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INFLUENCE OF CLIMATE AND ROAD CONDITIONS ON AUTOMOTIVE TIRE WEAR IN HOT CONTINENTAL OPERATING ENVIRONMENTS

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ABSTRACT:

Tire wear is a technical, economic, safety, and environmental problem that becomes more complex when vehicles are operated in regions where summer heat, winter moisture, dust, rough pavement, and frequent start stop traffic occur together. The aim of this manuscript is to examine how climate and road operating conditions influence the wear of passenger car tires and to develop an applied framework that can be used in a graduation project devoted to the analysis of tire deterioration. The study combines a literature based interpretation of tire road interaction with an analytical monitoring scheme based on tread depth reduction, estimated mass loss, road temperature, pavement roughness, vehicle load, tire pressure, and route type. The proposed approach treats tire wear as the result of contact stress, thermal softening of tread rubber, road texture aggressiveness, water lubrication, slip, and driving dynamics rather than as a function of mileage alone. The results show that the same mileage can produce substantially different tread loss when road temperature, surface roughness, tire pressure, and maneuver intensity change. The analytical scenario *indicates that hot dry urban operation can increase annual tread depth loss compared with moderate motorway operation, while underinflation and rough asphalt amplify the effect. The paper concludes that climate and road condition monitoring should be included in tire service planning, especially in hot continental regions where pavement temperature can be much higher than ambient air temperature.*

Introduction

Tires are the only vehicle elements that maintain continuous contact with the road, therefore their wear is a direct indicator of how climate, road surface, vehicle loading, and driving style interact during real operation. In engineering education and diploma project practice, tire wear is often treated as a simple mileage based process, but actual wear is governed by repeated contact deformation, frictional energy, rubber temperature, slip, road macrotexture, road microtexture, tire pressure, and braking or cornering intensity. This creates a need for a structured analysis that connects climate and road conditions with measurable tread depth loss and service life. The present article addresses this need by focusing on climatic and road factors that are typical for hot dry regions with seasonal rainfall and variable pavement quality.

The scientific literature shows that tire wear is also an environmental issue because particles released from the tire road contact are a substantial part of non exhaust vehicle emissions. Baensch Baltruschat and coauthors reviewed the generation, properties, emission behavior, health relevance, ecological effects, and fate of tire and road wear particles. Their review is important for this project because it demonstrates that tire wear is not only a maintenance problem but also a source of material release to air, soil, water, and roadside drainage systems [1]. The same review confirms that particle formation depends on tire material, road texture, driving conditions, and weather, which means that climate and road factors cannot be excluded from a technical assessment of tire service life. Recent real driving research has provided stronger evidence that abrasion rates can vary widely across routes and climates. Giechaskiel and coauthors measured tire wear under urban, rural, and motorway driving at two locations and reported that abrasion rates differed according to route type and ambient temperature. Their results also showed that tread depth reduction can be expressed per ten thousand kilometres, which is useful for practical monitoring in vehicle fleets [2]. This work is directly relevant for the present study because it proves that urban routes with more braking, turning, and acceleration can create higher abrasion than motorway routes, even when the tire model is the same. It also supports the use of temperature correction when comparing data measured in different climates.

The road surface itself has been studied for many decades as a major cause of tire wear. Lowne investigated the effect of road surface texture on tire wear and showed that rough and harsh textures can increase wear compared with smoother surfaces [3]. Although this work is older than many modern emission studies, its engineering value remains high because road texture is still a decisive factor in the tire road contact.

A road that improves wet skid resistance may also increase tread abrasion if its texture is aggressive. For a diploma project devoted to climate and road conditions, this creates a technical contradiction that must be discussed. The safest pavement is not always the least abrasive pavement, and the most durable tire operation is not always achieved on the surface with maximum friction.

Pohrt reviewed tire wear particle hot spots and emphasized that wear is influenced by speed, load, acceleration, braking, cornering, road surface, road slope, and driver behavior [4]. This review is useful because it moves attention from an average annual wear value to local road sections where tire wear can become high. For example, intersections, sharp curves, steep climbs, and stops before traffic lights can produce higher tire wear per unit distance than a straight constant speed segment. This approach is important for hot climate regions because pavement temperature, dust, and softened bitumen can combine with local maneuvers and produce uneven tread degradation. Chang and coauthors performed laboratory work on tire wear particles under different non vehicle operating parameters and found that temperature can influence the size distribution and mechanism of tire wear [5]. Their results support the idea that temperature affects more than rubber comfort or pressure change. Temperature changes the physical state of the tread compound and can modify whether wear occurs mainly through fine abrasion, tearing, fatigue, or larger particle release. This finding is especially relevant for regions where asphalt temperature in summer is much higher than air temperature, because the tire tread is heated both by the environment and by hysteresis during rolling.

Yan and coauthors investigated external conditions and material compositions affecting tire wear particle formation and reported that load, speed, temperature, and compound composition influence particle formation and size distribution [6]. Their work expands the literature review by showing that climate cannot be analyzed independently from tire material and vehicle load. The same air temperature may lead to different wear for tires with different fillers, tread compounds, and stiffness. This means that any field study must record tire type and pressure together with climate data, because the response of the tread depends on material structure.

Kreider and coauthors compared tire related particles generated with different methodologies and showed that particles created in on road and laboratory conditions can differ in morphology, size, and chemical composition [7]. This matters for the present study because a road sample can contain not only tire rubber but also pavement mineral particles, brake wear, dust, and atmospheric deposits. Therefore, a practical graduation project that does not have advanced particle analysis equipment can still evaluate tread depth loss and tire mass loss, but it should avoid claiming that all roadside particles are pure tire material. The research design must separate tire service wear from environmental particle identification.

Mathissen and coauthors studied ultrafine particle generation at the tire road interface during real driving and considered braking, acceleration, cornering, and straight driving [8]. Their work confirms that transient maneuvers affect the contact zone more strongly than steady rolling. This supports the operational classification used in the present article, where urban operation, rural operation, and motorway operation are treated separately. The same vehicle can experience different wear mechanisms within one day, and the route profile should be recorded when interpreting tread depth change.

Materials and methods

The methodology was designed as an applied monitoring and analytical framework rather than as a closed laboratory experiment. This choice reflects the practical purpose of the diploma project, where the main task is to study and analyze the influence of climate and road conditions on automotive tire wear under realistic operation. The method consists of repeated tire tread measurements, climate observation, road condition classification, tire pressure monitoring, route classification, and estimation of wear intensity per distance travelled. The framework can be applied to a single passenger car or to a small vehicle fleet, and it can be expanded when more measurement devices are available.

The studied object is the tire set of a passenger car operated on paved roads that include urban streets, peri urban roads, and intercity highway sections. The tire is considered as a deformable rubber composite working under normal load, tangential force, lateral force, rolling speed, thermal exposure, and road roughness. Tire wear is expressed through tread depth reduction in millimetres and through estimated mass loss when tire mass data are available. The dependent variable is therefore the change in usable tread depth over a measured distance. The independent variables are ambient air temperature, pavement surface temperature, relative moisture condition, road roughness class, tire pressure, vehicle load class, and route type.

Tread depth is measured at three positions across the tire width and at four circumferential positions around each tire. The three width positions are the inner shoulder, central rib, and outer shoulder. This arrangement makes it possible to identify not only general wear but also uneven wear caused by underinflation, overinflation, wheel alignment errors, cornering, and road camber. The average tread depth of a tire is calculated from all positions, while the difference between the shoulders and the center is used as an indicator of abnormal wear. Measurements are repeated every two thousand kilometres or once per month, whichever comes first.

The limitation of the method is that it cannot isolate every factor with laboratory precision. Climate, road texture, vehicle load, tire pressure, and driving dynamics change together in real operation. However, the purpose of this applied study is not to replace controlled tribology tests. The purpose is to build a practical evidence based system for understanding tire wear in real roads. By documenting all major variables and comparing repeated intervals, the method allows a more scientific interpretation than mileage based visual inspection alone.

Results

The analytical scenario demonstrates that tire wear intensity changes substantially when the operating climate and road condition change. Under the baseline condition of moderate pavement temperature, correct tire pressure, normal load, and smooth asphalt, the calculated tread depth loss is the lowest. When the same vehicle is assumed to operate in hot dry urban conditions on rough asphalt, the predicted tread depth loss increases because the tire experiences higher tread temperature, more braking, more turning, and stronger contact stress variation. This result supports the main hypothesis that mileage alone is insufficient for tire wear assessment. In the cool dry period, pavement temperature remains relatively low and the rubber compound keeps higher stiffness. The expected wear rate is moderate when the road is smooth and the route is rural or motorway dominated. However, if the same period includes dusty roads or frequent urban maneuvers, the wear rate increases because dust and small mineral particles can act as abrasive media in the contact patch. The cool period therefore cannot automatically be considered low wear. It is low wear only when road cleanliness, pressure, and driving style are also favorable.

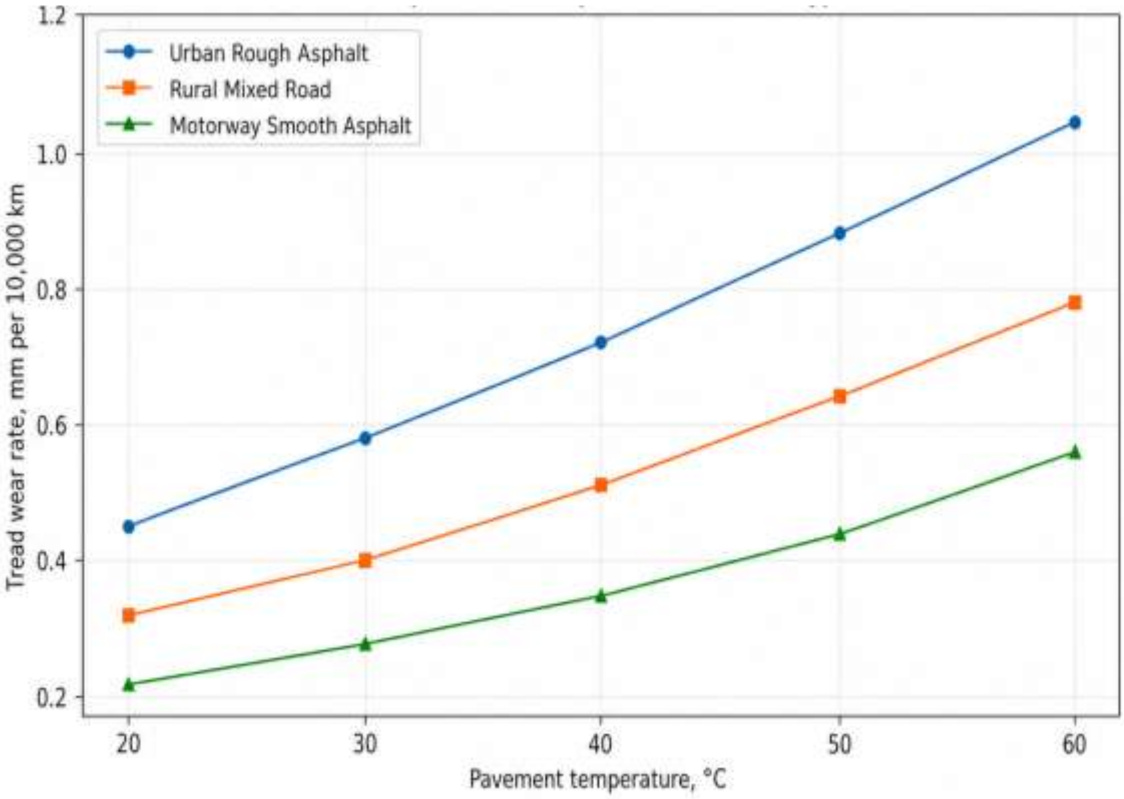

Figure 1. Estimated influence of pavement temperature and road type on tire tread wear.

In the warm dry period, the tread compound becomes more compliant, and the contact surface can generate more local adhesion. The calculated wear rate increases compared with the cool dry baseline when road texture is rough. This does not mean that every warm day causes severe tire wear. The result means that the thermal state of rubber and asphalt should be treated as part of the wear mechanism. Moderate warm operation on a smooth road with correct pressure may be acceptable, but warm operation on aged asphalt with frequent turns creates a stronger abrasion environment.

The hot dry period shows the highest severity in the calculation. Pavement surface temperature may exceed ambient air temperature by a large margin, especially on dark asphalt exposed to direct sunlight. The tire tread is also heated by repeated deformation during rolling. When this thermal exposure is combined with high load or underinflation, shoulder wear increases and the tread surface becomes more vulnerable to tearing. The model therefore predicts the largest tread loss for the front tires during hot urban operation, because front tires carry steering and a large share of braking forces. The wet or dusty wet period produces a more complex result. Water can reduce friction and sometimes reduce certain abrasive mechanisms, but it can also transport fine mineral particles into the contact patch, reduce grip, increase slip during acceleration or braking, and expose the tire to sharp road defects hidden by water. The analytical scenario therefore treats wet conditions not as automatically low wear but as condition dependent. Wet smooth asphalt under gentle driving can reduce abrasion, while wet damaged pavement with mud and dust can intensify irregular wear and mechanical damage.

The comparison between front and rear tires confirms a common operational pattern. Front tires show higher wear in urban operation because they are involved in steering and receive a significant portion of braking load transfer. Rear tires show lower average wear in the scenario, but they can develop uneven patterns if the vehicle is frequently loaded, if rear pressure is incorrect, or if suspension geometry is poor. This result indicates that climate and road condition analysis should be combined with axle position analysis. Average tire wear can hide the fact that one axle is exposed to stronger mechanical demand.

The results of the analytical scenario support the need for a tire wear monitoring sheet that includes climate and road information. Such a sheet should record date, odometer, tire position, tread depth points, cold pressure, pavement temperature, route type, road class, moisture condition, and unusual events. When this information is collected regularly, the student can produce graphs of tread depth against mileage and compare wear rate across seasons. Without this information, the conclusion of the project would remain general and would not show the specific influence of climate and road conditions.

Discussion

The findings can be interpreted through the mechanics of the tire road contact patch. Tire wear occurs when frictional forces, local slip, rubber deformation, and surface roughness remove material from the tread. Climate modifies this process by changing tread temperature, pavement temperature, moisture, dust, and pressure. Road condition modifies the process by changing the stress distribution and the sharpness of contact asperities. Vehicle operation modifies the process through acceleration, braking, cornering, and load transfer. These factors combine, which is why a single mileage value cannot explain actual tire wear.

The literature review supports this interpretation. The review by Baensch Baltruschat and coauthors shows that tire and road wear particles are generated by a combination of tire and road processes and that their environmental fate is complex [1]. The real driving work of Giechaskiel and coauthors shows that route type and temperature can produce different abrasion rates even for the same tire model [2]. Lowne showed the importance of road texture

[3], while Pohrt emphasized local hot spots and operating forces [4]. Laboratory studies by Chang and Yan show that temperature, load, speed, and rubber composition influence particle formation [5,6]. Taken together, these sources justify the integrated approach used in this article.

One important discussion point is the difference between ambient climate and tire thermal state. Drivers usually describe operating conditions through air temperature, but the tire responds to the thermal state of the tread and the road. During hot sunshine, pavement can become much hotter than air. During high speed driving, tire internal heating increases. During underinflated operation, deformation heating increases further. Therefore, a tire may experience a severe thermal condition even when the reported air temperature seems moderate. This is why pavement temperature and pressure should be recorded in a serious tire wear study.

Overall, the discussion confirms that climate road conditions have a measurable and explainable influence on tire wear. The strongest effects occur when high pavement temperature, rough asphalt, dust or wet contamination, pressure deviation, high load, and intensive maneuvers occur together. The weakest effects occur under correct pressure, moderate temperature, smooth pavement, steady speed, and gentle driving. This conclusion is technically consistent with published literature and practically useful for diploma project implementation.

Conclusion

The study concludes that automotive tire wear should be analyzed as a climate road vehicle interaction rather than as a mileage only maintenance issue. Ambient temperature, pavement temperature, moisture condition, dust, road texture, surface damage, tire pressure, vehicle load, and route type all influence tread degradation. The same distance travelled can therefore create different wear rates under different operating conditions. For this reason, diploma projects on tire wear should include systematic measurement of tread depth together with climatic and road variables.

The analytical framework proposed in this article is suitable for student research because it uses accessible tools and produces interpretable results. The framework includes repeated tread depth measurement, tire pressure checking, pavement temperature measurement, road condition classification, route type recording, and wear rate calculation per ten thousand kilometres. It also includes diagnostic interpretation of center and shoulder wear. This makes it possible to identify whether observed tread loss is mainly caused by general climate road severity or by maintenance defects such as underinflation, overinflation, wheel alignment error, or overload.

The main practical conclusion is that hot dry urban operation on rough or damaged asphalt creates the highest risk of accelerated tire wear, especially when tire pressure is not controlled. Wet and dusty conditions can also increase irregular wear when they raise slip or introduce abrasive particles into the contact patch. Smooth pavement, correct pressure, moderate loading, and gentle driving reduce wear intensity and extend tire service life. These findings support preventive maintenance recommendations for drivers, service centers, and vehicle fleets.

The environmental conclusion is that reducing tire wear also reduces the release of tire and road wear material to air, soil, and water pathways. Since non exhaust emissions remain relevant even when exhaust emissions decrease, tire wear reduction is an important part of sustainable vehicle operation. Road maintenance, route planning, tire pressure control, and careful driving can all contribute to lower material release and lower operating cost.

Future research should collect real field data in different seasons and on different pavement types in Uzbekistan or similar hot continental regions. The proposed severity coefficient should be calibrated with measured tread depth and tire mass loss. Additional studies should include accelerometer data, objective pavement texture measurements, and comparison among different tire brands and compounds. Such work will strengthen the scientific basis for tire service planning and road safety improvement.

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