8%), a finding that reinforces the detrimental role of fatigue and microsleep on safe driving (Source: Table in [14, pp. 54-55]). Serious traffic accidents occurred during the time when the body was supposed to be resting through sleep.

10. The effect of tire type on braking distance: a case study

An analysis of the data presented above showed that braking distance and vehicle speed are key factors in preventing and avoiding traffic accidents. Reducing driving speed and, consequently, a vehicle's braking distance are the basic components of preventive and defensive driving.

In addition to these two factors, the technical condition of the vehicle and the type of tires used directly influence the vehicle's ability to stop efficiently and effectively, and thus help prevent unwanted traffic incidents. We will now examine how these incidents can be avoided by presenting a braking test conducted with three types of tires: summer tires, all-season tires, and winter tires. The tire category directly influences braking distance through the rubber compound and tread pattern. Summer, winter, and all-season tires react differently to above freezing temperatures, and the grip they provide determines the distance required for a complete stop.

Differences in performance can be observed depending on specific characteristics:

- *Seasonal tires:* The rubber used in winter tires becomes stiff at low temperatures (below 7°C), dangerously increasing braking distance, while summer tires become excessively soft in the heat, significantly reducing traction;
- *Energy efficiency rating:* The European tire label includes a rating scale from A to G for wet grip. Moving from one class to another can reduce braking distance by a few meters during a simple emergency stop;
- Tread design and tread depth: A properly designed tread allows water to drain away, preventing hydroplaning. Severe wear drastically reduces traction and braking performance.

Testările au fost efectuate pe o pistă de încercări a automobilelor, în condiții optime, la temperaturi de 22º C, pe un carosabil uscat.

It is well known that effective braking of a vehicle on dry, wet, snowy, or icy surfaces is achieved by allowing the wheels to roll, not by locking them. When the wheels lock during braking, the vehicle loses traction, and the driver can no longer control it, causing it to skid. For this reason, a high-performance BMW 7 Series sedan was used for the experimental research; its braking system is also high-performance and equipped with the following systems to reduce braking distance:

- *ABS (Anti-lock Braking System):* Prevents the wheels from locking up during sudden braking, allowing you to maintain steering control and avoid obstacles;
- *BAS / EBA (Brake Assist System / Emergency Brake Assist):* Tetects an emergency braking maneuver (based on how hard you press the pedal) and automatically boosts braking force to the maximum, even if you haven't pressed the pedal hard enough;
- *EBD (Electronic Brakeforce Distribution):* Pptimally distributes braking force between the front and rear wheels, based on the vehicle's weight and road condition.;
- *Evasion Assistant*: In the event of a sudden obstacle, the system helps the driver perform a stable evasive maneuver and adjusts the braking force to maintain the vehicle's trajectory.

For safety, the car is also equipped with the following equipment:

- *ESP (Electronic Stability Program):* This is the most important active system for preventing skidding. It detects when the car begins to turn uncontrollably (understeer or oversteer) and applies the brakes individually to one or more wheels, correcting the trajectory and direction.
- *ASR / TCS (Traction Control):* Prevents the drive wheels from spinning during acceleration. If a wheel loses traction (on ice or mud), the system reduces engine power or applies light braking to prevent the car from losing control.

The car was equipped with Michelin Pilot Sport 5 summer tires (Fig 6), Michelin Pilot Alpin 5 winter tires (Fig 7), and Michelin Crossclimate 3 all-season tires (Fig 8), one set at a time. Note that for all tire types, tire pressure was set to the same value during testing (2.2 bar for the front wheels and 2.3 bar for the rear wheels of the car).

Fig 6: The Michelin Pilot 5 summer tire and its characteristics [19]

Fig 7: The Michelin Alpin Pilot 5 winter tire and its characteristics [18]

Fig 8: The Michelin Crossclimate 3 all seasons tire and its characteristics [20]

The tests were conducted at speeds of 50 km/h, 100 km/h, and 130 km/h.

The results of the tests are presented in Table 2.

Table 2: Results from the testing of the three types of tires [16]

Tire category	Michelin Pilot Sport 5 Summer Tires			Michelin Crossclimate 3 All-Season Tires			Michelin Pilot Alpin 5 Winter Tires		
Speed (Km/h)	50	100	130	50	100	130	50	100	130
Braking distance (m)	7,3	29	51	8,5	32,7	56	8,7	35	61

Immediate conclusions: Using winter tires in the summer exponentially increases braking distance. This is a dangerous and uneconomical decision (the rubber in the tires becomes softer, and the tread on the contact surface with the road wears down rapidly). A winter tire does not brake properly in the summer, mainly because of its rubber compound, which is much too soft and is designed to remain flexible at temperatures below 7° C. When used on hot asphalt, this compound becomes supersaturated, leading to a loss of traction and a significantly longer braking distance. This is also due to the numerous transverse grooves on the tread of winter tires. In winter, on snow, the transverse grooves are designed to trap snow between them, and when the tire comes into contact with the layer of snow on the road, a strong bond forms between the snow trapped in the grooves and the snow on the road surface, increasing traction.

Factors that illustrate this behavior include:

- *Deformation of the tread blocks:* Due to heat, the soft rubber becomes excessively pliable. When braking, the tread blocks and sipes (the small grooves specific to winter tires) fold under the weight of the car instead of gripping the road surface, dangerously increasing the stopping distance;
- *Improper material:* Winter rubber contains more silica and natural rubber to withstand freezing temperatures. In the summer, this compound does not dissipate heat efficiently, leading to accelerated wear and even an increased risk of thermal degradation;
- *Tire tread design:* Very deep grooves and a complex "Christmas tree" pattern optimize snow evacuation but reduce the contact area with dry pavement, diminishing stability and braking performance;
- *Increased fuel consumption:* Due to the tire's composition and profile, rolling resistance increases significantly, which directly leads to higher fuel consumption.

It has also been observed that winter tires used in the summer generate road noise and destabilize the vehicle during braking. This is due to the tire's high elasticity, which results from the soft layer in contact with the road surface a layer that becomes even softer at high temperatures.

All-season tires have been found to offer slightly better braking performance when used in the summer compared to winter tires, but their performance is not as good as that of summer tires. This is due to the composition of silica and other compounds in the tire, which are incorporated into the tire's compound so that it performs appropriately both in the summer at high temperatures and in the winter at low temperatures.

Using summer tires during the warm season is the best and safest option. They are specially designed for temperatures above 7°C, ensuring excellent traction, short braking distances, and stability during sudden maneuvers.

Every detail of a summer tire demonstrates its effectiveness during the warm season through:

- *Tire compound:* It is stiffer (harder) to prevent it from melting or deforming excessively on hot asphalt;
- *Tread pattern:* It has fewer small grooves (sipes) and more solid blocks on the shoulders, maximizing the contact area with the ground;
- *Efficiency:* The stiff compound reduces rolling resistance, which prevents rapid wear and helps reduce fuel consumption;
- *Effectiveness:* It is characterized primarily by excellent grip and short braking distances on dry or wet roads at temperatures above +7°C. It maintains its stiffness and offers superior handling thanks to its special rubber compound.

Using summer tires during the appropriate season is the most efficient choice.

Aspects of experimental research we are presented in Fig 9.

Fig 9: Aspects of experimental research [16]

11. Conclusions

Legislative provisions regarding driver fatigue among professional drivers are based on studies showing that after 4 hours of driving, a driver's reaction time can decrease by up to 75%, making fatigue just as dangerous as alcohol consumption. To prevent such risks and support drivers, the European Union has also established standards for creating safe and secure parking areas; this information can be accessed directly on specialized platforms.

Average speed is calculated by dividing the total distance by the total time. Do not confuse average speed with instantaneous speed.

If you fall asleep at the wheel for just 3 seconds on the highway, your car will travel over 108 meters without any control from the driver. This distance does not include the mechanical braking time required. In addition, when you doze off, the average reaction time to recognize the danger and press the brake pedal increases significantly, adding another few dozen meters before the brakes actually engage.

Studies show that driving a vehicle after sleeping for less than five hours is just as dangerous as driving under the influence of alcohol. Thus, drivers who lose between one and two hours of the recommended seven hours of sleep double their risk of having an accident. Drivers who lose between two and three hours of the recommended sleep quadruple their risk of having an accident.

Sleep deprivation has effects on drivers similar to those of alcohol consumption. Driving after being awake for 18 hours straight is similar to driving with a blood alcohol concentration of 0.05% (for reference, a blood alcohol concentration of 0.08% is considered drunk). If you've been awake for 24 hours and are driving, it's as if you have a blood alcohol concentration of 0.8–0.10%.

To compensate for delayed reaction times, road safety experts recommend adjusting your speed (slowing down) and taking regular breaks to combat the effects of fatigue.

In addition, sleeping only 4–5 hours a night for a week will impair your driving ability in a manner similar to a blood alcohol concentration of 0.05%–0.10%, according to studies.

If you wake up at 6 a.m. and stay awake all day, you'll reach 18 hours of being fully awake by 11 p.m. After that point, it's not recommended to get behind the wheel.

To prevent tragedies, it's vital to recognize the signs of fatigue and take regular breaks while driving.

Microsleep is often preceded by accumulated fatigue and is a major cause of road tragedies.

Driver fatigue monitoring systems are an important part of modern vehicle safety technology. By leveraging advanced features such as eye detection and recording capabilities, these systems provide real time alerts and valuable data to enhance road safety. As the automotive industry continues to prioritize safety and innovation, the integration of driver fatigue monitoring systems is expected to become more widespread, ultimately helping to reduce fatigue related accidents and save lives on the roads.

The implementation of driver fatigue monitoring systems benefits not only individual drivers but also fleet operators and transportation companies. By investing in these systems, companies can demonstrate their commitment to safety and reduce the risk of costly accidents and the liabilities associated with drowsy driving. In addition, the data collected by these systems can be used to identify trends and patterns, enabling targeted interventions and training programs to proactively address issues related to driver fatigue.

According to analyses on *"Driver Fatigue—A Factor in Road Safety"* conducted by the Ministry of Internal Affairs [17], Sleepiness is a major cause of serious accidents, especially on long, straight stretches of road. If you feel your eyelids getting heavy, the safest thing to do is to pull over and sleep for 15–20 minutes.

An analysis of the trends in traffic accidents that occurred in 2024, based on data published by the Romanian Police in the Road Safety Bulletin, shows that most serious traffic accidents occurred between 5 and 6 a.m., a phenomenon that we, the authors, attribute to sleep deprivation and sleepiness at the wheel.

Tire performance is the sole factor that determines when a vehicle's safety systems are activated. Using the right tires ensures that braking distances remain within safe limits.

To avoid risks, keep the following factors in mind: replace your tires seasonally to ensure you have the correct rubber compound; check tire pressure and tread wear regularly, as even a premium tire loses its properties if not properly maintained.

The braking distance of the vehicle (case study) in this research was considered an integral part of the total distance traveled "blindly" by a vehicle whose driver is tired or falls asleep at the wheel.

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