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The Impact of Wide-Base Tires on Pavement – A National Study

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Detailed Literature Review

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1 DETAILED LITERATURE REVIEW

The wide-base tire (WBT) technology was introduced as an alternative for the truck and hauling industry to increase assets by reducing operational and energy costs. The wide-base tire (WBT) studies related to pavement infrastructure can be divided into two periods. The first period corresponds to the time between the appearances of the first generation of wide-base tires (FG-WBT) in the early 1980s until the end of the previous century, although WBT was introduced earlier than that date. In the year 2000, the new generation of wide-base tires (NG-WBT) entered the market, and a new era of research regarding WBT started and continues today.

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1.1. IMPACT ON ROAD INFRASTRUCTURE

Most of the findings related to the effect of FG-WBT on the pavement structure generally agree with one fact: FG-WBT are more damaging than dual-tire assemblies. The studies included accelerated testing, modeling, and in-service pavement testing.

[redacted] Accelerated Pavement Testing

In 1986, instrumented test sections in Finland were used to investigate the effect of different axle configurations and type of tires on pavements (Huhtala 1986). Strain gauges at the bottom of the asphalt concrete (AC) layer and pressure cells at the base-subbase and subbase-subgrade interface in thin pavements (2-in, 3-in, and 6-in-thick AC layers) were installed. Three axle configurations (single, tandem, and tridem) and three different types of tires (single, tandem, and WBT) were considered in the experimental program. Based on the measurements, fatigue curves were calculated for various axle configurations. It was concluded that WBT caused more damage to the pavement than the dual-tire assembly. Furthermore, the tridem axle with WBT produced an amount of damage similar to the tandem with dual-tire assembly. In addition, the difference between the damage caused by WBT and dual-tire assembly decreased as pavement depth increased. Additional test using the same experimental setting were reported in 1989 (Huhtala et al. 1989). In this part of the investigation, dual-tire assembly (12R22.5) and WBT (445/65R22.5, 385/65R22.5 and 350/75R22.5) with three applied loads (16, 20, and 24 kip) and three inflation pressures (the recommended by the manufacturer and ±20%) were employed. Uneven load distribution in the dual-tire assembly was also considered. The study concluded that WBT caused more damage than dual-tire assembly: WBT caused between 2.3 and 4.0 times more damage than dual-tire assembly when using equal inflation pressure, and from 1.2 to 1.9 with uneven inflation pressure in the dual-tire assembly. The study also reported that the wider WBT (385/65R22.5) generated less damage than the 350/75R22.5.

Bonaquist (1992) presented results of accelerated pavement testing (APT) by the FHWA in Virginia. The aim of the experimental configuration was to compare a dual-tire assembly (11R22.5) with a WBT (425/65R22.5). Twelve flexible pavement sections were built and distributed in three lanes (four sections per lane). Two out of the three lanes were used for WBT testing: one for response analysis and the other one for performance analysis. Two different AC thicknesses (3.5 and 7 in) were constructed on top of 12.0 in-crushed aggregate. All the section were tested during three various seasons (spring, winter, summer), four loads (9.2, 12.1, 14.4, and 16.6 kip), and three tire inflation pressures (75.4, 103, and 139 psi). Horizontal strain at the bottom of AC, average vertical strain at different locations, and temperature profile were measured using strain gauges, differential deflectometer, and thermocouples, respectively. Six strain gauges per section were installed (three in traffic direction and three perpendicular to traffic direction). The differential deflectometers were located in the AC layer, crushed aggregate base, and the top 6.0 in of the subgrade. For each combination of applied load and tire inflation pressure, the footprint area was recorded. The instrument measurements were used to predict the response for various loading at different temperatures and inflation pressures using multi-linear regression analysis. The study found that WBT produced greater horizontal strain and average vertical strain in all layers (the average vertical strain was defined as the difference between the deflection of two differential deflectometers and its separation). Moreover, for 12.5-kip-load and 104-psi-tire pressure, WBT produced between 3.5 and 4.3 times more fatigue damage than dual-tire assembly and between 1.1 and 1.5 more rutting, using the measured AC strain and the average vertical strain. In general, WBT produced more permanent deformation in all pavement layers (two times as much as dual-tire assembly) and lower fatigue life (25% of dual-tire assembly).

Instrumented flexible pavement sections subjected to traffic loads traveling at 40 mph at Pennsylvania State University test track were studied by Sebaaly and Tabatabaee (1992). The study focused on the pavement response and the load equivalent factor created by various tire inflation pressures, tire types, axle loads, and axle configurations. Surface deflection, strain, and temperature were measured in two flexible pavement sections: 6 in (thin) and 10 in (thick). In addition to single and tandem axles having different loads and tire inflation pressures, four different tires were analyzed: two dual-tire assembly (11R22.5 and 245/75R22.5) and two WBT (425/65R22.5 and 385/65R22.5). In the case of thin pavement, it was found that the damage caused by single WBTs is between 50 and 70% greater than the fatigue damage caused by a single-axle with dual-tire assembly 11R22.5. In general, WBT loading (at the same load and tire pressure) resulted in greater strain and deflection than dual-tire assembly. Also, the wider the WBT, the less the damage: 385/65R22.5 resulted in greater strain and deflection than 425/65R22.5.

A study focused on rutting performance of two overlay systems was presented by Harvey and Popescu (2000). The two overlays analyzed are dense-graded asphalt concrete (DGAC) and asphalt-rubber hot mix gap-graded (ARHM-GG). Accelerated pavement testing was performed at high temperatures (104°F and 122°F) with four different types of tires: bias ply (Goodyear 10.00-20), radial (Goodyear G159A, 11R22.5), WBT (Goodyear G286, 425/65R22.5), and aircraft (BF Goodrich TSO, 46x16). The measurement of the rut depth showed that the worst performance was resulted from the aircraft tire followed by the WBT for DGAC at 122°F. The WBT resulted in greater rutting when compared to dual/radial in ARHM-GG. The number of repetitions to rutting failure of WBT varied between 10 and 60% of the value for radial dual-tire assembly. As a general conclusion, the study reported that WBT increased the rutting in highways.

The effects of WBT as compared to a dual-tire assembly were also investigated by COST 334 in Europe (COST 334 2001). Seventeen different tire types were considered in the study, eight of them dual-tire assembly, and nine of them WBT. It is worth noting that the new generation of wide-base tires (NG-WBT) in this study refers to the 495/45R22.5, while the proposed NG-WBT in North America corresponds to 445/50R22.5 (2000), and subsequently the 455/55R22.5 (2002). This discrepancy is due to the difference in axle configurations and load regulations between Europe and North America. The following field pavement tests were conducted in the study:

- British TRL Pavement Test:

Testing at the British Pavement Testing Facility compared a conventional wide-base tire (385/45R22.5) at a load of 10 kip and a tire pressure of 145 psi to a NG-WBT (495/45R22.5) at a load of10 kip and a tire pressure of 116 psi. Two pavement designs were considered; one with an AC thickness of 4 in, and the other with an AC thickness of 8 in. Pavement responses were measured for six tire types at several wheel loads and tire inflation pressures. The average rutting ratio of the conventional WBT (385/65R22.5) relative to the new WBT (495/45R22.5), was 1.7 for the medium thickness pavement (8 in) and 1.5 for the thin pavement (4 in).

- Dutch Lintrack Pavement Test

Full scale accelerated pavement tests were conducted at the Dutch Lintrack for four different tire assemblies. Tests were conducted at four pavement sections with the same pavement design (thick pavement with 10.6 in AC layer). After the tests were completed on the first design, the two top layers of AC were changed with the same mix design, but using a stiffer binder. Pavement temperature was maintained at 104°F using infrared heaters. The study concluded that the average rutting ratio of the conventional WBT (385/65R22.5) to the conventional dual-tire assembly (315/80R22.5) ranged from 1.94 to 2.73, whereas the average rutting ratio of NG-WBT (495/45R22.5) to the conventional dual-tire assembly (315/80R22.5) varied between 1.32 and 1.34.

- French LCPC Pavement Test

The accelerated pavement testing of the Laboratoire Central des Ponts et Chaussées (LCPC) in France conducted a study on various tires and wheel load configurations to evaluate rutting and fatigue performance of flexible pavements. The experimental program was conducted on a very stiff pavement structure consisting of 3.2 in wearing surface, on top of a 16 in AC base layer, 16 in granular base, and 12 in coarse subbase on a sandy clay subgrade. Due to the very thick and stiff pavement structure, the measured longitudinal and transverse strain amplitudes were very low, between 10 and 20 microstrains at the bottom of the AC, and the vertical strains at the top of the granular base were 40 to 70 microstrains. To eliminate the influence of temperature variation in pavement responses, a second analysis was performed using linear elastic multilayer software, "Alize," which was developed by the LCPC. After the model was successfully calibrated based on measured pavement responses, relative comparisons were made between the various tire configurations at a reference temperature of 59°F. For the WBT, the vertical and longitudinal strains induced by the conventional WBT (385/65R22.5) were very close to the responses exerted by the NG-WBT (495/45R22.5). In the case of dual-tire assembly, the 315/80R22.5 resulted in a 6.2% lower strain than the 95/60R22.5. This pattern of results could be attributed to the use of linear elastic theory, which does not consider nonuniform contact stresses or variation in the loading contact area. In addition, the impact of the tire contact area, uniformity, and pressure diminish with depth. Measurements in this study were taken at relatively deep locations within the pavements.

- Finnish Pavement Test

Accelerated pavement testing at the VTT Transportation Research Center in Finland measured pavement responses under two tire assemblies using pavement instrumentations. The primary objective of the study was to investigate the differences in dynamic loading between different tire types. A dual-tire assembly (315/70R22.5) and a WBT (495/45R22.5) were tested at inflation pressures of 110 and 130 psi, respectively. Testing was conducted at two different speeds (28 and 50 mph) on a pavement system consisting of 6 in of AC, 6 in crushed rock base, and 16 in granular subbase on sandy subgrade. Longitudinal strains at 50 mph indicated that the wide-base tire induced about 17% greater strain at the bottom of the AC than the dual-tire assembly. Vertical pressure at pavement interfaces indicated that the wide-base tire produces about 21% greater stresses on top of the base layer, and 14% greater stresses on top of the subbase layer than the dual-tire assembly, while vertical pressure on top of the subgrade were nearly equal between the tires.

Results of COST Action 334 (COST 334 2001) were formulated through the concept of tire configuration factor (TCF). The tire configuration factor is "a factor describing the pavement wear attributable to different tire types and sizes, when compared with an arbitrarily selected reference tire, at equal load" The selected reference tire with a TCF of 1.0 was the dual-tire assembly 295/80R22.5 under maximum recommended loading conditions. To evaluate the damage of the new generation of wide-base tires used in North America (i.e., 445/50R22.5 and 455/55R22.5) to the most equivalent dual-tire assembly in the tractor drive position (275/80R22.5), the following model developed during the COST study was used:

$$TCF = \left(\frac{width}{470}\right)^{-1.68} \left(\frac{length}{198}\right)^{-0.85} (pres.ration)^{0.81}$$

where: TCF = tire configuration factor;
$width$ = contact area width;
$length$ = length of the contact area; and
$pres.ratio$ = pressure ratio compared to the manufacturer recommended pressure (i.e., 1.0 means inflated as recommended).

Similar models were developed for fatigue and subgrade rutting. A correction factor is also used to account for real-world operating conditions (i.e., possible imbalance in load distribution in case of dual-tire assemblies, roughness of the road, and dynamic effects). These correction factors were 1.01 and 0.97 for dual-tire assembly and WBT tires, respectively. Table 1 illustrates the calculation of the TCF for the dual-tire assembly and WBT. As presented in this table, NG-WBT would cause approximately the same primary rutting damage as a dual-tire assembly on primary roads. In secondary roads, a weighted average was used, which assumes 20% primary rutting, 40% secondary rutting, and 40% fatigue cracking. Surface-initiated top-down cracking was not considered in the study. Based on this distribution, the new generation of wide-base tires (445/50R22.5 and 455/55R22.5) would be 44% and 52% more damaging than the equivalent dual-tire assembly.

Table 1. Damage Ratios between the NG-WBT and a Dual-Tire Assembly Based on the COST TCF Models.

			Primary Roads		Secondary Roads	
Tire Type	**W (mm)**	**D (mm)**	**TCF**	**Wide-base vs. dual**	**TCF**	**Wide-base vs. dual**
Dual (275/80R22.5)	368	1054	1.52	NA	1.51	NA
Wide (445/50R22.5)	380	947	1.56	2.7%	2.29	52.4%
Wide (455/55R22.5)	380	998	1.47	-3.1%	2.17	44.1%

1 mm=0.0394 in

COST 334 also estimated the relative damage between the steering axle and a reference dual-tire assembly axle. Assuming the same axle load, the steering axle, on average, was three to four times as aggressive as the reference axle on primary roads, and five to eight times as aggressive as the reference axle on secondary roads. Nevertheless, even under smaller loads, it is still expected a steering axle with 20 kip on two single tires to be much more detrimental than the reference axle. This agrees with the findings of Smart Road studies by Al-Qadi and his coworkers with respect to the steering axle (Al-Qadi et al. 2004).

Major research was conducted at Virginia Tech to assess the pavement damage caused by different tire types and axle configurations (Al-Qadi et al. 2004; Al-Qadi et al. 2005a; Al-Qadi et al. 2005b; Elseifi et al. 2005). Twelve pavement structures were built combining different types of wearing surfaces, intermediate layer with different thicknesses, asphalt layer under the intermediate layer, drainage layer, cement stabilized subbase, and subbase. In addition to sensor to determine moisture and frost penetration, each section was heavily instrumented with strain gauges, pressure cells, and thermocouples (Al-Qadi et al. 2004; Al-Qadi et al. 2005b). Four damage mechanisms were considered in this study: fatigue cracking, surface and subgrade rutting, and top-down cracking.

Each of these mechanisms was linked to a pavement response by the use of transfer functions. The experimental program considered two types of tires: dual-tire assembly (275/80R22.5) and NG-WBT (445/50R22.5). The built sections were subjected to truck load during May and November 2000 and July 2001 with two load configurations: 17 and 8.5 kip per tandem axle. The speed of the moving load was 45 and 5 mph for both tires, and two different speeds were incorporated in May 2000 for WBT: 15 and 25 mph. During the other two testing sessions, the dual and WBT were combined in the tandem axle. In addition to the program described above, the dual-tire assembly was tested at three tire inflation pressures (80, 95, and 105 psi) and four speeds (5, 15, 25, and 45 mph). A third loading condition was introduced, in which barrier walls were not used (Loulizi et al. 2001). Dual-tire assembly was also tested at different axle loads, tire-inflation pressures, environmental conditions, and speeds.

This NG-WBT were compared with dual-tire assembly at Section A of the Virginia Smart Road test (Al-Qadi et al. 2002). The study highlights the differences between the NG-WBT and conventional WBT: NG-WBT has greater loading carry capacity, has lower contact stresses, and requires less inflation pressure to carry the same load. The experimental program subjected the pavement to truck load traveling at different speed (5, 15, 25, and 45 mph) and two values of tandem axle load (17 and 8.5 kip per axle). The whole testing program consisted of three sessions at different seasons: May 2000, November 2000, and July 2001. During the first test session (May 2000) and based on strain at the bottom of AC, NG-WBT produced almost the same fatigue damage as dual-tire assembly. Regarding vertical compressive stress, the difference between dual and NG-WBT decreases with depth, even though it is higher for NG-WBT near the surface. Similar results were obtained during November 2000 and July 2001.

The effect of different tire types has also been studied in Canada (Pierre et al. 2003). An experimental section with a thickness of 4 in was built in Laval University, Quebec, and it was instrumented to measure longitudinal and transverse strains at different levels as well as vertical strain. The strains near the surface were measured using a slab built and instrumented in the laboratory, and attached later to the pavement structure. Diverse testing scenarios were created based on tire type, applied load, and tire inflation pressure. Four tire types (11R22.5, 12R22.5, 385/65R22.5, and 455/55R22.5) moving at a speed of 30 mph, five loads (13.3, 17.6, 22.0, 26.4, and 30.9 kip per axle), and three inflation pressures (81, 106, and 130 psi) comprise the experimental program. It was found that at an inflation pressure of 106 psi, dual-tire assembly produce less strain at the base than the WBT, and 455/55R22.5 produced less strain than 385/65R22.5. In general, all tests showed that 385/65R22.5 is more damaging than the other tires. In addition, the strains created by 455/55R22.5 and dual-tire assembly at the pavement's base during summer are comparable in magnitude. This situation changes during spring, when strains from 455/55R22.5 were greater than dual-tire assembly. A similar trend is shown for fatigue cracking. On the other hand, when the tire inflation pressure was increased to 130 psi, 385/65R22.5 and 455/55R22.5 produced lower vertical strain than the dual-tire assembly. Regarding rutting, WBT gave a better performance; they produced less permanent strain than the other two type of dual tire assembly, with 455/55R22.5 giving the lowest values. Finally, the deflection produced by dual-tire assembly is less than WBT.

Dual and WBT were mechanically compared by NCAT in 2006 (Priest and Timm 2006). A pavement section 6.73 in-thick was subjected to accelerated pavement testing using two types of tires: 275/80R22.5 and 445/50R22.5. The mentioned section was instrumented with longitudinal and transverse strain gauges at the bottom of the AC layer and pressure cell on top of the base and subgrade. The readings from the instrumentation were compared to analytical results calculated using WESLEA. The study concluded that there is insignificant difference in the horizontal strain at the bottom of the AC layer and the stress on top of the subgrade between WBT and standard dual-tire assembly.

Dual and WBT have been also compared in pavements with different thicknesses regarding response and damage (Al-Qadi and Wang 2009a; Al-Qadi and Wang 2009b). Flexible pavement sections with thicknesses varying between 6 and 16.5 in were instrumented and tested at the Advanced Transportation Research Engineering Laboratory (ATREL) of University of Illinois at Urbana-Champaign. Thermocouples and strain gauges (two longitudinal and one transverse) were installed in order to monitor the response on the three types of pavement: interstate (16.5 in-thick), primary road (10 in-thick), local road (6 in-thick). These three types of pavements were subjected to moving load (5 and 10 mph) using conventional dual-tire assembly (11R22.5), NG-WBT (455/55R22.5) and FG-WBT (425/65R22.5). All tires were inflated at three different pressures (80, 100, and 110 psi). The applied load was varied between 6 and 14 kips, with 2 kips increments. Pressure differential in dual-tire assembly was also considered. The measurements showed that the lowest longitudinal strain at the bottom of the AC is created by dual-tire assembly. Also, WBT-425 presented a higher response than WBT 455 for all testing condition. As previously noted by other researchers, the difference between WBT and dual-tire assembly is relevant close to the surface, but it becomes negligible as the depth increases. As a general trend, a linear increment of the longitudinal strain with the applied load was seen, and this strain is no significantly affected by the inflation pressure. Based on the experimental measurements, it was possible to conclude that WBT-425 is the most damaging tire regarding fatigue cracking followed by WBT-455.

A similar study focused on the damage caused by dual-tire assembly and WBT-455 on roads with low traffic volume was conducted by Al-Qadi and Wang (Al-Qadi and Wang 2009c). Three sections having the same surface layer (3- and 5-in-thick) but different base thickness (8, 12, and 18 in) were instrumented and modeled. The instrumentation included strain gauges at bottom of AC, linear variable differential transformers in granular layer in three directions and subgrade in vertical direction, and thermocouples at different depths. The investigation found that, in opposition to the case interstate highway, WBT caused more damage to the low-traffic volume when compared to dual-tire assembly.

One additional study regarding WBT and pavement damage was presented in 2009 by Greene et al. (Greene et al. 2009). The focus of this project was to evaluate rutting prediction. Two types of pavement were subjected to accelerated loading until a rut depth of 0.5 in was reached. The two pavements differ from each other in the kind of surface used: dense graded and open graded. The load applied on each of the four tires considered (445/50R22.5, 455/55R22.5, 425/65R22.5, and 11R22.5) was 9.0 kips, at 122°F traveling at 8 mph with different offset. A numerical model was also developed using ADINA; this model did not include all the details given by other researchers (Al-Qadi et al. 2008; Yoo et al. 2006). It assumed constant vertical contact stresses, and elastic materials. The type of tire with the greatest number of passes to create 0.5 in rut-depth was the dual-tire assembly, while WBT-425 needed the least. In addition, WBT-455 required similar number of repetitions as dual-tire assembly on open-graded surface and slightly less on dense-graded. Based on the readings of two surface sensors installed 5 in from the edge of the tire, it was concluded that WBT-425 generated the highest transverse strain. WBT-455 produced the lowest shear strain under the edge of the tire while the result for dual-tire assembly and WBT-445 were similar. Regarding tensile strain at the bottom of AC, WBT-445 generated slightly higher values, while WBT-455 and dual-tire assembly were similar. Finally, WBT-445 was found to be more damaging than dual-tire assembly and WBT-455; while WBT-455 and dual-tire assembly were similar. The numerical model proved that elastic material properties are not suitable to predict rutting.

Xue and Weaver (2011) analyzed the shear strain reading of the SPS-8 section built and instrumented in Ohio. Two AC layers with thickness of 4 and 8 in of AC were constructed on top of 6 in DGAB. The instrumentation was composed by strain gauges rosettes in order to measure shear strain, and longitudinal and transverse strain gauges at the bottom of AC and close to the surface. Four types of tires were tested: two types of DTA (275/80R22.5 and 295/75R22.5) and two of WBT (425/65R22.5 and 495/45R22.5). At the same time, four inflation pressures were tested: 70, 100, and 120 psi. It was reported that WBT-425 created higher shear strain; while all the others produced similar shear response.

[redacted] Numerical Modeling and Analytical Methods

The influence of the tire-width on the equivalent loading factor was studied by Hallin et al. (1983) based on an analytical study. Flexible and rigid pavement subjected to dual-tire assembly and single tire-loading were analyzed using the finite element method (ILLI-SLAB for rigid pavement, developed by University of Illinois and PSAD2A from University of Berkeley). The width of the single tire was varied in a range that included WBT (from 10 to 18 in). In the case of rigid pavement, the applied load contact area was assumed rectangular with uniform contact pressure and located at four different points. Not only the width of the tire varied but also the contact pressure and the joint spacing. It was found that, for rigid pavement, the maximum tensile strain decreases as the width of the tire increases. On the other hand, the flexible pavement was assumed as composed by one elastic layer with the load applied through a circular contact area. The reported load equivalent factor was based on the average of two different contact-area assumptions: two circles with constant radius but different contact pressure and one circle. Fatigue analysis based on warping and load stresses (concrete pavement) and strain at the bottom the AC layer (flexible pavement) allowed the calculation of the equivalent loading factor. The authors showed a reduction of the difference in the equivalent loading factor as the tire width is increased for different values of AC thickness. Furthermore, in the case of rigid pavement, this difference is almost constant as the tire width changes from 10 to 18 in

A modified version of the linear elastic program BISAR was used to assess the influence of tire inflation pressure and tire type on the response of flexible pavement (Sebaaly and Tabatabaee 1989). Radial (11R22.5) and bias (11-22.5) tires and WBT were used in the study. Each tire class was subjected to values of load and pressure that covers behaviors such as under and over-loaded and under and over-inflated tire. The resulting footprint and vertical contact pressures were measured in order to obtain the input required by BISAR. The analyzed flexible pavement, whose thickness was varied from 2 to 8 in, was assumed to be placed on top of 8 in granular base. The study concluded that if the pavement is 2 in-thick, the longitudinal strain at the bottom of the AC is 40% greater when the tire inflation pressure changes from 130 to 145 psi for an applied load of 20 kips. In addition, if the thickness of the AC is 6 or 8 in and the load changes from 10 to 17 kip, the change in the mentioned strain is less than 10%. Regarding the deflection at the surface, all three tires showed similar values with bias tire producing the greatest ones. The authors not only concluded that WBT generates the greatest strain at the bottom of the AC, but also the largest stress on top of the subgrade. In addition, it was found that WBT with high applied load were more critical in thin pavements.

A major effort was made in 1992 by the University of Michigan Transportation Research Institute to establish a relationship between truck characteristics and pavement response and performance (Gillespie et al. 1992). The characteristics of heavy-vehicles considered in this study are weight, axle load, axle configuration, suspension properties, tire types, tire pressure, tire contact area, tire configuration, and operating conditions. In addition, flexible and rigid pavements were built with different surface condition (smooth, rough, and joined surface). The analytical tool used depended on the type of pavement: VESYS-DYN for flexible pavement and ILLI-SLAB for rigid. Fatigue damage was assessed in both flexible and rigid pavement, and rutting was included in flexible pavement. Different tires were considered: dual-tire assembly (11R22.5), and WBT (15R22.5 and 18R22.5). In relation to the WBT, this study concluded that WBT produced between 2 and 9% more peak tensile stress in the rigid pavement than the dual-tire assembly. Moreover, WBT were more damaging than dual-tire assembly for the typical major highway pavement design if the axle load is 18 kip, and the damage of the WBT increased from 22 to 52% when compared to the damage caused by a 20 kip axle. The authors also observed that WBT caused wider but shallower rut depth than single and dual-tire assembly. If rut depth is considered as the variable in defining rut damage, conventional single tire and WBT are more harmful; however, this is not the case if rut volume is taken into account. The research also found that for WBT 15R22.5, the fatigue damage increases 9 times when the tire inflation pressure changes from 75 to 120 psi. In the case of dual-tire assembly with 11R22.5, the increment is 2.8 times for the same change in tire inflation pressure. In addition, it was concluded that changes in the inflation pressure do not affect rutting, no matter the type of tire used. As a final and general conclusion, it was recommended to use dual-tire assembly instead of WBT.

The software CYRCLY was used to assess the effect of WBT on the response of flexible pavements in 1993 (Perdomo and Nokes). This software accounts for shear contact stresses on a circular contact area, nonuniform contact stresses, and gradient of temperature in surface layers. In addition, it is able to consider the pavement structure as a multilayered elastic anisotropic system whose layers can be fully bonded or frictionless. The analyses considered thick flexible pavement with nonuniform vertical contact stresses and with and without shear contact stresses. In addition, temperature gradient and different axle configuration (single, tandem, and tridem) were included. Based on these analytical results, it was concluded that WBT produce between 15 and 40% higher critical strain and between 30 and 115% higher strain energy of distortion. The authors also claimed that the shear contact stresses increase the tensile strain between 6.0 and 6.7 times when compared to the case when they were ignored. Moreover, the inclusion of shear contact stresses increased the strain energy between 5.5 and 5.8 times. However, it is noticed that the shear contact stresses used by the authors are unreasonably high.

In order to measure the dynamic wheel force applied by a truck to the pavement, a new wheel load transducer was introduced by Streit et al. (1998). The experimental program included two types of suspension (steel lead spring ant air bag), three different types of tires (two dual: one low profile (295/75R22.5) and one radial (11R22.5), and one WBT (425/65R22.5)), and four values of axle static load (16, 20, 24, and 30 kip). In addition, different values of speed (15, 30, 45, and 60 mph), tire inflation pressure (70, 95, and 120 psi), and road roughness were analyzed. Gross contact area, net contact area, load-deflection curves, and contact pressure distribution were measured for each tire, inflation pressure and applied load. Based on linear regression, a relationship was established between the net contact area, applied load, and inflation pressure. Similarly, equations to determine the tire stiffness as a function of inflation pressure were given. The authors found that the maximum contact stress is 1.6 or 1.7 times the inflation pressure for both types of tires (WBT and dual-tire assembly), and that speed has negligible effect on the contact stress distribution. The authors also proposed equations to calculate the dynamic load coefficient (DLC) as a linear function of road roughness, speed, wheel load, and inflation pressure. The experimental results showed that WBT has a DLC between 10 and 12% lower than dual-tire assembly. This difference, according to the researchers of this study, is caused by the mismatch in stiffness (WBT are 30% softer than dual-tire assembly). In addition, DLC for the three types of tires analyzed is very similar if they are in the front axle. However, based on the Eisenmann’s stress factor, WBT have 85% more potential damage than dual-tire assembly.

Siddharthan et al. (1998) and Siddharthan and Sebaaly (1999) introduced an analytical method to calculate the response of flexible pavement. This continuum-based finite-layer approach consists of multiple layers with the same properties, and it accounts for moving load, contact area of any shape, elastic and viscoelastic materials, and three-dimensional contact stresses implemented using Fourier series. Siddharthan et al. (1998) used this method to compare the response of thin and thick asphalt pavement subjected to a moving tandem-axle load with both dual-tire assembly and WBT traveling at 44.7 mph. It was found that the strain at the bottom of the AC layer is 33% higher for WBT than dual-tire assembly in thin pavements and 16% in thick pavements. This same analytical procedure was used to develop a parametric study when the load is applied by a WBT 425/65R22.5 in thin and thick flexible pavement (Siddharthan and Sebaaly 1999). The parametric study showed that for WBT at high speed, transverse normal strain should be used when predicting fatigue life. The authors also affirmed that the contact stresses between the pavement and WBT are nonuniform and the loaded area is not circular.

In 1999, the effect of tire structure, applied load, and inflation pressure on pavement performance was assessed by Myers et al. (1999). Contact stresses were measured for three different types of tires: bias ply (General Ameri Freight), radial (Bridgestone R299), and wide-base (Bridgestone M844); three inflation pressures (90, 115, and 140 psi); and different applied loads. These laboratory measurements showed that WBT have the highest vertical and transverse contact stresses. Based on a finite element model created in ABAQUS, it was concluded that the contact stress distribution was not dependent of the material at which the tire was applying the load. The measured contact stresses were used in the software BISAR to determine the pavement response, and it was found that the vertical and transverse contact stresses of WBT at high values of applied load and inflation pressure can create considerably more damage than dual-tire assembly considering surface rutting and cracking. It was also reported that surface cracking and near-surface rutting were mainly influenced by lateral stresses, and the main difference between WBT and bias ply dual-tire assembly was due to lateral contact stresses.

Siddharthan et al. (2002) used the software 3D-MOVE to carry out an analytical study to determine the effect of the contact stress distribution on pavement response. 3D-MOVE is based on the continuum-based finite-layer approach (Siddharthan et al. 1998; Siddharthan and Sebaaly 1999). Two AC pavement thicknesses (5.9 and 9.8 in) were analyzed under tandem axle load with dual-tire assembly and WBT. Different contact conditions were assumed according to the tire. For the tandem axle with dual-tire assembly, circular and rectangular contact area with constant and nonuniform stress distributions were considered. On the other hand, for the tandem with WBT, circular contact area with uniform and constant stresses and non-uniform distribution represented the contact stresses. Three-dimensional contact stresses for WBT (425/65R22.5) were also included. For WBT, circular contact area brought greater longitudinal strain at the bottom of the AC and greater vertical strain at the top of the subgrade. In addition, the shear stresses and strains at 2 in from the surface for both thin and thick pavement were also higher in magnitude for WBT with circular contact area when compared to the other contact assumptions. The authors also concluded that the effect of shear contact stresses for WBT is not relevant unless the response near the surface is being studied.

Finite Element Modeling (FEM) is another important aspect of the Virginia Smart Road study (Al-Qadi et al. 2005a; Elseifi et al. 2005). The developed model included exact contact area between the tire and the pavement and vertical nonuniform contact stress distributions. The AC layers were assumed viscoelastic, while subgrade and granular materials were assumed linear with its elastic modulus determined from in-site FWD measurements. The viscoelastic characterization of AC was based on the indirect creep compliance test and variable creep loading test (time hardening model) (Al-Qadi et al. 2005a; Elseifi et al. 2005). This FEM was validated with the experimental measurements of the instrumented sections, and it was used to quantify the damage. This allowed the comparison of dual-tire assembly (11R22.5) and two sizes of NG-WBT: 445/50R22.5 and 445/55R22.5.

Based on the experimental measurements and the numerical model, the authors concluded that WBT 445/50R22.5 produced more subgrade rutting than dual-tire assembly. Regarding surface rutting, 445/50R22.5 was found to be more damaging than dual-tire assembly, but 455/55R22.5 caused as much damage as dual-tire assembly at low speed. In general, 455/55R22.5 tires were less damaging than 445/50R22.5 tires from the surface rutting perspective. In the case of top-down cracking, both sizes of NG-WBT were considerably less harmful than dual-tire assembly. Finally, WBT caused more fatigue cracking than dual-tire assembly, but NG-WBT showed a better performance than the first generation of WBT for this type of distress.

A direct comparison between 385/65R22.5 and 445/50R22.5 reasserts that the first generation of WBT is more harmful for the pavement than NG-WBT (Al-Qadi et al. 2005a). The experimental data also evidenced a reduction in the strain at the bottom of the AC layer as the speed increases. The rate at which these strains were reduced was greater for dual-tire assembly than for WBT. After all the damage mechanisms were combined, it was concluded that 385/65R22.5 tire is the most deteriorating type among the tires considered in this study, followed by 445/50R22.5 tires and dual-tire assembly.

In 2005, the impact of WBT on the subgrade was study using FEM (Kim et al. 2005). The mentioned model considered a 425/65R22.5 tire with inflation pressure of 125 psi and applied load of 11.4 kip. In the numerical model, the contact area was assumed to be rectangular with no treads and without longitudinal or transverse contact stresses. In addition, two types of models were compared: plain strain 2D and 3D. The pavement structure was composed by 6 in of asphalt on top of 6.75 in-thick base, 24 in-thick compacted clay, and 240 in-thick clay or sand subgrade. After comparing different assumptions, uniform contact stress distribution equal to the maximum vertical stress was selected for being more conservative. The material properties for all layers were obtained from the literature, and the subgrade was assumed to be governed by the Druvker-Prager model. Furthermore, three tire configurations were analyzed: conventional dual-tire assembly at 18 kip axle load, conventional dual-tire assembly at 22.8 kip axle load, and WBT (425/65R22.5) at 22.8 kip axle load. The FEM results indicated that WBT produced the highest vertical stress on top of the subgrade, and that WBT induced four times more permanent strain than dual-tire assembly. Moreover, single axle with WBT resulted in the largest vertical plastic strain on top of the subgrade when compared to the other axle configurations.

An analytical study was presented by Yoo et al. (2006) using FEM of flexible pavements to assess the validity of different assumptions commonly used to model such as layer interaction, amplitude of applied load, and tire contact stresses. The asphalt material was considered as viscoelastic with its parameter determined from the creep compliance test; while base and subbase were assumed linear with their modulus of elasticity given by FWD test. WBT and dual-tire assembly were modeled considering 3D contact stresses. In addition, two friction models (simple friction (Coulomb) and Stick model) and two load amplitude assumptions (trapezoidal and continuous) were investigated. Experimental measurements from Section B of the Virginia Smart Road project (Al-Qadi et al. 2004) were used to validate the numerical predictions. It was concluded, in general, that continuous amplitude loading and non-uniform 3D contact stresses improve the accuracy of the FEM and should be considered in any future study. In particular, it was found that results of the simple friction model for WBT are closer to the experimental measurements.

Three-dimensional contact stresses were measured for a variety of tires (WBT included), inflation pressures, and applied load in Texas (Emmanuel et al. 2006). In order to measure these contact stresses, the Stress-in-Motion system was used. In the case of WBT (425/65R22.5), measurements were taken at four inflation pressures (73, 102, 131, and 145 psi) and five applied loads (5.86, 10.4, 12.6, 14.9, 19.4, and 23.9 kip). Based on these readings, expressions to predict the contact area as a linear function of tire load and inflation pressure were proposed. The entire experimental results were compiled in software called TireView; this software can be used to predict the 3D contact stresses at any load and inflation pressure. This is done by interpolation between the experimental values. The authors also used the measured contact stresses to calculate the pavement response analytically. Three analytical calculations were included: 3D FE with 3D measured contact stresses, layered linear elastic with contact area equivalent to the measured one, and layered linear elastic with the contact area based on the load and inflation pressure. It was concluded that the 3D contact stresses and uniform circular pressure assumptions bring "quite comparable" results. It was also noted by the authors that WBT experimental values provided the worst repeatability.

The experimental readings obtained by NCAT in 2006 were compared to analytical results calculated using WESLEA (Priest and Timm 2006). This software uses the layered elastic theory and assumes circular contact area with uniform pressure. The elastic properties of each layer used as input in this program were backcalculated using EVERCALC 5.0. The testing program, where the only different parameter was the type of load used, showed that the strain and stresses of WBT and dual-tire assembly are virtually the same. On the other hand, the analytical result presented higher strains and pressures in the case of WBT. In addition, the difference between both tires decreased as the depth increased. Based on the numerical results, the fatigue life was found to be 69% less if the pavement is subjected to moving load using WBT. It was also noted that the difference in WESLEA's results was higher for WBT.

In addition to the experimental program described in the previous section, a detailed finite element model was developed during the investigation carried out by University of Illinois (Al-Qadi et al. 2008; Al-Qadi and Wang 2009a; Al-Qadi and Wang 2009b). This model included advanced characteristics such as dynamic implicit analysis, continuous loading amplitude, Coulomb friction between layers, three dimensional contact stresses, and viscoelastic asphalt materials. The aforementioned model was proved to predict the response of the pavement structure, since it brought good agreement with experimental readings of the peak strain and time history. The study showed that NG-WBT produced higher longitudinal strain at the bottom of the AC layer and higher stresses on top of the subgrade than dual-tire assembly. On the other hand, it resulted in less compressive and vertical shear strain close to the surface of the pavement. As in studies by other authors, the difference in the response of the pavement between both types of tires decreased as the depth increased.

The effect of the offset was also documented: as the offset was increased, the longitudinal strain at the bottom of AC for NG-WBT decreased at a higher rate. The numerical model was used to assess other failure mechanism (rutting and near-surface cracking). NG-WBT-445 resulted in higher strain damage at the bottom of AC (fatigue cracking) and compressive strain at top of the subgrade (secondary rutting), but less near the surface damage (primary rutting, top-down cracking, and near-surface cracking). The researcher of the study concluded that, based on combined damage, NG-WBT-445 caused less damage on interstate highways, but it is more harmful on local roads. Based on cost analysis, it was also affirmed that NG-WBT-445 could be more cost-effective for an interstate highway, but it is slightly more expensive for primary roads.

Al-Qadi and Wang (2009a; 2009b; 2009c) conducted a study on quantification of the damage caused by dual-tire assembly and NG-WBT-455 on roads with low-volume traffic. The main characteristics of the experimental set-up were presented in the previous section. The numerical model accounted for all the features used by the author in other studies (Al-Qadi et al. 2008). Even though the agreement between measured and predicted values was not strong, the ratio of NG-WBT to dual-tire assembly of the experimental measurements was similar to the FEM ratio. For all base thicknesses, the longitudinal strain at the bottom of AC was greater for the dual-tire assembly, but the transverse strain was very similar. It was also concluded that NG-WBT produced the lowest vertical shear stresses, no matter the thickness of the base layer. On the contrary, WBT-425 resulted in the greatest deviatoric and bulk stresses for all pavement structures analyzed.

The authors noted that the compressive strain and deviator stress on top of the subgrade decreased as the thickness increased. The analysis of the damage performed based on described analysis indicated that NG-WBT-455 was more harmful than dual-tire assembly: from 1.9 to 2.5 times more fatigue damage, from 1.3 to 2.3 times subgrade rutting, and from 1.3 to 1.8 times more AC rutting due to densification. On the other hand, NG-WBT-455 showed less AC rutting due to shear flow and less shear failure potential. The authors reported that after all the damage mechanisms were combined, NG-WBT-455 caused between 1.12 and 1.38 more combined damage than dual-tire assembly on secondary road. NG-WBT-455 was also showed to be more expensive on low-volume traffic.

[redacted] Sections subjected to real traffic

Multidepth deflectometers were used by Akram et al. (1992) to compare the damage produced by dual-tire assembly (11R22.5) and NG-WBT (425/65R22.5) in two flexible pavement sections open to real traffic. Each pavement section represented a thin and thick structure (1.5 and 7 in-thick respectively), and the speed varied between 4 and 60 mph. Not only was the offset of the tire taken into account, but also the WBT and the dual-tire assembly were switched between the tandem drive trailer axles. The authors found that a lower deflection is caused by the dual-tire assembly when compared to NG-WBT. It was also concluded that the maximum deflection occurred at a different location depending on the type of tire: around the center of the tire for NG-WBT and under one of the tires of the dual-tire assembly. Some important remarks were made regarding WBT: the maximum shear stress occurred at its edge, and its deformation basins were deeper and more concentrated. Moreover, NG-WBT was more damaging based on the vertical strain on top of the subgrade. The vertical strain on top of the subgrade was used to determine the number of repetitions to failure. It was reported that the number of repetitions increased 45% and 39% when the speed changed from 4 to 60 mph for dual-tire assembly and NG-WBT respectively. For thick pavement, the increment was 87% for dual-tire assembly and 26% for NG-WBT for the same change in speed, respectively. When the speed was kept constant at 55 mph, NG-WBT were 2.8 times more damaging on thin pavements and 2.5 times more damaging on thick pavements than dual-tire assembly, respectively.

1.2. IMPACT ON DYNAMIC TIRE LOADING

Since WBT have only two sidewalls, it is much more flexible than a pair of dual-tire assembly, which has four sidewalls. This flexibility means that the tire absorbs more dynamic bouncing of the truck; hence, less dynamic load is transmitted to the pavement. Tielking (1994) compared a single 425/65R22.5 and two 11R22.5 tires on an MTS servo-hydraulic machine. The author found that, except near the resonant frequency, the transmissibility of the WBT was less than that of the dual-tire assembly. At 10Hz, which is near the fundamental vibration frequency of a heavy highway vehicle, the force transmissibility of the WBT is 35% less than that of the dual-tire assembly. This indicates that the dynamic component of pavement load from a WBT is less than the dynamic component of pavement load from dual-tire assembly. Moreover, the research found that the sensitivity of the force transmissibility was negligible considering the load level, and it was slightly sensible to tire inflation pressure.

Similar results were found in a shaker table study by Streit et al. (1998). Two different types of dual-tire assembly (standard and low profile) were compared with a WBT (425/65R22.5). The magnitudes of the dynamic wheel loads produced by the dual-tire assembly were very similar. The Dynamic Load Coefficient (DLC is equal to standard deviation of tire load divided mean value) values of the standard radial tires were about 2% higher than those produced by the low-profile tire. The WBT produced DLC's from 10 to 12% lower than those of the dual-tire assembly.

1.3. IMPACT ON TRUCKING OPERATIONS

A review of the improvements provided by the NG-WBT was given by Elseifi and Al-Qadi (Elseifi et al. 2005). They mention how this type of tire decreases the rolling resistance, which translates in fuel saving from 2 to 10%. The gross weight of the truck having NG-WBT could be reduced by 744 lb, increasing the hauling capacity. The NG-WBT could have a 50% lower maintenance cost while the cost could be the same as dual-tire assembly. Regarding safety, NG-WBT has a sensor that controls the inflation pressure, so the probability of having a sudden flat tire is reduced. This is confirmed by the satisfactory performance of NG-WBT on the sudden-failure test. In addition, the drivers of trucks with NG-WBT installed noted similar truck handling as with dual-tire assembly.

Overall economic analysis of the use of wide-base tires from COST Action 334 (COST 334 2001) indicated that the benefits of this technology are considerably greater than the additional pavement maintenance costs they may cause. Items considered in the economic analysis included pavement maintenance costs, government tax income, vehicle operating costs, non-pavement related government expenditures (polluting emissions), and trucking operations spending (tires cost and recycling). It was estimated that the use of wide-base tires on the towed axles alone would be associated with a saving of €2,302 million in the European Union. Using wide-base tires on the towed, driven, and steering axles would provide an additional saving of €682 million.

[redacted] Fuel Economy

In 2000, the Energy Laboratory of the Massachusetts Institute of Technology (MIT) analyzed alternatives to reduce gas consumption and to improve fuel efficiency of class-8 trucks by reducing the rolling resistance and improving propulsion technologies (Muster 2000). A script using Matlab-Simulink was used to predict the fuel economy. The proposed model assumes a vehicle traveling on a flat road, and it considers the rolling resistance coefficient (RRC), aerodynamic drag coefficient (C_d), vehicle mass, frontal vehicle area, engine and transmission performance, and driving cycle (highway and urban). Also, the resistance (internal and external) that the vehicle must overcome in order to move was taken into account. The rolling resistance coefficient was varied between 0.007 and 0.005, 0.005 representing a truck equipped with WBT. The results of the modeling process show that the reduction of the RRC to 0.005 (WBT) increases the fuel efficiency of the truck by 10%.

The effect of reducing the rolling resistance and the aerodynamic drag on the gas consumption and the emission of oxides of nitrogen (NOx) was studied by Bachman et al. (2005). Class-8 trucks on a test track simulating the operating conditions of real traffic were used. The tests included two scenarios: highway conditions at two different speeds (55 and 65 mph) and suburban circumstances. The truck was equipped with aerodynamic devices and WBT, so the rolling resistance and dynamic drag could be varied. It was found that both aerodynamic devices and WBT improved fuel economy by similar values. However, WBT are more efficient in the suburban scenario. WBT improved fuel economy between 3 and 18%: 3% for no WBT in sub-urban conditions with aerodynamic devices, and 18% for the truck traveling at 65 mph on a highway and equipped with aerodynamic devices.

As explained by Genivar Consulting Groups (Genivar 2005), the energy used by a truck can be sorted in the following categories: 35% for rolling resistance, 50% for aerodynamic resistance, 5% for mechanical resistance (assuming that the truck travels at 60 mph), and 10% is used by auxiliary devices of the truck. The study collected information from hauling companies regarding savings resulting from reduction in fuel consumption when WBT were used. The fuel consumption was found to be reduced between 3.5 to 12%.

Ang-Olson and Schroeer (2002) analyzed the use of WBT as one of eight strategies to improve environmental performance and fuel efficiency in the truck industry. The authors affirmed that the use of WBT improves the fuel economy between 2 and 5% depending on the specific model of the WBT (tire manufacturer). This translates to savings of 424 gal/year for a typical long-haul truck.

Different alternatives to reduce the gas consumption of heavy truck vehicles from different points of view such as vehicle technology and driver skills were analyzed in Finland (Nylund 2006). The report highlights the benefits of WBT regarding weight, space, and reduction of rolling resistance when compared to dual-tire assembly. The fuel consumption was measured using a chassis dynamometer, and it compared WBT and dual-tire assembly. No significant difference was observed. The results obtained using the chassis dynamometer were verified with a test on a straight highway; similar results were reported. The authors affirmed that rolling resistance is a relevant factor that links tire with fuel efficiency. They also point out that the tire system (tire pressure, tire type, tread depth, etc.) can improve the fuel efficiency between 5 and15%.

Recently, Franzese et al. (2010) analyzed real performance data of class 8 trucks regarding its fuel efficiency when using NG-WBT. Six trucks were instrumented to measure not only instantaneous gas-consumption related data, but also information related to weather, speed, location, and weight among others. Three trucks were equipped with NG-WBT and the other three with conventional dual-tire assembly. Four combinations were used for the installation of the tires: tractor and trailer with dual-tire assembly, tractor and trailer with NG-WBT, tractor with dual-tire assembly and trailer with NG-WBT, and tractor with NG-WBT and trailer with dual-tire assembly. The authors concluded that truck equipped with NG-WBT improved the fuel efficiency by 6%. The data was also analyzed by grouping the truck by weight, and it was found that less fuel was consumed by trucks with NG-WBT in all truck-weight ranges. This increment becomes more important as the number of NG-WBT installed in the truck increases. It reached 10% improvement when all the tires were NG-WBT, and it augmented if the truck weight became higher.

[redacted] Hauling Capacity

WBTs increase the hauling capacity of trucks by reducing the total weight of the empty truck. As described by Markstaller et al. (2000), WBT are lighter than dual-tire assembly, so the total weight reduction in a truck with WBT can be as high as 896 lb. This reduction in total weight translates to an increment in hauling capacity of 2%.

[redacted] Tire Cost and Repair

The use of WBT also allows a reduction in maintenance costs (Genivar 2005). This is due to easier inspection and repair of trucks equipped with WBT. According to the referenced study, the time allotted for maintenance of a truck using WBT can be reduced by 50% when compared to a truck with dual-tire assembly. This report mentioned that WBT can be retread just once, while dual-tire assembly can be retread as many as three times under particular conditions. However, the new technology in WBT allows multiple retreads as in the case of conventional tires. Another source of savings is the rim cost. Even though the cost of one dual-tire assembly is as high as one WBT, a single wide-rim cost is cheaper than two rims for a dual-tire assembly (Environmental Protection

Agency 2004). Finally, it is easier to inspect the inflation pressure of a WBT when compared to dual-tire assembly, specially the interior tire of the dual set. Differential inflation pressure is a common problem in dual-tire assembly.

[redacted] Truck Operation and Safety

Concerns have emerged regarding tire inflation pressure controls in WBT; however, incidents have been reduced by enhancing pressure maintenance. Markstaller et al. (2000) conducted rapid air loss tests in trucks with WBT installed. It was found that the most critical situation appears when sudden air loss occurrs in the rare drive position on the exterior part of a curve. The traveling speed of the truck was 60 mph, and the radius of the curve was 1200 ft creating a lateral acceleration of 2g. The truck never left the corresponding lane during the test.

[redacted] Ride and Comfort

The driver's impression was also considered by Markstaller et al. (2000). According to the authors, both types of tires require similar degrees of handling, and the vibration was reduced by installing WBT. Constant-radius understeer test show a linear increase of understeer behavior with lateral acceleration. The steering wheel angle was lower in most of the ranges for WBT than dual-tire assembly.

Vehicle ride tests also showed advantages of WBT over dual-tire assembly. Power spectral density at the base of the seat base was measured using accelerometers showing a reduction in the acceleration level for the truck with WBT.

1.4. IMPACT ON ENVIRONMENT

Al-Qadi and Elseifi (2005) highlight the fact that NG-WBT is more environmentally friendly than dual-tire assembly: it generates less noise and fewer emissions due to less gas consumption. In addition, the amount of rubber needed to fabricate NG-WBT is less, so the disposed material at the end of its service life is reduced. In general, various studies have consistently concluded that NG-WBT causes similar damage to the pavement than dual tires.

[redacted] Gas Emission

The reduction in the gas consumption of trucks using WBT results in a reduction of the emission of contaminant from the truck to the air. The savings caused by less emission can be calculated based on the amount of contaminant produced by a gallon of gas and the amount of gas not consumed by a truck using WBT (Genivar 2005). Following this procedure, Genivar Consulting Groups calculated environmental savings of $17.8 million.

In addition, Ang-Olson and Schroeer affirmed that the use of WBT can reduce the gas emission by 1.1 million metric tons of carbon equivalent (MMTCE) in 8 years (Ang-Olson and Schroeer 2002).

The effect of reducing the rolling resistance and the aerodynamic drag on the emission of oxides of nitrogen (NOx) was studied by Bachman et al. (Bachman et al. 2005). The authors reported a reduction of NOx emission between 9 and 45% when NG-WBT compared to dual-tire assembly.

[redacted] Tire Recycling

According to Riesman (1997), landfill and stockpiles in the United States store between 2 and 4 billion of scrap tires. Genivar calculated the amount of savings resulting from the reduction of tire disposal. The calculation was based on the amount of disposed material according to the type of tire (118 lb for a WBT and 160 lb. for conventional dual-tire assembly), the amount of tires disposed, and the cost of disposing used tires (Genivar 2005). The authors calculated savings of $415,900/year in their study if WBT were disposed instead of conventional dual-tire assembly.

[redacted]Noise

In a noise test conducted by Markstaller et al. (2000), WBT produce slightly less noise when compared to trucks that use conventional dual-tire assembly.

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