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Identification of Risks of Failure of Pneumatic Tyres of Passenger Vehicles in Ghana

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Abstract: **In-transit failures of pneumatic tyres of heavy vehicles such as passenger buses, which ply some major intercity highways in Ghana remain a great source of worry in Ghanaian transportation system. The study seeks to identify major causes of the in-transit failures of pneumatic tyres of heavy vehicles, and how to prevent such failures. Five thousand (5000) pneumatic tyres were sampled using a simple random sampling method and idiosyncrasies of some drivers of these heavy passenger buses were observed. The data gathered was analyzed using cross tabulation and simple statistics. It was found out that tubeless pneumatic tyres used by these heavy passenger buses have higher risk of failure than the tubed ones. In addition, the study revealed that some brands of tyres have higher failure rates than others under conditions such as nature of road, loading capacity and tyre maintenance. The study recommends that tyre usage rules should be complied with in order to reduce the risk of failure of pneumatic tyres among passenger vehicles.**

Keywords: **Risk, in-transit failure, pneumatic tyre, transportation, automobile, passenger vehicles, road safety.**

1. INTRODUCTION

Transportation is a necessity for allowing production and consumption of products to occur at different locations. Transport has throughout history been a spur to expansion; better transport allows more trade and a greater spread of people. Economic growth has been reliant on increasing the capacity and rationality of transport. Transport is a crucial driver of economic and social development, bringing opportunities to the people and enabling economies to be competitive. Transport infrastructure connects people to jobs, education, and health services; enables the supply of goods and services around the world and allows people to interact and generate knowledge and solutions that foster long-term growth. But the infrastructure and operation of transport has a great impact on the land and is the largest consumer of energy, making transport sustainability a major issue.

The fundamental mechanism used in road transportation is the wheel. The wheel is a device that enables efficient movement of an object across a surface where there is a force pressing the object to the surface. Tyres provide a gripping surface for traction and serve as a cushion for the wheels of a moving vehicle. Tyres are found on **automobiles**, trucks, buses, aircraft landing gear, tractors, farm equipment, industrial vehicles such as forklifts, and common conveyances such as baby carriages, shopping carts, wheel chairs, bicycles, and motorcycles.

A tyre is a strong, flexible rubber casing attached to the rim of a wheel. Tyres for most vehicles are pneumatic; air is held under pressure inside the tyre. Until recently, pneumatic tyres had an inner tube to hold the air pressure, but current pneumatic tyres are designed to form a pressure seal with the rim of the wheel and as such, require no inner tubes.

Wheels have evolved with time from brands of iron or steel to the complex pneumatic tyres that we see today. Pneumatic or air-filled tyre is made up of an airtight inner core filled with pressurized air. A tread, usually reinforced with steel belting or border materials covers this inner core and provides the contact area with the road. The pressure of the air inside a tyre is greater than atmospheric air pressure, so the tyre remains inflated even with the weight of a vehicle resting on it.

2. PROBLEM STATEMENT

The main contact between a car and the road is the few square inches of area occupied by the tyre. A heartbreaking declaration is that, not many drivers attach the importance that the tyre deserves to vehicle care and maintenance. In the year 2000, tyre failure accounted for 2,045 accidents in Germany and 46 of them were fatal. Data shows that 41.9% of these accidents are directly or indirectly related to tread depth (Bako, 2013). Therefore, this study seeks to establish the causes of failures of pneumatic tyres of heavy Passenger Buses or vehicles and to suggest some benchmarks for the effective usage of these tyres to prevent failures.

Figure 1: A failed pneumatic tyre

3. LITERATURE REVIEW

A tyre derived from the word ‘tie’ is a ring-shaped component of a vehicle that covers and protects the wheel rim and enable better vehicle performance (Guo, 2004). The very first tyres were brands of iron placed on the wooden wheels of carts and wagons. Luckily, with the discovery of rubber, things changed. A Pneumatic tyre is a flexible, hollow rubber tyre which is inflated and maintains its shape because of air pressure. Pneumatic tyres may be of a tube type (having a separate inner tube which is filled with air within the body of the tyre which has a construction permeable to air) or a tubeless design (which is constructed from coated layers and an inner coating of rubber which resists the passage of air through its constructed layers) commonly known as radial ply and standard on most current vehicles (Beer, Fisher & Jooste, 1997).

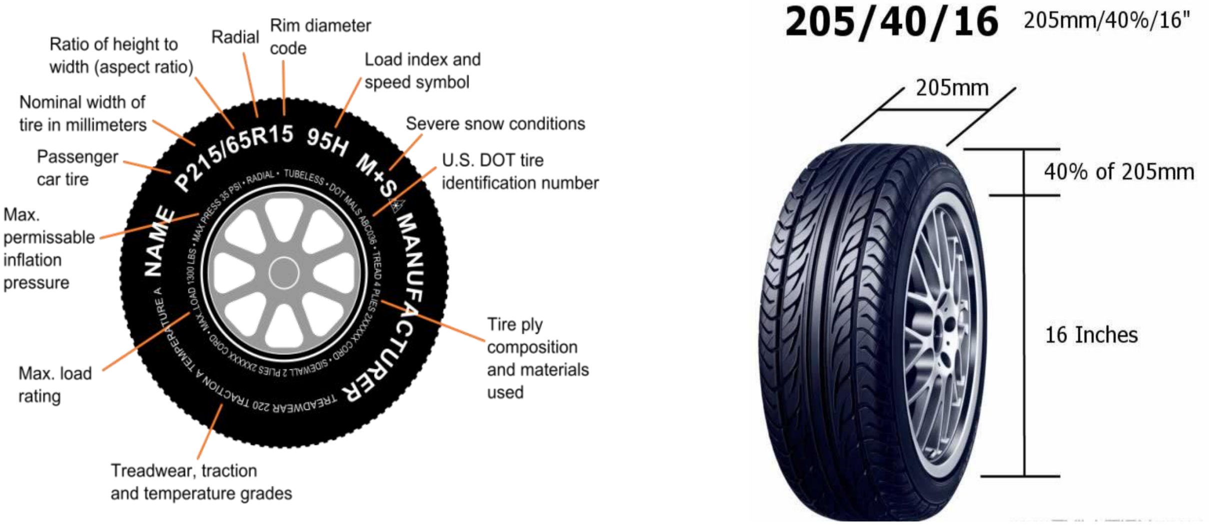

Figure 2: Tyre markings and codes (source: www.tireguides.com)

Tyre pattern can be classified in many ways. Some of these classifications according to (Committee for the National Tire Efficiency Study, 2006) are given below.

i. **P (on the side of the tyre).** It is an International Organization Standardization (ISO) Metric tyre code which consists of a string of letters and numbers. The “P” indicates the tyre is for passenger vehicles. Other related codes are

a. **LT**: Light Truck

b. **ST**:h Special Trailer

c. **T**: Temporary (restricted usage for "space-saver" spare wheels)

ii. **Next number:** This three-digit number (215) gives the width in millimeters of the tyre from sidewall edge to sidewall edge. In general, the larger the number, the wider the tyre.

iii. **Next number:** This two-digit number (65), known as the aspect ratio, gives the tyre’s ratio of height to width. Numbers of 70 or lower indicate a short sidewall for improved steering response and better overall handling on dry pavement.

iv. **R:** The “R” stands for radial. Radial ply construction of tyres has been the industry standard for over 20 years.

v. **Next number:** This two-digit number (15) is the wheel or rim diameter in inches. If you change your wheel size, you will have to purchase new tyres to match the new wheel diameter.

vi. **Next number:** This two- or three-digit number (95) is the tyre’s load index. It is a measurement of how much weight each tyre can support. Though this information may not be available because it is not required by law, it should be available in most owner’s manuals. If it is not available in the owner’s manual, a local tyre dealership may be contacted.

vii. **M+S:** The “M+S” or “M/S” indicates that the tyre has some mud and/or snow capabilities. Most radial tyres have these markings; hence, they have some mud and snow capabilities.

Table 1: Tyre speed capabilities (source: www.tireguides.com)

Letter Rating	Speed Rating
Q	99 mph
R	106 mph
S	112 mph
T	118 mph
U	124 mph
H	130 mph
V	149 mph
W	168 mph
Y	186 mph

For tyres with a speed capability over 149 mph, tyre manufacturers sometimes use the letters ZR.

The quality of pneumatic tyres is directly related to its installation, maintenance, alignment and regular inspection. Failure of pneumatic tyres starts immediately upon its repairs, mixing, pressure, faulty suspension parts and wheel alignment. Checking the load ratings of the tyre, inspecting tyres after installation, replacing worn-out tyres, and cautiously checking the pressure ratings of the tyre will maintain the quality of the tyre (Clark, 1975). Some of the factors responsible for tyre wear and failure are: poor repairs of damaged tyres, tyre mixing, wrong tyre pressures, faulty suspension parts and wheel alignment, storage, overloading, tyre brand and construction, driving style, road conditions and a few other factors which cannot be properly placed into specific categories.

In the event of tyre damage, usually the damage is just considered as injury to the outer rubber. At times the damage can extend down to the reinforcing materials of the tyre. Damage to the reinforcing materials caused by a nail for example is a serious problem because moisture and dirt or other tiny particles may penetrate the tyre during the time between damage and detection of the damage. This may cause a more serious damage to the reinforcing materials. Damage to the inside of the tyre can also cause a slow puncture. The tyre is then driven underinflated hereby causing undue strain. Hence, before damage is detected, the tyre can be damaged beyond repair. In repairing a tyre, not all areas of the tyre can be repaired. Other cases in which the tyre must not be repaired are when the tyre's structural integrity is broken down, aged and deteriorating tyre rubber, bead or liner damage, exposed cords and faulty or poor previous repairs (Wang & Roque, 2011).

For best performance, it is usually recommended that the same size and type of tyre be used on all wheels position unless the vehicle manufacturer specified different sizes, front and rear. Such information is usually contained in the vehicle placard. If only two radials are mounted with two non-radials, the radials should be mounted on the rear (Bell, 2002). If tyres of different types are mixed on a vehicle in any configuration, they should not be used for long time and speeds should be kept to a minimum. Tyre mixing is not encouraged so avoid using tyres of different constructions, sizes, speed, load and pressure ratings.

According to Bell (2002), when tyres of different speed ratings are used, it is possible that one of the speed ratings will be exceeded while acceptable speed ratings will be within range for another tyre. Exceeding the speed rating is a risk because it leads to extra strain on the overloaded tyre; Thereby causing the tyre with extra strain to wear out faster than the others. Tyres may have the same ratings though not of the same brand but it does not necessarily imply that they will wear uniformly. Different 'manufacturers' means that different production methods can be used or even different standards and tolerances can be used where the same production methods are used. This can cause uneven wear of tyre as the durability may not be the same.

Tyre inflation pressures specified by vehicle and tyre manufacturers are contained in vehicle placard and tyre sidewalls respectively. The stated tyre pressures are always specified for cold conditions. Tyre pressures always increase during driving. This is due to the ambient temperature, tyre-road friction and the vibration of the air molecules in the tyre due to vehicle motion. Pressures should be checked when the tyres are cold (vehicle should have been parked for at least two hours and has not been driven more than one to three miles). Different tyre pressures should never be used in the same axle. The spare tyre should be inflated to at least the maximum tyre rating of the vehicle placard (Pernetti & Scalera, 2002). The tyre pressure ought to be appropriate to ensure proper vehicle handling and to prevent irregular tyre wear.

Over-inflation is caused by excessive pressure in the tyre and it highly reduces the contact area between the road and tyre surface. The reduced contact area decreases traction and the tyre is likely to wear out quickly and irregularly (usually at the center of the contact area). Excessive pressure prevents the tyre from being flexible enough to absorb shocks from bumpy and pothole infested roads. When an overinflated tyre (that is, inflated above the recommended air pressure limit) hits a stone or bump, the cords may snap, leading to tyre failure. In addition, the center of the tread wears more rapidly and does not permit equal wear across the entire tread. Hard riding from too much air pressure also increases wear (Bullas, 2004).

Under-inflation occurs when the tyre pressure is low, meaning that underinflated tyre does not contain enough air for its size and the load it must carry; this phenomenon is more common than over-inflation. It flexes excessively in all directions and gets hot. In time, the heat weakens the cords in the tyre and may cause a blowout. Under-inflation also causes tread edges to scratch the road, which puts uneven wear on the tread and shortens the tyre life. Driving on an under-inflated tyre for any distance increases the chances of ruining the tyre beyond repairs. The sidewalls of under-inflated tyres tend to bulge and as such, the tyre treads wear out faster on the sides of the contact area. This phenomenon increases the rolling pressure and fuel consumption (Pernetti & Scalera, 2002).

Tyres should be stored in a cool, dry and lightly ventilated room. Intense sunlight or extreme heat may cause tyres to crack and effective air circulation accelerates this process. Tyres which are not fitted to the rim should be stored standing up. Contact should not be made with fuels, lubricants, solvents or chemicals (Beer, Fisher & Jooste, 1997). Precautions must be taken against the deliberate or accidental ignition of tyre stock piles. The major risk is that a fire could gather pace without the possibility of preventing it from spreading to all of the tyres being stored. In such an eventuality, several different types of pollution of the air, water and soil can occur (Beer, 2005).

The maximum load ratings of tyres are usually on the sidewalls of the tyres. These loads ratings must never be exceeded. Vehicle placards or vehicle manuals usually show the gross axle weight ratings. These gross axle weight ratings must also not be exceeded. When placing original tyres with tyres of a different size, the replacement tyres must have a load carrying equal to or greater than the original tyre (Bell, 2002). Overloading a tyre, results in the combined effect of over-inflation and under-inflation. The tyre then becomes open to excessive tread and sidewall movement. It can also result in cord tension and bead stress, which lead to excessive heat generation. These causes premature failure such as separation, impact fractures, penetrations and reinforcement flex breaks (Bullas, 2004; Pernetti & Scalera, 2002).

(i) Gross axle weight rating: The weight specified by the vehicle manufacturer as the load-carrying capacity of a single axle system. The gross axle weight rating is limited by the minimum tyre and wheel load ratings.

(ii) Gross combined weight ratings: The weight specified by the manufacturer as the maximum loaded weight of a vehicle and its trailer. The sum of the weights of the loaded vehicle or truck and trailer should not exceed the gross combined weight rating.

(iii) Gross vehicle weight rating: This is the maximum allowable weight of the fully loaded vehicle (including passenger and cargo) (Beer, Fisher & Jooste, 1997).

The type of construction as well as the brand of the tyre also relate to tyre life. Certain tyre brands are known to be long lasting compared to other brands under the same handling, driving and loading conditions. It is widely accepted that radial tyres are better than cross-ply tyres. When a tubeless tyre gets punctured, air escapes only through the hole created by the piecing object. This gives a substantial time between a puncture and a flat tyre. There is less damage to the tyre in the case of running on flat tyres when dealing with tubeless tyres (Bell, 2002).

Driving styles vary from driver to driver. Some drivers are far more careful than others. Some of the factors in driving style that affect tyre life span are:

i. **Sudden stopping or braking-** this is when brake is instantaneously pressed down to bring the vehicle to a halt. This causes additional load on the front tyres, thus the wear effects of overloading are experienced on the front tyres. The intensity of the friction also causes additional wear on the tyres.

ii. **Sudden starting or acceleration-** this is when the accelerator is instantaneously pressed down to move the vehicle forward. The acceleration causes load to transfer to the rear tyres of the vehicle. This causes additional load on the rear tyres, thus the wear effects of acceleration and overloading are experienced on the rear tyres.

iii. **Hard cornering and over speeding-** this is when curves are taken sharply and at high speeds. This causes load to transfer to the side of the vehicle on the outer of the curve and the overloading effect is again experienced. At high speeds, even with the correct inflation pressures, a road hazard is more difficult to avoid and if contact is made, has a greater chance of causing tyre damage than at a lower speed (Pernetti & Scalera, 2002; Bell, 2002).

Tyre wear mainly originated from sliding in the rear part of the tyre-road contact patch (Bell, 2002). It is mostly affected by the micro texture of the road surface and tyre temperature the wear is affected by the normal pressure distribution on the tread element, which is directly affected by road surface texture. Increased tyre temperature leads to tyre wear. Thus, if use of a tyre on a specific road surface causes excessive heat build-up (i.e. through excessive flexing), and the wear rate of the tyre will also increase (Beer, Fisher & Jooste, 1997). The road texture is therefore an important factor in tyre wear. A road with coarse texture causes excessive flexing of the tyres, excessive heat buildup and hence quicker tyre wear. Debris such as scrap materials and sharp discarded material can cause tyre wear.

To utilize the full potential life built in a tyre, periodic rotation is necessary. Changing the position of tyres at regular intervals is generally favored to compensate for any difference in the working tread pattern wear, or uneven wear due to different working positions, thereby to obtain a longer overall tread pattern life, tyre efficiency and stability in cornering and braking. When rotating bias, belted bias, and radial tyres, the spare tyre is also rotated (in accordance with established measurements). After all of the tyres are rotated, the tyre that becomes the spare should be interchanged with the smallest diameter tyre on the vehicle, in accordance with proper tyre matching (Beer, Fisher & Jooste, 1997).

4. METHODOLOGY

The study site covered three major passenger bus loading stations in Greater Accra Region of Ghana. These are the Tema Community 1 lorry station, the Tema Station near Accra Metropolitan Assembly Office Complex and the Kaneshie lorry stations in Accra. All major cities in Ghana including Kumasi, Tamale, Cape Coast, Koforidua, Wa and Bolgatanga are places where the study can be investigated. Though, these loading stations are not the only places where the failure of passenger bus tyres can be studied, they were chosen because they serve as both the origin and the destinations of major transport service providers in the country. The main motivation for selecting these stations is because of easy access to the

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passenger buses, their workshops and mechanics. Five thousand (5000) pneumatic tyres were sampled using a simple random sampling method and idiosyncrasies of some drivers of these heavy passenger buses were observed. Data collection was mainly done through observation of the pneumatic tyres used by these vehicles some of which were still being used by the passenger busses and other removed and packed ones at the various workshops by the mechanics and vulcanizers. There were also some interviews on the reasons for choosing a particular brand of tyres, road and human factors responsible for tyre failures among others.

5. PRESENTATION OF DATA AND ANALYSIS

One of the objectives for carrying out this research was to identify the factors responsible for the failures of tyres among Ghanaian Passenger Buses. A sample of 500 failed pneumatic tyres was drawn from 45 passenger bus drivers/owners' store houses. The sampled buses are buses that travel long-distances on the Accra-Winneba, Accra-Kumasi, Accra-Cape Coast/Takoradi, Accra-Aflao as well as Kumasi-Tamale intercity routes. Most of these failed tyres were found at main lorry stations in Accra (Tema Station & Circle Neoplan/VVIP stations). These failed tyres were physically examined and observed. The owners, drivers and/or conductors of the vehicles with failed tyres were interviewed for clarifications on the exact cause of their failures.

(i) Causes of Pneumatic Tyre Failures among Passenger Buses

Considering the different causes of tyre failures among Passenger Buses the study revealed that overloading contributes to failures of about 1051 out of 5000 tyres representing 21% of tyres sampled.

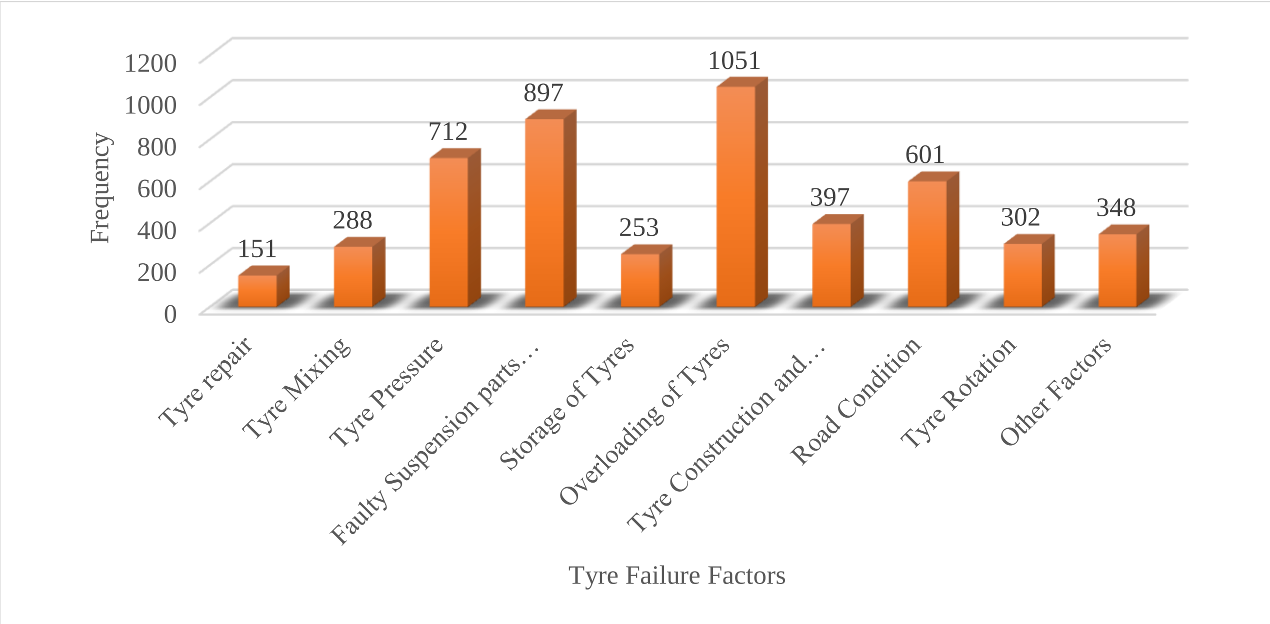

Figure 3: Causes of tyre failure of passenger buses

(a) Wrong repair of Passenger Buses tyres

From Figure 3, 151 out of 5000 samples of tyres failed due to wrong repair of tyre. It can be inferred that 3% of the total sample failed because of wrong repair. The first step in repairing tubeless tyres is to locate the piercing object. The object is removed and the area is roughened. Adhesive glue is applied to both the roughened area and the cold patch, then left for about five to six minutes to dry. The cold patch is then firmly pressed on the roughened area. After about ten to twenty minutes, the tyre is fitted to the wheel. After about twenty minutes, the tube is fitted to the tyre, inflated and fitted to the wheel. When tubeless tyres are badly damaged by a piercing object, the vulcanizers fit an inner tube into the damaged tubeless tyre, hence, using it as tubed tyre. In the repair of tubeless tyres of Passenger Buses, only cold patch fittings were used instead of the recommended plug and patch fittings for tubeless tyres. The recommended second coating adhesive glue used to the patch and roughened tyre area were not applied to these Passenger Buses. Therefore, it was observed that the tyre repair procedure is flawed hence tyre repair is one factor of tyre failure of the sampled Passenger Buses.

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(b)Tyre mixing among Passenger Vehicles

Figure 3 shows that 288 out of the 5000 damaged tyres that were sampled failed due to tyre mixing representing 5.8%. From careful observations, radial tyres are the predominantly used tyres by Passenger Buses. It was observed that tyres of different sizes and types are used on all wheel positions, which were not specified by the vehicle manufacturer in the placard. In fact, tyre mixing poses hazard to the tyres because each brand of tyre has different resistances to heat, wear and different traction qualities even if they have the same ratings. This is why tyre mixing should not be encouraged in order to avoid using tyres of different constructions, sizes, speed, load and pressure ratings. It was also observed that tyres of smaller radii were wearing at a faster rate as compared to those of bigger radii, as the vehicle tends to lean in the direction of the smaller tyre. Furthermore, when tyres of different pressure ratings are used, it causes a problem of either under-inflation or over-inflation on one tyre and abnormal tyre wear leads to damages.

Table 2: Tyres used on the left and right sides of each axle of selected Yaxing Buses

Axle	Left Side	Right Side
A	Kumho 65R22.5	Linglong 65R22.5
B	Linglong 65R22.5	Linglong 65R22.5
C	Double Star 12R20	Double Star 12R20
D	Alexanderia 12R20	Double Star 12R20
E	Wanli 11R20	Wanli 11R20

From Table 2, we see tyres of different brands and load ratings being used. With the different load ratings at the same pressure, we expect their load bearing capabilities to differ at different pressures. Under a load of 3270kg, the Double Star Tyre will be able to carry the load without failure while under the same load, the Otani Tyre is expected to fail due to its smaller load rating.

Table 3: Tyres used on the left and right sides of each axle of Neoplan VDL Bus

Neoplan VDL Bus		
Axle	Left Side	Right Side
A	Linglong 65 R 22.5	Linglong 65 R 22.5
B	Kumho 65 R 22.5	Kumho 65 R 22.5
C	Double Star 12 R 20	Double Star 12 R 20
D	Otani 12 R 20	Double Star 12 R 20
E	Otani 12 R 20	Nutech 12 R 20

From Table 3, on axle D of Neoplan VDL Bus, Otani tyres are used on the left side of the axle while Double Star Tyres are used on the right side of the axle. The tyres are of different load ratings. Their ratings are as follows:

1. Double Star – Max Dual: 3270kg at 105 psi
2. Otani – Max Dual: 3150kg at 105 psi

This is a clear case of tyre mixing, which is a recipe for tyre failure and disaster waiting to occur.

Table 4: Comparison of the tyres and axles of Yaxing Bus and Neoplan VDL Bus

Axle	Yaxing Bus	Neoplan VDL Bus
A	65 R 22.5	65 R 22.5
B	65 R 22.5	65 R 22.5
C	12 R 20	12 R 20
D	12 R 20	12 R 20
E	11 R 20	12 R 20

Table 4 shows comparison of the tyres and axles of the Yaxing Bus and Neoplan VDL Bus, comparing the tyre sizes on the equivalent axles of the buses, axle E of Yaxing Bus uses tyres of sizes 11R20. On axle E of Neoplan VDL Bus, however, tyres of sizes 12R20 are used. This is a case of wrong tyre specification usage that leads to tyre failure.

(c) Tyre pressure of Passenger Buses

From Figure 3, it can be seen that 712 out of 5000 samples of damaged tyres failed because of improper tyre pressure, depicting 14.2% of the sample. No routine checks on tyre pressure is done on these Passenger Buses and the issue of tyre inflation and pressure only come up after repairs or when it is observed that a tyre has lost a noticeable amount of pressure. This is usually after the tyre goes down noticeably or the effects of under-inflation are noticed while driving. Most of these vehicles do not have a function Tyre Pressure Monitoring Systems (TPMS), which could be useful in determining loss of tyre pressure.

Per the survey, it was observed that vulcanizers usually inflate tyres to pressures exceeding the recommended pressure rating within ten to twenty psi. The exact pressure value is chosen based on the vulcanizers' discretion instead of adhering to the vehicle manufacturer's specification on the vehicle placard or the side marking on the tyre. Therefore, maintaining the right tyre pressure is dependent on the experience of the vulcanizer and on the alertness of the driver. Therefore, it is inferred that the failure of tyres is caused mainly by failing to maintain the correct pressure of the tyres of Passenger Buses.

(d) Faulty suspension parts and wheel alignment of the Passenger Buses

According to Figure 3, 897 out 5000 sampled tyres have visible signs of high probability of failure due to faulty suspension parts and wheel alignment, corresponding to 17.9% of the total sample. Faulty suspension parts are clearly evident among Passenger Buses because of the number of tyres that show wear patterns consistent with those caused by faulty suspension parts. Wheel alignment is done when signs of faulty suspension parts become evident in vehicle handling and in some cases when fitting new tyres. However, not all reports of faulty suspension parts are attended to immediately or as soon as they ought to be. Hence, faulty suspension part is an element of risks of Passenger Buses pneumatic tyre failure.

(e) Overloading of tyres by Passenger Bus operators

As shown on the graph (Figure 3), 1051 out of 5000 sample tyres failed due to overloading of tyres. This could be inferred that 21% of the sampled damaged tyres are due overloading. An Iveco Bus, which transports commuters from Tema Station in Accra to Aflao was examined. The gross vehicle weight rating of the Iveco bus as stated on the bus placard is 22680kg at 105 ***psi***. The tyre specification as recommended from the placard is 11R22.5 and 105 ***psi***. The gross axle weight ratings as stated on the placard are 5,442kg (front) and 17,326kg (rear). What is the evidence of overload?

(f) Tyre construction and brands used by Passenger Buses

Figure 3 shows that 397 out of 5000 sampled tyres failed and it can be interpreted as 7.9% of the total damaged tyres failed because of tyre construction and brands at Passenger Buses. Radial tyres are predominantly used by Passenger Buses with different brand names. Some are tubed tyres while others are tubeless. The table below shows, in percentages, the different types of damaged tyres, indicating their brands.

Table 5: Cross tabulation of brand and type of damaged samples

Brand Name	Number Sampled	Tyre type	%Damaged
Nutech	451	Tubed	9
Wanli	319	Tubed	6.4
Linglong	828	Tubeless	16.6
Bridgestone	901	Tubeless	18
Dunlop	249	Tubeless	5
Supermax	748	Tubed	15
Double Star	686	Tubed	13.7
Pirelli	357	Tubed	7.1
Alliance	461	Tubed	9.2
Total	**5000**		**100**

According to the drivers interviewed, the Bridgestone tyres and Pirelli tyres wear evenly across the tyre-road contact surface area. Otani tyres are used on the buses but no damaged Otani tyre samples were found. There are 3022 damaged tube tyres and 1978 damaged tubeless tyres see Table 5. However, from the sample data, the drivers were of the view that the Linglong, Double Star, Bridgestone and Supermax tyre brands were observed as not very durable tyre brands. Dunlop and Otani brands were relatively durable tyre brands. Hence, tyre brand and construction can be actually associated as a factor of tyre failure among the Passenger Buses.

(a) Road conditions in Ghana

From Figure 4, 601 out 5000 samples of tyres failed due to road condition. This represents 12% of the sampled tyres. The roads that the Passenger Buses ply in Ghana are relatively flat roads with few hills in the Western and Volta regions respectively, some of which are unpaved or flooded with potholes are present. Normally because of unevenness of the roads and carelessness of drivers, when the buses approach potholes with high speed, breaks are applied abruptly leading to faulty suspension parts. This is because of the sudden vibration that is transmitted to the suspension system which makes the wear pattern of the tyre treads become uneven. Due to the bad conditions of the roads that these Passenger Buses ply, it was noticed that as the tyres enter and leave potholes, cuts are made on the tyre treads, which lead to tyre failure.

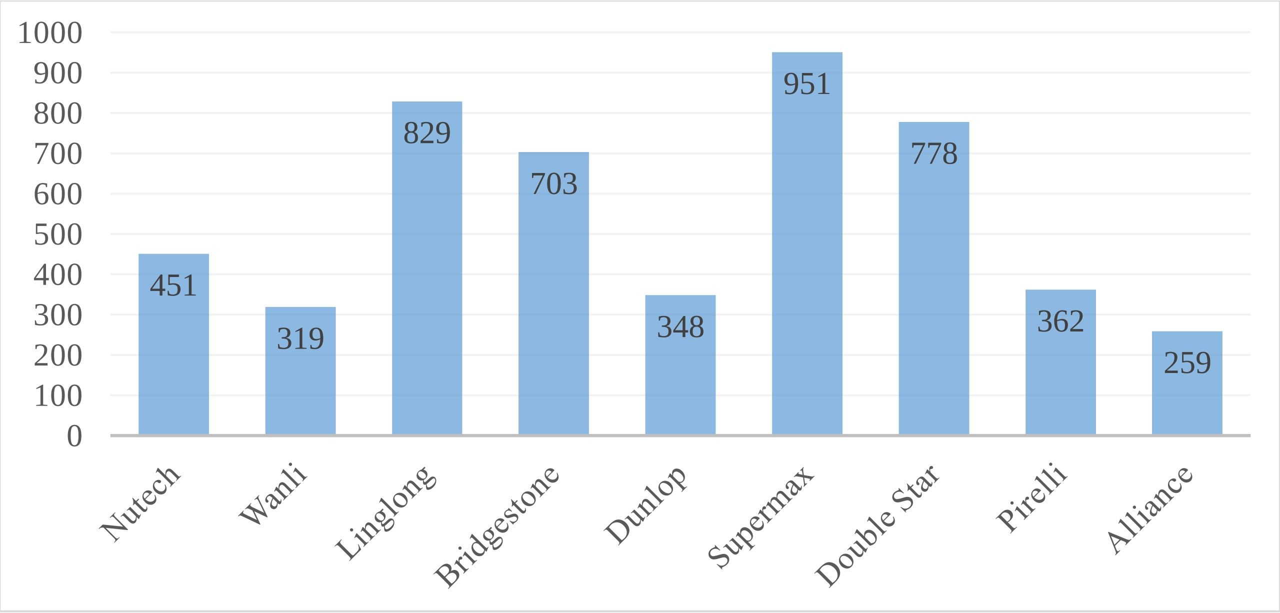

Figure 4: A bar chart showing the distribution of damaged tyre samples by brand

(b) Tyre rotation pattern among the Passenger Buses

As can be seen from Figure 4 above, 302 out of 5000 sample tyres failed due to seldom rotation of tyres. This could be inferred that 6% of the sampled damaged tyres failed due to lack of tyre rotation. Changing the position of tyres at regular intervals is generally favored to compensate for any difference in the working tread pattern wear, or uneven wear due to different working positions; hence to obtain a longer overall tread pattern life, tyre efficiency, and stability in cornering and braking. This was not the case among the selected Passenger Buses. Tyre rotation is hardly done as they see it as not necessary, waste of time and loss of revenue. That is, for them the moment the buses are off the roads it means loss of revenue. Also, in those isolated instances where tyres are rotated, it was observed that the spare tyres were not rotated in accordance with the established measurements.

(c) Other factors causing tyre failures of Passenger Buses

Figure 3 shows that the factors leading to the evidence of damage on 348 out of 5000 sampled tyres are unknown. That is to say 7% of the sampled tyres are damaged by factors, which have not been determined. However, it was observed that vehicle mechanics do not go according to the vehicle maintenance manual when servicing is done.

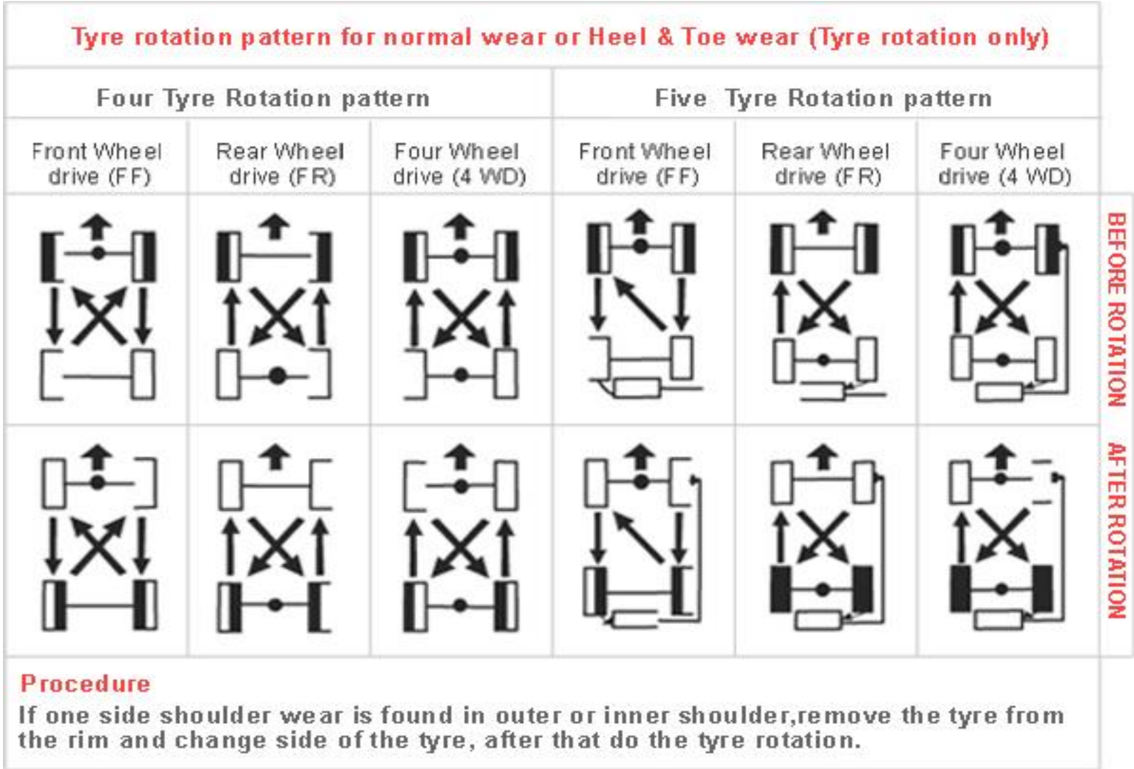

Figure 5: Tyre rotation pattern including the spare tyre

6. CONCLUSIONS & RECOMMENDATIONS

It was observed that most of the pneumatic tyre failures occurring among Passenger Buses were largely due to human errors such as tyre mixing and driving with inappropriate tyre pressure. Drivers and vulcanizers need to follow the laid down procedures in the maintenance manual as well as the instruction on the vehicles' placards. The right or required machines, tools, materials and methods were not used when repairs were done. The Motor Traffic and Transport Department (MTTD) of the Ghana Police Service must enforce the provisions of Regulation 62 of the Road Traffic Regulation 2012, Legislative Instrument (LI) 2180. In addition, Driver and Vehicle Licensing Authority (DVLA) inspection center officers must ensure all vehicles seeking to renew their annual road worthy certificates have tyres, which are in good condition and are highly probable to remain in good condition until the next inspection date.

The following recommendations have been arrived at to drastically reduce the failure of pneumatic tyres used by these commercial passenger busses:

1. Passenger bus tyres must be regularly inspected for traces of abnormal tread wear or damage to ensure maximum tyre life and safety, and to reduce the risk of tyre failures. The inspection must be done at the same time when checking tyre pressure. It is important to ensure that tyres are not under or over inflated at any time before a start of a journey. Excessive or uneven tread wear, which may indicate improper inflation or steering and suspension misalignment are symptoms of higher risk of tyre failure.

2. In addition to uneven tread wear and an uncomfortable ride, out-of-balance tyres cause excessive wear on the suspension and other components. An out-of-balance tyre can be detected by a severe thumping, usually most pronounced at highway speeds. If such a condition occurs, tyres must be dynamically balanced as soon as possible. Tyres should always be balanced when first installed, and whenever they are remounted.

3. Alignment should be checked after a vehicle has been involved in a collision or if it is used continuously on rough roads, particularly roads with large potholes. Alignment is needed when the steering wheel "pulls" the vehicle in a particular direction when traveling straight on a flat road with no crosswind, or when uneven wear on the tyres, particularly front tyres occur. Alignments must be checked and adjusted as often as possible to minimize the risk of tyre failure.

4. The maximum passenger and cargo load for which the vehicle and tyres are designed is printed on the same label that designates recommended tyre pressures. The load must be substantially less than the vehicle is physically able to contain. It is critical that the maximum allowable load should never be exceeded. Tyres of the same load, pressure and speed ratings must be used on the same axle. The tyres must also have the same size specifications. If possible, tyres of the same brand must be used on the same axle. The axle load stations on our roads must inspect the tyre load ratings and ensure they are not exceeded.

5. The tyres should be replaced if any portion of the tread is worn to the "wear indicator bars" – lateral bars molded into the tyre 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.

6. Tyre rotation is essential to achieve even tread wear and maximum tread life. A "cross-rotation pattern" (that is, moving the left-front tyre to the right-rear axle, the right-front tyre to the left-rear axle, etc.) can best balance tread wear and maximize tyre life (see Figure 6). The sequence can be performed on any vehicle equipped with four non-unidirectional tyres. Designated by an arrow on the sidewall, unidirectional tyres must be rotated only from front to rear and rear to front, on the same side of the vehicle, so their direction of revolution does not change. Note, however, that 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.

7. Tyre mixing significantly adversely affects the stability of a vehicle in so many ways. For that reason, it is imperative that tyre mixing should be completely eliminated to minimize the risk of tyre failure.

(i) If it is impossible to avoid tyre mixing, the front and rear pairs should be of the same construction, size, brand and type, with approximately the same tread wear.

(ii) People must desist from buying one new tyre and consider buying at least a pair of new tyres at a time even though a complete set is recommended. It is essential that side-to-side pairs be the same just as it is highly desirable that front and rear pairs be matched.

(iii) If replacing only two, the new tyres should generally go on the rear wheels, regardless of whether the vehicle is Front Wheel Drive (FWD), Rear Wheel Drive (RWD), or All Wheel Drive (AWD). It is important to maintain maximum traction at the rear wheels to ensure stability. Putting new tyres on the front and nearly worn-out tyres on the rear wheels of any vehicle is a recipe for instability. It is very important to avoid drastic differences in tread wear, especially front-to-rear tyre mixing.

(iv) Under no circumstances should one have tyres 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.

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