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Mathematical modeling of tire cold inflation pressure

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Abstract: *The paper is trying to give an enlightening about pneumatic tires services in Sudan especially and in the most developing countries. The paper suggested that the tire now a day's shows low time life duration and less safety. It also gives the condition of maintaining correct cold tire inflation pressure rate for different sizes that helps optimize tire performance and fuel economy with respect to tire load capacity and tire size. The paper also recognizes that correctly inflated tires receive appropriate support from the contained air pressure, this provide an even distribution of load across the footprint and help stabilize the tire's structure which has a significant impact on tire wear, rolling resistance, durability and allows drivers to experience tire comfort, and performance. Also the paper shows that the tire fitter men have a relatively low scientific base to know how to deal with providing tires a proper cold inflation pressure rate. The nominated industry tire load and cold inflation pressure standards are in a continuous condition of change and all tires manufacturers ask the side of tire users to follow these changes to update their product information to reflect these changes. Therefore the printed information's at the side of tire may not reflect the latest load and inflation pressure rate standards. The paper also recorded that car accident due to tire explosion due to incorrect tire rate inflation is so high in Sudan and also in developing countries that reflect the poor dealing with tires. The paper suggested a mathematical modeling for guarantee an optimal relationship between cold tire inflation pressure rate with the relative to tire load, tire size, tire speed, trip duration and temperature in general condition and practically in Sudan. The paper is also suggested that an international effort should be done extremely in the field of unifying tire quality control and to give tire fitter personnel considerable training and simple manuals to help proper tire maintenance that insure safety car running and to lengthen tire life duration. These factors generally help to decrease worn tire accumulation, car stoppage failure of tires and car accident.*

Keywords: *Pressure rate modeling, Tire cold inflation pressure rate, Tire size, Tire load*.

I. Introduction

Tires are normally inflated with air (a combination of gasses comprised of about 78% nitrogen (N_2), 21% oxygen (O_2) and 1% argon (Ar) along with traces of other gasses) from the local gas station. Unfortunately, using air permits moisture and the amount of water vapor in the air that varies from place to place, time of the year and due to weather conditions. While air is all around the world is extremely different sometimes, finding a convenient source of an ideal compressed air is becoming difficult, and finding a source of "dry," vapor free compressed air is even more difficult and this as a result has a negative influence to tire performance and its time life [6].Correctly inflated tires receive appropriate support from the contained air pressure to provide an even distribution of load across the footprint and help stabilize the tire's structure. And while most drivers recognize that proper inflation rate has a significant impact on tire wear, rolling resistance and durability, only a few realize that under inflation also has a noticeable influence on how quickly and precisely the tires respond to the driver's input.

Since typical tire pressures range from 30 to 35 psi for cars (with light truck tire pressures often higher), there is a constant force trying to push the air through the tire. This allows some of the air to escape (called permeation) right through the microscopic spaces between the rubber molecules and somewhat like a rubber balloon; the air will eventually escape if it is not replenished [1]. Generally, a tire's inflation pressure rate will go down by about 1 psi every month. This means that if air isn't added for two to three months, the tire's inflation pressures will probably be 2 to 3 psi low, but normal car owners are not paying great attention to that in order to help maintain more constant tire pressures, tires should be checked more frequently, once a month and before trips is the minimum but once a week is preferred. This will allow us to refill lost pressure that escapes over time, as well as discover any pressure losses due to slow leaks caused by minor punctures before significant pressure is lost and the tire's internal structure is damaged.

An underinflated tire will tend to wear the shoulder areas of the tread faster than the center. This is because there is insufficient air pressure to allow the center of the tread to carry its fair share of the weight. A correctly inflated tire receives appropriate support from the contained air pressure to provide an even distribution of load across the footprint. While most drivers recognize that proper inflation rate has a significant impact on tire wear, rolling resistance and durability, only a few realize that also has a noticeable influence on how effectively the tires can resist hydroplaning to maintain wet traction. An underinflated tire can't maintain its shape and becomes flatter than intended while in contact with the road. If a vehicle's tires are under inflated by only 6 psi it could lead to tire failure. Additionally, the tire's tread life could be reduced by as much as 25%. Lower inflation pressure will allow the tire to deflect (bend) more as it rolls. This will build up internal heat, increase rolling resistance and cause a reduction in fuel economy of up to 5%. Drivers would experience a significant loss of steering precision and cornering stability. While 6 psi doesn't seem excessively low it usually represents about 20% of the tire's pressure [2].

An overinflated tire is stiff and unyielding and the size of its footprint in contact with the road is reduced that increasing a local stress. If a vehicle's tires are overinflated by 6 psi, they could be damaged more easily when running over potholes or debris in the road. Higher inflated tires cannot isolate road irregularities well, causing them to ride harsher. However, higher inflation pressures usually provide an improvement in steering response and cornering stability up to a point. This is why participants who use street tires in auto-crosses, track events and road races run higher than normal inflation pressures. The pressure must be checked with a quality air gauge as the inflation pressure cannot be accurately estimated through visual inspection. In order to evaluate the influence of inflation pressure on response and handling, the tire rack conducted a performance test track drive purposely, comparing properly inflated tires to underinflated tires [2][3].

Figure (1)

The first part of the test was visual. The drivers were asked to look at the tires and decide which of the two vehicles was equipped with the underinflated tires. While perhaps this visual test might have been easier with taller tires of the past, today's low profile tires fitted to the car demonstrated how difficult it has become. The drivers agreed that the tire appearance alone did not provide irrefutable confirmation of the tire pressure contained inside see figure (1). Therefore person can't use naked eyes as a tire pressure gauge [3].While driving at the edge of a tire's ability in wet conditions is challenging, the car with the properly inflated tires provide handling that was predictable. Driving the car with the underinflated rear tires proved to be much more difficult to drive and forced the driver to slow down to retain control, producing lap times that were several seconds slower than the properly inflated car. While tire manufacturers can develop tires with great hydroplaning resistance and wet traction, poor maintenance of tire inflation pressures can make a great tire awful like excessive wearing and car disorder resulting even to car accident. Therefore adjusting tires pressures as indicated on the vehicle tire placard or in the owner's manual is very important. Checking tire inflation pressures at least once a month and before highway trips is a must. Driving at high speeds certainly helps make a trip go faster, however with the exception of events like the road rally or a driver's school on a racetrack; so it's difficult to find a place that allows unlimited speeds. The tires on the vehicle should be properly sized, inflated and inspected when planning to drive fast because the tires will be subjected to tremendous stresses.

Because of the weight they bear, pneumatic tires' sidewalls bulge and their treads flatten as they roll into contact with the road. The tires flatten treads results in dimensional difference between the tire's "unloaded" radius and its "loaded" radius). Increasing vehicle speed will cause the tires to deflect quicker and increasing vehicle load will cause the tires to deflect farther (if tire pressure isn't increased).The European Tire and Rim Technical Organization (ETRTO) establishes the standards for tires sold in Europe, and recognizes that the tire's deflection must be minimized and controlled in order to surpass high speed driving stresses. In order to accomplish this, the tire inflation pressure recommendations and the tire's rated load capacities are customized when speeds exceed 160 km/h (99 mph) for all tires up to be nominate as a V-speed rating, and when speeds exceed 190 km/h (118 mph) for all tires that are Z-speed rated. Beginning with the vehicle manufacturer's recommended tire pressure for normal highway conditions, tire cold inflation pressures are initially increased and then the tire's rated load capacities (branded on the sidewalls) are reduced as speeds climb up. As an example shown below, the vehicle manufacturer's recommended 35 psi for a 225/45R17 91W Standard Load tire installed on a vehicle initially rises in 1.5 psi increments for every 10 km/h (6.2 mph) increase in speed until the inflation pressures max out with an increase of 7.5 psi when the vehicle's top speed has increased 50 km/h (31mph). Then as the vehicle's top speed continues to climb, the rated load capacity of the tire is reduced in 5% increments for every additional 10 km/h until the vehicle's top speed has increased an additional 30 km/h (18.6 mph). In this case the 225/45R17 91W standard load size's rated load capacity of 1,477 lbs. is reduced to 1,255 lbs. when applied to a vehicle with a 270 km/h (168 mph) top speed [4].

The tire life cycle according to most manufacturers is rated up to four years, but in fact tires almost are functioning for no more than two years. To improve tires performance and increasing their time life they can be identified by the following six steps:

- Product developments and innovations such as improved compounds and camber tire shaping increase tire life, increments of replacement, consumer safety, and reduce tire waste.
- Proper manufacturing and quality of delivery reduces waste at production.
- Direct distribution through re-tailors reduces inventory time and ensures that the life span and the safety of the products are explained to customers.
- Consumers' use and maintenance choices like tire rotation affect tire wear and safety of operation.
- Manufacturers and retailers set policies on return, re-tread, and replacement to reduce the waste generated from tires and assume responsibility for taking the 'tire to its grave' or to its reincarnation.
- Recycling tires by developing strategies that combust or process waste into new product creates viable businesses and fulfilling public policies [4][5].

Shredded tires are now being used in landfills, replacing other construction materials, for a lightweight backfill in gas venting systems; leach ate collection systems, and operational liners. Shredded tire material may also be used to cap, close, or daily cover landfill sites. Scrap tires as a backfill and cover material are also more cost-effective, since tires can be shredded on-site instead of hauling in other fill materials.

Maintenance:

Tires are one of the most important -- and soft-overlooked -- components of our cars. Tires are the only things that attach our cars to the road, and tire problems affect the car's ride comfort, handling and safety, maintenance of tires is therefore is very important. Forces steering, braking and accelerating between a vehicle and the road are mediated by the tires. The tires are the most active safety equipment of your car - your car is kept on the road and in control of car by four contact areas the size of your palm. The role of the tires in the safety of a car is especially pronounced under demanding and quickly-changing conditions like on snow or ice, on a wet road or in surprising situations.

The demanding conditions of the north require much from tires. The tire must retain its grip on the road even under wretched weather conditions. Road surface friction in the wintertime varies between the fractions coefficients 0.1 for wet ice to the coefficient of almost one for dry roads. In addition to absolute grip, the correct relation between lateral and longitudinal grip ensures good anticipatory properties and steering response even in a blizzard or watery slush. The most important aspect of tire maintenance is proper inflation of the tires. 75% of drivers wash their cars monthly while only 1 out of 7 (14%) correctly checks tire pressure. The air pressure should be checked on all tires, including the spare, at least once a month. Regular rotation of tires will also help prevent irregular and premature wear. 40% of drivers have not rotated their tires within the recommended interval of at least 8,000 miles. A healthy habit many people follow is to rotate their tires with every oil change [6].

Generally there are some simple tire safety tips to help keep the car's occupants safe:

- Checking tires pressure and to be adjusted at least once a month. According to studies conducted by the National Highway Traffic Safety Administration (NHTSA) on tire-related crashes, the leading cause of tire failure is under inflation. Under inflation can have many causes, including a gradual loss of pressure through membranes in the tire itself? It is typical for pressure to drop approximately 1 psi per month and 1 psi for each 8-degree loss in ambient temperature. Under inflation have immediate effects on vehicle handling as well as fuel consumption, but its potential impact on overall safety and tire life are even greater. It results in premature and uneven tread wear on the outer edges. Under inflation also increases stress on the carcass itself, through flexing and overheating, which can lead to structural failures such as tread separation. That's why it is imperative to check and adjust tire pressure at least once a month and before every long trip (over 250 miles). Recommended pressures are printed on a label located on the driver's doorframe or in the glove box.
- Inspection of tires regularly for abnormal wear or damage, to ensure maximum tire life and safety, tires should be given a visual inspection at least once a month and before long trips. This is easily done at the same time when checking pressures.

The checking should include:

- Excessive or uneven tread wear, which may indicate improper inflation or steering and suspension misalignment;
- Cracks or bulges on the sidewalls or tread;
- chunking of the tread or any indication of tread separation from the carcass;
- Signs of puncture, or nails, screws, glass, pieces of stone or any foreign object imbedded in the tire. If you detect any of these conditions, take the vehicle in for further diagnosis immediately. In most cases, punctures can be repaired if their size is not excessive [6][7].
  In general, external "plugs" are not recommended. Repairs should be made from the inside, and a complete inspection made while the tire is off the rim. Sealing compounds and other emergency aids should be treated only as a means of moving the vehicle to a safe location for repair. If abnormal tire pressure loss occurs, check the valve stems for leakage, as well as the tire itself.
- Rotating tires every 6,000 miles or according to owner's manual.
  Tire rotation is essential to achieve even tread wear and maximum tread life. On front-wheel-drive cars, for example, most of the braking, steering and driving forces are carried by the front tires, which inevitably wear much faster. A "cross-rotation pattern"—that is, moving the left-front tire to the right-rear axle, the right- front tire to the left-rear axle, etc.—can best balance tread wear and maximize tire life. That sequence can be performed on any vehicle equipped with four non- unidirectional tires. Designated by an arrow on the sidewall, unidirectional tires must be rotated only front to rear and rear to front, on the same side of the vehicle, so their direction of revolution does not change.
  All-wheel-drive and four-wheel-drive vehicles are best suited to a lateral rotation—left to right and right to left—at the same end of the vehicle [8].
- Maintaining tires in proper balance.
  Out-of-balance tires can not only cause uneven tread wear and an uncomfortable ride but also excessive wear on the suspension and other components. An out-of-balance tire can be detected by a severe thumping, usually most pronounced at highway speeds.
  If such a condition occurs, have your tires dynamically balanced as soon as possible. An experienced technician can usually determine which tire is out-of-balance by driving the car.
  Tire balancing involves placing weights in appropriate places on the bead or inner circumference of the wheel. Tires should always be balanced when first installed, and whenever they are remounted.
- Maintaining steering and suspension in proper alignment.
  Misalignment of the steering and suspension, front or rear, can not only adversely affect the steering feel and stability of a vehicle, but also cause rapid and uneven tire wear. If not corrected, this misalignment can ruin a tire in a short time and distance.
  If one feels the steering "pulling" in one direction or another when traveling straight ahead on a flat road with no crosswind, or if you notice uneven wear on the tires, particularly front tires, you should have the alignment checked and adjusted as soon as possible.
  Alignment should also be checked after a vehicle has been involved in a collision or if it is used continuously on rough roads, particularly those with large potholes.

1.1 Loading of a tire

Overloading is the second leading cause of tire failure, next to under inflation. All tires are designed to operate within a maximum load range designated by a code on the tire sidewall. Exceeding this can result in both excessive wear and reduced tire life due to structural damage, including the potential for sudden failure.

In most vehicles, the maximum passenger and cargo load for which the vehicle and tires are designed is printed on the same label that designates recommended tire pressures. That load, particularly in the case of trucks and SUVs, may be substantially less than the vehicle is physically able to contain. It is critical that the maximum allowable load never be exceeded.

When determining the actual load in your vehicle, don't forgot the tongue-weight of a trailer if you are trailer towing, since it also acts directly on the vehicle's tires [9].

1.2 Avoiding overheating tires

Heat, like load, is the enemy of tire life. The higher the heat it is subjected to, the shorter the tire's life—in terms of both treads wear and structural resistance.

High speeds, high loads, under inflation, coarse pavement or concrete, and aggressive driving, including high cornering loads and hard braking, all contribute to high tire temperatures. Combined with high ambient temperatures and continuous use, they can create extreme circumstances and cause sudden tire failure [9][10].

To maximize tire life and safety, therefore, it is important to minimize the simultaneous occurrence of such conditions. Be particularly vigilant at high temperatures and adjust your driving style to consider its effect on tire life and performance.

- Replacing tires when required:

The vehicle's tires should be replaced if:

- Any portion of the tread is worn to the "wear indicator bars"—lateral bars molded into the tire grooves at about 20 percent of their new tread depth—or to a depth, as measured in a groove, of 1/16th inch or less.
- Tread wear is severely uneven (in which case have the wheel alignment checked) or the center is worn much more than the edges (be more vigilant about tire pressures).
- Tire sidewalls are severely cracked or there are bulges anywhere on the tire.
- An indication of tread separation from the tire carcass is detected.
- Tire has been punctured and cannot be satisfactorily repaired.

There are other reasons you may need new tires, as well. If you have been running on winter tires, then a change is in order in the spring. Using snow tires on dry roads accelerates their wear significantly and diminishes both traction and handling ability.

- Installing tires in matched pairs or complete sets.
  Installing different tires on the left and right sides can significantly upset the handling balance of a vehicle—not to mention its operation. For that reason, it is imperative that tires be installed in front or rear pairs, or complete sets.
  Those pairs should be the same construction, size, brand and type, with approximately the same tread wear. In most cases, if you have to buy one new tire, you should buy a pair. It is essential that side-to-side pairs be the same and highly desirable that front and rear pairs also be matched, except in cases such as high-performance cars with larger tires in the rear. 14 If replacing only two, the new tires should generally go on the rear wheels, regardless of whether the vehicle is FWD, RWD, or AWD. It is important to maintain maximum traction at the rear wheels to ensure stability. Putting new tires on the front and nearly worn-out tires on the rear wheels of any vehicle is a recipe for instability. It is thus very important to avoid dramatic differences in tread wear, front-to-rear.
  Under no circumstances should you have tires of different construction (radial and bias ply) or different classification (all-season and winter) on opposite ends or sides, since handling can be adversely affected.
- Selecting the right tires for your vehicle and driving environment.
  Recent improvements in "all-season" tires have substantially advanced the concept of one-tire-for-all-needs. On the other hand, more tires than ever are now available for high performance, rain, snow, ice, off-road and touring. Some are even uni-directional, "run-flat" and even "green."
  Most drivers are happy just to know they have "all-season" tires, and that is the way most new vehicles are equipped. These are a general compromise, sacrificing exceptional capability in any one area of performance for acceptable capability in all.
  Within that compromise, however, there are huge variations in actual performance. Unfortunately, factors that improve one tire characteristic tend to diminish another. For example:
- a hard tread compound may enhance tread life and fuel economy but detract from both wet and dry traction;
- Short, stiff sidewall construction may enhance cornering power and directional stability but detract from ride quality;
- a wide tread with minimal grooving may enhance dry grip but detract from traction in wet and snowy conditions;
- An aggressive, open tread may enhance snow traction but aggravate tire noise and sacrifice tread life on pavement. 15 In addition to dry asphalt, tires may be expected to function on mud, snow, ice, sand or gravel, in temperatures from above 140°F to below -40°F. This will give an idea of the multiple tradeoffs designers have to make.
  Consideration should be taken that exceptional virtues are probably achieved at the expense of others. Therefore we have to determine what the primary needs are, and narrow the choices accordingly. Then, if possible, drive a similar vehicle equipped with the tires you are considering.

1.3 Tire Work load

The work load of a tire is monitored so that it is not put under undue stress, which may lead to its premature failure. Work load is measured in Ton Kilometer per hour (TKPH). The measurement's appellation and units are the same. The recent shortage and increasing cost of tires for heavy equipment has made TKPH an important parameter in tire selection and equipment maintenance for the mining industry. For this reason, manufactures of tires for large earth-moving and mining vehicles assign TKPH ratings to their tires based on their size, on construction, tread type, and rubber compound. The rating is based on the weight and speed that the tire can handle without overheating and causing it to deteriorate prematurely. The equivalent measure used in the United States is Ton mile/ hour (TMPH).

Determining the actual tire loads:

The weight of several tractor/trailer vehicle combinations that best represent actual maximum load conditions for these vehicles while in operation. Mathematically determine the mean (average) weights per axle of these weightings and divide that value by the number of tires on that axle to determine actual tire loading. While there are different ways to determine tire loading for a given vehicle, actual weighting is preferable, and will provide the best tire load information for setting inflation pressures.

Determining minimum cold inflation pressures for each tire per axle: 17 The actual tire load should be compared to the tire load limits on the chart for the particular tire size and ply rating. The corresponding recommended cold inflation pressure is indicated for the load in the chart heading. In all cases, the tire load limit on the chart should be the same or a larger amount than the actual determined tire load for the ply rating of the tire. If the actual tire loads are heavier than the ply rating of the applied tire, it may be necessary to install a tire with a higher ply rating.

The minimum inflation values:

In all cases, the determined inflation pressures based on actual load conditions should be considered minimum pressures. Operational air pressure can be set higher, but in no circumstances should they be set lower. Correct tire inflation is a key component in tire care. The recommended maximum inflation pressures for your tires are indicated on the certification label or in your owner's manual. Since RVs can be loaded with many different configurations, the load on each tire will vary. For this reason, actual air pressure required should be determined based on the load on each individual tire. Inflation pressure should be adjusted to handle the tire carrying the heaviest load, and all tires on the axle should be adjusted to this standard.

Each manufacturer provides load and inflation tables specific to their products to help determining the correct tire inflation pressure for the vehicle's loading.

Under inflation brings a higher risk of susceptibility to damage due to road hazards, reduces casing durability, and causes a loss in fuel economy, plus uneven or irregular tire wear. Severe or prolonged under inflation brings about an increased risk of tread separation.

It's a common practice for RV owners to lower tire pressure in their search for a smoother ride. This is not only dangerous, it's relatively ineffective, as the difference in ride quality is not significant. When minimum inflation pressure requirements are not met, tire durability and optimum operating conditions are compromised. Tire inflation pressure should always meet at least the minimum guidelines for vehicle weight [10][11].

II. Material And Methods

The materials of modern pneumatic tires are synthetic rubber, natural rubber, fabric and wire, along with carbon black and other chemical compounds. They consist of a tread and a body. The tread provides traction while the body provides containment for a quantity of compressed air. Before rubber is 18 developed, the first versions of tires were simply bands of metal that fitted around wooden wheels to prevent wear and tear. Early rubber tires were solid (not pneumatic). Today, the majority of tires is pneumatic inflatable structure, comprising a doughnut-shaped body of cords and wires encased in rubber and generally filled with compressed air to form an inflatable cushion. Pneumatic tires are used on many types of vehicles, including cars, bicycle, motorcycle, trucks, earthmovers, and aircraft. Metal tires are still used on locomotives and railcars, and solid rubber (or other polymer) tires are still used in various non-automotive applications, such as some casters, carts, lawnmowers and wheelbarrow.

2.1 Tire manufacturing

Tire production starts with bulk raw materials such as rubber, carbon black, and chemicals and produces numerous specialized components that are assembled and cured. Many kinds of rubber are used; the most common materials are styrene-butadiene copolymer. Regardless of how well a product meets design specifications and quality standards, it also must meet economical criteria in order to be competitive in the domestic and global marketplace. The first strict liability concept of product liability generally prevails in the United States. This concept states that the manufacturer of an article is liable for any damage or harm that results because of a defect and it doesn’t matter whether the manufacturer knew about the defect, or even could have known about it.

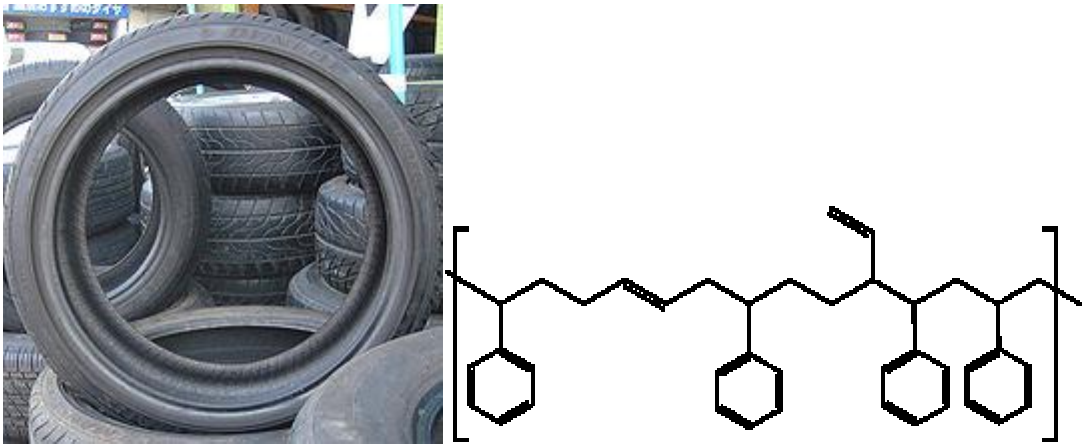

Figure 2

Styrene-butadiene copolymer (chemical structure pictured) is the most popular material used in the production of rubber tires. In 2004, $80 billion of tires were sold worldwide; in 2010 it was $140 billion. The top five tire manufacturing companies by revenue are Bridgestone, Michelin, Goodyear, Continental, and Pirelli. Many tires used in industrial and commercial applications are non-pneumatic, and are manufactured from solid rubber and plastic compounds via molding operations. Solid tires include those used for lawn mowers, skateboards, golf carts, scooters, and many types of light industrial vehicles, carts, and trailers. One of the most common applications for solid tires is for material handling equipment (forklifts). Such tires are installed by means of a hydraulic tire press. Semi-pneumatic tires have a hollow center, but they are not pressurized. They are light-weight, low-cost, puncture proof, and provide cushioning. These tires often come as a complete assembly with the wheel and even integral ball bearings. They are used on lawn mowers, wheelchairs, and wheelbarrows. They can also be rugged, typically used in industrial applications and are designed to not pull off their rim under use. Tires that are hollow but are not pressurized have also been designed for automotive use, such as the Towel (a portmanteau of tire and wheel), which is an experimental tire design being developed at Michelin. The outer casing is rubber as in ordinary radial tires, but the interior has special compressible polyurethane springs to contribute to a comfortable ride. Besides the impossibility of going flat, the tires are intended to combine the comfort offered by higher-profile tires (with tall sidewalls) with the resistance to cornering forces offered by low profile tires. They have not yet been delivered for broad market use [11][12].

Aircraft tires are designed to withstand extremely heavy loads for short durations. The number of tires required for aircraft increases with the weight of the plane (because the weight of the airplane has to be distributed better). Aircraft tire tread patterns are designed to facilitate stability in high crosswind conditions, to channel water away to prevent hydroplaning, and for braking effect. Aircraft tires are usually inflated with nitrogen or helium to minimize expansion and contraction from extreme changes in ambient temperature and pressure experienced during flight. Dry nitrogen expands at the same rate as other dry atmospheric gases, but common compressed air sources may contain moisture, which increases the expansion rate with temperature. Aircraft tires generally operate at high pressures, up to 200 pounds per square inch (14 bar; 1,400 kPa) for airliners, and even higher for business jets. Tests of airline aircraft tires have shown that they are able to sustain pressures of maximum 800 pounds per square inch (55 bars; 5,500 kPa) before bursting. During the test the tires have to be filled with water, instead of helium or nitrogen, which is the common content of aircraft tires, to prevent the test room being blown apart by the energy when the tire bursts.

Figure 3

Aircraft tires also include fusible plugs as in figure (3) (which are assembled on the inside of the wheels), designed to melt at a certain temperature. Tires often overheat if maximum braking is applied during an aborted takeoff or an emergency landing. The fuses provide a safer failure mode that prevents tire explosions by deflating in a controlled manner, thus minimizing damage to aircraft and objects in the surrounding environment [13].The requirement that an inert gas, such as nitrogen, be used instead of air for inflation of tires on certain transport category airplanes was prompted by at least three cases in which the oxygen in air-filled tires combined with volatile gases given off by a severely overheated tire and exploded upon reaching auto ignition temperature. The use of an inert gas for tire inflation will eliminate the possibility of a tire explosion.

Tire safety:

Proper vehicle safety requires specific attention to inflation pressure, tread depth, and general condition of the tires. Over-inflated tires run the risk of explosive decompression. On the other hand, under-inflated tires have a higher rolling resistance and suffer from overheating and rapid tread wear particularly on the edges of the tread. As tire treads decreases, there is more traction between the tire and the road resulting in better grip. However, there is an increased risk of hydroplaning, so as the tire wears the performance in the dry generally improves, but gets worse in the wet. Tires worn down past their safety margins and into the casing run the very real risk of rupturing. Also, certain combinations of cross ply and radial tires on different wheels of the same vehicle can lead to vehicle instability, and may also be illegal [14].

Tire Load and Inflation Standards:

The load range or ply rating branded on a tire's sidewall helps identify how much load the tire is designed to carry at its industry specified pressure. Passenger tires feature named load ranges while light truck tires use load ranges that ascend in alphabetical order (letters further along in the alphabet identify stronger tires that can withstand higher inflation pressures and carry heavier loads). Before load ranges were adopted, ply ratings and/or the actual number of carcass plies were used to identify the relative strength with higher numeric ratings or plies identifying tires featuring stronger, heavier duty constructions. Today’s load range/ply ratings do not count the actual number of body ply layers used to make up the tire's internal structure, but indicate an equivalent strength compared to early bias ply tires. Most radial passenger tires have one or two body plies, and light truck tires, even those with heavy-duty ratings (10-, 12- or 14-ply rated), actually have only two or three fabric plies, or one steel body ply.

In all cases, when changing tire sizes or converting from one type of size to another, it is important to confirm that the Load Index in the tire's s service description of the new tire is equal to or greater than the Load Index of the original tire and/or that the new tire’s rated load capacity is sufficient to carry the vehicle's Gross Axle Weight Ratings.

Tire pressure monitoring system:

Tire pressure monitoring systems (TPMS) are electronic systems that monitor the tire pressures on individual wheels on a vehicle, and alert the driver when the pressure goes below a warning limit. There are several types of designs to monitor tire pressure. Some actually measure the air pressure, and some make indirect measurements, such as gauging when the relative size of the tire changes due to lower air pressure.

Since air is a gas, it expands when heated and contracts when cooled. In most parts of North America, this makes fall and early winter months the most critical times to check inflation pressures...days are getting shorter...ambient temperatures are getting colder...and your tires' inflation pressure is going down. The rule of thumb is for every 10° Fahrenheit change in air temperature, your tire's inflation pressure will change by about 1 psi (up with higher temperatures and down with lower) [15].In most parts of North America as an example, the difference between average summer and winter temperatures is about 50° Fahrenheit...which results in a potential loss of about 5 psi as winter's temperatures set in and a 5 psi loss is enough to sacrifice handling, traction, and durability. Additionally, the difference between cold nighttime temperatures and hot daytime temperatures in most parts of the US country is about 20° Fahrenheit. This means that after setting tire pressures first thing in the morning, the vehicle's tire pressures will be almost 2 psi higher when measured in the afternoon (if the vehicle was parked in the shade), while that is expected, the problem is when setting the vehicle's tire pressures in the heat of the day, their cold pressures will probably be 2 psi low the following morning. So if the vehicle is parked in the sun, the sun's radiant heat will artificially and temporarily increase tire pressures.

We put some of these theories to the test at the Tire Rack. First, we mounted two tires on wheels. We let them sit overnight to equalize and stabilize their temperatures and pressures. The following morning we set them both to 35 psi. One tire and wheel was placed in the shade while the other was placed directly in the sun. We then monitored the ambient temperatures, tire temperatures and tire pressures through all the day. As the day's temperatures went from 67° to 85° Fahrenheit, the tire that was kept in the shade went from our starting pressure of 35 psi to a high of 36.5 psi. The tire that was placed in the sun and subject to the increase in ambient temperature plus the sun's radiant heat went from our starting pressure of 35 psi to a high of 40 psi. In both cases, if we had set our tire pressures in the afternoon under the conditions of our evaluation, they would have been between 2 and 5 psi low the following morning. Next we evaluated the effects of heat generated by the tire's flexing during use. We monitored the changes in tire pressure in 5-minute intervals. The test tires were inflated to 15 psi, 20 psi, 25 psi and 30 psi. Running them all under the same load, the air pressure in all of the tires went up about 1 psi during every 5 minutes of use for the first 20 minutes of operation. Then the air pressures stabilized, typically gaining no more than 1 psi of additional pressure during the next 20 minutes. This means that even a short drive to inflate your tires will result in tires that will probably be under-inflated by a few psis the following morning. Adding all of these together, we can understand why the conditions in which vehicle's tire pressures are set are almost as important as the fact that we do set it. It's important to remember that the vehicle's recommended tire pressure is its cold tire inflation pressure. It should be checked in the morning before driving more than a few miles, or before rising ambient temperatures or the sun's radiant heat affects it.

The tire contact patch is readily reduced by both overinflated and under inflation. Over-inflation may increase the wear on the center contact patch, and under-inflation will cause a concave tread, resulting in less center contact. Most modern tires will wear evenly at very high tire pressures, but will degrade prematurely due to low (or even standard) pressures. An increased tire pressure has many benefits, including decreased rolling resistance. It has been found, that an increased tire pressure almost exclusively results in shorter stopping distances, except in some circumstances that may be attributed to the low sample size. If tire pressure is too low, the tire contact patch is changed more than if it were over-inflated. This increases rolling resistance, tire flexing, and friction between the road and tire. Under-inflation can lead to tire overheating, premature tread wear, and tread separation in severe cases [16].

High performance and dynamic drivers often increase the tire pressure to near the maximum pressure as printed on the sidewall. This is done to sacrifice comfort for performance and safety. A tire at higher pressure is more inclined to keep its shape during any encounter, and will thus transmit the forces of the road to the suspension, rather than being damaged it. This allows for an increased reaction speed, and “feels" the driver perceives of the road. Modern tire designs allow for minimal tire contact surface deformity during high pressures, and as a result the traditional wear on the center of the tire due to reasonably high pressures is only known to very old or poorly designed tires. Therefore very high tire pressures have only two downsides: The sacrifice in comfort; and the increased chance of obtaining a puncture when driving over sharp objects, such as on a newly scraped gravel road. Many individuals have maintained their tire pressures at the maximum side wall printed value (inflated when cold) for the entire lifetime of the tire, with perfect wear until the end. This may be of negative economic value to the rubber and tire companies, as high tire pressures decrease wear, and minimize side wall blow outs [17]. It is dangerous to allow tire pressure to drop below the specification recommended on the vehicle placard. Low pressure increases the amount of tire wall movement resulting from cornering forces. Should a low-pressure tire be forced to perform an evasive maneuver, the tire wall will be more pliable than it would have been at normal pressure and thus it will "roll" under the wheel. This increases the entire roll movement of the car, and diminishes tire contact area on the negative side of the vector. Thus only half the tire is in contact with the road, and the tire may deform to such an extent that the side wall on the positive vector side becomes in contact with the road. The probability of failing in the emergency maneuver is thus increased. When driving on sand or in deep snow, tire pressure is sometimes lowered to reduce the chance of bogging down.

Furthermore, the tire will absorb more of the irregular forces of normal driving. With this constant bending of the side wall as it absorbs the contours of the road, it heats up the tire wall to possibly dangerous temperatures. Additionally, this flexing degrades the steel wire reinforcement; this often leads to side wall blow-outs. Low pressure tires can be subjected to pinching. If the vehicle drives into a pot-hole, the side wall can temporarily collapse, thereby pinching the tire between the steel wheel and road. This can result in a tire laceration and blow-out, as well as a damaged wheel. Feathering occurs on the junction between the tire tread and side wall, as a result of too low tire pressures. This is as a result of the inability of the tire to perform appropriately during cornering forces, leading to aberrant and shearing forces on the feathering area. This is due to the tire moving sideways underneath the wheel as the tire pressures are insufficient to transmit the forces to the wheel and suspension [18].

2.2 Speed rating

The speed rating denotes the maximum speed at which a tire is designed to be operated. Nowadays for passenger vehicles these ratings range from 99 to 186 miles per hour (159 to 299 km/h).

(Table 1)

For W-Speed Rated Tires						
Vehicle Top Speed		Required Tire Pressure Increase		Tire Load Capacity % of Branded Maximum	W-Speed Rated Tire 35 psi O.E. Example	
mph	km/h	psi	Bar	% of value branded on sidewall	psi	lbs.
118	190	0	0	100%	35.0	1000
124	200	1.5	0.1	100%	36.5	1000
130	210	3.0	0.2	100%	38.0	1000
136	220	4.5	0.3	100%	39.5	1000
143	230	6.0	0.4	100%	41.0	1000
149	240	7.5	0.5	100%	42.5	1000
155	250	7.5	0.5	95%	42.5	950
161	260	7.5	0.5	90%	42.5	900
168	270	7.5	0.5	85%	42.5	850

In our example shown below, the vehicle manufacturer's recommended 35 psi for a 225/45R17 91W Standard Load tire installed on a vehicle initially rises in 1.5 psi increments for every 10 km/h (6.2 mph) increase in speed until the inflation pressures max out with an increase of 7.5 psi when the vehicle's top speed has increased 50 km/h (31mph). Then as the vehicle's top speed continues to climb, the rated load capacity of the tire is reduced in 5% increments for every additional 10 km/h until the vehicle's top speed has increased an additional 30 km/h (18.6 mph). In this case the 225/45R17 91W Standard Load size's rated load capacity of 1,477 lbs. is reduced to 1,255 lbs. when applied to a vehicle with a 270 km/h (168 mph) top speed see table (1) [19].

2.3 Mathematical calculation Analysis:

It is important to know which standard is applicable for any given tire size designation as the load capacity may differ at any inflation pressure value. The TRA developed the P-metric standard and the ETRTO developed the ISO Metric/Hard Metric standard. For example, TRA P225/55R17 95T has a maximum load capacity of 1521 lbs. and 35 psi while 225/55R17 97T has a maximum load capacity of 1609lbs. and 36 psi see table (2). Tires with the same load index, regardless of tire size, may carry the same load, but not always, and they may require substantially different inflation pressures. The load index may not be used independently to determine replacement tire acceptability for load capacity. An equal or greater load index does not always correspond to equal or greater load capacity at all inflation pressure settings, particularly when comparing P-metric and Euro-metric passenger car tires.

(Table2)

Table 2. E.T.R.T.O. Load Inflation Table 97 load index.

load Index	Inflation Pressure (PSI)										
	26	27	28	29	30	31	32	33	34	35	36
97	1235	1272	1290	1345	1400	1421	1455	1510	1530	1554	1609

Original equipment:

- Locate tire information placard to confirm OE tire size and cold inflation pressure. (The tire information placard can be found on the vehicle door edge, door jam, glove-box door, or inside of the trunk lid.)
- Identify the standard used (TRA for P-metric, LT-metric, and flotation sizes and ETRTO for Euro metric sizes) and refer to the appropriate load inflation table. An example to that the OE size is P225/60R18 (P-metric), so we would refer to the TRA Load Inflation Table.
- Find the corresponding load for the OE tire size(s) at the recommended cold inflation pressure.
-

2.4 Replacement of tire

In case the standard tires are to be replaced by other standard the following additional steps should be preceded:

- Use the appropriate load inflation table for the replacement tire size(s).
- Find the inflation pressure to which the corresponding load is equal to or greater than the OE tire.
- Inflate tires to the appropriate inflation pressure.

If the replacement tire requires a different inflation pressure than OE, the installer should inform the owner of the new required inflation pressure and should also place a sticker or decal over the vehicle tire placard showing the new tire size and recommended inflation pressure for future reference. Generally never use an inflation pressure lower than what is recommended by the vehicle manufacturer.68

Examples of implementing this procedure are carried out in the following:

2.5 Example1

Replace O.E. P235/45ZR17 93W with a Plus-1 245/40ZR18 97W reinforced on a 2006Mitsubishi Lancer Evolution IX. The O.E. tire is P-metric; therefore use the TRA Load Inflation Table (see Table 3) to look up the load capacity at the O.E. inflation pressure. For the standard load P235/45ZR17 93W, at 32 psi the load carrying capacity of the front is 1354 lbs and the rear load at 29 psi is 1272 lbs according to table (3) TRA Load Inflation Table (3).

(Table 3)

Table 3. TRA Load Inflation Table.

Load Index	Tire Size	Inflation Pressure (PSI)			
		26	29	32	35
93	P235/45R17	1188	1272	1354	1433

If replacing the O.E. tires with Proxies T1R245/40ZR18 97W RD which is a reinforced ETRTO spec; therefore, refer to the ETRTO Reinforced Load Inflation Table (Table 4). As indicated previously, always maintain any differences in inflation pressures front to rear that are shown on the vehicle placard. In order to maintain the same staggered inflation pressure from front to rear, while still carrying an equal or greater load, the front tire must be inflated to 35 psi (1378 lbs.) in the front, while the rear tires will need to be inflated to 32 psi (1290 lbs.).
Table (4) shows the ETRTO Reinforced Load Inflation:

(Table 4)

Table 4. ETRTO Reinforced Load Inflation Table.

Load Index	Inflation Pressure (psi)														
	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
97	1146	1190	1246	126[illegible]	1290	1334	1359	1378	1433	1454	1477	1521	1547	1565	1609

In order to adequately support the load, the 2006 Mitsubishi Lancer Evolution IX with aplus 1 fitment of245/40ZR18 97W RD must be inflated to front 35 psi and rear 32 psi.
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Application of load inflation tables from LT-metric to LT-Metric as follows:

2.6 Example2

Replace the O.E. LT315/70R17 121R with a plus zero LT325/70R17 122R on a 2006 HummerH2.
The original equipment size is LT- metric; therefore use the TRA Light Truck Load Inflation Table (see Table5) to find the load carrying capacity at the recommended 42 psi.

(Table 5)

Table 5. TRA Light Truck Load Inflation Table

Tire Size	Single/Dual	psi_35	psi_40	psi_45	psi_50	psi_50 load range
315/70R17	Single	2535	2685	2915	**3195**	**D**

It's seen that in this table that the 42 psi falls between the published values, so by extrapolation, the load is 2595 lbs. This can be calculated as follows [19]:

$$\frac{2915\ lbs. - 2685 lbs.}{45\ psi - 40\ psi} = \frac{230}{5} = 46\ lbs. per\ each\ 1\ psi\ increase\ from\ 40\ to\ 45\ psi$$

Therefore, add 92 lbs. to 2685 lbs. to calculate the load at 42 psi to get 2777 lbs.
Then if the O.E. tires also is to be replaced with the Open Country A/T LT325/70R17 122R D/8, so we use the Open Country A/T Load Inflation Table 6, we extrapolate again to find that the tires at 42 psi will sufficiently carry the O.E. load based on the O.E. inflation pressure. The corresponding load at 37 psi is 2667 lbs.

(Table 6)

Table 6. Open Country A/T Load Inflation Table.

Tire Size	Inflation Pressure (PSI)			
	35	40	45	50
LT325/70R17 122R D/8	2555	2835	3085	**3305 (D)**

In order to adequately support the load, the 2006 Hummer H2 with a plus zero fitment of LT325/70R17122R D/8 must be inflated to 42 psi (front and rear).O.E. Information (Obtained from the T.I.P.) [20][21]:

III. Conclusions

It was observed that availability of information on tire specifications form all tire manufacturers is extremely poor, with a general absence of a central monitoring information management system. As a result of this it is impossible for tire fitter men and individuals' dealers to assess really the extent of good tire operation and maintenance and to formulate appropriate tire failures solution. It was noted that there was poor networking and functional relations between industries, academic institutions, Non-Governmental Organizations and Community Based Organizations to transfer or share of needed tire properties information, dissemination of lessons learned from tire failure and to insure best practices among tire national and international stakeholders.

Most countries are not heavily industrialized to produce any advanced technology for tire quality control, maintenance and tire waste processing.

In some cases tire operation and maintenance management problems are due to poor technology of manufacturing of some tire manufacturers industries and outdated technology of maintenance in other cases and low trained cadre. Inadequacy of legislation for tire manufacturing industries and tire maintenance workshops in most part of the world as the result of that tire quality is continuously declined.

Lack of trained personnel in most countries to establish, enforce, and implement strong tire quality control system in stage of manufacturing and in tire operation stage to standard limit tire failure is expected to be in continuous rising.

Lack of experience cadre to understand and use appropriate technologies that can be used in tire maintenance processing especially in tire auto repair workshop; to set a proper tire inflation is becoming impossible this resulted badly to tire time life and safety.

IV. Recommendations

Tire mathematical inflation rate modeling in the automotive tire workshops are defined and links to a series of case studies. The conceptual and procedural approach to that demand all phases of the tire life cycle of an automobile with its service process. This should be addressed with the objective of proper tire inflation pressure putting in consideration all around circumstances of tire loading, time, ambient temperature and size. This in a short and long term will minimize risks to humans when tire subjected to failure, to guarantee safe car running and long life of used tires. To insure proper tire inflation pressure rate an effort should be done including the following:-

- Memorandum of a need to technical study for proper understanding of tire contracts on manufacturing and purchasing for any kind of tires.
- Need for investment in research and development for new technology of tire risk minimization options before it can be let in use in the country.
- Formulating easy funding mechanisms in studying tire quality control in all tire life stage according to different needed conditions if possible.
- To limit the use of high tire manufacturers mark number as far as possible to help in the process of quality assurance following.
- Good and efficient tire maintenance management will result to a reduction in earlier tire failure.
- Encouraging international standardization cooperation of all tire stages of designing, manufacturing and exploitation to guarantee high safety and acceptable tire duration.
- Persuade the use of latest technology in tire manufacturing and maintenance.
- Promote supportive relevant legislations and regulation in order to empower efficient management of tire quality control in all countries of the world.

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