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Study of the speeds of vehicles involved in collisions through analysis of the mechanical deformations of structural parts

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ABSTRACT
This study consists of describing a method of calculating the speed of vehicles involved in traffic accidents through the analysis of mechanical deformations in various parts of these vehicles. The method is not unique in the world but in Brazil the studies are in the embryonic stage, being applied some methods like the conservation of total energy and the conservation of the amount of movement, but in both the deformations of the pieces are not taken into account account, although considerable part of the energy or amount of movement is used to cause the deformation itself. Some authors describe in their scientific work each of these methods to calculate speed, but do not take into account, for example, the moment of inertia of each of the vehicles, when they consider it as an estimate to be added in the calculation of the speeds of each one of the vehicles the faults observed in vehicles, but fails to take into account the mechanical deformations occurring in the structures thereof. The purpose of this is the analysis of deformations in structural parts of motor vehicles involved in traffic accidents and a possible way to determine or estimate the traffic speed of each of the vehicles before the collision. This study applies the knowledge about mechanical deformations in the practice of calculating collision speeds in traffic accidents in the field of forensic engineering, and with this, seek to point out, in many cases, the true cause of the violation of speeding, or a closer estimate of the true speed value of vehicles involved in a collision.

Keywords: Mechanical stress and strain, Calculation of speeds, Vehicle collisions, Crash Tests.

INTRODUCTION

This scientific initiation project aims to lead the scholarship holder to academic evolution, that is, to expand their knowledge in the area of mechanical engineering, with regard to applications of knowledge about deformations of vehicle parts and the energy responsible for causing these deformations. It is known that the evolution of solid mechanics knowledge has provided increasingly better applications, one of the most studied areas being that of material deformations, leading such knowledge to be used in the field of criminal investigations, specifically in determining vehicle speeds. involved in traffic accidents.

According to a report published in November 2015 by the World Health Organization (WHO), in 2013 alone, more than 41 thousand people lost their lives on Brazilian roads and streets . Since 2009, the

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number of traffic accidents in the country has increased from 19 per 100 thousand inhabitants to 23.4 per 100 thousand inhabitants, the highest record in South America.

In 2014, the number of deaths reached a record 52,226, only those who were compensated by DPVAT insurance (VIAS SEGURAS, 2019).

Among the ten most populous countries in the world, however, Brazil appears as a highlight in the report, fulfilling four of the five main risk factors in traffic, which are: use of seat belts, helmets, speed limits, child safety and prohibition of drinking alcoholic beverages before driving. The list of the ten most populous also includes states such as China, the USA and India. These States account for 4.2 million people and 56% of deaths due to traffic accidents (NAÇÕES UNIDAS BRASIL, 2018).

In Brazil in 2014, the number of people injured in traffic accidents reached 596,000. In the state of Amazonas, according to information from DENATRAN, the number of deaths in 2014 and 2015, respectively, reached the following amounts: 457 and 418 people (VIAS SEGURAS, 2019).

Traffic accidents are one of the main causes of death in the world, killing 1.25 million people per year, accumulating deaths mainly in poor countries. According to the WHO, low- or middle-income countries account for 90% of traffic deaths, while they account for 54% of the world's vehicles. Europe has the lowest per capita rates, and Africa, the highest. Despite the high number of accidents, the study states that the number of traffic deaths is stabilizing, even with the rapid increase in vehicles in the world. In Brazil alone, according to data from 2013, there are more than 81 million registered vehicles. The document shows that 79 countries saw a reduction in traffic fatalities, while 68 increased them. According to the WHO, the countries with the greatest success in reducing road deaths have developed their legislation, enforcement and improving the safety of roads and cars (NAÇÕES UNIDAS BRASIL, 2018).

Most traffic accidents have another consequence, which is damage to the vehicles involved. These deformations can be a field to be researched, specifically relating, in some situations, the knowledge of the deformations caused by impacts between two vehicles and through these deformations finding a relationship with the value of the speed that each vehicle was traveling before the collision. According to records from the Ministry of Transport (2023), 5,246,238 traffic accidents occurred across the country, with 7,345,775 motor vehicles involved.

Therefore, it is extremely important that such a study be carried out, the analysis of deformations in motor vehicles involved in traffic accidents and a possible way to determine or estimate the traffic speed of each vehicle moments before the collision.

TENSION

We say that it is the intensity of the internal force that acts on a specific point (area) selected on a body. There are two types of stress: normal stress and shear stress. They are basically classified into two types:

- Normal Voltage;
- Shear stress;

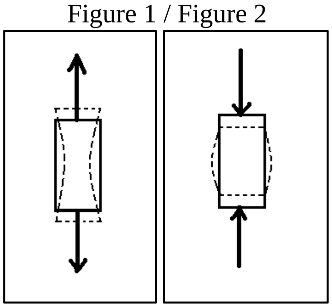
NORMAL VOLTAGE

The intensity of force or force per unit area, which acts perpendicular to ΔA , is defined as normal stress, σ (sigma). Therefore it can be written that:

$$\sigma = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A}$$

If the normal force or tension pulls the element of area Δ A, as shown in figure 1, it will be called tensile normal stress, and if it compresses the element Δ A, it will be called compressive normal stress as shown in figure 2.

Figure 1 / Figure 2

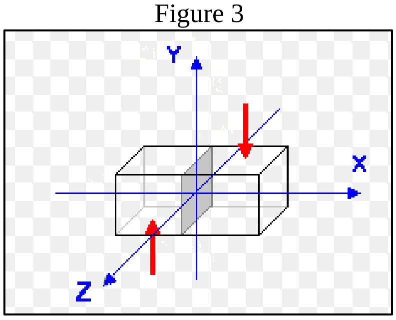


SHEAR STRESS

The intensity of force, or force per unit area, that acts tangent to Δ A, is called normal shear stress, (tau), as shown in figure 3. It can be written that:

$$\tau = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A}$$

Figure 3



DEFORMATION

When a force is applied to a body, it tends to change its shape and size. These changes are called deformation and can be perfectly visible or practically imperceptible.

TYPES

There are two types:

- Normal Deformation
- Shear Deformation

Normal Deformation

It is the elongation or contraction of a straight line segment per unit of length. Calculated by the equation:

$$\boldsymbol{\varepsilon = \frac{\Delta s' - \Delta s}{\Delta s}}$$

where $\boldsymbol{\Delta s}$ is the initial and $\boldsymbol{\Delta s'}$ final length of the object.

Shear Deformation

It is the change in angle that occurs between two straight segments originally perpendicular to each other. Calculated by:

$$\boldsymbol{\gamma = \frac{\pi}{2} - lim\ \theta`}$$

where $\boldsymbol{\theta`}$ is the final angle.

CRASH TESTS

The impact test (crash test) consists of the impact of motor vehicles against non-deformable barriers (concrete or iron blocks) or deformable barriers (metallic deformable block). Its objective is to evaluate automotive safety to verify whether they comply with certain safety standards for collision protection in traffic accident situations.

BRANDS

- Honda
- Fiat
- Volkswagen
- Ford

Honda Fit + 2 Airbag (2015)

This model received five stars for adults and children's room. ´´The vehicle structure showed stable performance, as well as advanced elements that allowed it to offer good levels of safety,`` states Latin NCAP.

Fiat Mobi + 2 Airbags (2017)

Mobi did poorly in the safety test and only received one star. ´´The structure of the car proved to be inappropriate to withstand a side impact, according to Latin NCAP; Child protection reached two stars.

Volkswagen Golf VII + 7 Airbags (2017)

It joined the list of cars manufactured in Brazil that offer maximum safety to all passengers and is the first car sold here to win the Advanced Awards seal, which recognizes models with accident prevention technologies. The model achieved five stars for adult protection and another five for child safety, according to Latin NPAC.

Ford Ka + 2 Airbag (2015)

The model received 4 stars for adults and only 3 for children. ´´The structure was classified as stable, being able to withstand heavy loads, states Latin NPAC.

EXPERIMENTAL STUDY

EXPERTISE IN ORDER TO DETERMINE SPEED IN TRAFFIC ACCIDENTS

Determining speed is essential in the analysis of traffic accidents. The possibility of doing so is directly dependent on the existence of material elements, such as: braking marks, skidding marks, material damage and residual space.

In the study to assess speed, experts will use all the elements produced at the event. The disappearance of any of them will definitely make it impossible to accurately reflect reality.

This observation refers to locations not preserved, and even in cases where vehicles are removed from their original positions resulting from the collision.

Main traces

The remains found at the site must be described in detail (with their relevant characteristics) and photographed by the Expert. The main characteristics of these traces will be presented, as well as the most used way to record them.

Pneumatic brands

They are among the most important remains at the site, serving to determine the speed and point of the collision. The descriptive record of pneumatic marks must include: length in meters, location and reference of starting and ending points and particular characteristics such as distortions, interruptions, etc. They can be classified into:

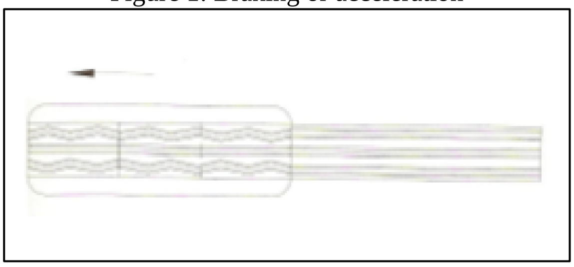
- Braking

These are marks produced by the tire rubbing against the surface. When braking on asphalt or concrete pavement, the vehicle produces marks that are generally continuous and dark in color, in varying shades of gray. The ABS system is a device used today in the brakes of some cars that also produce marks, but more faint and generally sectioned and, sometimes, in the form of friction marks on the pavement.

- Skid

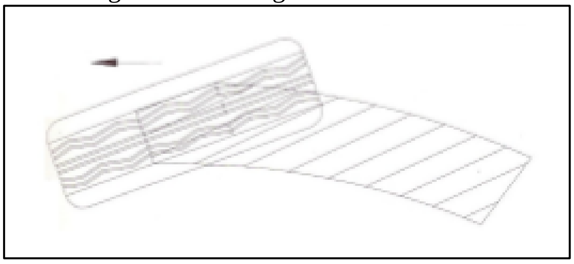
They are produced by tires without complete locking, that is, they continue in a rotary movement in curves or in a curvilinear movement, with a displacement that diverges from the orientation indicated by the vehicle's longitudinal axis. Skid marks can also be collected using the radius of curvature. According to the direction of the hatches, we can also determine whether these marks were produced during acceleration, deceleration, or neutral, as illustrated in the figures below.

Figure 1: Braking or acceleration



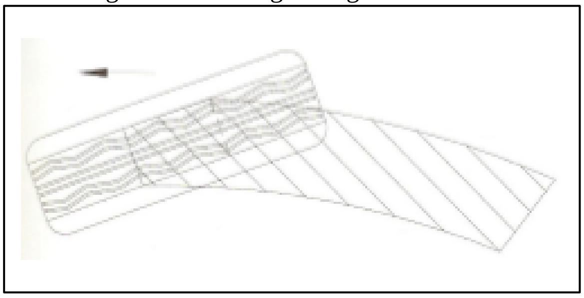
SOURCE: SANTOS & SANTOS. 2008

Figure 2: Skidding under acceleration



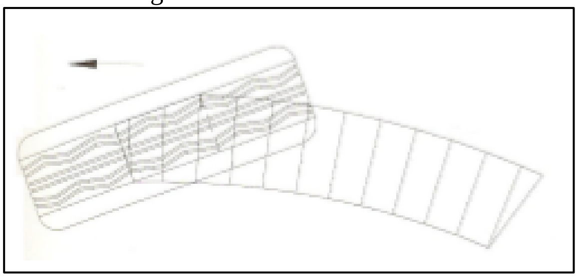
SOURCE: SANTOS & SANTOS. 2008

Figure 3: Skidding during Deceleration



SOURCE: SANTOS & SANTOS. 2008

Figure 4: Neutral or Free Skid



SOURCE: SANTOS & SANTOS. 2008

- Acceleration Marks

They are marks very similar to braking marks, however, with different characteristics in their initial regions. Due to the application of a large amount of torque to the driving wheels, distortions are generally observed at the beginning and progressive lightening, that is, they are darker at the beginning.

Friction marks

They appear when parts of a vehicle's structure slide against the surface, without removing material from the surface. They are generally accompanied by adhesion of surface covering material (paint or rubber) or groove marks.

Final rest position

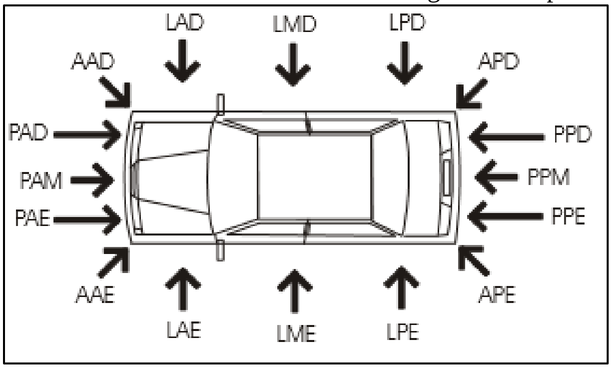
The final positions that vehicles assume after an accident are called resting positions, and they are also important for establishing the dynamics of the accident and determining the speeds at which the vehicles were traveling.

Breakdowns

The damage observed in vehicles involved in accidents is the result of deformations produced by the contact of their structures. The description of damage primarily involves determining the impact seat.

The impact seat actually represents the initial point (or region) of impact on the vehicle structure.

Figure 5 - Impact headquarters.



PA – parte anterior (D, M, E);
PP – parte posterior (D, M, E);
LD – lateral (A, M. P) direita;
LE – lateral (A, M, P) esquerda.
A – ângulo (A, P) (D,E)
D – direita; E – esquerda; M – média;
A – anterior; P – posterior.

Source: SANTOS & SANTOS. 2008.

Main types of damage: crushing, breaking, rupture, warping, deformation, etc. We treat **damage** occurring in ductile metal parts, subject to permanent deformation without a rupture process, such as bodywork parts, as dents. Breakages occur in parts subject to brittle fracture, that is, without plastic deformation**,** such as cast iron metal parts or rigid plastic parts. The terms **rupture** and **deformation** are most used in the case of non-metallic parts, such as tires and bumper covers.

METHODS FOR CALCULATING SPEED

Energy conservation

In physics, the law or principle of conservation of energy establishes that the total amount of energy in an isolated system remains constant, that is, the total energy before is equal to the total energy after a certain process.

For the analysis of the speed developed by a vehicle, the beginning of the braking marks will be considered as a reference point, which correspond to the materialization of the beginning of the deceleration process. Thus, the energy available before the start of the speed reduction process is transformed into distinct portions. As a general rule, part of this energy is dissipated in the form of drag (production of braking marks), another in the form of damage (damages experienced and/or produced) and a third, in residual movements. Thus, one can represent

$$\boldsymbol{And}_{\text{before}} = \boldsymbol{And}_{\text{then}} \quad (1)$$

before portion basically consists of the energy due to the initial velocity, while the ***after portion*** can be represented by the equivalent portions of the transformed energy, that is:

$$E_{before} = E_{entrainment} + E_{damage} + E_{residual} \quad (2)$$

Considering each of the terms above as equivalent to the kinetic energy of a body of mass m and speed v, one can represent:

$$Ec = \frac{1}{2} m v^2 \quad (3)$$

One can then write, for a given object (vehicle):

$$\frac{1}{2} m\, V_0 = \frac{1}{2} m\, V_a^2 + \frac{1}{2} m\, V_d^2 + \frac{1}{2} m\, V_r^2 \quad (4)$$

Canceling the common terms, it is demonstrated that the speed before the impact can be represented by the portions corresponding to the “velocities” transformed after the impact, resulting in:

$$V_o^2 = V_a^2 + V_d^2 + V_r^2 \quad (5)$$

where:

V_o = initial speed

V_a = drag speed

V_d = damage speed ic

V_r = residual speed

To interpret an accident, it is often important to evaluate the speed at the time of the collision (Vic), which is defined by:

$$V_{ic}^2 = V_d^2 + V_r^2 \quad (6)$$

When there are two vehicles, all installments must be considered separately, for each of them.

Thus, one can write:

$$\frac{1}{2}m_1 V_{o1}^2 + \frac{1}{2}m_2 V_{o2}^2 = \frac{1}{2}m_1 V_{a1}^2 + \frac{1}{2}m_1 V_{d1}^2 + \frac{1}{2}m_1 V_{r1}^2 + \frac{1}{2}m_2 V_{a2}^2 + \frac{1}{2}m_2 V_{d2}^2 + \frac{1}{2}m_2 V_{r2}^2 \quad (7)$$

To solve the practical problem of determining the speeds of two vehicles that were involved in a collision, it is observed that in the equation above two values are unknown, which are the initial speeds, that is, those at which they were traveling before the impact occurred. among them, which are Vo1 and Vo2. The other installments may be determined based on movements after the collision and the assessment of the damage experienced.

Drag portion

It is the portion of the speed (energy) dissipated during the vehicle braking process. This component of the vehicle's speed is calculated based on measuring the extent of the pneumatic marks at the location. The calculation of this portion is also made with the extent of the pneumatic skid or rolling marks measured on site.

In addition to the length of the pneumatic marks, the calculation of this portion of speed uses the coefficient of friction between the tires and the road. It is essential to know the characteristics and conditions of the road: whether flat or inclined, dry or wet, types of surface, presence or absence of other substances on the surface, the type of vehicle (size: passenger, utility vehicle, medium-duty, cargo, etc.) and the type of your braking system (ABS, conventional, etc.), in addition to its operating status.

From the concepts of Kinematics and Dynamics, based on the equivalence of the Work of the Friction Force with the Variation of Kinetic Energy in the deceleration process, it can be demonstrated that the portion of the speed corresponding to braking (V_f) is:

$$V_f = \sqrt{15.938\, df \cdot k} \quad (8)$$

where:

df = braking space (m)

k = pavement friction coefficient

Friction coefficients may vary according to the speed developed by the vehicle, the type of pavement and its general conditions. Regarding speed, according to the tables published by Traffic Institute, what is observed is a constant behavior below 48 km/h and another, also constant, for speeds above this value. In the following tables you can find friction coefficients for light vehicles in braking processes on different types of pavement, dry and wet conditions, for both speed ranges and also for different types of material.

Table 1 – Friction coefficients for braking (light vehicles).

Surface		DRY		WET	
		V<48.37km/h	V>48.37km/h	V<48.37km/h	V>48.37km/h
Cement	rough	1.00	0.85	0.65	0.58
	average	0.70	0.68	0.58	0.55
	polished	0.65	0.58	0.55	0.53
Asphalt	rough	1.00	0.83	0.65	0.60
	average	0.70	0.63	0.58	0.53
	polished	0.65	0.55	0.55	0.50
Gravel	compact	0.70	0.65	0.60	0.50
	loose	0.55	0.55	0.60	0.60
Stones		0.65	0.65	0.65	0.65
Paving stone	rough	0.88	0.80	0.78	0.79
	polished	0.60	0.55	0.40	0.38
Sand		0.60	0.60	0.70	0.70

Source: SANTOS & SANTOS. 2008.

Table 2 – Friction coefficients for different types of material.

type of material	coefficient	
	dry	wet
steel on steel	0.120	0.080
steel over bronze or gray cast iron	0.180	0.060
steel on ice	0.014	**
steel over wood	0.500	0.100
gray cast iron on cast iron	0.280	0.080
gray cast iron over bronze	0.200	0.080
leather over metal	0.480	0.150
leather on wood	0.400	**
rubber on metal	0.500	**
brake lining on steel	0.500	**
stone upon stone	0.650	**
wood on wood	0.500	**

Source: SANTOS & SANTOS. 2008

Table 3 – Friction coefficients for different situations Source: SANTOS & SANTOS. 2008.

Type of situation	Coefficient
Truck sliding on its side on concrete	0.30 – 0.40
Passenger vehicle sliding supported on concrete roof	0.30
Passenger vehicle sliding on its roof on rough asphalt	0.40
Passenger vehicle sliding on gravel roof	0.50 – 0.70
Passenger vehicle sliding on its roof on dry grass	0.50
Metal surfaces sliding on asphalt	0.40
Metallic surface sliding over land	0.20
Metal rubbing against metal (side friction)	0.60
Vehicle with vehicle (ride)	0.55

Engine brake engaged in heavy gear	0.10
Engine brake engaged in light gear	0.10 – 0.20
Free bearing without gear and tires with normal inflation	0.01
Gearless free bearing and partially inflated tires	0.013
Free bearing without gear and flat tires	0.017
Sliding on packed snow	0.15
Sliding on ice or sleet	0.07
Motorcycle sliding overturned	0.55 – 0.70
Human body sliding	1.10
Human body rolling	0.80

Portion of damage

This portion is a value obtained through an assessment of the extent of damage (damages) experienced and caused in a collision. Although it is an estimated value, it is obtained through comparison with “crash test” results from the automobile industry, as well as in collisions where vehicles are equipped with speed recorders.

There are methods for evaluating this speed considering measurements carried out in the damaged region. Such methods are based on the resistance to deformation of the structure and require knowledge of specific resistance coefficients of the vehicle structure, which depend on the structural design and the composition of the materials used in manufacturing. These values are, in general, tabulated according to the model or class (platform dimensions) and also to the affected region (for example, the front part is more resistant than the sides and back. In our country we still do not have reliable data for safe use in our vehicles, given that we do not have a central body responsible for carrying out crash tests and providing this data for use by accident analysis professionals.

Table 4 – Damage speeds.

Intensity of breakdowns	Vd (km/h)
Light	0 to 20
average	20 to 40
serious	40 to 60
very serious	Over 60

Source: SANTOS & SANTOS. 2008.

Table 5 – Damage rates according to the type of damage.

TYPE OF FAULTS	Vd (km /h)
01. bend bumper at the tip	05
02. bend bumper in the center	10
03. bend bumper in skirt	15/20
04. dent fender	05/10
05. denting fender tearing	10
06. dent fender tearing off	15

07. Sink radiator grille	30/35
08. sink radiator grille, more honeycomb	40/45
09. start suspension	40/45
10. tear off steering wheel	40/45
11. break spar	50/60
12. remove the engine from the chocks	60/70
13. tear off driving wheel	50/60

Source: SANTOS & SANTOS. 2008.

Table 6 – Damage speeds, according to the type of damage.

Type of Breakdown	Vel. damage (km/h)
Bend bumper	05
Break bumper	10
Break bumper and radiator grille	15/20
Breaking bumpers, headlights, sinking grille, denting hood, deforming previous bodywork	20/30
Breaking the bumper, headlights, sinking the grille, deforming the previous bodywork until it touches the engine without moving it	30/40
Breaking the bumper, headlights, sinking the grille, deforming the previous bodywork until it touches the engine without moving it, deforming the suspension	40/50
Sink radiator grille plus honeycomb	40/45
Start suspension	40/45
Start guideline	40/45
Break stringer	50/60
Remove engine from chocks/move engine	60/70
Starting drive wheel	50/60

Source: ALMEIDA. 2015.

Residual portion

In most accidents, after the collision, the vehicles travel some more space, as a result of the residual portion of Energy. This space can be used to determine one more component of the total velocity.

After the collision, the vehicle may continue braking, skidding, overturning or simply rolling freely until it reaches its resting position. In order to use the appropriate coefficients, it is very important that the site survey identifies the type of marks that were produced after the collision, measuring their extent.

The residual speed (Vr) is then calculated in km/h by the equation:

$$\boldsymbol{V_r = 15.938 \sqrt{d_r \cdot k} \quad (9)}$$

where:

d_r = residual space (m)

k = pavement friction coefficient

Calculation of speeds based on the radius of curvature

A vehicle in the process of turning at a constant speed has two forces acting on it, which are: the radial force that keeps it in the curvilinear movement and the friction force provided by the tires. From the moment the vehicle's speed in the curve becomes higher, its radial acceleration increases and when the radial force overcomes the friction force, slipping will occur. This speed is called limiting speed or critical speed.

The radial force is given by

$$\boldsymbol{F_r = m \cdot a_r = m \cdot (v^2 / R)} \quad \textbf{(10)}$$

The friction force is

$$\boldsymbol{F_{attr} = k \cdot N = k \cdot m \cdot g} \quad \textbf{(11)}$$

Equating the two expressions and isolating the speed, we will have:

$$\boldsymbol{{}_{Critical}V = \sqrt{g} \cdot {}_{Critical}R \cdot k} \quad \text{m/s} \quad \textbf{(12)}$$

where:

g = acceleration of gravity (9.81m/s2)

k = pavement friction coefficient for skidding conditions

$_{\textbf{Critical}}$**R =** critical radius in meters

It is important to highlight that, in order to determine the speed that a vehicle was developing when escaping a curve, it is not enough to indicate the radius of the curvature of the track, as this will provide the value of the limit speed for that curve. What should be measured is the radius of curvature of the skid marks produced, as these will give a good approximation of the speed the vehicle had when it “went away”. The values obtained for the marks can differ greatly from those obtained for the curvature of the track, as one of the factors that can define the skidding conditions is the “attitude”.

CONSERVATION OF MOMENTUM METHOD

Principle of Impulse and Quantity of Linear Motion

The method based on the principle of impulse and momentum can be used to solve problems involving force, mass, speed and time, being of particular interest in solving problems involving impulsive movements or shocks.

Considering a body of mass m subjected to the action of a force F, Newton's second law can be expressed as

$$F = \frac{d}{dt}(mv) \quad (13)$$

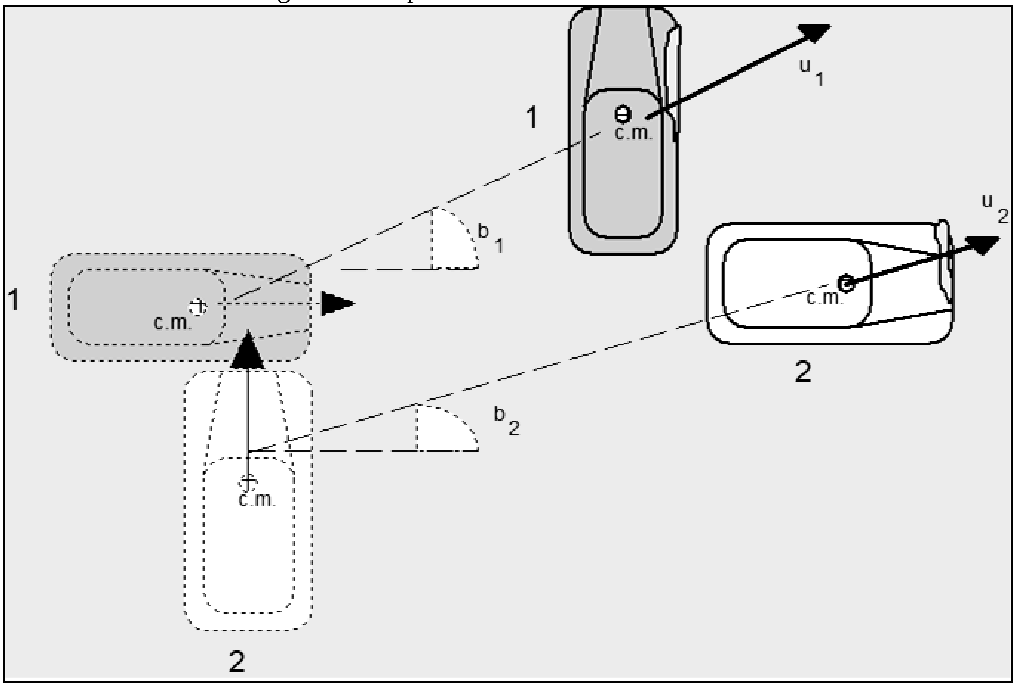
where ***mv*** is the momentum vector. By multiplying both sides of the equation by ***dt*** and integrating from time t_1 to t_2, we can write

$$\mathbf{F}.\,dt = d\,.\,(m\,\mathbf{v})\ (14)$$
$$\int_{t1}^{t2} F.\,dt = \mathbf{mv}_2 - \mathbf{mv}_1\ (15)$$

The integral of the previous equation is a vector defined as the linear impulse, or simply as the impulse of the force F, during a certain time interval. It is represented as P the impulse.

Accident dynamics

Figure 6 – Perpendicular collision between cars



$$v_1 = u_1 . \sin(a_2 - b_1) + m_2 / m_1 . [u_2 . \sin(a_2 - b_2)] / \sin(a_2 - a_1)\ (16)$$
$$v_2 = m_1/m_2 . [u_1 .\sin(b_1 - a_1)] + u_2 .\sin(b_2 - a_1) / \sin(a_2 - a_1)\ (17)$$

where:

a_1 and a_2 = vehicle entry angles

b_1 and b_2 = departure angles

u_1 i $_2$ = speeds after collision

Table 7: Calculation of collision speeds

m_1 (kg)	m2 (kg)	to $_1$	at $_2$	b_1	b_2	x_1	x_2	u_1	u_2	v_1 (m/s)	v2 (m/s)
2025	980	0	two	0.07	0.21	28.9	28.3	20.11	19.9	28.02	3.54
2025	1080	0	6	0.07	0.23	28.9	28.3	20.11	18.9	29.57	1.16
2025	1110	0	10	0.07	0.25	28.9	28.3	20.11	17.9	29.53	0.71
2025	1175	0	14	0.07	0.27	28.9	28.3	20.11	16.9	29.63	0.5
2025	1240	0	18	0.07	0.29	28.9	28.3	20.11	15.9	29.61	0.39
2025	1260	0	22	0.07	0.31	28.9	28.3	20.11	14.9	29.19	0.32
2025	1280	0	26	0.07	0.33	28.9	28.3	20.11	13.9	28.74	0.27
2025	1650	0	30	0.07	0.35	28.9	28.3	20.11	12.9	30.47	0.22

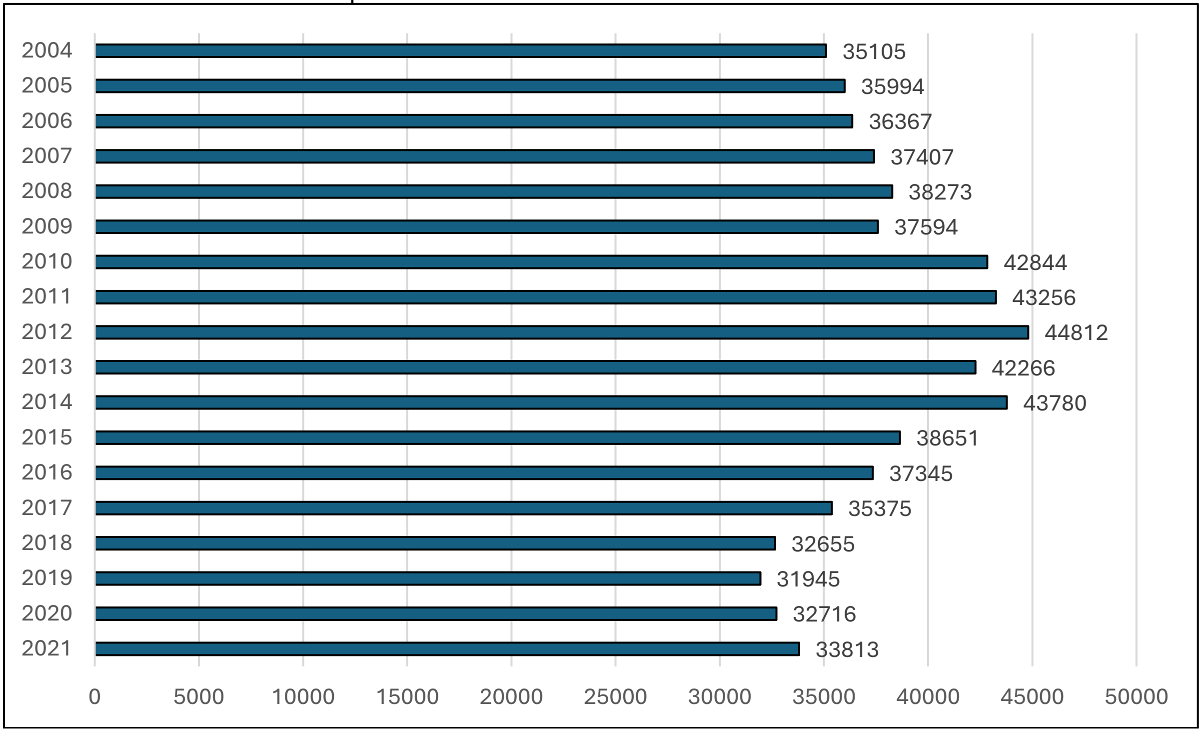
CONCLUSIONS

STUDY OF THE CAUSES OF TRAFFIC ACCIDENTS

Based on data collected at sites of traffic accidents between two or more motor vehicles during traffic accident investigations in order to establish the cause, or causes, of the accident. All the steps already taken, since surveying the site, are aimed at this issue.

In Brazil, approximately 45,000 people lose their lives annually in traffic accidents, however it is believed that these numbers are higher because the statistics are flawed. In 2001 alone, on São Paulo highways there were 61,000 accidents with 2,300 deaths and 23,000 people seriously injured. Traffic takes lives all over the world, but the Brazilian numbers are alarming and are ahead of any country in the world.

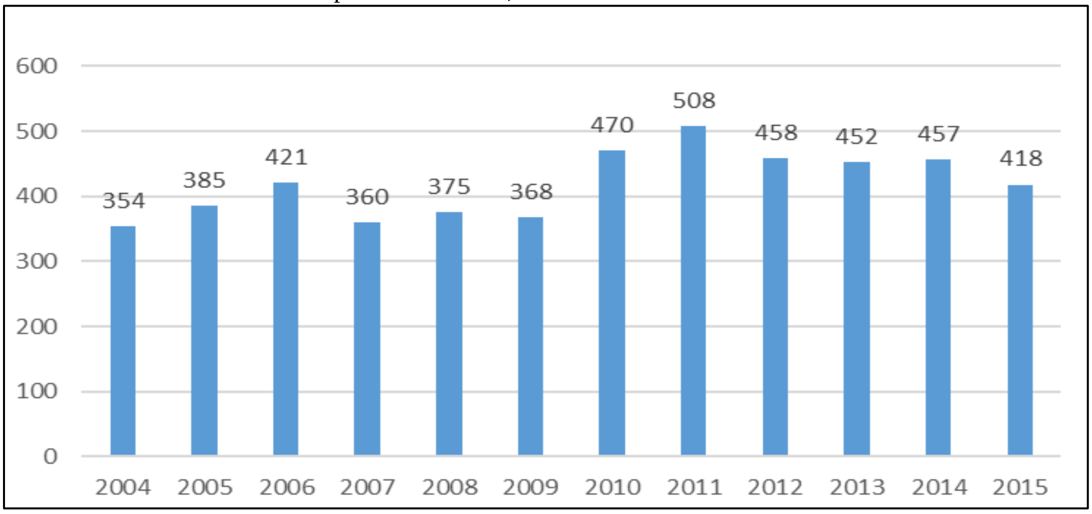
Graph 1: National statistics: deaths in traffic accidents.



Source: DATASUS, 2023.

The number of annual deaths in Brazilian traffic has grown for two consecutive years. In 2021, Brazil showed an increase of 3.35% in the total number of deaths recorded in traffic, totaling 33,813 deaths from traffic accidents, an increase of 1,097 deaths compared to data from 2020. The percentage change of 3.35% in 2021 it was similar to the increases that occurred in 2014 and 2012.

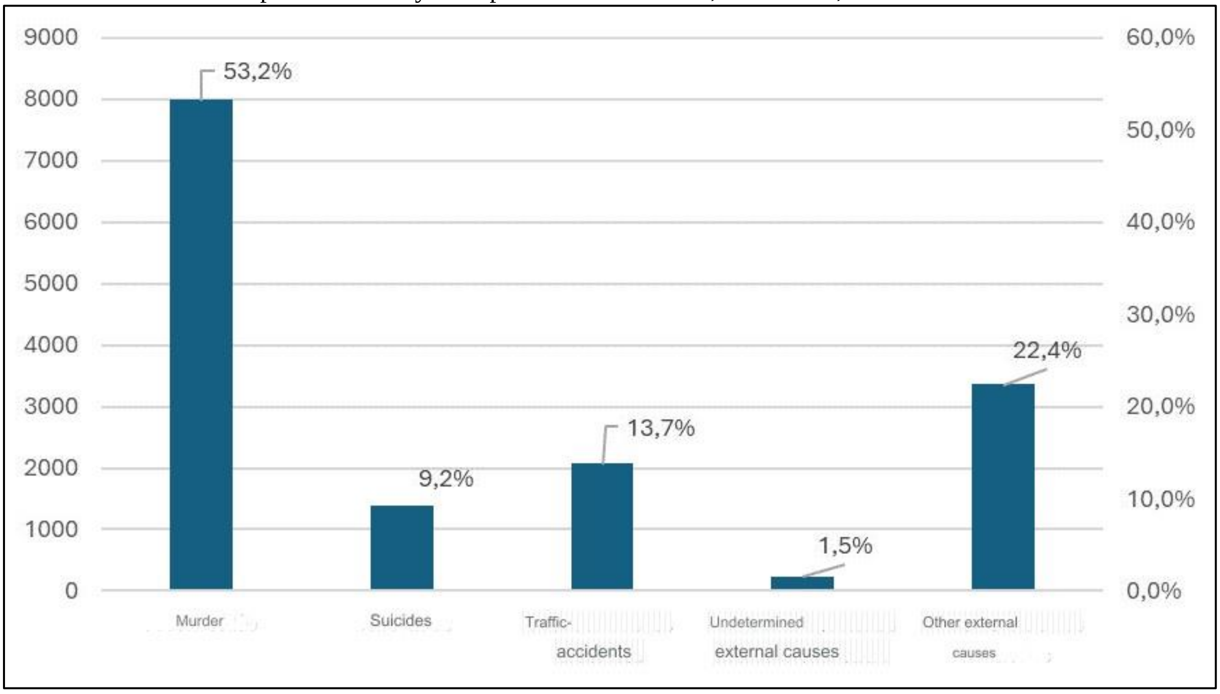
Graph 2: Amazonas, deaths in traffic accidents.



Source: DATASUS, 2023.

In the period from 2018 to 2022, the state of Amazonas totaled 114,511 deaths reported in the Mortality Information System (SIM). Of this total, 15,061 (13.2%) were deaths due to external causes, of which 8,006 (53.2%) were due to homicide, 2,070 (13.7%) were due to Land Transport Accidents (ATT), 1,386 (9.2%) due to suicides, 3,371 (22.4%) due to other external causes and 228 (1.5%) due to undetermined external causes (SES-AM, 2023).

Graph 3: Deaths by Group of External Causes, Amazonas, 2018 to 2022.



Source: SES-AM, 2023.

The human element can participate directly or indirectly, actively or passively, and it is necessary to understand the role or function of each of the protagonists in the context of the accident. Are they:

- **Active direct protagonist (PDA):** is the one who carries out the action from which the accident directly occurred;
- **Passive direct protagonist (PDP):** is the one who directly suffers the action carried out, directly by another;
- **Active indirect protagonist (PIA):** one who, for some reason, performs an action or creates a situation that induces another to perform an action which results in an accident with another driver;
- **Passive indirect protagonist (PIP):** does not contribute anything to the accident, however it suffers direct consequences.

DETERMINING CAUSES

Determining cause is one that, once removed, the accident does not occur. It is generally associated with an infraction of some traffic rule. In other words, it is legal to assume that without a violation of traffic rules there is no cause for an accident.

Theoretically, the Determining Causes are divided into mediate or circumstantial and immediate or direct.

Mediate or circumstantial causes are subjective, so it almost always becomes impossible to materialize them. The elements of distraction, physical and mental situation of drivers (fatigue, sleep) and actions on the part of passengers are good examples to explain that it is unlikely that the expert will have the conditions to verify them. They can also originate from other adverse situations existing in Traffic, caused by other vehicles, pedestrians, animals or even natural phenomena. Despite the impossibility of determining the circumstantial cause by the expert, relevant traces can be found at the sites. These must be mentioned in the reports and can be used to clarify the truth.

In turn, the immediate or direct causes are perfectly discoverable, because, if they exist, they are materialized by the traces produced.

The Determining Causes are related to man, machine and the environment, subdivided as follows:

- Man
- Machine
- Quite

Man (driver)

a) Behavior - must be understood as a state of knowledge, on the part of the driver, of a Dangerous situation created by him/herself, and his/her persistence in it until the culmination of the event. It therefore reflects an action that will be illegal, dangerous or unusual.

Illegal behavior is characterized when it is found that the driver was traveling in complete disobedience to an overt or obvious signage. E.g.: advancing a continuous line, traveling in the wrong direction, etc.

Dangerous behavior is related to abnormal maneuvers and vehicle traffic conditions. For example: overtaking on the shoulder, traveling zigzagging on the road, with the vehicle without brakes, or even with the tire layers exposed, etc.

Finally, unusual behavior is attributed to the driver who maneuvers his vehicle in an unexpected and unconventional way, as the title itself indicates, unusually. E.g.: traveling over flowerbeds, sidewalks, balloons, lawns, etc.

b) **Speed –** Speed is at the level of behavior, in relation to the danger it represents, to the point where it can be stated, without the need for statistical data, that, if regulatory signs were obeyed, the rate of serious and fatal accidents would be markedly reduced.

c) **Lack of reaction** and/or **delayed reaction** – occurs in those cases in which the driver does not react to the obstacle in front of him or reacts at a point on the ground, from which it is no longer possible to stop the vehicle in time to avoid the collision. collision.

Factors that influence reaction time:

- Definitive: age, physical disability (vision, hearing, paralysis, etc.);
- Temporary: temporary illnesses (common cold, headache, etc.), alcohol, drugs, medications, emotional state, sleep

ALCOHOL AND DRUGS - can considerably slow down reaction time. American traffic accident statistics indicate that alcohol is involved in almost 50% of fatal accidents. Some experts indicate that depending on the person, just two glasses of beer can increase their reaction time to 2 seconds.

EMOTIONAL STATE - can also slow down a driver's reflexes and reaction time. The individual who takes to the wheel his worries about: job, salary, marital issues, and frustrations arising from his daily life, can greatly alter his reaction time, mainly due to the low level of concentration in the activity of driving.

SLEEP – is one of the most important elements in the cause of traffic accidents, it is very little studied, mainly due to the difficulty of researching this variable after the occurrence of an accident. Two rates are used to estimate the number of accidents per motor vehicle caused by drowsiness.

The first is based on the total percentage of accidents and the total number of fatal accidents that occur during the hours of greatest drowsiness, from 2 am to 7 am and from 2 pm to 5 pm (42% of the total and 36% of the fatal ones). The second is the percentage of total accidents that occur at night (54%), when reaction and performance times are considerably reduced. The tendency to fall asleep is also increased by sleep deprivation and interruption, the effect of this loss being cumulative.

Table 8 – Minimum distance required to stop a vehicle based on reaction time and vehicle speed.

SPEED (km/h)	NORMAL (0.75 sec.)	DELAYED (2 sec.)
	DISTANCE (m)	DISTANCE (m)
50	10	28
80	16	44
90	18	37
100	20	41
110	22	45
120	25	66

SOURCE: SANTOS & SANTOS. 2008.

d) **Inadequate solution** – this case is applied when it is found that the driver saw a danger and acted incorrectly to avoid it and thus caused the accident.

Machine (vehicle)

The need for a detailed site examination, including complementary examinations (checking mechanical and pneumatic systems, among other components), must be observed with greater attention.

From a chronological point of view, the irregularity that could have caused the accident will occur before, during or after the collision.

If it occurred during or after the event, it will obviously be immediately ruled out as a Determining Cause. It is perfectly possible to establish whether the failure occurred as a result of the event or whether it was produced intentionally.

If it occurred before the accident, the objective aspects that may or may not attest to its predictability, as well as its pre-existence. Pre-existence is equivalent, in terms of responsibility, to predictability, and the driver, in this case, must assume it, characterizing the type of dangerous behavior. For example: the driver is aware of the deficiency in the vehicle and assumes the risk of putting it in traffic.

By exclusion, we finally arrive at the unpredictable failure, which surprises the driver and gives immediate cause to the event, and only in this hypothesis is it given as a Determining Cause. Ex.: rupture of a new tire, as well as the rupture of a steering arm on a well-maintained vehicle, etc.

Quite

Finally, there remain the causes related to the environment, here understood as the road, whether or not it is equipped with signs. When the Determining Cause is attributed to the means (road), the responsibility will fall on the representatives of the bodies responsible for the design, construction and maintenance, exempting the driver directly or indirectly. In this case, the causes are divided into predictable and unpredictable.

Although rare, predictable causes record some accidents whose reason is attributed to the environment. E.g.: deposition of a layer of tar on the roadway without proper signage to prevent vehicle traffic. The technician should be alerted that the limit of predictability is exactly the case of fortuitous circumstances and/or force majeure, and the characterization, whenever possible, should be recorded.

The unpredictable causes linked to the environment are those resulting from force majeure, caused by floods, windstorms, etc. E.g.: collapse of viaducts, bridges, etc.

Various materials are used in the manufacture of a car because the functions they have to perform are also diverse. So, depending on the part and also the brand of vehicle, we will find different materials and different ways of producing them.

Form, function, cost and safety are unknowns to consider when selecting these materials and depending on what is desired, the choice of these also varies.

Chassis

The chassis is the least remembered part when it comes to maintenance, however, it is one of the most important parts. Although it is responsible for withstanding the torsions and loads that a vehicle undergoes throughout its life, it must also be flexible enough when excessive torsion occurs.

In cases of collisions, it must absorb the shock, preventing the vehicle's occupants from being hit. To achieve this, current models are designed to create a survival cell around the vehicle.

Modern vehicles have computer-designed chassis, which gives them greater precision and efficiency.

Currently, most cars no longer have the old chassis, what they have is a unibody body. In this structure, the floor is stamped together with the rest of the bodywork, so all parts of the car's body leave the assembly line as a single piece, due to this characteristic it was called monoblock.

Structured monoblock, a variation of the monoblock, known as a trellis chassis as it is assembled in such a way that only the vehicle structure forms part of the chassis, all the bodywork and other parts will be attached later. Reducing the weight of the structure and, at the same time, offering superior rigidity and greater resistance to collisions is the objective of this type of chassis, which is why it is chosen by most manufacturers of competition vehicles.

This technology was used for the first time in series production by Audi, in the A8, launched in 1994. More recently, Fiat adopted this concept and has already applied it to the Fiat Múltipla, equipped with a structured chassis made of high-strength steel.

Two metallic materials are predominantly used in the bodywork, steel and aluminum. But they can also be made from carbon fiber, Kevlar and, currently, chassis are manufactured with magnesium and composite materials, a mixture of aluminum with carbon fiber or Kevlar and carbon fiber, among others.

Steel is a metallic alloy formed essentially by iron and carbon.

In the past, mild steel was the metal most used in the manufacture of different automobile components, however, with the aim of making cars lighter, safer and more resistant, mild steel gave way to high-strength steels.

Since then, the use of this type of steel has been favored for the following reasons:

- They allow the vehicle's mass to be reduced, by reducing the thickness of the different structural elements and body panels, without compromising resistance;
- These metals are less expensive than plastic materials or aluminum;
- Numerous body parts can be made from high-strength steel without changing traditionally used

molds and tools.

Aluminum is abundant in the Earth's crust and is relatively easy to exploit. It is also being increasingly used in automobiles, particularly in bodies, due to the following advantages:

- Its density will be approximately one third of that of steel;
- The aluminum oxide forms a thin layer, which is renewed periodically - degradation of the material is avoided;
- Alloys of this metal are easily recyclable;
- Be easy to machine;
- Having a great capacity to absorb energy, a characteristic that makes it very suitable for areas of programmed bodywork deformation.

However, aluminum also has disadvantages:

- Because it is soft, ductile and malleable, deformations easily arise due to stress;
- The electrical resistance is five times lower than that of steel, making resistance spot welding processes impossible;
- The material's coefficient of expansion is twice that of steel, which can cause deformation of parts during welding.

Analyzing the data, we realized that there is no perfect material, but rather one that is more suitable for different situations and parts of the vehicle. Thus, when the objective of a certain component is to have a reduced mass, it will be produced in aluminum and not in steel.

When the objective is to reduce the mass and also increase the rigidity of a part of the car, such as pillars, for example, low-weight steels with ultra-high tensile strength are used. These are steels with high Magnesium and Boron contents, cold pressed and subsequently coated with Aluminum and Silicon to increase their resistance to corrosion. In this way, a lightweight structural element is achieved, with rigidity and resistance to corrosion.

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