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

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ABSTRACT

This work aims to describe a method for calculating the speed of vehicles involved in traffic accidents by analyzing mechanical deformations in various parts of these vehicles. The method is not unheard of in the world, but in Brazil the studies are in the embryonic phase, being applied some methods such as the conservation of total energy and the conservation of the amount of movement, but in both the deformations of the parts are not taken into account, although a considerable part of the energy or the amount of movement is used to cause the deformation itself. Some authors describe in their scientific works 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 to the calculation of the speeds of each of the vehicles the damage observed in the vehicles, but do not take into account the mechanical deformations that occurred in their structures. 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 that, seeks to point out, in many cases, the true cause of the speeding violation, or a more approximate calculation of the true value of speeds of the vehicles involved in a collision.

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

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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 the applications of knowledge about deformations of vehicle parts and the energy responsible for causing these deformations. It is known that the evolution of the knowledge of solid mechanics has provided increasingly better applications, being one of the areas much studied the deformations of materials, leading such knowledge to be used in the field of forensic forensics, specifically in the determination of speeds of vehicles involved in traffic accidents.

According to a report published in November 2015 by the World Health Organization (WHO), in 2013 alone, more than 41,000 people lost their lives on Brazilian roads. Since 2009, the number of traffic accidents in the country has jumped from 19 per 100,000 inhabitants to 23.4 per 100,000 inhabitants, the highest record in South America.

In 2014, the death toll reached a record 52,226, only those who were compensated by the DPVAT insurance (Safe Roads, 2019).

Among the ten most populous countries in the world, however, Brazil appears as a highlight in the report, complying with four of the five main risk factors in traffic, which are: use of seat belts, helmets, speed limits, safety for children and prohibition of alcohol intake before driving. In the list of the ten most populous, there are also states such as China, the USA and India. These states account for 4.2 million people and 56% of deaths from traffic accidents (UNITED NATIONS BRAZIL, 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 leading causes of death in the world, victimizing 1.25 million people per year, accumulating deaths mainly in poor countries. According to the WHO, low- and middle-income countries account for 90% of road traffic deaths, while they account for 54% of the world's vehicles. Europe has the lowest per capita rates, and Africa has 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 2013 data, there are more than 81 million registered vehicles. The report shows that 79 countries have seen a reduction in traffic fatalities, while 68 have increased. According to the WHO, the countries most successful in reducing road fatalities have developed their legislation, enforcement, and improved road and car safety (UNITED NATIONS BRAZIL, 2018).

In most traffic accidents, it brings another consequence, which is the breakdown of the vehicles involved. These deformations can be a field to be researched, specifically relating, in some situations, the knowledge of the deformations caused in the impacts between two vehicles and through these deformations find a relationship with the value of the speed that each of the vehicles was traveling before the collision.

According to records from the Ministry of Transport (2023), there were 5,246,238 traffic accidents across the country, with 7,345,775 motor vehicles involved.

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

TENSION

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

- Normal Voltage;
- Shear Stress;

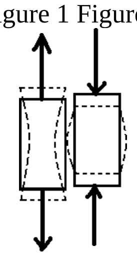
NORMAL VOLTAGE

The force intensity or force per unit area, which acts perpendicular to Δ A, is defined as **normal tension** , 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 area element Δ A, as shown in figure 1, it is called the *normal tensile stress* , and if it compresses the element Δ A, it is called the *normal compressive stress* as shown in figure 2.

Figure 1 Figure 2

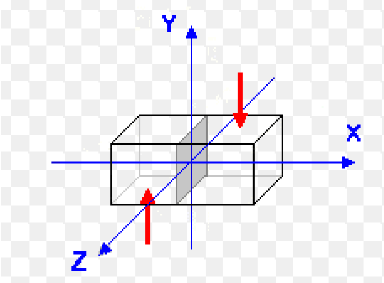


SHEAR STRESS

The force intensity, or force per unit area, acting tangent to Δ A, is called ***the normal shear stress*** , τ (tau), as shown in figure 3. You can write 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 stretching or contraction of a line segment per unit length. Calculated by the equation:

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

where Δs is the start length of the object and $\Delta s'$ the end length.

Shear Deformation

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

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

where θ`the end angle is.

CRASH TESTS

The crash test consists of the impact of motor vehicles against non-deformable (concrete or iron blocks) or deformable (metal deformable block) barriers. Its purpose is to assess automotive safety to verify that 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 four for children. "The structure of the vehicle showed stable performance, as well as advanced elements that allowed it to offer good levels of safety," says Latin NCAP.

Fiat Mobi + 2 Airbags (2017)

Mobi did poorly in the safety test and earned only one star. "The structure of the car proved to be unsuitable to withstand a side impact," according to Latin NCAP; Child protection has 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 earned 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 has been rated as stable, being able to withstand heavy loads," says Latin NPAC.

EXPERIMENTAL STUDY

FORENSICS IN ORDER TO DETERMINE SPEED IN TRAFFIC ACCIDENTS

Speed determination is essential in the analysis of traffic accidents. The possibility of doing so is directly conditioned to the existence of material elements, such as: brake marks, skidding marks, material damage and residual space.

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

This observation refers to unpreserved locations, 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 form for their registration.

Pneumatic Marks

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

- Braking

These are marks produced by friction of the tire against the surface. When braked 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 automobiles that also produce marks, but more tenuous and usually sectioned and sometimes in the form of friction marks on the pavement.

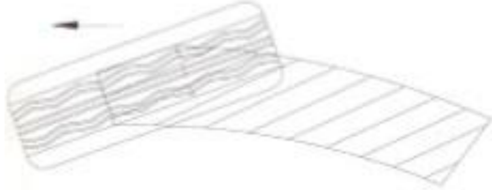
- Skid

They are produced by tires without total locking, ie, they continue in rotational motion in curves or in curvilinear motion, with displacement divergent from the orientation indicated by the longitudinal axis of the vehicle. Slip marks can also be collected using the bend radius.

Figure 1: Braking or acceleration

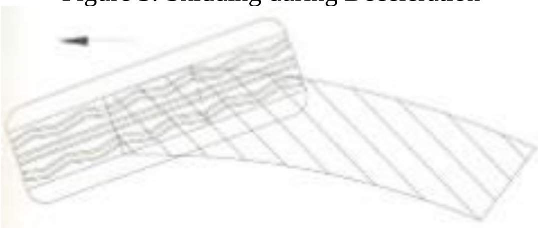
SOURCE: SANTOS & SANTOS. 2008

Figure 2: Skidding under acceleration



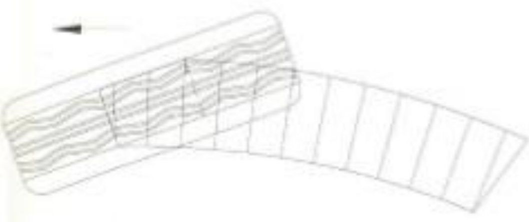
SOURCE: SANTOS & SANTOS. 2008

Figure 3: Skidding during Deceleration



SOURCE: SANTOS & SANTOS. 2008

Figure 4: Neutral or Free Skid



SOURCE: SANTOS & SANTOS. 2008

- Acceleration Marks

They are very similar marks to braking marks, however, with different characteristics in their initial regions. By applying a large amount of torque to the drive wheels, distortions are usually observed at the beginning and progressive lightening, ie, 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. In general, they are accompanied by adhesion of surface coating material (paint or rubber) or groove marks.

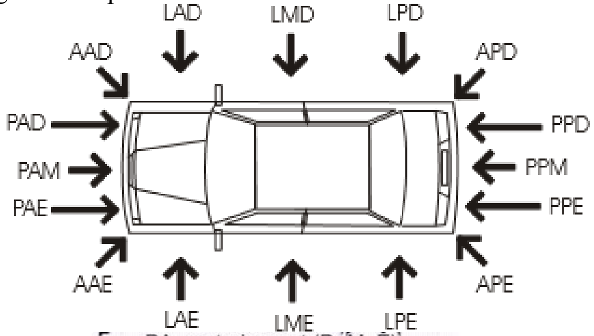
Final Resting Position

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

Malfunctions

The breakdowns observed in vehicles involved in accidents are the result of deformations produced by the contact of their structures. Fault description primarily involves determining the **impact seat.**

Figure 5- Impact seats. Source: SANTOS & SANTOS. 2008.



PA - anterior part (D, M, E);

PP - back part (D, M, E);

LD - lateral (A, M. P) right;

LE - left side (A, M, P).

A - angle (A, P) (D,E)

D - right; E - left; M - average;

A - previous; P - posterior.

The impact seat represents the starting point (or region) of the impact on the vehicle's structure.

Main types of breakdowns : denting, breaking, breakage, warping, deformation, etc. We treat as **dents** the damage that occurs in ductile metal parts, subject to permanent deformation without a breakage process, such as bodywork parts. Breakage occurs in parts subject to brittle fracture, ie without plastic deformation such as cast iron metal parts or rigid plastic parts. The terms **rupture** and **deformation** are most commonly 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 states that the total amount of energy in an isolated system remains constant, ie, the total energy before is equal to the total energy after a given 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 corresponds to the materialization of the beginning of the deceleration process. Thus, the energy available before the speed reduction process begins 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 (experienced and/or produced breakdowns) and a third in residual movements. Thus, one can represent

$$Before = And\ after \quad (1)$$

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

$$Eantes = Eentrang + E\ damage + E\ residual \quad (2)$$

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

$$ec = \frac{1}{2} mv2 \quad (3)$$

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

$$\frac{1}{2} mV0 = \frac{1}{2} Mv_a^2 + \frac{1}{2} Mv^2{}_d + \frac{1}{2} mV^2{}_r \quad (4)$$

Canceling out the common terms, it is shown that the velocity before the impact can be represented by the plots corresponding to the "velocities" transformed after the impact, resulting in:

$$Vo2 = V_a 2 + V_d 2 + Vr2 \quad (5)$$

Where:

VO = initial velocity

Va = drag speed V d = damage speed ic

Vr = residual velocity

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

$$Vic^2 = Vd^2 + Vr^2 \qquad \textbf{(6)}$$

When there are two vehicles, all the parcels must be considered separately for each of them. Thus, one can write:

$$\frac{1}{2}m_1V_{o1}^2 + \frac{1}{2}m_2V_{o2}^2 = \frac{1}{2}m_1V_{a1}^2 + \frac{1}{2}m_1V_{d1}^2 + \frac{1}{2}m_1V_{r1}^2 + \frac{1}{2}m_2V_{a2}^2 + \frac{1}{2}m_2V_{d2}^2 + \frac{1}{2}m_2V_{r2}^2 \qquad (7)$$

For the solution of 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 with which they traveled before the occurrence of the impact between them, which are Vo1 and Vo2. The other tranches may be determined on the basis of post-collision movements and the assessment of the damage experienced.

drag plot

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

In addition to the extent of the pneumatic marks, the calculation of this portion of the speed uses the coefficient of friction between the tires and the track. It is essential to know the characteristics and conditions of the road: whether flat or sloping, dry or wet, types of surface , presence or absence of other substances on the surface, the type of vehicle (size: tour, utility, medium, cargo , etc.) and the type of its braking system (ABS, conventional, etc.), as well as its operating condition.

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

$$Vf = 15.938\sqrt{df\,.\,towards} \qquad \textbf{(8)}$$

Where:

DF = braking space (m)

k = coefficient of friction of the pavement

The coefficients of friction can vary according to the speed developed by the vehicle, with the type of pavement and its general condition. Regarding speed, according to the tables published by the *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 coefficients of friction 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) Source: SANTOS & SANTOS. 2008.

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

Table 2- Friction coefficients for different types of material Source: SANTOS & SANTOS. 2008

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

Table 3- Coefficients of friction for different situations

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

Part of damage

This portion is a value obtained through an assessment of the extent of the damage (breakdowns) experienced and caused in a collision. Although it is an estimate, it is obtained by comparing it with the results of crash tests in the automobile industry, as well as in collisions where vehicles are equipped with speed records.

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

Table 4- Damage speeds. Source: SANTOS & SANTOS. 2008.

Intensity in breakdowns	V_d (km/h)
Light	0 at 20
average	20 The 40
serious	40 The 60
very serious	Above in 60

Table 5- Damage rates according to the type of damage Source: SANTOS & SANTOS. 2008.

TYPE IN FAULTS	V_d (km/h)
01. bend bumper at tip	05
02. bend bumper at the center	10
03. bend bumper at skirt	15/20
04. crumple fender	05/10
05. crumple fender tearing	10
06. crumple fender plucking	15
07. Sink grid of radiator	30/35
08. sink grid of radiator, more hive	40/45
09. rip out suspension	40/45
10. rip out wheel guideline	40/45
11. leave spar	50/60
12. rip out O motor of the shims	60/70
13. rip out wheel driving	50/60

Table 6- Damage speeds, according to the type of damage Source: ALMEIDA. 2015.

Type in Breakdown	Vel. damage (km/h)
Warp bumper	05
To break bumper	10
To break bumper It is grid of radiator	15/20
To break bumper, headlights, sink grid, crumple hood, deform bodywork previous	20/30
To break bumper, headlights, sink grid, deform bodywork previous until lean to the engine without move it	30/40
To break bumper, headlights, sink grid, deform bodywork previous until lean to the engine without displace it, deform suspension	40/50
Surface	40/45
DROUGHT	WET
rip out guideline	40/45
V<48.37km/h	V>48.37km/h
V<48.37km/h	V>48.37km/h
Cement	rough

Residual plot

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

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

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

$$VR = 15{,}938\sqrt{dr \, . \, towards} \qquad (9)$$

Where:

DR = residual space (m)

k = coefficient of friction of the pavement

Calculation of speeds based on bend radius

A vehicle in the process of cornering with constant speed has two forces acting on it, which are: the radial force that keeps it in the curvilinear movement and the friction conferred by the tires. From the moment the speed of the vehicle in the curve is higher, its radial acceleration increases and when the radial force exceeds the frictional force, sliding occurs. This speed is called the limit speed or critical speed.

The radial force is given by

$$Fr = \mathbf{m}.\ on = m\ .\ (\ v2\ /\ R\ )(\ 10)$$

The frictional force is

$$Fatr = towards\ .\ N = towards\ .\ m\ .\ g \qquad (11)$$

Equating the two expressions and isolating the velocity, we get:

$$Vcritical = \sqrt{g}\ .\ Rcritical\ .\ towards\ \ \text{m/s} \qquad (12)$$

Where:

g = acceleration of gravity (9.81m/s2)

k = coefficient of friction of the pavement for skid conditions

Critical = critical radius in meters

It is important to note that, in order to determine the speed that a vehicle developed when escaping on a curve, it is not enough to indicate the radius of the curvature of the road, 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 that the vehicle had when it "went astray". 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 skid conditions is the "attitude".

METHOD OF CONSERVATION OF QUANTITY OF MOTION

Principle of Thrust and Amount of Linear Motion

The method based on the principle of impulse and quantity of motion can be used to solve problems involving force, mass, velocity and time, and is 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 vector amount of motion. Multiplying both sides of the equation by ***dt*** and integrating from the instant ***t1*** to ***t2*** , one can write

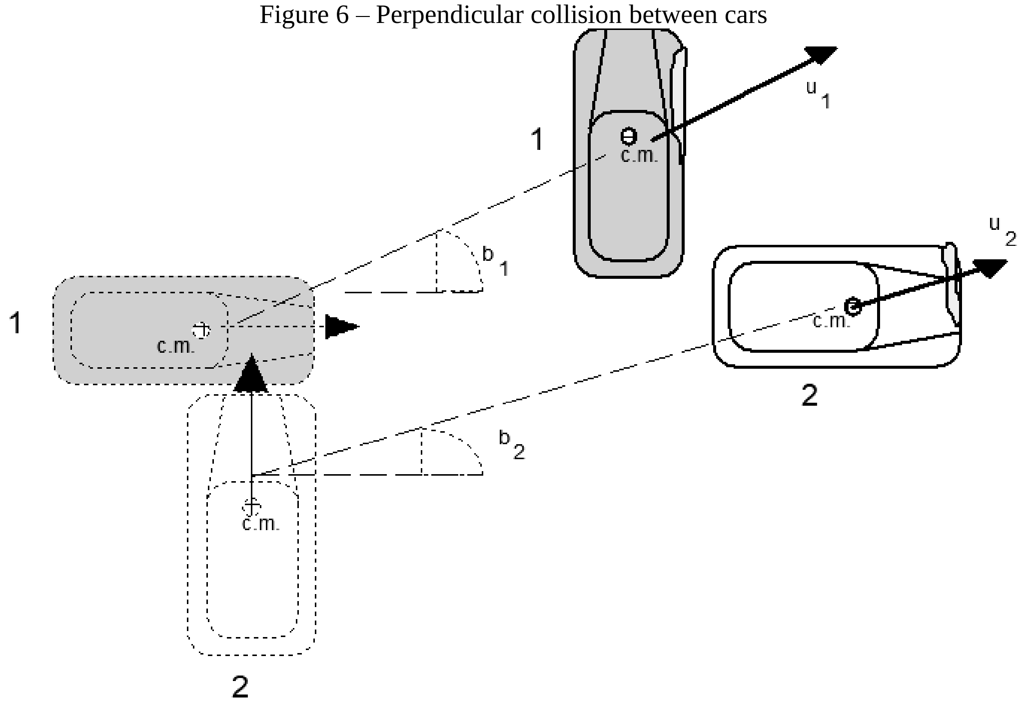
$$F.\,dt = d\,.\,(mv) \quad (14)$$

$$\int_{t1}^{t2} F.\,dt = MV2 - MV\,1 \quad (15)$$

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

Accident dynamics

Figure 6 – Perpendicular collision between cars



$$v1 = u1 . its (a2 - b1) + m2 / m1 . [u2 . its (a2 - b2)] / its (a2 - a1) (16)$$

$$v2 = m1 / m2. [u1.sen(b1 - a_1)] + u2.sen(b2 - a_1) / \sin (a2 - a_1) (17)$$

Where:

A1 and A 2 = Vehicle entry angles B1 and B 2 = Departure angles

U1 and U2 = Speeds after collision

Table 7: Calculation of collision speeds

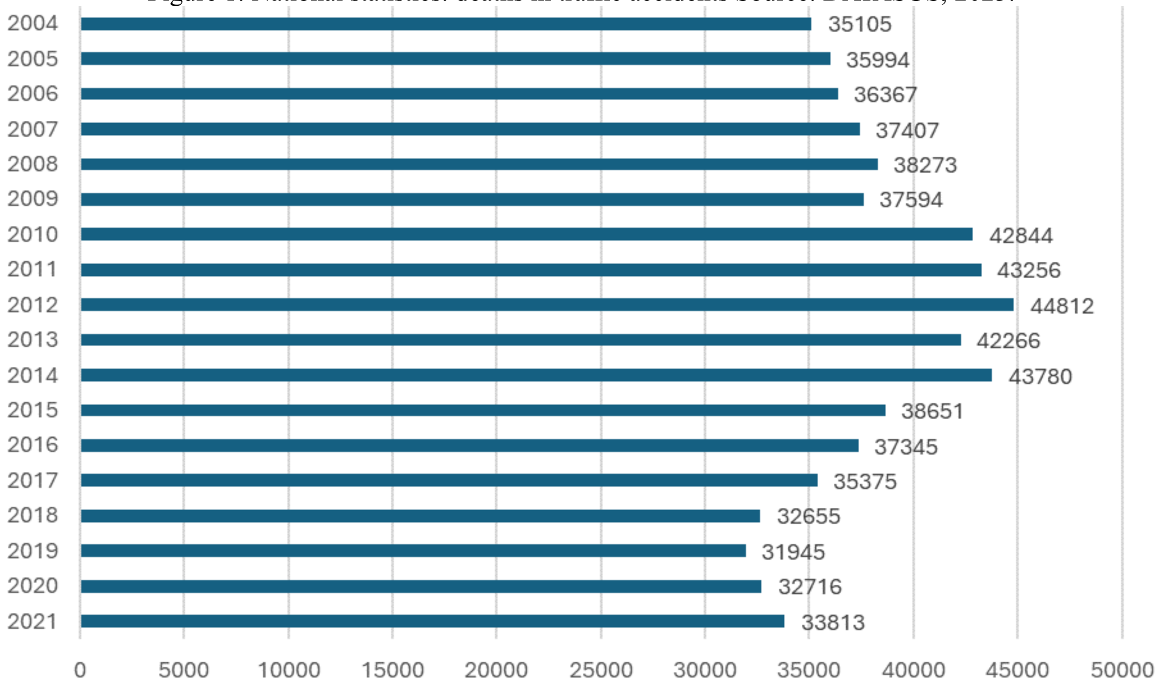
m1(kg)	m2(kg)	a1	a2	b1	b2	x1	x2	u1	u2	v1(m/s)	v2(m/s)
2025	980	0	2	0,07	0,21	28,9	28,3	20,11	19,9	28,02	3,54
2025	1080	0	6	0,07	0,23	28,9	28,3	20,11	18,9	29,57	1,16
2025	1110	0	10	0,07	0,25	28,9	28,3	20,11	17,9	29,53	0,71
2025	1175	0	14	0,07	0,27	28,9	28,3	20,11	16,9	29,63	0,5
2025	1240	0	18	0,07	0,29	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 traffic accident sites between two or more motor vehicles on the occasion of the forensic examination of traffic accidents in order to establish the cause, or causes, of the accident. All the steps already taken, since the survey of the site, are aimed at this issue.

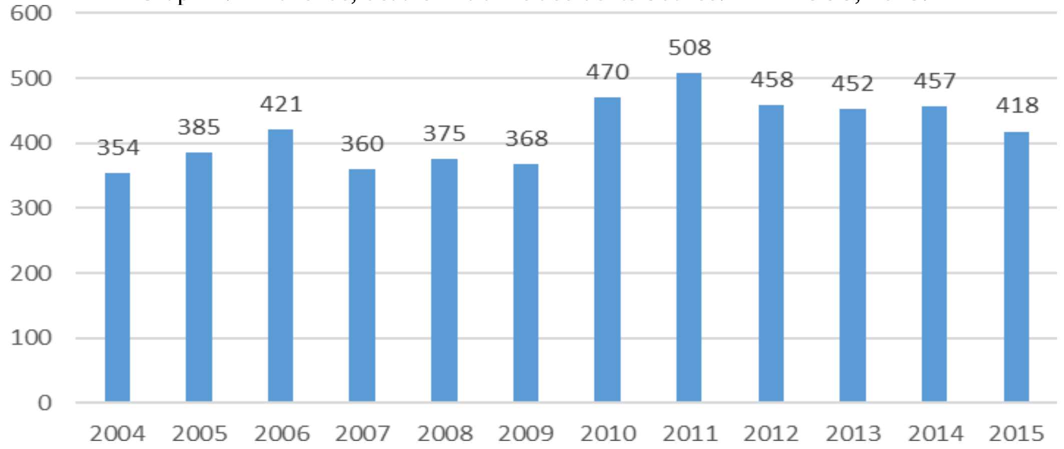
In Brazil, approximately 45,000 people lose their lives annually in traffic accidents, but it is believed that these numbers are higher because the statistics are flawed. In 2001 alone, there were 61,000 accidents on São Paulo highways with 2,300 deaths and deaths 23,000 people seriously injured. All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

Figure 1: National statistics: deaths in traffic accidents Source: DATASUS, 2023.



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

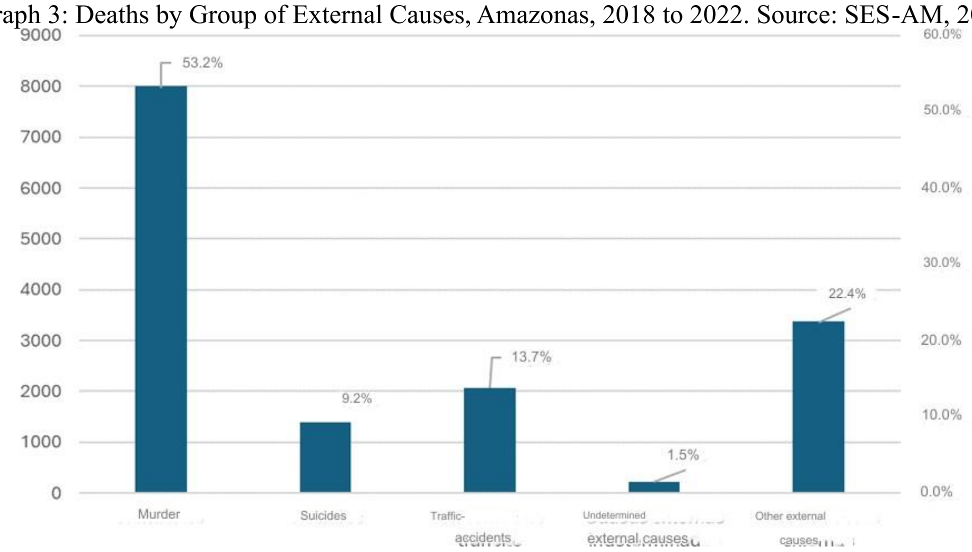
Graph 2: Amazonas, deaths in traffic accidents Source: DATASUS, 2023.



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, 8,006 (53.2%) due to homicide, 2,070 (13.7%) due to accidents involving injuries.

Land Transport (RTA), 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. They are:

- **Active direct protagonist (PDA):** is the one who performs the action from which the accident directly occurred;
- **Passive direct protagonist (PDP):** is the one who directly suffers the action practiced, directly by another;
- **Active indirect protagonist (IAP):** one who, for some reason, performs an action or configures a situation that induces another to practice an action that results in an accident with another driver;
- **Passive indirect actor (PIP):** does not contribute in any way to the accident, but suffers direct consequences.

DETERMINING CAUSES

Determining Cause is considered to be the one that, when removed, the accident does not occur. In general, it is associated with a traffic violation. In other words, it is lawful to assume that without an infringement of a traffic rule there is no cause of an accident.

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

Mediate or circumstantial causes are subjective, so it is almost always impossible to materialize them. The elements of distraction, the physical and mental situation of the drivers (fatigue, sleepiness) and acts on the part of passengers are good examples to explain that it is unlikely that the expert will be able to verify them. They can also originate from other adverse situations existing in traffic, caused by other vehicles, pedestrians, animals or even by natural phenomena.

Despite the impossibility of determining the circumstantial cause by the expert, traces pertinent to it can be found at the sites. These should be mentioned in the reports and may be used to clarify the truth.

On the other hand, the immediate or direct causes are perfectly verifiable, since, when 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
- Middle

man (driver)

a) **Behavior** - should be understood as a state of knowledge, on the part of the driver, of a situation of Danger created by him/herself, and his/her persistence in it until the culmination of the event. It thus 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 sign. Eg: going on a direct line, driving in the wrong direction, etc.

Dangerous behavior is related to abnormal maneuvers and the traffic conditions of the vehicle. Eg overtaking on the shoulder, zigzagging on the road, with the vehicle without brakes, or with the tire linings 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. Eg: driving over the flowerbed, sidewalk, balloons, lawns, etc.

b) **Speed –** Speed is at the level of behavior , in relation to the danger it represents, to the point that it can be said, without the need for statistical data, that, if the 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 where the driver does not react to the obstacle in front of him or reacts at a point on the terrain, from which it is no longer possible to stop the vehicle in time to avoid the collision.

Factors influencing reaction time:

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

ALCOHOL AND DRUGS - can slow down the reaction time considerably. 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 make your reaction time increase to 2 seconds.

EMOTIONAL STATE - can also slow down a driver's reflexes and reaction time. The individual who brings to the wheel his worries of: job, salary, marital, 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 – it is one of the most important elements in the cause of traffic accidents, it is very little studied, mainly due to the difficulty of investigating 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 sleepiness, from 2 am to 7 am and from 2 pm to 5 pm (42% of the total and 36% of fatal accidents). The second is the percentage of all 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, and the effect of this loss is cumulative.

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

SPEED (km/h)	**NORMAL (0.75 segs.)**	**DELAYED (2 segs.)**
	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 cause is applied when it is found that the driver has seen 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 (verification of mechanical and pneumatic systems, among other components), should 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.

Whether it occurred during or after the event, it will obviously be dismissed immediately 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 foreseeability, as well as its pre-existence. Pre-existence is equivalent, in terms of liability, to foreseeability, and the driver, in this case, must assume it, characterizing the modality of dangerous behavior . Eg the driver is aware of the defect in the vehicle and assumes the risk of putting it in traffic.

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

Middle

Finally, there are the causes related to the environment, here understood as the road, garrisoned or not by signaling. When the Determining Cause is attributed to the medium (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, the foreseeable causes register some accidents whose reason is attributed to the environment. Eg: deposition of a layer of tar on the roadway without proper signage to prevent the transit of vehicles. The technician should be alerted that the limit of predictability is exactly the fortuitous and/or force majeure event, and the characterization, whenever possible, should be recorded.

The unforeseeable causes linked to the environment are those resulting from force majeure, caused as a result of floods, windstorms, etc. Eg collapse of viaducts, bridges, etc.

Various materials are used in the manufacture of a car, not least because the functions they have to perform are also diverse. So, depending on the part and also the brand of the vehicle, we will find different materials and different ways of producing them.

Form, function, cost and safety are unknowns to consider in the selection of these materials and varying what is intended, so does the choice of these.

CHASSIS

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

In cases of collisions, it must absorb the shock, preventing the occupants of the vehicle from being hit. To do this, current models are designed in such a way as to create a survival cell around the vehicle.

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

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

There is also the structured monocoque, a variation of the monocoque, known as a truss chassis because it is assembled in such a way that only the structure of the vehicle is part of the chassis, all the bodywork and other parts will be fixed later. Reducing the weight of the structure while offering superior rigidity and greater resistance to collisions is the goal of this type of chassis, which is why it is chosen by most manufacturers of racing vehicles.

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

In the bodywork, two metal materials are used predominantly, steel and aluminum . But they can also be made of 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 metal alloy made up essentially of iron and carbon.

In the past, mild steel was the most used metal in the manufacture of the different components of the automobile, however, in order to make automobiles lighter, safer and stronger, mild steel gave way to high-strength steels.

Since then, the use of this type of steel has been favored by the following Reasons:

- They reduce the mass of the vehicle by reducing the thickness of the different structural elements and body panels, without compromising strength;
- These metals are less expensive than plastics or aluminum ;
- Numerous body parts can be made of high-strength steel without altering the molds and tools traditionally used

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

- Its density is approximately one-third that of steel;

- Aluminum oxide forms a thin layer, which is periodically renewed- degradation of the material is avoided;
- Alloys of this metal are easily recyclable;
- Be easy to machine;
- It has a great capacity to absorb energy, a characteristic that makes it very suitable for programmed deformation areas of the body.

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 it impossible to weld by resistance points;
- The coefficient of expansion of the material is twice as high as that of steel, which can cause parts to deform 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 purpose of a given component is to be of reduced mass, it will be produced in aluminum and not in steel.

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

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