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The Importance and Role of Tyres on Road Vehicles: Their influence on Breaking Distance

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Abstract
It is considered that tyres play the primary role in terms of road safety on dry, wet, snowy or icy roads. This is due to their importance, as they are the element of support, of contact, of the car with the road (the track). This scientific paper presents concrete research carried out by the author with a view to implementing theoretical and practical concepts, in which the technical aspects of tyres fitted to road vehicles are presented. In this way, those interested can find out how tyres and wheel rims are labelled and marked; specific data are presented on summer and winter tyres; the phenomenon of of the aquaplaning of car wheels is defined, presented and explained; the forces and moments acting during braking are presented and defined; the braking distance (space) and the two second rule in road traffic are presented and explained. The paper concludes with a case study presenting the contribution of road car transmissions to braking distance reduction and an original research on braking distance, carried out using the second order active factorial experiment method, in which two cars of different classes (a Lamborghini Huracane Technica and a Dacia Logan), equipped with different tyre categories, were used. Finally, results and conclusions are presented.

Keywords: Tyres, Vehicle, Aquaplaning, Braking Force, Braking Space, Experimental Research

1. Introduction

Starting, rolling, braking, following the trajectory when changing direction or exiting a skid with a road vehicle is carried out exclusively by means of the tyres, provided there is perfect, ideal adhesion between them and the road surface. Maintaining good grip is directly dependent on the condition and quality of the tyres, the condition and quality of the road surface and the driving style of the road vehicle. Stopping the vehicle safely is defined by the braking distance and is dependent on certain factors affecting the reaction distance (driver fatigue, driving under the influence of alcohol or drugs or inattention at the wheel), and factors affecting the braking distance (vehicle technical faults in the steering and/or braking system, road and weather conditions, tyre condition and vehicle weight). The main determinants of braking distance for a vehicle such as tyre condition and driving style depend on the user of the vehicle and the road condition is influenced by the environment (weather) of the area (area) where the road is built [1]. It is important to choose and use car tyres correctly, depending on the season, type, condition and wear. According to current standards, the tread depth of a new tyre is 8 mm, and the maximum limit allowed by European legislation for wear up to the tyre wear indicator is 1.6 mm. Therefore, for the safety of road users and other road users, it is important that tyres are replaced by 2.5 mm before tyre wear reaches the wear indicator. For this reason, vehicle tyres must be checked regularly, at least once a month, to observe their condition and then, if any non-conformities are observed, it is compulsory to take the car to an authorised service to certify certain problems discovered (premature wear, cuts, punctures, punctures, deformation of the tread, sidewall or bead, sharp objects that have penetrated the tread, etc.). Excessive speed not adapted to the road or traffic conditions and incorrect assessment of the optimum braking distance by the driver are frequently classified as causes of road accidents. When behind the wheel, as a driver, it is important to adapt the speed of the vehicle you are driving to the weather or traffic conditions, to keep an appropriate distance between vehicles and to concentrate on driving. Experts estimate that by hesitating to press the brake pedal for 0.3 seconds at a speed of 60 km/h, the braking distance of a road vehicle is 5 metres higher. At 1 second it increases exponentially. So one second of inattention at the wheel can delay the brake pedal application by a considerable amount, causing the vehicle to travel an additional distance to a stop of almost three and a half times the previous distance. This distance can be fatal for vehicle users, pedestrians or other road users. Therefore, the main objective of this scientific work is to explain some of the principles, causes and phenomena underlying the unsafety of vehicles in road traffic through the use of nonconforming tyres on their rolling system. Tyre non conformity refers to tyre failure, wear or inappropriate use depending on the season.

2. Theoretical considerations on car tyres Literature review

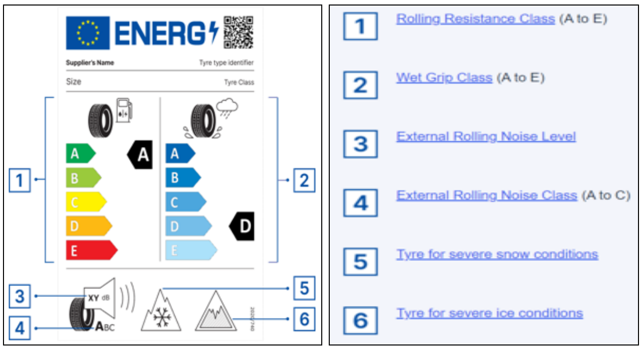

Fig 1: Tyre labelling in the European Union [2]

Based on the three criteria of safety, fuel efficiency and noise, the EU tyre label provides information on the environmental and safety characteristics of a tyre. All tyres sold in the European Union are subject to mandatory tyre labelling.

A new tyre labelling scheme in the European Union came into force from May 01, 2021. It provides more comprehensive information on selected tyres and also includes heavy vehicle tyres (Fig 1). This new system provides objective, reliable and comparable information based on three important tyre performance characteristics: Rolling resistance and thus fuel efficiency, wet grip and external rolling noise [2].

Additional pictograms indicate the suitability of the tyre for difficult winter conditions (3PMSF symbol) and/or its grip in icy conditions, although the latter only applies to passenger car tyres. The 3PMSF symbol indicates that the tyres are both reliable and safe for driving on snow-covered surfaces. The new labelling scheme covers car, bus and truck tyres [2]. Understanding the European Union label and its icons helps car users or fleet managers to make informed decisions about tyre-related road safety, reducing CO_2 emissions and increasing fuel economy. Fuel economy and road safety depend to a large extent on weather and road conditions, vehicle type and, in particular, driving style.

According to the new European tyre labelling scheme the reading and interpretation of data is done as follows [2]:

- **Wet grip** (Fig 2a). Reliable grip in wet conditions is fundamental to safe driving. Wet grip grading indicates how well the tyre will perform in wet conditions, with performance graded from class A to class E. The highest grading is represented by short braking distances on wet roads;

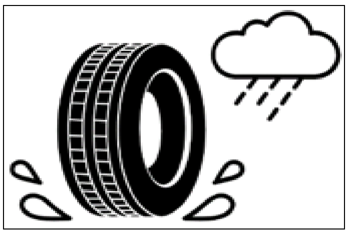

Fig 2a: Wet grip tyre labelling [20]

- **Fuel economy** (Fig 2b). Depending on the rolling resistance of the tyre, fuel economy will vary from class A (which denotes the best fuel economy) to class E. Fuel consumption plays an important role from an economic and environmental point of view. This is because low fuel consumption has a positive effect on the carbon footprint of the vehicle, and in particular heavy duty vehicles;

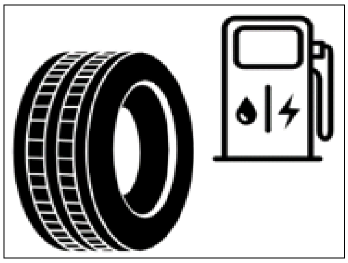

Fig 2b: Fuel economy tyre labelling [20]

- **Noise level** (Fig 2c). This is the external rolling noise level generated by the tyre, measured in decibels. The label shows the noise level rated in classes A to C;

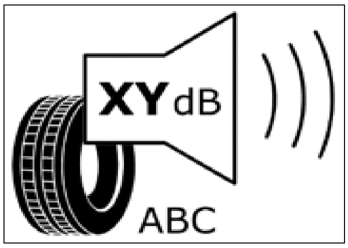

Fig 2c: Noise Tyre labelling [20]

- **Additional pictograms for snow and icy conditions** (Fig 2 d). In addition to the standard label, there are also pictograms, if required, for difficult winter conditions (3PMSF) and/or grip in icy conditions (for C1 vehicles/tyres only). The snow grip pictogram (3PMSF) will be displayed for winter tyres and for all seasons tested in defined winter conditions and which provide the required performance in difficult winter conditions. The ice grip pictogram will be present for winter tyres with outstanding ice performance confirmed by a specific ice grip test. These tyres are specifically designed for ice and packed snow covered road surfaces and should only be used in very difficult climatic conditions (e.g. cold temperatures in northern Europe). The use of grip tyres on ice covered terrain in less severe climatic conditions (e.g. wet conditions or warmer winter temperatures) could lead to sub-optimal performance, particularly in terms of wet grip, handling and wear.

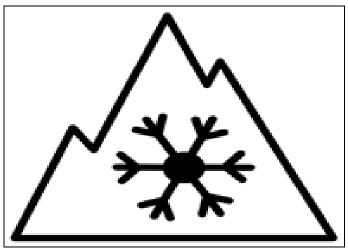

Fig 2d: Tyre labelling with additional icons for snow and icy conditions [20]

2.1 Markings, notations and terms specific to car tyres and rims

The markings on the sidewall of a car tyre are very important because they tell you everything about the tyre. They are printed (stamped) in the form of alphanumeric indications or important shapes, which must be taken into account when replacing tyres (Fig 3).

Fig 3: Markings, notations and terms specific to car tyres [3]

This is how to read the information on a tyreă [3]:

- **195:** Tyre tread width measured in mm;
- **60:** Tyre sidewall - tyre width is the percentage of the tread width, in mm, i.e. 60% of 195 mm in this case;
- **R15:** Tructure - radial tyre construction and 15 represents the inside diameter of the tyre in inches;
- **DOT:** XXXX - PPPP – WWYY.

where,

- **DOT** represents Departament of Transportation;
- **XXXX** - country of origin and manufacturer identification code;
- **PPPP** - internal manufacturer code;
- **WWYY** - date of manufacture, where WW = week number of the year of manufacture indicated by two digits and YY - year of manufacture also indicated by two digits.

Fig 4: Example of a tyre DOT combination [3]

An example of the DOT is inscribed on a tyre shown in Fig 4, as follows [3]: For the DOT combination... 4507 date of manufacture is week 45 of year 2007. DOT - XXXX - PPPP - WWYY where, DOT stands for Department Of Transportation; XXXX - country of origin and manufacturer identification code; PPPP - manufacturer's internal code; WWYY - date of manufacture.

- **PDV9:** Code of the factory where the tyre was manufactured;
- **INHR:** Tyre size code;
- **M+S:** (in some cases the MS, M+S or M&S mark is also shown). The tyres have been tested by the manufacturer on **snow** & **mud** and are therefore legally approved for winter use (snow and ice). This marking is mandatory on winter tyres, but there are some states where this symbol is not approved for winter tyres and the Snowflake Piss symbol is required (Fig 5). Snowflake Piss: Tires offer superior winter performance. It is an optional marking added by the manufacturer and not approved by law in Romania;

Fig 5: Picture of the snowflake peak inscribed on winter tyres [19]

- **XL (eXtra Load)** notation: Indicates that the tyre has a higher resistance than a normal tyre. It may even say Extra Load;
- The **speed indices** of car tyres are shown in Table 1 [3]:

Table 1: Speed indices of car tyres

Indices	Maximum speed (km/h)
J	100
K	110
L	120
M	130
N	140
P	150
Q	160
R	170
S	180
T	190
H	210
V	240
W	270
Y	300
ZR	240+

- The load indices of car tyres are shown in Table 2 [3]:

Table 2: Load indices of car tyres

Index	Load supported/ tyre	Index	Load supported/ tyre	Index	Load supported/ tyre	Index	Load supported/ tyre
60	250	**87**	545	**114**	1180	**141**	2575
61	257	**88**	560	**115**	1215	**142**	2650
62	265	**89**	580	**116**	1250	**143**	2725
63	272	**90**	600	**117**	1285	**144**	2800
64	280	**91**	615	**118**	1320	**145**	2900
65	290	**92**	630	**119**	1360	**146**	3000
66	300	**93**	650	**120**	1400	**147**	3075
67	307	**94**	670	**121**	1450	**148**	3150
68	315	**95**	690	**122**	1500	**149**	3250
69	325	**96**	710	**123**	1550	**150**	3350
70	335	**97**	730	**124**	1600	**151**	3450
71	345	**98**	750	**125**	1650	**152**	3550
72	355	**99**	775	**126**	1700	**153**	3650
73	365	**100**	800	**127**	1750	**154**	3750
74	375	**101**	825	**128**	1800	**155**	3875
75	387	**102**	850	**129**	1850	**156**	4000

76	400	**103**	875	**130**	1900	**157**	4125
77	412	**104**	900	**131**	1950	**158**	4250
78	425	**105**	925	**132**	2000	**159**	4375
79	437	**106**	950	**133**	2060	**160**	4500
80	450	**107**	975	**134**	2120	**161**	4625
81	462	**108**	1000	**135**	2180	**162**	4750
82	475	**109**	1030	**136**	2240	**163**	4875
83	487	**110**	1060	**137**	2300	**164**	5000
84	500	**111**	1090	**138**	2360	**165**	5150
85	515	**112**	1120	**139**	2430	-	-
86	530	**113**	1150	**140**	2500	-	-

Note: The load index indicates the maximum load a given tyre can carry at maximum speed as indicated by the speed symbol.

- **RF** (Ranforsat) – is a marking that is added next to the tyre size marking to indicate that the tyre has a higher load carrying capacity than a standard tyre. The main application for 'reinforced' tyres is on vans and light trucks, but they are also suitable for some family cars and caravans;
- **RFT** (RunFlat System) – is the marking for tyres that have been produced using Run-Flat technology. This system ensures a maximum travel of 80 km at speeds up to 80km/h in fault conditions;
- **RR** (Rolling Resistance) - is a force acting in the opposite direction to the direction of travel of the tyre. Due to the vehicle load, the tyre is deformed in contact with the road surface. This deformation induces internal energy loss, just like a rubber ball that falls and does not rise to the same height from which it fell. Rolling resistance can be expressed as a force (Newton) or as a coefficient (CRR). The rolling resistance coefficient (CRR) is defined as the force RR (N) distributed over the tyre load. The advantage of this coefficient is that it allows a simpler comparison of tyres designed to fit different vehicles. Seal Inside tires can significantly reduce the chances of getting a flat tire, but unlike run-flat tires, they are not built to be driven with reduced pressure or deflated. In terms of fitting and balancing, there is no difference between Seal Inside and standard tyres. Pirelli Seal Inside tyres do not require dedicated rims, so they can be mounted on standard rims. Seal Inside tyres must be stored in the same conditions as standard tyres. Between products with the same profile, there is no difference in performance (rolling resistance, comfort, noise, wet or dry performance) between a Seal Inside tyre and a standard tyre. Seal Inside technology does not require dedicated rims or a tyre pressure monitoring system (TPMS) to operate the vehicle safely; it can be used on any vehicle, depending on tyre size;

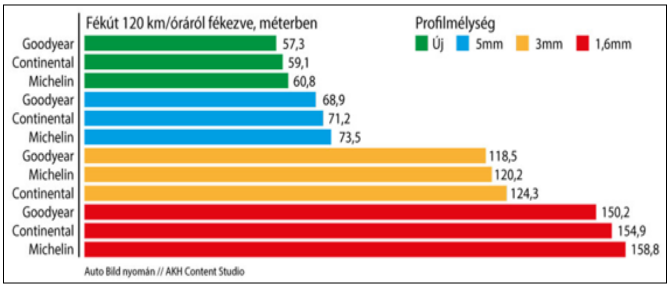

Fig 6: Influence of tyre wear on braking distance [11]

Fig 7: Tyre wear indicator [21]

- **SPIKE** – winter tyres with sharp studs for increased traction on ice. These tyres must be fitted in sets of four. Most states prohibit the use of such tyres;
- **TL - Tubeless** (tyre type without inner tube);

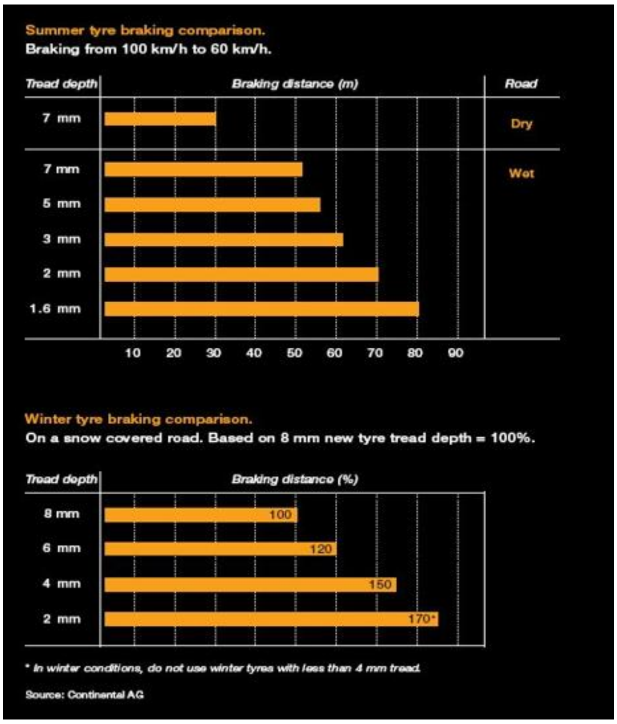

Fig 8: Influence of tyre tread depth on vehicle braking distance [7]

- **TPMS** - tyre pressure monitoring system. Run Flat tyres must be fitted together with TPMS (Tyre Pressure Monitoring System). The fitting of tyres and TPMS must be carried out by an authorised person. There is a wide range of tyre pressure monitoring systems (TPMS) so the vehicle manufacturer should be consulted for specific information. There are broadly two types of systems, indirect systems take advantage of the fact that the loss of pressure causes the wheel to rotate faster, and when they detect this difference they send an alert to the driver. Direct systems check the pressure values, compare them with previously recorded values and warn when the pressure drops below the correct values.
- **Tyre wear:** Wear grade is a comparative rating based on the rate of tire wear under controlled test conditions on a specific government route [4, 5]. For example, a tyre rated 150 will wear 1.5 times slower on that route than a tyre rated 100. Fig 6 shows the influence of wear [6] the profile of a tyre on the braking distance of vehicles

fitted with tyres from three major manufacturers: Goodyear, Continental and Michelin. All tyres at this date are fitted with wear indicators (limiters) (Fig 7). The relative performance of tyres depends on the conditions in which they are used, but in any case, they can deviate widely from the norm due to variations in driving styles, operating practices and differences in road and climate characteristics.

- **Adherence:** The adherence grades, from highest to lowest, are AA, A, B and C. These grades represent the tire's ability to brake on wet roads, measured under controlled conditions on government test surfaces, both asphalt and concrete. Any tire marked C may have poor grip performance. Please note: The degree of grip given to each tyre is based on a previous braking test and does not include acceleration, cornering, aquaplaning and maximum traction characteristics. In this respect, the specialists at the major tyre manufacturer Continental have made available to car users the results of research on the influence of tyre profile depth on braking distance (Fig 8). Theoretically, according to the major tyre manufacturer Continental, a car equipped with summer tyres will brake from 100 to 60 km/h in 50 m on a wet road, provided that the tyres have a tread depth of 7 mm, and at a braking distance of 80 m provided that the tyres have a tread depth at the legal limit of 1.6 mm. As can be seen, the difference is enormous: 30 m (160%). On snow covered roads the difference in braking distances is 170% in favour of tyres with a tread depth of 8 mm compared to those with only 2 mm [7];
- **Temperature:** The temperature grades are A (highest), B and C, representing the tyre's resistance to heat and its ability to dissipate heat during testing under controlled conditions in a specified laboratory. Sustained high temperature can have various effects on tyres, such as shortened life, and excessive temperature can lead to tyre damage. Grade C corresponds to a level that all passenger vehicle tyres must meet according to Federal Highway Safety Standard No 109. Grades B and A represent higher levels of laboratory performance. Caution: The temperature grade for these tires is established for tires that are properly inflated and that are subjected to an appropriate load. Excessive speed, tyres inflated below the manufacturer's specified figure, or excessive loading, may lead, singly or in combination, to tyre failure.

2.2 Reading information on car rims [3]

Rims are marked for example: **6Jx15 ET40 4x108** where,

- **6J** is the inside width of the rim. It is the first number in the code - 6Jx..., where 6 is the inside width of the rim, measured in inches, and is measured between the edges of the rim where the tyre fits. For example, 7J is 7 inches, or 170.78 mm, which means that we can use a tyre around 170 mm wide. If we have 9J, we can fit tyres that are 225 mm wide; and so on. Taking into account the tolerance of the rim edges, we can also fit tyres with a larger tread, generally by a maximum of 2 cm. Thus, for optimum performance and to meet the rim and tyre specifications, on 7J we can fit tyres up to 175 mm and on 9J we can fit up to 235 mm;
- **15 - total diameter**. The rims diameter is measured in inches and is measured from one side of the outer surface to the other through the centre of the rim. The choice of rim diameter depends solely on the dimensions written on the rim bead or technically feasible personal taste. You will always find the rim diameter written on the rim, usually the second number - 6Jx15... where 15 is the wheel diameter. Of course, the diameter of a rim will influence the weight, stability, starting and other parameters of the vehicle.
- **ET - central bore** is the distance from the wheel hub, where it attaches to the car, to the middle of the rim.ET = Offset and is measured in mm. Basically this ET is the distance between the "back" of the wheel hub and the "middle" of the rim. The higher the ET, the more the rim goes inside the body and vice versa. In the example given above, the ET is 40 mm;
- **4x - the number of studs** represents the number of bolts with which the wheel is fixed. In our example it is 4x108, where 4 is the number of studs;
- **108 - distance between the studs** is the space between the bolts holding the rim to the wheel hub. This parameter must be known exactly when choosing the right rims. The distance between spokes is usually stamped (printed) on the rim as: 4x108, where 4 is the number of spokes and 108 is the distance in millimetres between spokes. On vehicles with 4, 6 or 8 studs, the distance between pre-sets is measured from the imaginary centre of the two opposing holes. For vehicles with 5 pillars, the distance between them is measured from the far edge of one hole to the centre of the second hole.

2.3 Summer tyres

In order to drive in optimal conditions and to increase traffic safety, it is recommended that drivers equip their vehicles with summer tyres as temperatures rise (above 7ºC). The use of summer tyres between April and October (the above-mentioned period is only a guideline; if it snows during this period, drivers are legally obliged to use winter tyres) provides better handling when cornering, better contact with the road and a considerable reduction in braking distance (this is the most important quality of a summer tyre); according to ADAC (Allgemeiner Deutscher Automobilclub) tests, in summer temperatures, winter tyres brake from 100 km/h on average 16 metres further; however, even the best performing all season tyres have a slightly longer braking distance than summer tyres on both wet and dry roads). Fitting your vehicle with the right seasonal tyres (winter and summer tyres) is very important for your own comfort and safety, as well as for the safety of other road users. The chemical composition and technical characteristics of summer tyres make them able to perform at high temperatures. Thus, summer tyres should not have grooves in the tread profile (large block profiles provide very good grip) and the rubber should be very hard due to the chemical composition of the added additives (polymers, hydrocarbons, etc) [8]. It is also not recommended to combine summer and winter tyres as the use of both types of seasonal tyres at the same time will significantly affect the performance of the tyres and therefore the vehicle. The main difference between summer and winter tyres is their composition. Summer tyres have a stiffer rubber structure which gives them greater resistance to high temperatures and reduces the risk of blowouts. The mechanical strength of rubber, the raw material from which tyres are made, is defined by the amount of carbon in its structure. Summer tyres are distinguished by their outstanding performance on wet and dry surfaces at high temperatures. The primary attributes of a quality summer tyre are handling, braking distance and resistance to aquaplaning. Summer tyres have higher speed indices (H, V, W, Y) compared to winter (R, S or T) or all season tyres. According to current standards for summer tyres, the minimum profile accepted is 1.6 mm, but specialists recommend changing summer tyres at 3 mm tread depth, arguing that a lower profile than this leads to difficulties in traffic (considerably longer braking distance, reduced grip on wet surfaces). It should also be mentioned that in some European countries failure to comply with the minimum legal profile is punishable by a fine (the amount differs from country to country) and penalty points. To avoid such inconveniences in traffic, it is best to use a set of summer tyres that comply with specific European standards.

2.4 Winter tyres

In winter, grip and rolling conditions are specific. According to studies, the use of winter tyres starts when the ambient temperature drops below 7°C. Below this temperature, the rubber in a summer tyre hardens and loses its elasticity and grip, i.e. its effectiveness. Consequently, in winter, braking distances for summer tyres can be up to 20% longer, depending on the weather conditions and the tyres fitted to the vehicle. At temperatures below 7°C, winter tyres offer more grip/safety and reduce braking distances on all types of road compared to summer tyres. On the other hand, in winter we are often tempted to fit winter tyres only on the two driving wheels. This is by no means sufficient for good performance and safe driving. With only two winter tyres on the drive wheels you only get good traction but not good control of the vehicle. For optimal road safety conditions, it is recommended to equip your vehicle with winter tyres on all wheels in winter. A vehicle fitted with winter tyres only on the rear drive axle will be unbalanced and may be more difficult to start from a standing start and may skid backwards. The same is true for a vehicle fitted with winter tyres on the front drive axle only. In this case it will become unbalanced and risk missing turns.

2.5 Aquaplaning of tyres

The contact patch of a 275/35/R20 tyre is equal to the area of an A5 sheet of paper (a quarter of the size of an A4 sheet of paper). So all four wheels of a car touch the ground on an area equivalent to an A4 sheet of paper. This happens when the vehicle is stationary and not in motion. At a speed of 100 km/h, all four wheels still tread on the asphalt (touch the road) with the equivalent of half a sheet of A4 paper. At a speed of 130 km/h, on a motorway when it is raining heavily, all four wheels of a car are still touching the ground (the road) to an area equivalent to the size of an A5 paper (1/4 of an A4 sheet). If a vehicle travelling at such a speed has to be stopped, it is important to know that the grip force in this case is related to the contact area of the tyre with the road surface mentioned above. With this in mind, things get even more complicated when a film (a layer) of water appears between the tyre and the road surface and the phenomenon of aquaplaning occurs. When a motor vehicle drives on a wet surface (road), depending on the speed and the amount of water on the surface, there is a risk that a layer (film) of water may be interposed between the contact surface of the tyres of the running vehicle and the road. In other words, the car wheel loses contact with the ground, the grip force is reduced to zero and the driver loses control of the vehicle. It is essential what role tyres play in such a situation, how they can help us regain control of the vehicle and why it is good to use quality tyres. As can be seen in Fig 9a, there are grooves (grooves) on the longitudinal surface around the circumference of the tread, about 7-8 mm deep. Through these longitudinal grooves, while the vehicle is in motion, the wheel is spinning on the track and the tyre is draining water from underneath it. Under ideal conditions a single wheel can evacuate up to 300 litres of water per minute. Basically, the tyre acts like a water pump. Due to long use of the vehicle, over time, frictional forces wear the tyres and these water drainage grooves under the tyre are cut deep. This tells us that under the same conditions the water pump will no longer cope and the chances of regaining grip in good time diminish considerably. This is why it is important that when the tyres wear out, and those longitudinal indentations (grooves) on the tyre running surface decrease to 3-4 mm, it is necessary to replace them with new ones. Fig 9b shows the profile of a winter tyre. As can be seen, in this case the indentations (grooves) are no longer longitudinal. They are arranged in the shape of a letter "V" on the tyre profile, in order to remove water, or snow, from under the wheel. At the same time the profile is defined in the form of lugs with fine serrations. The walls of these grooves are designed to rub against each other when the tyre comes into contact with snow or ice. The frictional forces between these surfaces release a certain amount of heat which melts the surface layer of snow or ice, thus preventing the snow or ice from depositing on the tyre's running surface. The phenomenon of aquaplaning was studied in detail by researchers working on aircraft landings. Aircraft are known to land at high speeds (over 250-300 km/h) and their pilots brake their aircraft both aerodynamically and by means of the undercarriage in order to fit within the length of the runways. This causes the phenomenon of aquaplaning, which leads to loss of ground adhesion and increases the braking distance [9].

Fig 9a: Profile of a summer tyre

Fig 9b: Profile of a winter tyre

According to the data shown in Fig 10, there are three forms of aquaplaning of the ruts in contact with wet ground [9, pp. 21-22]:

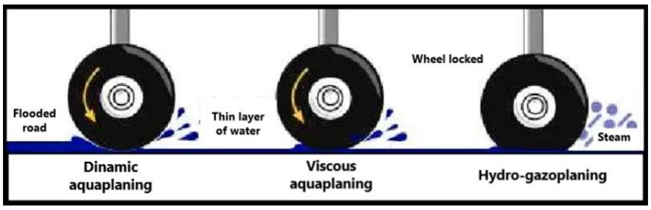

Fig 10: Forms of aquaplaning [9, p. 21]

- ***Dinamic aquaplaning***, occurs when running wheels on a surface covered with a substantial layer of water. In this case, the water cannot be drained from under the tyre, forming a hydraulic wedge whose size increases until the wheel loses contact with the road and lifts off the track. The wheel lifts off the ground when the pressure applied to the area under the tyre equals the weight on each wheel of the vehicle. If the wheel is not a drive wheel it will stop spinning and the drive wheel will spin continuously, making steering, braking and traction control totally ineffective. Fig 11 shows the contact of a tyre with the road surface, where dynamic aquaplaning occurs;

Fig 11: Tyre in aquaplaning [9, p. 23]

- ***Viscous aquaplaning,*** is defined by changes in the properties of the water layer (film). The phenomenon is similar to dynamic aquaplaning, but occurs at much lower vehicle speeds. It occurs when the road surface is very thin and the water film contains contaminants that lubricate it. In this case, the water film formed between the tyre and the road has a coefficient of adhesion similar to that of wet ice;
- ***Hydro-gazoplaning*** (in free translation from english - *reverted rubber hydroplaning*), occurs when tyres overheat, a phenomenon that practically vaporises the water film between the tyre and the road. This phenomenon has the following phases of evolution: The wheel becomes stuck due to hydrodynamic aquaplaning; the speed decreases; the aquaplaning stops and due to contact with the road the stuck wheel overheats (slides on the road surface); intense frictional forces cause the tyres to overheat; the overheated tyres then encounter a layer of water, which they vaporise due to the high temperature; the water vapour in turn causes the wheels to lose contact with the road. Due to this phenomenon, the tyres abrade heavily on the track (the tyres will be *"chewed"* all over the surface that had contact with the ground).

The influencing parameters of the aquaplaning phenomenon are as follows [9, pp. 22-23]:

- **High vehicle speed:** At high speeds the same amount of water must be drained from under the wheels in a short time;
- **Thickness of the water layer on the roadway:** A large layer increases the volume of fluid to be evacuated from under the tyres;
- **Viscosity and mass of the water layer:** The fluid has a high inertia in the dissipation process (exhaust from under the tyre);
- **Tyre wear:** Lack (insufficiency) of longitudinal grooves in the tyre tread for water drainage;
- **Tyre width:** A wider tyre means a larger ground contact patch and therefore more fluid has to be drained from the wheel to the road.

The speed of overtaking is defined as the minimum speed of a vehicle at which overtaking begins. The main parameters that have a significant influence on this phenomenon are:

- Road microprofile;
- The thickness of the layer of water on the roadway;
- The pressure in the vehicle tyres;
- Tyre tread profile and tread depth (tyre wear);
- Load (weight distributed on each wheel of the vehicle).

2.6 Forces and moments acting on the wheels when braking the vehicle

The forces acting on car tyres are not applied from a specific point, but are exclusively the result of normal or shear pressures distributed in the contact patch of the tyre with the road. The pressure distribution in the contact patch is not uniform. It varies along two axes: Longitudinal and transverse. When a vehicle's tyre presses on the road, the pressure distribution is not symmetrical to the left or right of the Y-axis. It always tends to be higher at the front of the contact patch with the road. Both phenomena are shown in Fig 12. Due to the viscoelasticity of the tyre, any deformation occurring at the front of the contact patch creates a forward displacement of the vertical pressure (Fig 13). Due to this phenomenon, the resultant vertical forces do not pass through the rotational axis of the tyre, thus generating high *rolling resistance* of the wheel. During vehicle rolling, tractive and lateral forces are the result of a shear mechanism. Each element passing through the contact patch exerts a shear pressure which, integrated on the contact patch, is equal to the traction/side force developed by the tyre. Tyre adhesion is achieved by two primary mechanisms as shown in Fig 14. *Adhesion* occurs due to intermolecular bonds between the tyre and the tread material. Adhesion is higher on dry surfaces, but when the road becomes wet it is substantially reduced resulting in reduced friction on wet roads.

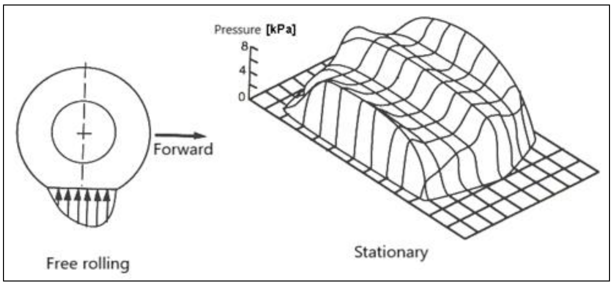

Fig 12: Pressure distribution in the contact surface [10]

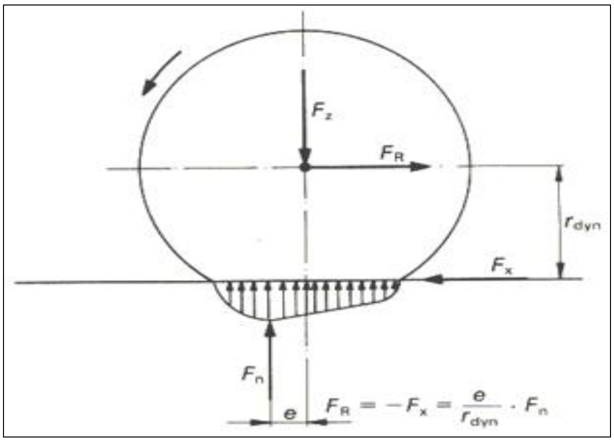

Fig 13: Occurrence of rolling resistance due to eccentricity of the point of application of the resultant normal forces [10]

Hysteresis is the loss of energy in the rubber through deformation when it slides over the tread material. Hysteresis friction is not so affected by tread moisture, however, improving wet traction can be done by using tyres with high hysteresis rubber in the tread.

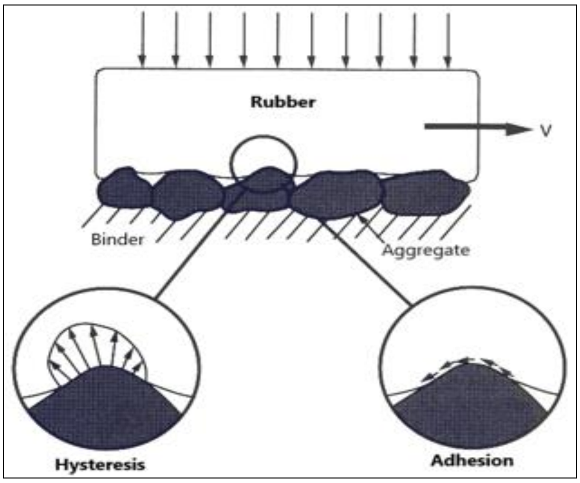

Fig 14: Mechanisms of adhesion generation [10]

Both friction mechanisms depend to a relatively small extent on the slippage between the tire and the road. For maximum power efficiency at the braked wheel, specialists in the field have sought solutions that they have continuously improved. Car tyres must be able to withstand forces along all three coordinate axes (x, y, z) and take up all moments occurring around these axes. For the best possible active safety and optimum road holding, the requirements on the development of longitudinal (acceleration or braking) and lateral forces, straight running properties, high speed resistance and wear resistance are maximum.

The maximum value of the forces that can be transmitted through the surface connecting to the track (ground contact patch) depends on the friction conditions. The maximum transmissible longitudinal force *(F_{xmax})* is proportional to the normal force *(Fn)*.

$$Fxmax = \mu H * Fn \tag{1}$$

where, μH is the proportionality factor and is called the coefficient of adherence.

If the tyre is acted upon with a moment of force greater than $F_{xmax} * r_{sta}$ the tyre loses grip and the wheel locks during braking, causing the tyre to slip between the tyre and the track (Fig 15).

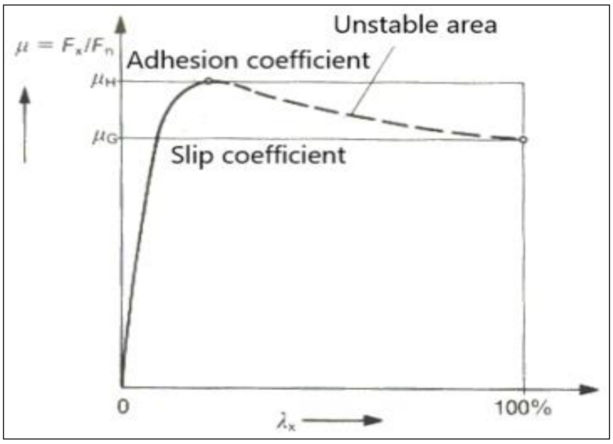

Fig 15: Variation of the coefficient of adhesion with longitudinal skidding [10]

But the maximum longitudinal force transmitted in this case is defined by the slip coefficient μG:

$$Fxg = \mu G * Fn \tag{2}$$

Usually the coefficient of friction at adhesion is higher than the coefficient of friction at sliding.

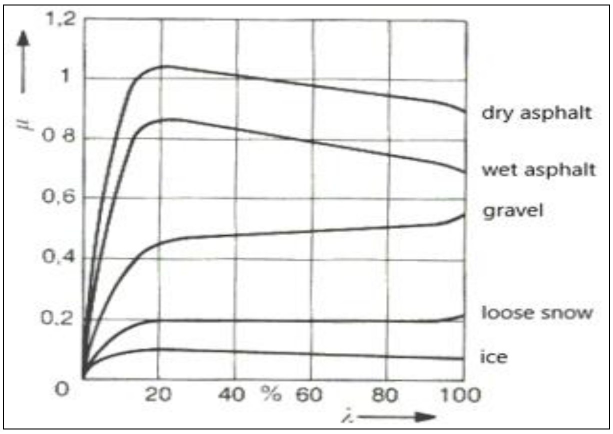

Fig 16: Variation of the coefficient of adhesion with skidding, for different rolling conditions [10]

If an engine or braking moment is applied, a difference occurs on the wheel between the vehicle speed (the speed at which a point on the tyre tread passes through the contact patch) and the angular velocity of the wheel. Due to this difference in speed, deformation occurs in the contact patch of the tyre with the track, linked by a relative movement of the tyre with respect to the track, resulting in a longitudinal slip λ_x, defined mathematically by comparing the speed of the vehicle v [m/s] and the relative speed between the wheel and the track $r_{din}*\omega_R$. In order to obtain positive values for acceleration or braking, the numerator terms of the slip calculation relation must be reversed, so for acceleration we use the calculation relation [10]:

$$\lambda xa = \frac{rdin*\omega R - v}{rdin*\omega R} \quad (3)$$

and for braking we use the calculation relation [10]:

$$\lambda xf = \frac{v - rdin*\omega R}{rdin*\omega R} \quad (4)$$

The dynamic radius is calculated with the relation [10]:

$$rdin = \frac{U}{2*\pi} \quad (5)$$

Fig 16 shows the variation of the coefficient of adhesion with skidding for different rolling conditions.

Friction coefficient $\mu = F_x/F_n$ is dependent on the amount of longitudinal slip. As shown in Fig 15 the maximum value of the coefficient of friction is given by the coefficient of adhesion and is obtained, for tyres used on normal cars, at a slip of about 10% - 25%. As the slip increases the coefficient of friction decreases to the value of the slip coefficient reached at 100% slip. The area between mH and mG is an unstable area, meaning that immediately after exceeding the maximum point, the slip immediately reaches 100%, which means that the wheel skids completely. The shape of the dependence curve between friction coefficient and longitudinal slip depends on several factors. Fig 16 shows curves for different surfaces of the wheel track. The coefficients of friction and slip are much lower for snow and ice than for dry or wet asphalt. However, an increasing tendency can be observed in sand and snow, especially in the 100% skidding area. The values of these coefficients also decrease with increasing speed, a phenomenon shown in Fig 17.

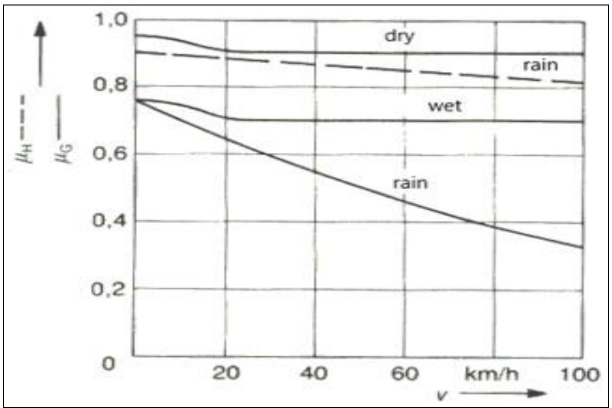

Fig 17: Variation of the coefficient of adhesion or slip as a function of car speed and road condition [10]

From the analysis of the data shown in Fig 18, it can be seen that the braking moment Mf has a negative value, being opposite to the rotational movement of the wheel. When the driver applies the brake pedal, the tyres of the car wheels compress tangentially, decreasing in the attack zone and increasing in the release zone. This phenomenon intensifies and is directly proportional to the brake pedal force.

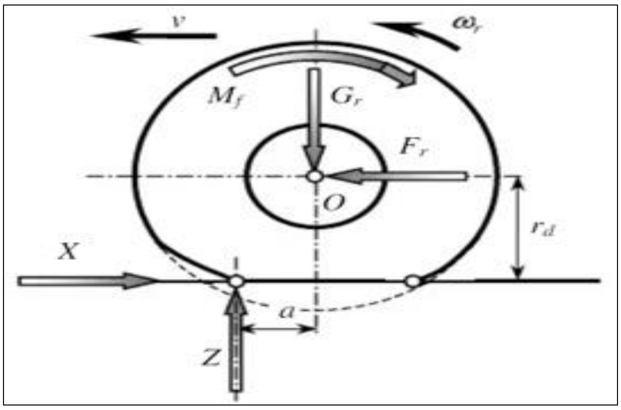

Fig 18: Forces and moments acting on the wheels when braking the vehicle [9, p. 13]

The following phenomena occur on tyrese [9, p. 13]:

- Along the entire length of the contact patch with the roadway, there is a transition from the extended tread elements (front side) to the compressed tread elements (rear side);
- The compression in the rear (clearance) area produces a sliding of these elements towards the front, thus reducing the amount of sliding of the front elements;
- At high values of the applied braking moment, the elements in front of the release zone have a slight forward slip. In the middle of the clearance zone the slip cancels (has zero value) and in the rear of the clearance zone (at the exit of the contact with the track) there is a rearward slip of the tread elements, the equilibrium equations are as follows:

$$\begin{cases} Fr = X \\ Z = Gr \\ Mf = Fr * Rd - Z * a \end{cases} \quad (6)$$

2.7 Braking distance (space) of a vehicle

The need for instant braking arises when there is an imminent danger, but the vehicle does not stop as soon as the driver presses the brake pedal. It stops after a certain distance until it comes to a complete stop, from the moment the hazard is sensed by the driver and the brake pedal is rigorously pressed. The distance travelled by the car until it comes to a complete stop is called the ***total stopping distance*** and is in turn composed of the ***reaction distance***, the ***braking delay time (operational delay)*** and the ***braking distance***.

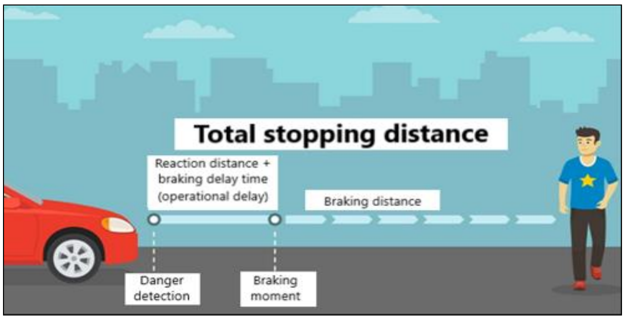

Fig 19: Total stopping distance [12]

- ***Reaction distance*** (Fig 19), is the distance tr avelled by the vehicle from the moment the driver is aware of the need to stop (senses the danger) to the moment of actual braking (application of the brake pedal). Fractions of a second, the time it takes to react, are the defining factor because the vehicle moves a few metres further depending on the speed of the vehicle. Reaction distance is the distance travelled between the detection of an emergency situation and the driver's response to braking. The average reaction time is between 0.5 and 2 seconds. It is generally true that people with more driving experience are able to react to emergency situations in a shorter time. Reaction time is fastest between the ages of 40 and 50, while response time is often slower for people with a recent driving licence and older drivers. Reaction distance is significantly affected by the speed of the car. If the speed is twice as high, the reaction distance is also doubled [11].
- ***Braking delay time (operational delay)*** (Fig 19). Braking delay time (operational delay) refers to the time between pressing the brake pedal and activating the braking system. Before the braking system starts to reduce speed, certain components must be moved. In addition to the increased driving speed, the braking delay time can mean a few metres extra stopping distance [11].
- ***Braking distance*** (Fig 19), is the distance of (road) space travelled from the moment the driver presses the brake pedal until the vehicle comes to a complete stop.
- ***Stopping distance*** (Fig 19). It represents the sum of the three steps outlined above, i.e. the distance travelled between the perception of the emergency situation and a complete shutdown.

So, ***reaction distance*** + ***braking delay time (operational delay)*** + ***braking distance*** = ***TOTAL stopping distance*** (Fig 19).
The main factors influencing the braking distance (space) of a road vehicle are presented below.
a) Factors influencing reaction space (distance) [12]**:**

- **The drivers state of fatigue:** Lack of sleep severely affects the driver's attention, awareness of danger and reaction time. For this reason, experts recommend that when you have a longer journey, it is very important to take a break from driving every two hours. Various studies have shown that after this driving interval, concentration decreases and reaction speed is slower;
- **Driving a motor vehicle under the influence of alcohol or prohibited substances: (**narcotic drugs or drugs containing hallucinogenic substances - sedatives, sleeping pills, tranquilizers). Hallucinogenic substances slow down the driver's reaction speed. This effect causes a delay in reaction from the moment danger is detected until the brake pedal is pressed;
- **Inattention (lack of attention) at the wheel:** If there is no driver attention to the road, there is no prompt reaction to braking in the event of potential imminent danger. The use of mobile phones, gadgets or talking to passengers in the car while driving are the main determinants that negatively affect the driver's reaction speed.

b) Factors influencing stopping distance [12]**:**

- **Brake or steering system failure:** If a road vehicle has even minor defects, the braking distance (gap) increases exponentially with the degree of wear of the components of these systems. The ABS (Anti Brake System) supports the braking process, reducing the risk of wheel lock and ensuring efficient braking (efficient braking is achieved by the wheels rolling, not by the tyres rubbing on the road);
- **Road and weather conditions:** The distance travelled by the road vehicle after braking may be greater if the running surface of the wheels is wet or covered with snow or ice, reducing adherence;
- **Tyre state, degree of tread wear and tyre pressure:** If the tyres are not suitable for the season, braking distance may be affected. The grip of car tyres is different on wet, snowy or icy roads compared to dry roads. Braking distance is affected when tyre pressures are not correct;
- **Vehicle weight:** The heavier the vehicle, the longer the braking distance will increase.

Since we started with calculations, talking about the length of the braking distance of a moving vehicle, we use the simple physical formula known to every student. It is used to calculate the transition from incident energy to kinetic energy at the end of the path *(mgh = mVx2 / 2)*. We obtain that at a speed of about 30 km / h the body receives a blow equal to a drop from a height of three meters. Therefore, when driving at a speed of 60 km / h, the impact force is equal to drop from a height of 15 m, and already at 90 km / h - with a height of about 32 m at 120 km / h - this is a height of 55 meters. Even with the airbag deployed, surviving a frontal impact at 60 km/h is highly unlikely.
According to American Association of State Highway and Transportation Officials, Inc. (AASHTO), the braking distance of a vehicle can also be calculated mathematically with the relation [13]:

$$s = (0.278 * t * v) + v^2 / (254 * (f + G))\ [m] \qquad (7)$$

where,
s: Is the stopping distance (space) [metres];
t: Response time [seconds];
v: Vehicle speed [km/h];
f: The coefficient of friction between the tyres and the road. It is usually 0.7 in dry conditions and between 0.3 and 0.4 in wet conditions. In this case the value is 0.3;
G: The slope of the road (if applicable), expressed as a decimal value. A positive value indicates an upward slope and a negative value indicates a downward slope;
0.278 and **254** are two constant values.

The general formula for calculating the deceleration rate is calculated with the relation [14]:

$$V = 0.5 * t3 * j + \sqrt{2 * S * j}\ [km/h] \qquad (8)$$

where,
tz - The deceleration rise time of the car. Measured in seconds;
j - The deceleration of the car when braking (j = 6,8 m);
c_2, and on wet - 5 m/s^2;
S - The length of the braking distance.

Table 3 shows the braking distance of a road vehicle as a function of speed, both in ideal road conditions (dry asphalt) and in difficult road conditions (wet, snow covered or icy roads):

Table 3: Braking distance of a vehicle as a function of speed in ideal road conditions (dry asphalt) and in difficult road conditions (wet, snow covered or ice road) [15]

Speed (km/h)	Braking distance/space (meters)			
	Dry	**Rain**	**Snow**	**Ice**
60	20.2	35.4	70.8	141.7
70	27.5	48.2	96.4	192.9
80	35.9	62.9	125.9	251.9
90	45.5	79.7	159.4	318.8
100	56.2	98.4	196.8	393.7
110	68	119	238.1	476.3
120	80.9	141.7	283.4	566.9
130	95	166.3	332.6	665.3
140	110.2	192.9	385.8	771.6
150	126.5	221.4	442.9	885.8
160	143.9	251.9	503.9	1,007.8
170	162.5	284.4	568.8	1,137.7
180	182.2	318.8	637.7	1,275.5
190	203	355.3	710.6	1,421,2
200	224.9	393.7	787.4	1,574.8

In order to avoid undesirable events in traffic (incidents or road accidents), it is important to keep an appropriate distance between the vehicle we are driving and the vehicle in front at all times, as we will have a better view of the road, we will have time to react and stop in time if the vehicle in front brakes suddenly and we will make significant fuel savings due to eco-preventive driving. In this case, we will not have to use the brakes of the vehicle we are driving every time the vehicle in front brakes or slows down. The calculated distance between vehicles according to speed is shown in Table 4.

Table 4: Distance to be maintained between vehicles according to speed [12]

Speed (km/h)	50	70	90	100	110	120	130	140
Reaction distance (m/sec)	13.8	19.4	25	27.8	30.55	33.3	36.1	38.8
Braking distance (m/sec)	19	37	61	78	90	108	130	147
Total stopping distance (m)	**32.8**	**56.4**	**86**	**105.8**	**120.6**	**141.3**	**166.1**	**185.8**

The Highway Code states: the driver of a vehicle travelling behind another vehicle is obliged to keep a sufficient distance from that vehicle to avoid a collision. However, the Highway Code does not stipulate the distance that must be maintained between vehicles in traffic. It must be set by the following driver, who must determine the distance between his vehicle and the one in front of him, according to his speed.

2.8 The contribution of the vehicle's transmission to reducing braking distance. Case study

a) **b)** **c)**

Fig 20: The three braking modes of a vehicle

Most drivers make a mistake when emergency braking a vehicle with a manual gearbox by stepping on the clutch pedal before the brake pedal. This action decouples the clutch of the vehicle's transmission from the engine and amplifies the vehicle's rolling (the vehicle runs freely on the road without any restraint from the transmission). The rolling is determined in this case by the inertia force of the vehicle's weight in dynamics.

This case study explicitly shows how the correct braking of the vehicle is achieved by the driver's intervention on the controls (correct operation of the brake pedal and clutch pedal), and the efficiency of the braking distance obtained by their correct operation. Drivers are usually experienced in three ways of applying the two pedals when braking a vehicle in emergency braking, as follows:

- operate in order, clutch pedal - brake pedal (incorrect method - Fig 20 a);
- operating simultaneously the two pedals (incorrect method - Fig 20 b);
- operate in order, brake pedal - clutch pedal (correct method - Fig 20 c).

In emergency braking in the third case (Fig 20 c), which is considered the most efficient, the brake pedal is applied until the transmission locks, without the engine stopping. When the engine tends to stop due to the vehicle's transmission locking, the brake pedal is also applied urgently. In this way, braking becomes much more efficient because the mechanical resistance of the transmission in combination with the pressure force in the engine cylinders contributes to the braking force of the vehicle and thus to the reduction of the braking distance.

To test the braking distance in the two cases (clutch pedal-brake pedal and brake pedal-clutch pedal operating order), a Romanian manufactured Dacia Duster equipped with summer tyres was used. The emergency braking was carried out on a new asphalt road with maximum grip, after the car had achieved a maximum speed of 60 km/h in all cases. Fig 21 shows aspects of the experimental research. The braking distance results obtained are shown in Table 5.

Fig 21: Images from experimental research

Table 5: Braking space results obtained in the two cases

How to operate the pedals	Braking distance obtained (m)
Clutch pedal-brake pedal (or operate at the same time)	17.20
Brake pedal-clutch pedal	15.70

From the analysis of the data presented in Table 5, it results that an efficient and effective braking distance is achieved by operating the pedals in the order: Brake pedal-clutch pedal and not in the other modes. The difference between the two braking distances is 1.5 metres at 60 km/h. We have to imagine that at higher speeds the difference is even greater and the braking distance, which is essential at an emergency stop, increases exponentially. For this reason, drivers need to get used to braking correctly.

3. Braking space: The proposed experiment

In order to study how car tyres influence the braking distance, it is proposed to carry out an experimental research on two cars of different type and category, a high performance Lamborghini Huracan Technica equipped with Bridgestone Potenza Sport top class summer tyres and a low performance Romanian car, Dacia Logan equipped with medium budget all seson tyres from tyre manufacturer Kumho (Fig 22).

Fig 22: The cars used in the research process and the tyres fitted to them

I would have liked the tyres fitted to the cars to be in the same class, but to complicate the experiment a little and to see if there were any differences in braking distance, I used tyres from different classes and types. The proposed experiment belongs to the class of active type experiments (second order compound factorial method). The test was carried out on a track of a specialised polygon, with asphalt quality as the road surface.

In order to obtain accurate experimental research data, the braking distance was marked with milestones positioned at a distance of 2 metres from each other along the entire length of the braking distance, and a high-performance electronic decelerometer, type DEC-2, was mounted on the cars, which simultaneously measures average deceleration, average left or right braking shift and speed over the stopping and braking distance. Images from the experiment are shown in Fig 23. Braking gap distances obtained on the electronic decelerometer, were compared with distances measured with the milestones arranged along the braking gap to obtain data of high accuracy. In order to obtain the desired results, a considerable distance was travelled with each individual car to reach the speeds set for the research, after which the service brake was suddenly applied when driving through the braking distance without the cars skidding.

Fig 23: Pictures of the experiments

4. Results and discussions

Factors influencing braking distance were: Tyre grip and runway surface quality; braking system performance; car weight and inertia force; speed and reaction time; weather conditions and visibility. The results of the experimental tests are shown in Table 6.

Table 6: Results obtained from the experimental tests

Test speed (km/h)	Braking distance obtained (metres)	
	Lamborghini Huracan Technica car	**Dacia Logan car**
50	9.7	9.6
60	13.7	12.2
70	16.1	17.9
80	21.3	23.2
90	25	29.5
100	32.8	36.3
146	68.7	80.9

From the analysis of the results presented in Table 6, at speeds up to 90 km/h the distances (gaps) in which the two cars braked to a stop are approximately close. The results change above 90 km/h because the Lamborghini Huracane Technica is equipped with a very efficient braking system. Experts believe that the braking systems of new, modern cars are oversized. That is why I believe that equipping these cars with such braking systems is not justified unless the car is fitted with tyres at least equal to the performance of these braking systems. Tyres are not capable of transmitting high braking forces to the ground (on the road).

In this case, the efficient braking distances achieved by the two cars was also due to the ABS systems fitted to them. ABS (loosely translated from eglish Anti-lock Braking System or german language Antiblockiersystem) is a system for motor vehicles that prevents the wheels from locking during braking.

ABS technology was invented by the German company Bosch as early as the 1930s, but the first cars, namely trucks and limousines made by Mercedes-Benz, were not equipped with ABS until the 1970s. The first production car to be equipped with ABS was the Mercedes-Benz W116. This was followed by Ford, BMW, Lincoln and others who decided to use the technology. Initially, ABS was designed and used for aircraft when braking on landing. Since 2011, the European Union has required all car manufacturers to use an ABS safety system. So, for several years now, all cars have come with ABS from the factory [16]. How the ABS system works to avoid an imminent collision is shown in Fig 24. It has two advantages: It allows the driver to maintain steering control during braking and shortens the braking distance.

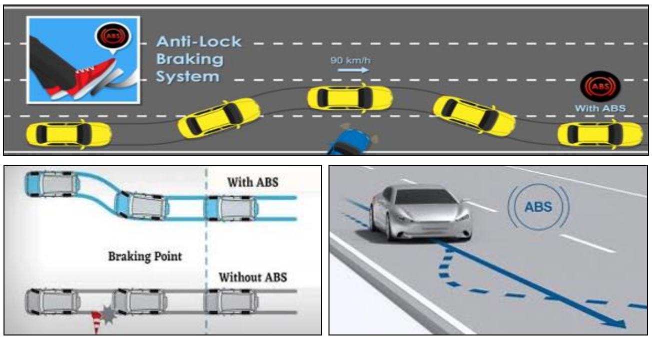

Fig 24: The importance of ABS in avoiding an imminent collision [16]

5. Conclusions

From the analysis of the results presented in Table 4, at speeds up to 90 km/h the distances (gaps) in which the two cars braked to a stop are approximately close. The results change above 90 km/h because the Lamborghini Huracane Technica is equipped with a very efficient braking system. Experts believe that the braking systems of new, modern cars are oversized. That is why I believe that equipping these cars with such braking systems is not justified unless the car is fitted with tyres at least equal to the performance of these braking systems. Tyres are not capable of transmitting high braking forces to the ground (on the road).

A reduced and efficient braking distance was achieved by rolling the braked wheels of the two cars, not locking them. The ABS system in each car's braking system managed the wheel rolling.

Winter tyres, compared to summer tyres, have a special construction that results in increased grip, which is essential in snow and ice conditions and helps the car to corner and stop safely. They have unique tread patterns and wider grooves that improve traction on snow and ice, drain water and remove snow. Their tread components are also optimal on mud or water and improve grip, preventing aquaplaning. All in all, they offer superior traction, almost 25-50% higher than all season tyres. This safety margin is crucial for timely braking and avoiding problems that can arise in traffic.

Efficient and effective braking is achieved by immediately depressing the brake pedal with the transmission coupled to the engine until the engine locks (stops), and then depressing the clutch pedal to decouple and declutch the transmission. Disengaging the transmission from the engine via the clutch will be done when the engine starts to vibrate and tends to stop.

As regards the use of tyres depending on the season, the specialist recommendation is to replace summer tyres when they have reached a maximum profile wear of 3 mm, and winter tyres at a maximum of 4 mm. If retreaded tyres are used, it is advisable that they come from within the EU, as from 1 January 2004 manufacturers are obliged to comply with ECE (Economic Commission for Europe) regulations 108 and 109 [17, 18]. This type of tyre can be recognised by the *"e"* marking.

The obligation to use winter tyres on public roads covered with snow, ice or ice was introduced in Romania by the Romanian Government Ordinance no. 5/2011 amending and supplementing with Romanian Government Ordinance no. 195/2002 on traffic on public roads, republished in 2006. It is important to note that the law does not stipulate a deadline from which vehicles must be fitted with winter tyres or a minimum temperature to trigger the process. Therefore, specific tyres are required if the car is driven on a public road covered with ice, ice or snow, regardless of the season, and these provisions have not changed since the law was drafted. The Romanian Car Register specifies that the name all seasons is a commercial name used by tyre manufacturers, but which has no equivalent in Romania's national legislation. Regardless of the commercial name of a tyre, if it is marked with the letters M and S (meaning mud and snow), in the form: M+S, M.S. or M&S, it meets the requirements for use in specific winter conditions laid down in national road legislation. According to the source cited, the penalty for not having the appropriate tyres under the conditions specified in the law is a fine in the fourth class of penalties (between 9 and 20 penalization points). The difference between winter tyres and all-season tyres is that if you don't cover many kilometres in a year, it makes economic sense to use this type of tyre. They are also accepted by legislation in winter. From a technical point of view, all-season tyres have the following disadvantages when used in summer as they are noisier and increase fuel consumption by 1-2 l/100 km. When used in winter, they have less grip than winter tyres and an increase in braking distance of almost 30%, according to a study by Transport Canada (Fig 25).

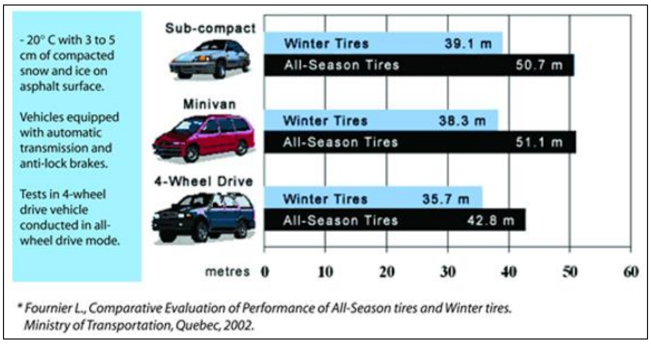

Fig 25: Comparative evolution of performance off all-season and winter tires [7]

Summer tyres are usually fitted to vehicles when an average temperature of at least 7ºC is recorded for three consecutive days, and winter tyres are fitted if the ambient temperature drops below this temperature for at least three consecutive days.

This scientific paper has achieved the purpose for which it was written, by achieving its main objective.

6. References

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