

Article

Finite Element Modeling of Different Autonomous Truck Combinations, Tire Types and Lateral Wander Modes

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Abstract

Autonomous trucks can be used in different loading combinations, including different axle configurations, tire types, and lateral wander mode scenarios. In this research, four different truck types have been selected with varying gross weights and axle configurations. The four different truck types include a 5-axle long-haul semi-truck, a 6-axle electric autonomous truck, a 6-axle autonomous truck platoon leader, and a 5-axle autonomous truck platoon follower. Furthermore, three different tire footprint scenarios, consisting of a conventional dual wheel assembly, a wide base tire, and a new generation wide base tire, have been used. In order to utilize the possibility of lateral wander programmed into the autonomous trucks, three different lateral wander models, including zero lateral wander, a human-driven probabilistic lateral wander, and an optimum uniform wander mode, have been used. Finite element analysis has been employed to incorporate the effects of various scenarios on a conventional pavement section. Results showed improved pavement life with the use of uniform wander mode, where trucks T1 and T2 improved the pavement life by 47% and 56%, respectively, when compared to truck T3. Furthermore, the use of uniform wander mode decreases rutting and fatigue damage by 36% and 28%, respectively, on average for all scenarios. The use of new generation wide-base tires is recommended, since it reduces damaging strains by 38% when compared to the dual tire configuration.

Keywords: autonomous trucks; finite element modeling; rutting; fatigue

1. Introduction

Autonomous freight trucks (AFTs) are expected to bring new challenges to the current transport infrastructure system. The impacts range from transportation logistics patterns to the physical infrastructure system. Although autonomous trucks are expected to reshape freight transportation by improving safety, fuel efficiency and supply chain reliability, their impacts on the flexible pavement structure may vary based on the lateral wander pattern used [1]. Furthermore, the combination of platoon coordination and arrangement of axle/loading configurations for the autonomous trucks also brings a significant impact on the pavement structure in terms of rest period and elastic response [2].

Major manufacturers now produce Level 4 autonomous trucks capable of prolonged highway operation, often relying on consistent lane tracking and optimized fuel efficiency. However, autonomous operational patterns, tight platooning, minimal lateral wander, and precise wheel path tracking may unintentionally accelerate pavement damage by concentrating repetitive loads [3]. The level 4 autonomous trucks combine artificial intelligence, sensor fusion and connectivity to improve the performance in terms of safety and fuel efficiency [4].



Academic Editor: Suchao Xie

Received: 13 February 2026

Revised: 1 March 2026

Accepted: 4 March 2026

Published: 5 March 2026

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Usually, two of the most fundamental distress mechanisms are evaluated in order to evaluate the damage from moving truck traffic in terms of fatigue cracking and rutting. Fatigue cracking initiates at the bottom of the asphalt concrete layer due to repeated tensile strain under traffic loading, eventually propagating to the surface [5]. Rutting is the accumulation of permanent vertical deformation in the AC layer and underlying unbound granular materials caused by compressive strain at the top of the subgrade [6]. Moreover, the relationship between axle load and pavement damage is nonlinear and often described by the fourth power law, where a small increase in load can lead to a disproportionate increase in damage [7].

Therefore, the axle configuration and tire pavement interaction are fundamental determinants of these critical pavement responses [8]. AFTs may employ non-traditional configurations consisting of additional axles or tridem groups, to accommodate higher Gross Vehicle Weights (GVWs) while complying with bridge formula laws [9]. Multi-axle arrangements can mitigate peak subgrade strain and reduce rutting rates compared to single axle or concentrated tandem arrangements. Furthermore, recent electrification trend for long-haul autonomous trucks often increases vehicle mass or redistributes it across more axles for battery packs and multiple drive motors, which will alter these effects relative to present-day human-driven fleets [10]. Concurrently, the trucking industry's drive for fuel efficiency has popularized Wide Base Single Tires (WBSTs), which have been shown to increase contact pressure and near-surface stresses compared to conventional dual tire assemblies, reducing rutting and top-down cracking [11,12]. Furthermore, the use of WBSTs with AFTs hasn't been previously studied in more detail.

Furthermore, the use of lateral wander mode in human-driven and autonomous trucks is another governing factor for inducing channelized or unevenly distributed loading patterns on the pavement. Human drivers naturally exhibit a lateral wander, which is a probabilistic distribution of wheel paths across a traffic lane and usually considered to follow a normal distribution pattern [13]. This wandering distributes wear, allowing the pavement structure to undergo periodic recovery between load applications at any given point. However, AFTs operating with precise lane keeping will channelize traffic, applying every load repetition to an identical path, leading to significantly accelerated accumulation of fatigue and rutting damage [14].

In terms of application of lateral wander modes and tire pavement interaction, Wenlu et al. [15] have developed a flexible evaluation method specifically for assessing lateral control impacts of truck platoons on asphalt pavement performance, proposing a truck platoon axle load lateral distribution function to characterize cumulative damage effects. Zhenlong et al. [16] have addressed load-sensitive tire to road friction modeling and dynamic stability analysis of multi-axle trucks, integrating load-sensitive friction models with friction ellipse concepts and static rollover thresholds. Results stated that ignoring load sensitivity systematically overestimates safe speeds and underestimates lateral deviations. Cardenas et al. [17] have used a decoupled tire pavement interaction approach using 3D finite element modeling techniques, using a full truck model to evaluate the impact of road surface roughness on vehicle dynamics. Results showed that roughness induced dynamic loading has a significant impact on bottom-up cracking, near-surface cracking and rutting. Wang et al. [18] have developed a 3D model of a tire to evaluate the tire pavement contact stresses. The influence of shear stresses and the superimposition of contact stress values were evaluated. Results showed that the distribution of vertical stress values is the same for both the dynamic rolling tire and the static tire.

A further critical distinction exists between analytical models and finite element models, each with inherent limitations. Analytical approaches employing layered elastic theory in traditional pavement design guides offer computational efficiency for parametric studies;

however, they are constrained by assumptions of material linearity, layer homogeneity, and simplified loading representations [19]. These models cannot capture the nonlinear stress-dependent behavior of unbound materials, the viscoelastic response of asphalt concrete, or the complex three-dimensional stress fields arising from non-uniform tire contact pressures [20]. However, FE studies have focused on specific aspects in isolation, with Liang et al. [21] having developed a 3D finite element pavement model incorporating a non-linear Burger model for asphalt concrete permanent deformation, calibrated through flow number and dynamic modulus tests. This study showed that higher wander and increased platoon penetration distributed loading evenly, thereby reducing localized rutting.

Recent modeling and experimental studies have quantified these effects. Finite element and mechanistic studies show that reduced lateral wander, which includes the zero wander concentrates stress and strain within a narrow wheel path, increasing predicted rutting and reducing predicted fatigue life relative to human-driven wander distributions. Therefore, distributing wheel positions laterally using uniform wander can spread load repetitions and slow deterioration at any single longitudinal location [22].

An AFT could be programmed to execute a uniform wander pattern, which leads to systematically distributing its load across the lane width to actively mitigate pavement damage. Several studies have used Finite Element modeling to analyze tire pavement interaction [23,24], theoretically explored the impact of autonomous truck platooning on bridges and pavements [25,26]. However, a detailed analysis that integrates specific AFT axle configurations, modern tire types, and a comparative analysis of different lateral wander patterns within a single advanced computational framework has not been mentioned in the current literature [27]. Furthermore, previous studies do not include the use of different tire type footprints based on tire size and the coupled use of tire pressure concentration path that directly affects the pavement response under loading at varying speeds. Previously, only one type of 5-axle truck-trailer combination has been taken into consideration. Therefore, critically, no existing study has simultaneously integrated: (1) realistic autonomous truck axle configurations with varying gross vehicle weights, (2) multiple tire footprint designs including next-generation wide-base singles, (3) comparative analysis of lateral wander patterns encompassing both the risks of channelization and the opportunities of programmable uniform distribution.

Therefore, in this research, the gap is addressed by performing a comprehensive, multi-scenario 3D finite element investigation of asphalt pavement response to four representative truck types consisting of conventional long haul, urban rigid and emerging autonomous electric axle layouts along with three representative tire footprint/tread pressure patterns, under three lateral wander modes: (1) human like stochastic wander, (2) autonomous precise lane centering and (3) autonomous uniform controlled wander designed to uniformly distribute wheel loads laterally. The analysis employs viscoelastic material models for HMA, viscoplastic permanent deformation and mechanistic empirical accumulation rules to estimate rutting and fatigue life differences across scenarios. Therefore, different tire footprint options, axle configuration variability and alternative lateral wander options have been used to evaluate the pavement deterioration.

This research introduces a novel comparative methodology that simultaneously evaluates the interacting effects of autonomous truck axle configurations, tire footprint designs, and lateral wander patterns. Furthermore, it provides the first quantitative assessment of a programmable uniform wander operational strategy specifically designed for autonomous vehicles and establishes a mechanistic framework for quantifying the relative damage factors of emerging autonomous truck technologies against conventional human-driven baselines regarding weight regulations, tire standards and operational requirements for future freight corridors.

2. Materials and Methods

This research employs a comprehensive and integrated computational framework to systematically quantify the impact of autonomous truck operations on pavement performance. The methodology uses the development of a 3D finite element model in ABAQUS, simulating a multi-layered flexible pavement system with nonlinear material properties, including a viscoelastic asphalt concrete layer. The investigation evaluates four distinct truck configurations consisting of standard human-driven to autonomous truck with varying gross vehicle weights and axle arrangements under the influence of three critical tire types: conventional dual tire assemblies, traditional wide base singles, and new-generation wide base singles. Furthermore, the modeling of three lateral wander patterns: simulating human drivers, zero wander for channelized autonomous traffic and a proposed uniform wander and optimized autonomous mode is performed. The pavement's mechanical response, characterized by horizontal tensile strain at the bottom of the asphalt layer and vertical compressive strain at the top of the subgrade, is extracted to compute fatigue and rutting damage using mechanistic empirical transfer functions. The relative damage factor for each truck-tire wander scenario is calculated.

2.1. Asphalt Layer and Material Properties

A complete pavement section consisting of all the fundamental layers has been selected for modeling, with mixture and thickness details shown in Table 1.

Table 1. Pavement structure characteristics.

Layer	Thickness [mm]	Material
Asphalt concrete surface course	200	Polymer-modified dense-graded asphalt (PG 70-22)
Granular Base Course	200	Crushed aggregate base, well-graded
Granular Subbase Course	400	Crushed aggregate base, well-graded
Subgrade	Semi-infinite at 2350	Medium-plasticity clay/silt foundation soil

The properties of the PG 70-22 binder are shown in Table 2.

Table 2. Properties of bitumen.

Property	Value	Standard
Penetration 25 °C (0.1 mm)	74.4	ASTM D5 [28]
Softening point (C)	46.5	ASTM D36 [29]
Ductility (cm)	69.3	ASTM D113 [30]
Mass loss (%)	0.52	
Rolling thin film oven	Penetration ratio (%)	70.7
	Ductility (cm)	9.4
Elastic recovery at 25 °C	73	ASTM D6084 [32]
Viscosity at 135 °C (Pa.s)	1.4	ASTM D4402 [33]

Asphalt mix gradation has been selected by using a well-graded aggregate mixture having a nominal maximum aggregate size of 19 mm, with gradation shown in Table 3.

Table 3. Aggregate gradation.

Sieve Size	Upper Limit	Lower Limit	Percentage Passing
19	100	100	100
16	90	100	94.3
13.2	76	92	85.5
9.5	60	80	67.2
4.75	34	62	48.0
2.36	20	48	33.4
1.18	13	36	25.3
0.6	9	26	16.4
0.3	7	18	10.1
0.15	5	14	7.6
0.075	4	8	6.6

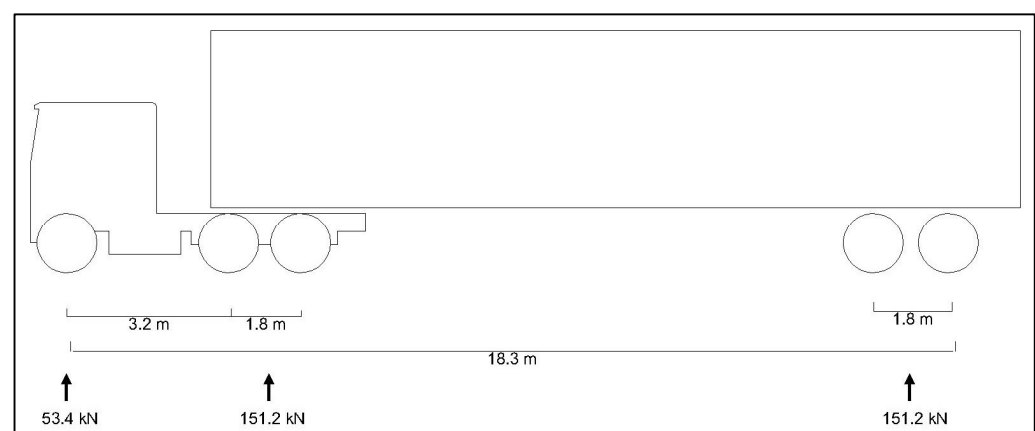
2.2. Loading and Axle Details

Four different truck types with varying axle and loading configurations, designated as T1 to T4, have been selected and shown in Table 4.

Table 4. Truck types and axle configurations.

Truck Type	Axles	Axle Configuration	Total Load [kN]
T1	5-axle long haul semi-truck	1 steer + 2 drive tandem + 2 trailer tandem	356
T2	6 axle electric autonomous truck	1 steer + 2 drive tandem + 3 tandem trailer	400
T3	6 axle autonomous truck platoon leader	1 steer + 2 drive tandem + 3 tandem trailer	489
T4	5-axle autonomous truck platoon follower	1 steer + 1 drive tandem + 3 tandem trailer	356

Truck T1 is shown in Figure 1. It is a human-driven 5-axle semi-truck. As observed, the total axle-to-axle length is 18.3 m, with the maximum gross weight of 356 kN. The tandem axles on the tractor head are spaced at 1.8 m with a spacing of 3.2 m from the steering axle to the center of the first drive axle. Both tandem axles on the tractor head and trailer support the loading of 151.2 kN.

**Figure 1.** Truck T1.

Truck T2 is shown in Figure 2. As observed, T2 is an electric autonomous truck with a tandem axle that allows for the storage of extended battery packs. The maximum gross weight has been increased to 400 kN, with 213.4 kN exerted by the tridem trailer axle. The loading magnitude decreases at the tandem drive axle to 133.4 kN and 53.4 kN at the steering axle. The total spacing from the steering axle to the last axle of the tridem trailer is 20.1 m.

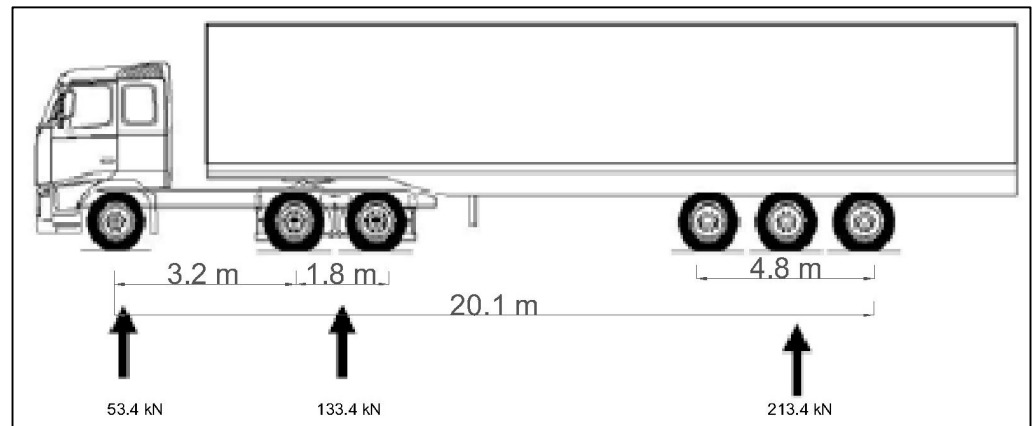


Figure 2. Truck T2.

Truck T3 is shown in Figure 3. This truck is a platoon leader with a heavier maximum gross weight of 489 kN. The axle spacings and axle count are the same; however, the axle load has now been increased as part of the extended range of this internal combustion engine truck with the same axle configurations as truck T2. The tridem trailer axle exerts a load of 248.1 kN, with 177.9 kN on the drive tandem axle and 62.3 kN on the steering axle.

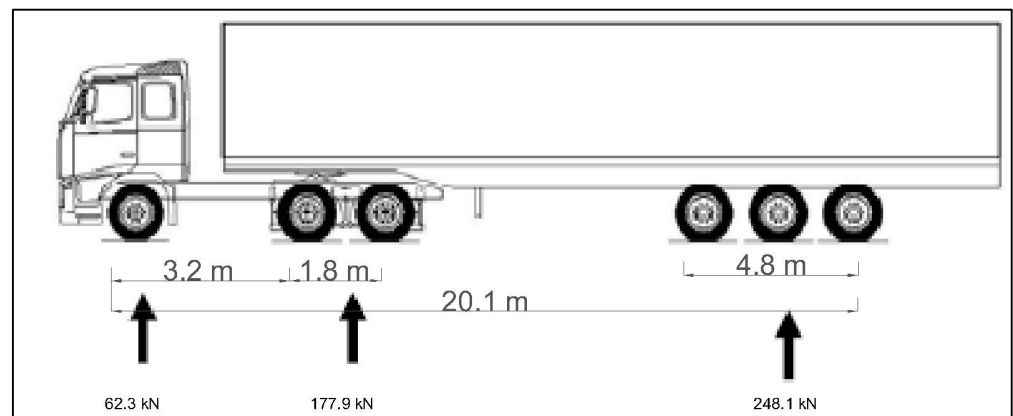


Figure 3. Truck T3.

Truck T4 is a 5-axle autonomous semi-trailer; however, unlike truck T1, it has only one drive axle and the trailer has mono-tridem axles as shown in Figure 4. The overall length of T4 is 16.5 m. Maximum load is at the tridem axles with a magnitude of 200.2 kN. Loading at the drive axle of the tractor head is 97.9 kN, with 57.8 kN on the steering axle.

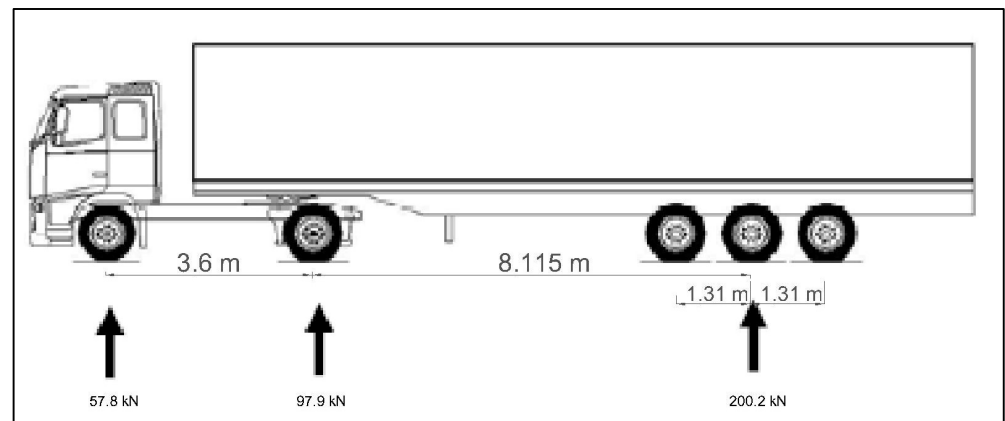


Figure 4. Truck T4.

Three tire types' footprint patches are modeled by applying a non-uniform vertical contact pressure over their respective footprint areas, with details shown in Table 5.

Table 5. Tire types.

	Dual Tire	Wide Base Tire	New Generation Wide Base Tire
Type	F1	F2	F3
Total contact area	76,030	57,200 mm ²	65,970 mm ²
Major axis length	220	280	300
Major axis width	530	260	280
Edge pressure	810 kPa	690 kPa	550 kPa

The dual tire used is a Bridgestone R287 Ecopia with size 295/75R22.5. The pressure distribution for the dual tire assembly is shown in Figure 5. Maximum pressure in the center of the tire reaches 820 kPa and gradually reduces to 810 kPa.

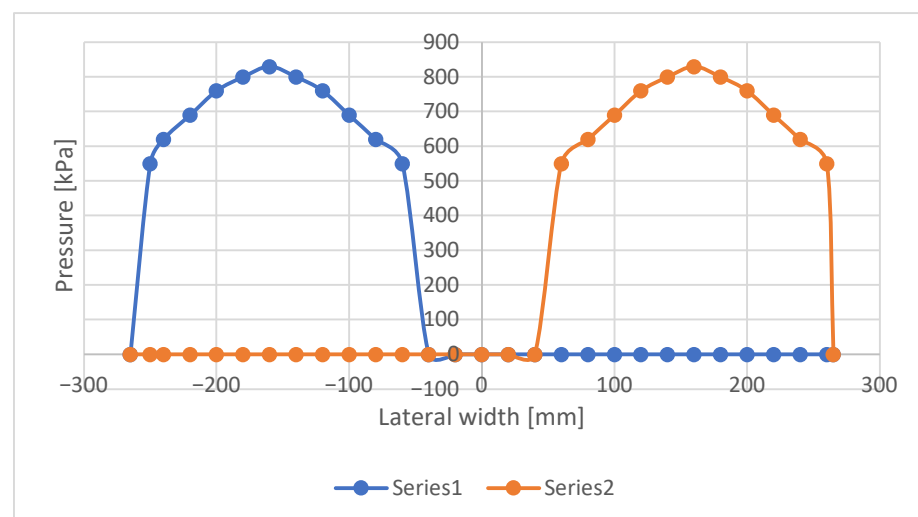


Figure 5. Tire pressure distribution for tire F1.

The traditional wide base tire used is a Michelin X ONE LINE GRIP D type with size 445/50R22.5. The pressure distribution for the wide base tire is shown in Figure 6. As observed, the wide base tire shows a much more gradual pressure distribution along its width, with maximum pressure reaching 900 kPa; however, spread to a much wider area with edge pressure at 690 kPa.

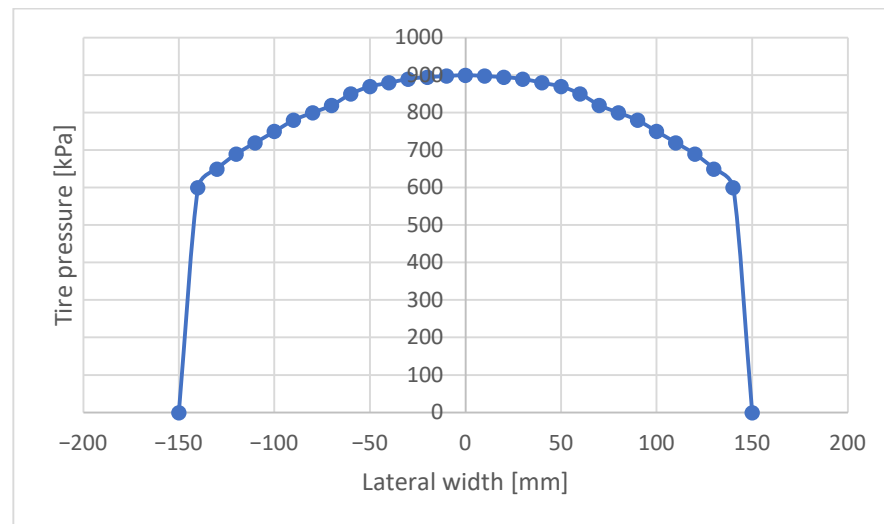


Figure 6. Tire pressure distribution for tire F2.

The pressure distribution for the new generation wide-base single tire is shown in Figure 7. The new generation wide base tire is manufactured by Giti Tire USA with a 455/50R22.5 size. Due to the nature of the tire footprint, the pressure underneath the tire is evenly distributed, and therefore, a lower concentration of overall pressure exists at 830 kPa.

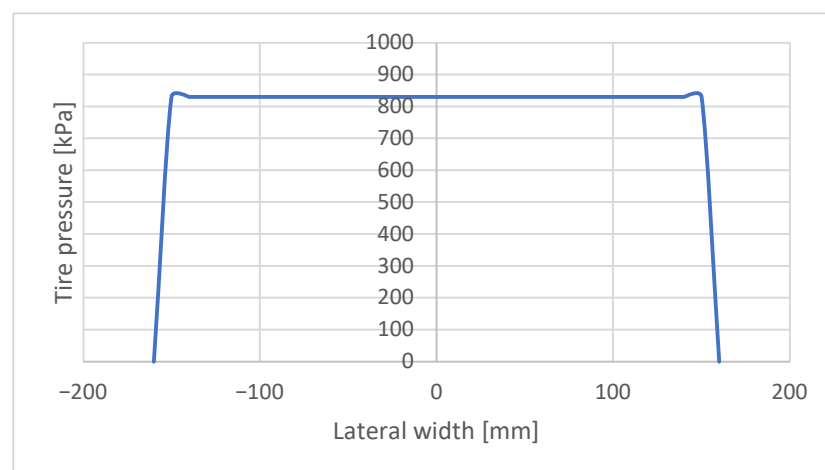


Figure 7. Tire pressure distribution for tire F3.

2.3. Lateral Wander Mode Details

Three different lateral wander mode options have been selected, consisting of a normal distribution, zero lateral wander, and a uniformly distributed lateral wander option, as shown in Figure 8. The human-driven lateral wander mode uses the T1 truck type. Three analyses are run at lateral offsets of $Y = +0.3$ m, $+0.5$ m, and $+0.7$ m from the lane center. The results are combined using a weighted average based on a normal distribution with Mean = $+0.5$ m and Std. Dev. = 0.15 m. The zero wander mode is used by autonomous trucks in the form of trucks T2, T3, and T4. Therefore, a single analysis is performed with loads applied at the frequent path of $Y = +0.5$ m. For the uniform lateral wander mode, three analyses are conducted at lateral offsets of $Y = +0.3$ m, $+0.5$ m, and $+0.7$ m. The values are averaged arithmetically to simulate a perfectly uniform distribution of traffic across the wheel path. The selection of lateral offsets at $Y = +0.3$ m, $+0.5$ m, and $+0.7$ m is justified by extensive empirical field data from weigh-in-motion studies and the Long-Term Pavement Performance database, which consistently identify the mean wheel path for heavy trucks

at 0.5 m from the lane center with a standard deviation of 0.15 m. This offset range of ± 0.2 m from the mean statistically captures approximately 80–85% of all truck passes under normal distribution assumptions.

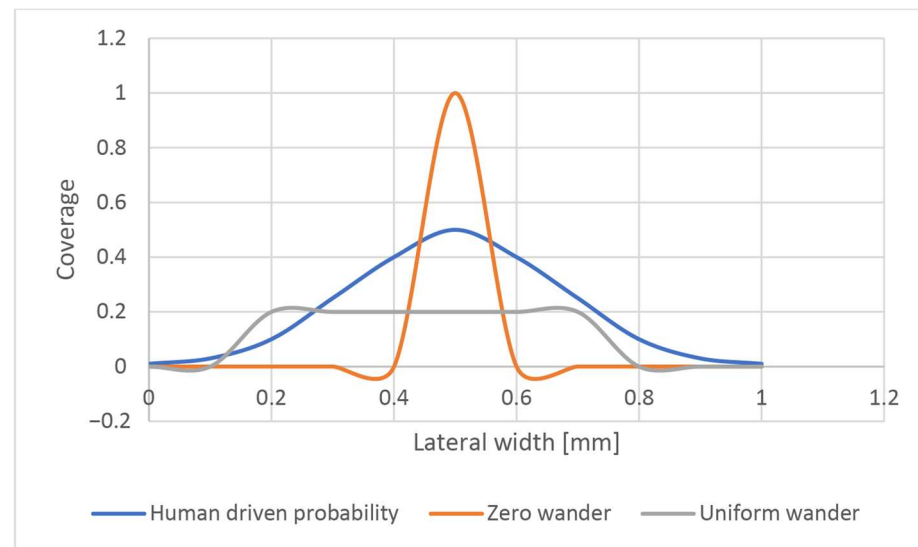


Figure 8. Coverage of different lateral wander modes.

The tire path wander, based on its location from the center line at $Y = 0.5$, is shown in Figure 9. As observed, a normal distribution of human-driven trucks stays closer to the middle of the lane, with a random distribution along the traffic lane. For the zero wander, the autonomous truck is programmed to follow a straight path without any lateral wander; therefore, it stays at a 0.5 m location represented by the red line. The gray line represents the uniform distribution of the loading path for each autonomous truck. When the autonomous trucks are moving in the platoon, different equal distribution patterns are assigned so that the following truck does not follow the same pattern as the leading truck.

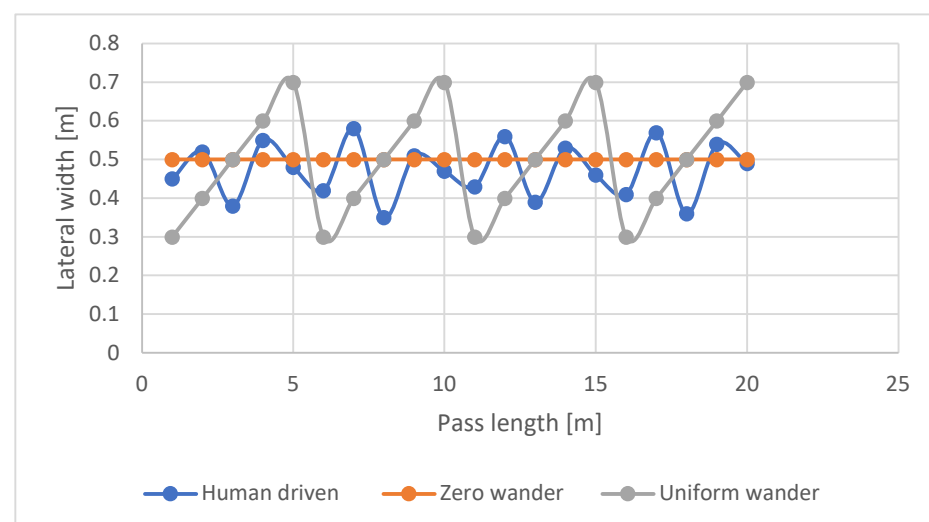


Figure 9. Coverage pattern of each lateral wander mode.

The normal distribution for human-driven trucks is given by the probability distribution function. Mathematical representation for the probabilistic wander in the case of human-driven trucks is given in Equation (1).

$$P(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(y-u)^2}{2\sigma^2}} \quad (1)$$

where, $P(y)$ is probability density at lateral position y , y is the lateral position across the lanes, u is Mean lateral position at 0.5 m and σ is Standard deviation at 0.15 m. This equation describes a bell-shaped curve where the trucks are most likely to travel near the lane center (u) with decreasing probability as they move toward the lane edges. The zero wander mode is given by the Dirac Delta function. This function represents a perfectly channelized traffic pattern where all vehicles follow exactly the same path at position y_0 . The delta function is a mathematical idealization that has infinite height but integrates to 1 as shown in Equation (2).

$$P(y) = \delta(y - y_0) \quad (2)$$

where, $P(y)$ is Probability density at lateral position y , δ is the Dirac Delta function, infinite at y_0 , and y_0 is the fixed lateral position at 0.5 m. The uniform distribution for the wheel paths of autonomous trucks is given using Equation (3).

$$P(y) = \frac{1}{b-a}, y \in (a, b) \quad (3)$$

where $P(y)$ is Probability density at lateral position y , a is the lower bound of wander range at 0.3 m, and b is the upper bound of wander range at 0.7 m. Therefore, a perfectly distributed pattern where trucks systematically and evenly use all positions between a and b with equal probability is shown in Equation (4).

$$W_{eff} = \int_{y_{min}}^{y_{max}} I(P_y > P_{threshold}) dy \quad (4)$$

where W_{eff} is effective coverage width (meters), y_{min} and y_{max} are minimum and maximum lateral positions in lane, $P_{threshold}$ is minimum probability density considered significant and indicator function $I(P_y > P_{threshold})$ identifies positions that receive meaningful traffic frequency. Therefore, a larger W_{eff} means load is spread over a wider area and less damage concentration. The summarized characteristics for each lateral wander mode are shown in Table 6.

Table 6. Properties of each lateral wander mode.

Pattern Type	Normal Distribution	Zero Wander	Uniform Distribution
Standard deviation	0.15 m–0.25 m	0 m	0.17 m
Coefficient of variation	50%	0	30%
Pavement coverage	60% lane width	Single path	80% lane width
Drive	Human	Basic autonomous	Optimized autonomous

3. Finite Element Modeling

3.1. Data for Modelling

For the finite element analysis, the asphalt layer has been modeled using the Generalized Maxwell model using its Prony series expansion. The Generalized Maxwell model is a linear viscoelastic model, and it captures the time and temperature dependency used for the evaluation of rutting and fatigue cracking. It represents viscoelastic materials as a combination of N Maxwell elements in parallel with a single spring element. The model

consists of N Maxwell elements with a spring and a dashpot in series. The relaxation modulus is shown in Equation (5).

$$G(t) = G_{\infty} + \sum_i G_i e^{\frac{-t}{\tau_i}} \quad (5)$$

where $G(t)$ is Shear relaxation modulus at time t , G_{∞} is long term shear equilibrium modulus, G_i is shear modulus of i th Maxwell element, τ_i is relaxation time of i th Maxwell element.

The dynamic modulus master curve represents the frequency and temperature-dependent stiffness of asphalt concrete through time-temperature superposition principles. Therefore, the WLF (Williams–Landel–Ferry) equation is used, which enables shifting of viscoelastic properties across different temperatures to a single reference temperature of 20 °C. The shift factor is evaluated using Equation (6).

$$\log(a_T) = \frac{-C_1(T - T_{ref})}{C_2 + (T - T_{ref})} \quad (6)$$

where C_1 is 18.5 and it controls the magnitude of horizontal shifting on the logarithmic frequency scale, C_2 is 145.2 °C and it represents the temperature offset from the glass transition temperature T and T_{ref} is the current temperature. The sigmoidal function is used to describe the dynamic modulus master curve as shown in Equation (7).

$$\log_{10}(E^*) = \frac{\delta + \alpha}{1 + e^{(\beta + \gamma \log_{10} w_r)}} \quad (7)$$

where E^* is dynamic modulus, δ is lower asymptote at 0.69, α is vertical span at 3.2, β is shape parameter at -1.45 , γ is shape parameter 2 at 0.65, and w_r is reduced frequency from 10^{-8} to 10^8 rad/s.

The Prony series parameters for the dense graded asphalt binder at 20 °C are shown in Table 7. For the first asphalt layer, the elastic modulus is at 30,000 MPa with Poisson's ratio at 0.39 and density of 2.4×10^{-9} t/mm³. The model to simulate material response from impact loading during tire contact to long-term creep and rutting accumulation. The 20 term Prony series accumulation has been used since it evaluates the frequency-dependent modulus from high-frequency tire impacts.

The validation against the experimental data with various loading frequencies has been performed for the experimental and model elastic modulus values and shown in Table 8. As observed, the maximum error exists for the frequency of 10 Hz with a magnitude of 0.7%, and the minimum error at -0.2% at a frequency of 1 Hz.

Table 7. Prony series parameters.

Term (i)	Shear Modulus G_i (MPa)	Bulk Modulus K_i (MPa)	Relaxation Time τ_i (s)	Normalized Weight g_i	Viscosity η_i (GPa·s)
1	4500.0	10,000.0	1.00×10^{-5}	0.1500	0.0450
2	3800.0	8444.4	3.16×10^{-5}	0.1267	0.1201
3	3200.0	7111.1	1.00×10^{-4}	0.1067	0.3200
4	2700.0	6000.0	3.16×10^{-4}	0.0900	0.8532
5	2250.0	5000.0	1.00×10^{-3}	0.0750	2.2500
6	1900.0	4222.2	3.16×10^{-3}	0.0633	6.0040

Table 7. Cont.

Term (i)	Shear Modulus G_i (MPa)	Bulk Modulus K_i (MPa)	Relaxation Time τ_i (s)	Normalized Weight g_i	Viscosity η_i (GPa·s)
7	1600.0	3555.6	1.00×10^{-2}	0.0533	16.000
8	1350.0	3000.0	3.16×10^{-2}	0.0450	42.660
9	1125.0	2500.0	1.00×10^{-1}	0.0375	112.50
10	950.0	2111.1	3.16×10^{-1}	0.0317	300.20
11	800.0	1777.8	1.00	0.0267	800.00
12	675.0	1500.0	3.16	0.0225	2133.0
13	562.5	1250.0	1.00×10	0.0188	5625.0
14	475.0	1055.6	3.16×10	0.0158	15,010
15	400.0	888.9	1.00×10^2	0.0133	40,000
16	337.5	750.0	3.16×10^2	0.0113	106,650
17	281.3	625.0	1.00×10^3	0.0094	281,300
18	237.5	527.8	3.16×10^3	0.0079	750,500
19	200.0	444.4	1.00×10^4	0.0067	2.00×10^6
20	168.8	375.0	3.16×10^4	0.0056	5.33×10^6
∞	1200.0	2666.7	∞	0.0800	∞

Table 8. Comparison of elastic modulus between experimental and modeled values.

Frequency (Hz)	Experimental (E)	Model (E)	Error (%)
25	25,000	24,850	−0.6%
10	18,000	18,120	+0.7%
5	13,500	13,455	−0.3%
1	8200	8180	−0.2%
0.1	4500	4515	+0.3%
0.01	2800	2790	−0.4%

The properties used for base course, subbase course, and subgrade are shown in Table 9. As observed, the Granular Base Course is the primary load-distributing layer with an elastic modulus of 200 MPa. The Subbase Course is modeled as linear elastic with a modulus of 100 MPa and Poisson's ratio of 0.40. The subgrade layer has an elastic modulus of 80 MPa with a Poisson's ratio of 0.45.

Table 9. Pavement layer properties for modeling.

Layer	Thickness (mm)	Elasticity (MPa, ν)	Poisson's Ratio	Density (t/mm ³)
Granular Base	200	200	0.35	2.1×10^{-9}
Subbase	400	100	0.40	1.95×10^{-9}
Subgrade	Semi-infinite	80	0.45	1.8×10^{-9}

Modeling has been performed using the step loading functions for the traffic speed of 90 km/h. The tire loading for each tire type has been modeled using the circular and elliptical patches. The parabolic form of variation in contact pressure values along the tire footprint has been used for tires F1 and F2. However, for tire F3, a uniform distribution of contact pressure has been employed. The parabolic pressure distribution for dual tires and traditional wide-base tires was selected since inflated radial tires naturally produce higher contact pressure at the centerline that gradually decreases toward the tread edges, reflecting the mechanical behavior of belt stiffened rubber structures under load. The elliptical footprint geometry approximates the actual deformation pattern of a loaded tire, where the circular cross-section flattens into an elliptical contact patch with the longer

axis aligned with the direction of travel. For new generation wide-base tires, a uniform pressure distribution has been assumed to represent their optimized tread design and casing construction, which distributes load more evenly across the contact patch to reduce stress concentrations. Constant inflation pressure has been maintained across all tire types to ensure that observed differences in pavement response are attributed to footprint geometry and pressure distribution pattern. Detailed pressure and patch dimensions are shown in Table 10.

Table 10. Loading area details for modeling.

Tire Type	Pressure (kPa)	Contact Area	Shape	Dimensions (mm)
F1: Dual-Tire	830 (max)	Two circles	Circular	Diameter of 220 each, 310 spacing
F2: WBST	900 (max)	Single ellipse	Elliptical	280 × 260
F3: NG-WBST	830 (uniform)	Single ellipse	Elliptical	300 × 280

3.2. 3D Model Details

Recent advances in finite element modeling offer alternatives for enhancing solution accuracy without resorting to excessive mesh refinement. Therefore, enriched finite element formulations have gained attention for their ability to capture localized phenomena with coarser meshes. Dell’Accio et al. [34] have presented quadratic and cubic polynomial enrichments of the Crouzeix–Raviart finite element that improve stress resolution and convergence properties for problems involving steep gradients. Therefore, A 3D finite element model has been developed in ABAQUS with a length of 20 m and a width of 3.75 m. The total depth of the model is kept at 2.8 m, including all the fixed depths for granular layers and the asphalt layer. The model type used is an 8-node linear brick element with reduced integration and hourglass control, C3D8R. The model consists of a total of 256,879 elements with element size kept at 25 mm for increased accuracy and reduced simulation time by utilizing a convergence study. The mesh details are shown in Figure 10.

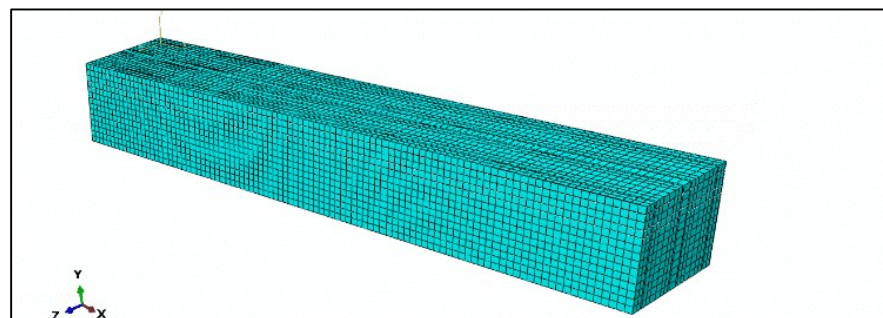


Figure 10. Mesh details.

The tied constraints enforce displacement compatibility at the interfaces and ensure that no slip or separation occurs between layers. The bottom boundary is completely fixed with $U1 = U2 = U3 = 0$, with deformation allowed only in the normal vertical direction. Therefore, any form of artificial reflection is avoided using these boundary conditions. The visual representation of loading and boundary conditions is shown in Figure 11. As observed, the nodes are free to move in the normal vertical direction; however, the movement is restricted under normal horizontal and perpendicular directions in order to remove the bias of measuring strain values under wheel loading. A normal surface-to-surface contact with hard and frictionless characteristics is provided.

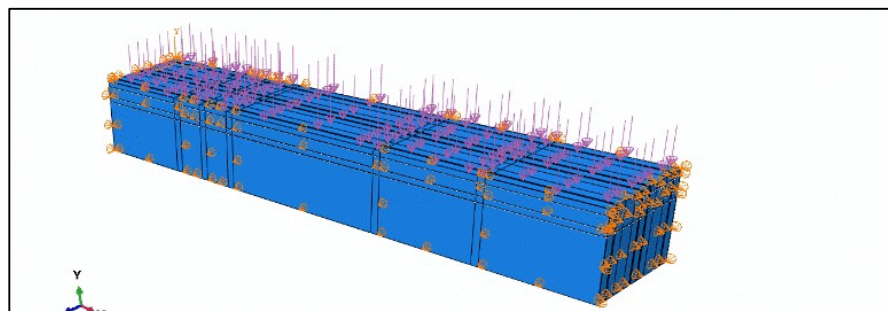


Figure 11. Loading and boundary conditions details.

3.3. Modeling Results and Discussion

Simulations have been performed for the design life of 15 years, with annual average daily truck traffic for each truck type kept at 11,000 trucks/day. Simulations were performed for each truck type, lateral wander mode, and tire type.

Screenshot taken from the T1 truck type with F2 WBST under zero wander mode is shown in Figure 12. As observed, the tire footprints stay in the middle of the lane throughout the pass of the truck without any lateral movement, leading to the development of channelized loading.

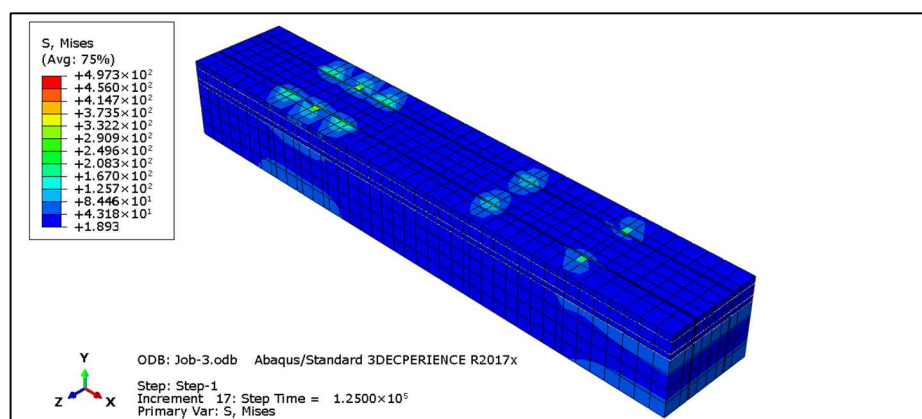


Figure 12. Screenshot for T1 with F2 WBST tire under zero wander.

Figure 13 shows the T3 truck moving under uniform wander mode, where the screenshot was taken during the pass along the leftmost part of the lane. The use of uniform wander mode distributes the paths evenly throughout the lane width during the truck's pass through a specified section on the highway, thereby reducing the overlapping of wheel patches. Therefore, the tensile strain values for all available scenarios were calculated.

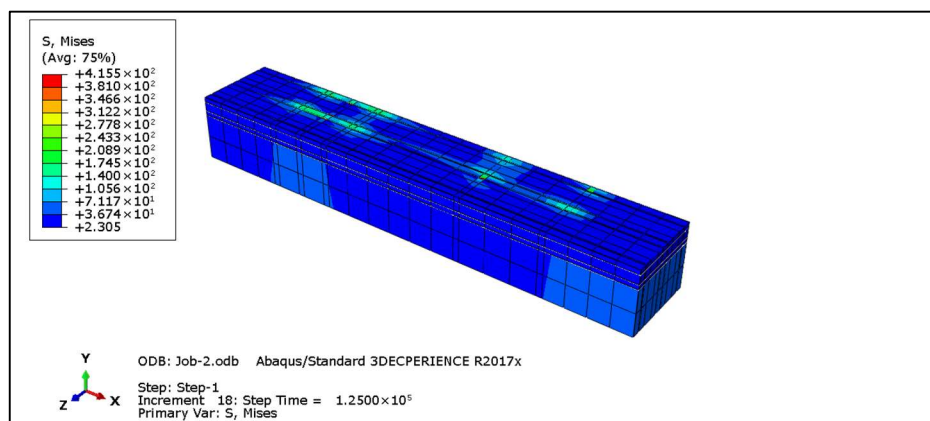


Figure 13. Screenshot for Truck T3 with NG WBST under uniform wander.

3.4. Tensile Strain, Tensile Stress and Von Mises Stress Analysis

The maximum tensile strain at the bottom of the asphalt layer for all scenarios is shown in Table 11. As observed, higher tensile strains indicate greater potential for bottom-up fatigue cracking. There is a significant increase of 27.6% from T1-F1 at 125 $\mu\epsilon$ to T3-F2 at 185 $\mu\epsilon$. The least cumulative strains are exhibited by the T2 electric autonomous truck with the new generation wide base tire moving in uniform wander mode. Furthermore, the magnitude of strains for the new generation wide base tire is closely followed by the wide base tire. The dual tire assembly, on the other hand, exhibits the highest accumulation of strains under the asphalt layer.

Table 11. Maximum tensile strain at bottom of asphalt layer.

Truck Type	Tire Type	Zero Wander	Probabilistic Wander	Uniform Wander	Ratio (P/Z)
T1 (Std 5-Axle)	F1: Dual	165	142	118	0.86
	F2: WBST	145	128	105	0.88
	F3: NG-WBST	135	122	102	0.90
T2 (A-6-Axle)	F1: Dual	155	135	112	0.87
	F2: WBST	138	122	99	0.88
	F3: NG-WBST	130	118	96	0.91
T3 (A-Heavy)	F1: Dual	225	185	175	0.82
	F2: WBST	185	158	125	0.85
	F3: NG-WBST	175	152	120	0.87
T4 (EU Std)	F1: Dual	175	152	130	0.87
	F2: WBST	155	138	102	0.89
	F3: NG-WBST	148	132	100	0.89

Compressive strains under the top of the subgrade for all scenarios are shown in Table 12. Compressive strains drive rutting in unbound layers. As observed, there is a 70% increase from T1-F1 at 325 $\mu\epsilon$ to T3-F2 at 365 $\mu\epsilon$, which shows significantly accelerated permanent deformation. Furthermore, the highest accumulation of strains is exhibited by T3-F1 at zero wander mode. The use of uniform wander significantly reduces the rutting progression by 26% for all scenarios; however, the reduction in compressive strains is more notable in the case of the T2 truck with the new generation wide base tire option.

Table 12. Maximum compressive strains on top of subgrade.

Truck Type	Tire Type	Zero Wander	Probabilistic Wander	Uniform Wander	Ratio (P/Z)
T1 (Std 5-Axle)	F1: Dual	325	285	255	0.88
	F2: WBST	285	255	225	0.89
	F3: NG-WBST	250	230	210	0.92
T2 (A-6-Axle)	F1: Dual	295	260	235	0.88
	F2: WBST	270	240	210	0.89
	F3: NG-WBST	240	220	200	0.92
T3 (A-Heavy)	F1: Dual	455	385	350	0.85
	F2: WBST	365	315	275	0.86
	F3: NG-WBST	340	300	265	0.88
T4 (EU Std)	F1: Dual	340	295	270	0.87
	F2: WBST	295	260	230	0.88
	F3: NG-WBST	265	235	215	0.89

The Von Mises stress accumulations are shown in Table 13. As observed, the highest accumulation of stresses based on the tire type is exhibited by the dual tire assembly in combination with zero wander mode. The T3 truck exhibits the highest magnitude of stress values. An overall reduction in Von Mises stress by 13.5% exists for the uniform wander mode when compared to the zero wander mode. The human-driven probabilistic wander

performs slightly better than the zero wander mode. The T2 type electric truck exhibits the least magnitude at 1.38 MPa with the combination of a new generation wide base tire under uniform wander mode. For the NG-WBST, the peak stress is reduced by 26% when compared to the dual tire assembly.

Table 13. Von Mises stress values for each scenario.

Truck Type	Tire Type	Zero Wander	Probabilistic Wander	Uniform Wander	Ratio (P/Z)
T1 (Std 5-Axle)	F1: Dual	2.85	2.45	1.95	0.86
	F2: WBST	2.35	2.05	1.55	0.87
	F3: NG-WBST	2.10	1.85	1.45	0.88
T2 (A-6-Axle)	F1: Dual	2.65	2.30	1.85	0.87
	F2: WBST	2.20	1.92	1.48	0.87
	F3: NG-WBST	1.95	1.72	1.38	0.88
T3 (A-Heavy)	F1: Dual	3.85	3.25	2.65	0.84
	F2: WBST	2.95	2.55	1.85	0.86
	F3: NG-WBST	2.75	2.40	1.75	0.87
T4 (EU Std)	F1: Dual	3.15	2.70	2.10	0.86
	F2: WBST	2.55	2.25	1.65	0.88
	F3: NG-WBST	2.35	2.10	1.55	0.8

The graphical representation of variation in Von Mises stress values based on the truck type, wander mode, and tire type is shown in Figure 14. As observed, T3 shows the highest accumulation of stress values due to the highest gross weight of the truck-trailer combination. The least accumulation of Von Mises stress values is exhibited by T1 under a uniform wander mode. The uniform wander mode decreases the stress values significantly by 36% for all trucks, where the decrease is highly significant in the case of truck T3, with stress levels reducing by 415 $\mu\epsilon$ when moving from dual to NG-WBST tire type.

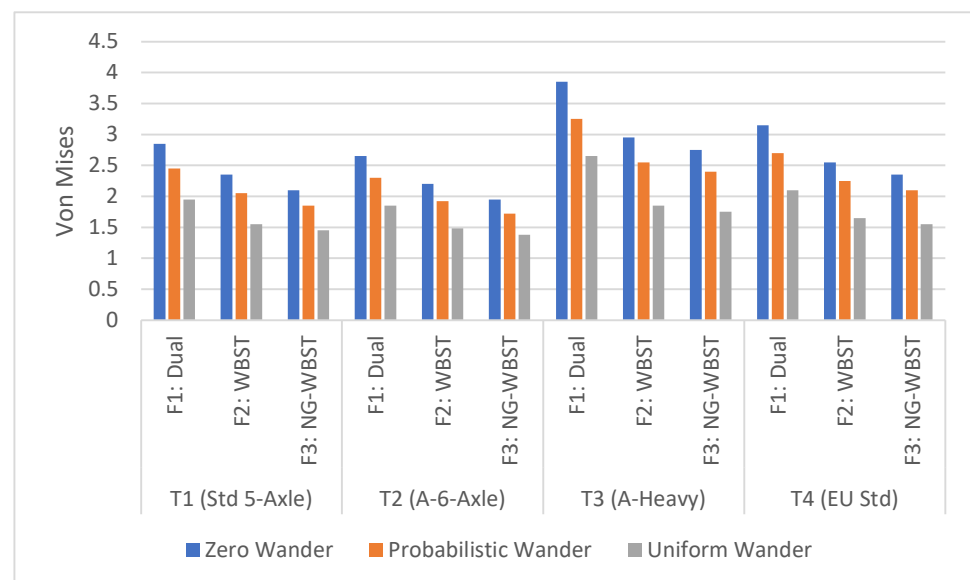


Figure 14. Comparison of Von Mises stress values.

3.5. Stress Concentration and Stress Influence Analysis

The stress concentration analysis for each scenario is shown in Table 14. Based on the contact pressure and loaded area, the dual tire assembly exerts the highest concentration of stress on the pavement. Furthermore, the width of a combined dual tire assembly is more than that of each of WBST and NG-WBST. Therefore, dual tires create stress overlap

between adjacent tires with 310 mm spacing, producing 45% higher combined stress at shallow depths of 50–100 mm. This overlap effect diminishes with depth; however, critical fatigue strains occur at shallow depths.

Table 14. Stress concentration for each tire type based on finite element modeling.

Parameter	F1: Dual-Tire	F2: WBST	F3: NG-WBST	Unit
Stress Overlap Factor	1.45	1.00	1.00	-
Contact Area	76,030	57,200	65,970	mm ²
Contact Pressure	830	900	830	kPa
Stress Concentration	1.85	1.25	1.15	-
Load Transfer Depth	450	650	600	mm
Lateral Stress Spread	0.65	0.85	0.90	-

The stress distribution factors for each truck type are also shown in Table 15. The stress uniform depth for both F2 and F3 tires is higher than that of F1, leading to a wider area. However, the lateral spread for F1 is higher since it will cause overlapping even in the uniform wander mode. Therefore, the maximum shear stress is highest at 1.15 MPa for the dual tire assembly, and both for shear stress depth is also the highest for the F1 scenario.

Table 15. Shear stress influence for each tire type.

Parameter	F1: Dual-Tire	F2: WBST	F3: NG-WBST	Unit
Stress Influence Depth	800	950	850	mm
Lateral Spread (95% energy)	1200	900	1000	mm
Maximum Shear Stress	1.15	0.93	0.87	MPa
Shear Stress Depth	53	41	35	mm
Confining Pressure Ratio	0.45	0.25	0.35	-
Stress Uniformity Index	0.75	0.55	0.85	-

4. Fatigue and Rutting Damage Analysis

The fatigue damage is normalized to the zero wander mode at a magnitude of 1.00 for all scenarios, as shown in Table 16. Furthermore, the percentage change in the damage factor when compared to the dual tire is shown for all truck types along with the lateral wander mode combinations. Highest fatigue damage occurs for the T3-F1 scenario with the combination of dual tire and zero wander at 4.850, which is significantly higher than the baseline T1-F1 scenario. Truck T4 also exhibits the second-highest fatigue damage on pavement; however, with the combination of NG-WBST with uniform wander mode, the fatigue damage ratio is reduced to 0.280 using Equation (8).

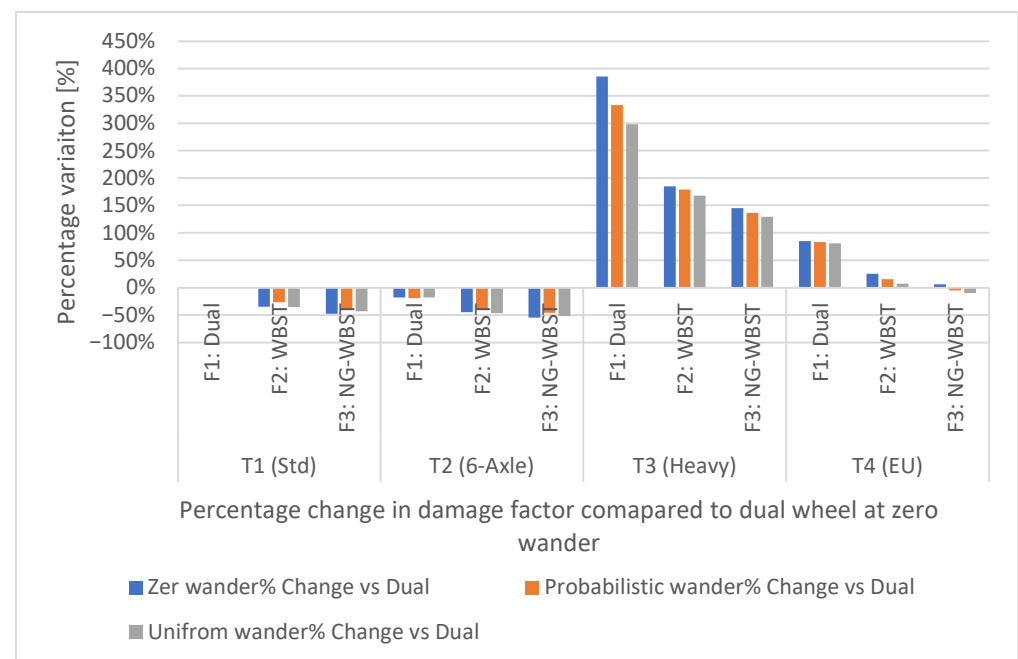
$$D_f = N \int P(y) \varepsilon_{t(y)}^{3.949} dy \quad (8)$$

where D_f is fatigue damage with lateral wander distribution, N is the total number of load repetitions, $P(y)$ is the probability function of lateral position and $\varepsilon_{t(y)}$ is tensile strain as a function of lateral position.

Table 16. Fatigue damage normalized to F1 Dual at zero wander.

Truck Type	Tire Type	Zero Wander	% Change vs. Dual	Probabilistic Wander	% Change vs. Dual	Uniform Wander	% Change vs. Dual
T1 (Std)	F1: Dual	1.000	0%	0.520	0%	0.280	0%
	F2: WBST	0.650	−35.0%	0.380	−26.9%	0.180	−35.7%
	F3: NG-WBST	0.520	−48.0%	0.320	−38.5%	0.160	−42.9%
T2 (6-Axle)	F1: Dual	0.820	−18.0%	0.420	−19.2%	0.230	−17.9%
	F2: WBST	0.550	−45.0%	0.310	−40.4%	0.150	−46.4%
	F3: NG-WBST	0.450	−55.0%	0.280	−46.2%	0.140	−52.2%
T3 (Heavy)	F1: Dual	4.850	+385%	2.250	+333%	1.850	+298%
	F2: WBST	2.850	+185%	1.450	+179%	0.750	+168%
	F3: NG-WBST	2.450	+145%	1.350	+136%	0.700	+129%
T4 (EU)	F1: Dual	1.850	+85%	0.950	+83%	0.550	+81%
	F2: WBST	1.150	+25%	0.650	+15%	0.300	+7%
	F3: NG-WBST	0.950	6%	0.550	−5%	0.280	−10%

Graphical representation of the percentage change in fatigue damage compared to the dual wheel at zero wander mode is shown in Figure 15. As observed, both trucks, T1 and T2, exhibit decreases in the damage factor, with permanent decreases in the damage factor exhibited under uniform wander mode for both scenarios. However, T3 and T4 truck types show increased damage accumulation in terms of fatigue damage. T3 with F1 dual configuration exhibits the highest fatigue damage magnitude under zero wander mode; however, even with the use of uniform wander mode, the damage still remains prominent when compared to T1 and T2 trucks.

**Figure 15.** Fatigue damage variation for each scenario with normalized F1-T1 at zero wander.

The rutting damage ratio for each scenario, normalized to the zero wander mode scenario at 1.00, is shown in Table 17. As observed, the rutting damage ratio follows the same patterns as the fatigue damage ratio. The use of WBST reduces the rutting damage

by half when compared to the dual tire. Furthermore, the use of NG-WBST reduces the damage further by a quarter when compared to the dual tire assembly. Moreover, the uniform wander mode significantly reduces the rutting damage by 56% in the case of the T1 truck scenario. Therefore, the even distribution of loading by each truck pass reduces the rutting damage factor significantly, using Equation (9).

$$D_r = N \int P(y) \epsilon_{c(y)}^{4.477} dy \quad (9)$$

where D_r is total rutting damage over pavement life, N is total number of loading repositions, $P(y)$ is probability density function of lateral position and $\epsilon_{c(y)}$ is compressive strains as a function of lateral position.

Table 17. Rutting damage normalized to F1 dual at zero wander.

Truck Type	Tire Type	Zero Wander	% Change vs. Dual	Probabilistic Wander	% Change vs. Dual	Uniform Wander	% Change vs. Dual
T1 (Std)	F1: Dual	1.000	0%	0.450	0%	0.320	0%
	F2: WBST	0.520	−48.0%	0.280	−37.8%	0.190	−40.6%
	F3: NG-WBST	0.350	−65.0%	0.210	−53.3%	0.150	−53.1%
T2 (6-Axle)	F1: Dual	0.780	−22.0%	0.350	−22.2%	0.260	−18.8%
	F2: WBST	0.450	−55.0%	0.240	−46.7%	0.165	−46.9%
	F3: NG-WBST	0.320	−68.0%	0.180	−60.0%	0.140	−61.5%
T3 (Heavy)	F1: Dual	8.100	+710%	3.250	+622%	2.850	+791%
	F2: WBST	3.850	+285%	1.850	+311%	1.350	+322%
	F3: NG-WBST	3.100	+210%	1.550	+244%	1.250	+291%
T4 (EU)	F1: Dual	1.850	+85%	0.850	+89%	0.620	+94%
	F2: WBST	1.050	+5%	0.520	+16%	0.360	+13%
	F3: NG-WBST	0.820	−18%	0.420	−7%	0.320	+0%

Graphical representation of percentage variation in rutting damage factor for all other scenarios, compared to F1 dual tire under uniform wander mode, is shown in Figure 16. As observed, both F2 WBST and F3 NG-WBST configurations for truck T1 show reduced rutting damage, with performance further improved for truck type T2. Truck T3, however, exhibits the most serious rutting damage when compared to both T1 and T2 trucks. Truck T4 exhibits increased rutting damage by 13% in the case of the F1 dual tire scenario; however, the rutting damage decreases under the F2 WBST and F3 NG-WBST scenarios.

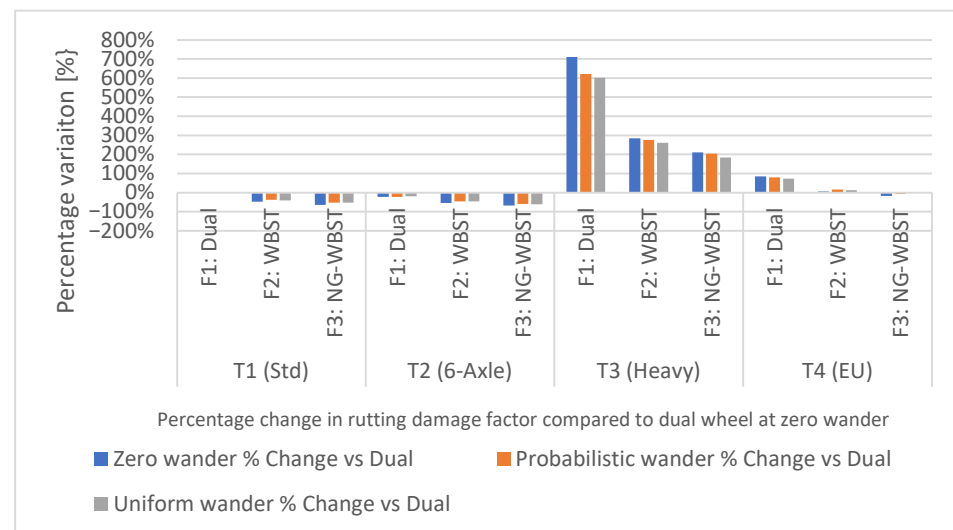


Figure 16. Rutting damage variation for each scenario with normalized F1-T1 at zero wander.

The combined damage index comprising of 60% fatigue and 40% rutting is shown in Figure 17, where the most serious damage is accumulated by truck T3 with F1 dual tire assembly at 6.070. The dual tires in all truck types exhibit the highest damage factor; however, the accumulation of damage factor can be reduced by incorporating a uniform wander mode.

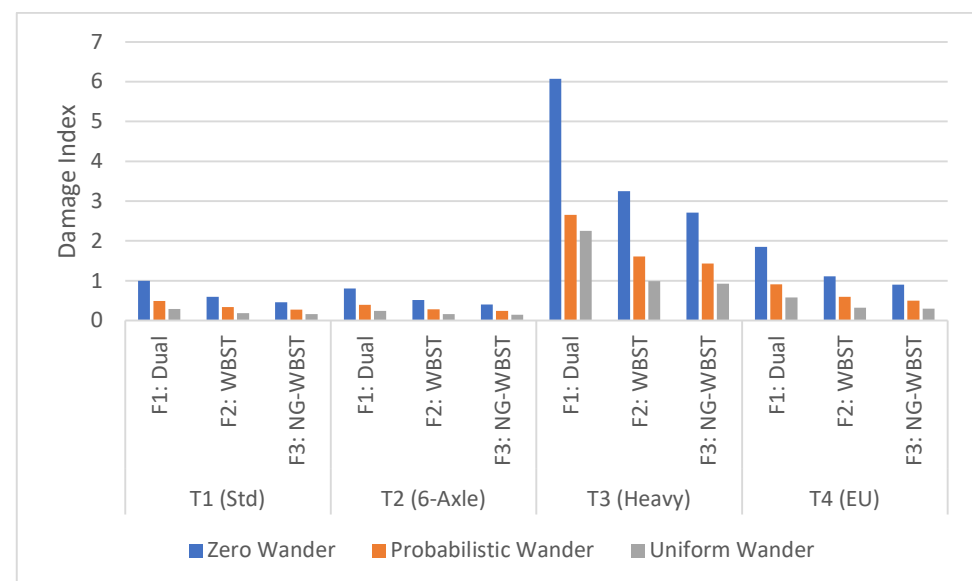


Figure 17. Combined damage comparison for each scenario.

Pavement life in terms of the number of truck tire passes in millions for each scenario is shown in Table 18. As observed, the highest accumulation in allowable passes is shown by the uniform wander mode with the T2-F3 scenario. Therefore, the use of uniform wander mode for all truck scenarios further increases the allowable number of passes. Since the zero wander mode exhibits the least pavement life in terms of the combination of 60% fatigue and 40% rutting damage, the combination T3-F1 exhibits the least number of allowable passes at only 1.28 million, which is 56% less than the optimum T2-F3 scenario with uniform wander mode at 62.5 million tire passes. Pavement life has been computed from the combined damage indices as shown in Equation (10).

$$D_{Total} = 0.6 \times D_f + 0.4 \times D_r \quad (10)$$

where D_f is fatigue induced damage and D_r is rutting induced damage.

Table 18. Pavement life in number of truck passes [Millions] for each scenario.

Configuration	Zero Wander	Probabilistic Wander	Uniform Wander
T1-F1	8.57	17.4	30.8
T1-F2	15.0	26.3	50.0
T1-F3	20.0	31.3	55.6
T2-F1	10.7	21.7	38.5
T2-F2	17.6	31.3	58.8
T2-F3	22.6	36.4	62.5
T3-F1	1.28	3.03	3.57
T3-F2	2.50	5.56	8.33
T3-F3	3.03	6.25	9.09
T4-F1	4.63	9.52	15.2
T4-F2	7.93	14.7	27.8
T4-F3	9.73	17.5	30.3

The graphical representation for the pavement life in terms of allowable tire passes before rutting and fatigue damage is shown in Figure 18. As observed, the highest number of allowable passes is exhibited for truck T2 in all wheel type configurations; however, T2-F3 with the NG-WBST tire takes the lead with the highest number of allowable passes. Performance of truck T2 is closely followed by truck T1, where the total number of allowable passes under T1-F3 surpasses the passes for T2-F1. The least number of passes is exhibited by truck T3, where the best scenario, T3-F3, only exhibits 3.03 million passes. The performance of truck T3 is followed by truck T4, where the best scenario, T4-F3, has 30.03 million passes.

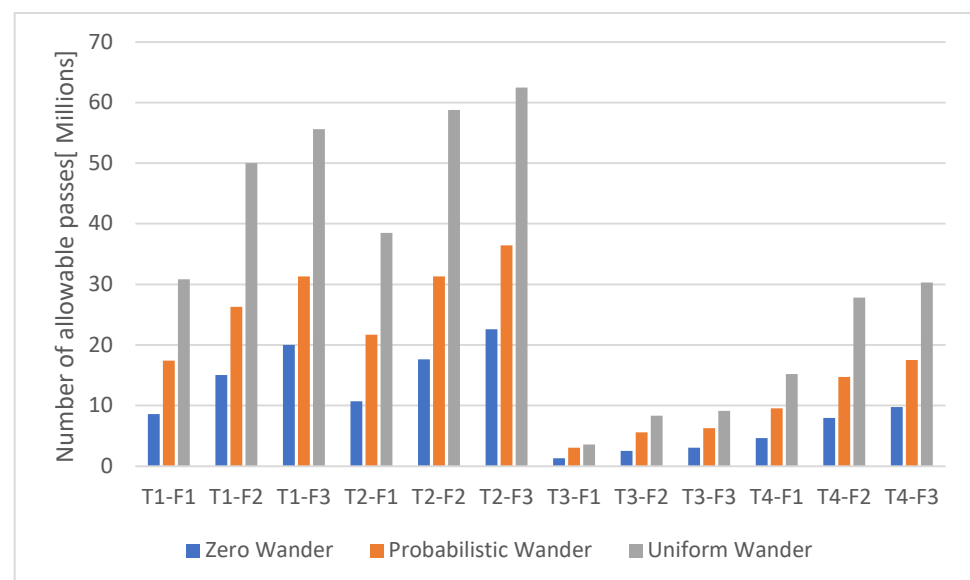


Figure 18. Comparison of pavement life in tire passes.

Heat Maps for Stress Concentration and Optimum Scenarios

A combination of all optimum scenarios in the form of a matrix, showing the truck type, lateral wander mode, and tire type, is shown in Figure 19. These values are normalized combined damage indices calculated using a weighted formula that incorporates both fatigue and rutting damage mechanisms. The damage values in the matrix represent normalized pavement deterioration rates, where 1.00 equals zero wander mode. Tire type

change to new-generation wide-base tires reduces damage by 35–65% compared to dual tires through better pressure distribution, and wander patterns where uniform wander reduces damage by 48% when compared to channelized traffic. Based on the exponential damage law, small strain reductions yield large damage decreases; therefore, truck T2 with new-generation tires and uniform wander achieves a low value of 0.144, representing an 86% reduction in pavement damage. The highest accumulation of damage exists for truck T3 under dual tire and zero wander mode, highlighted in the matrix with red colour.

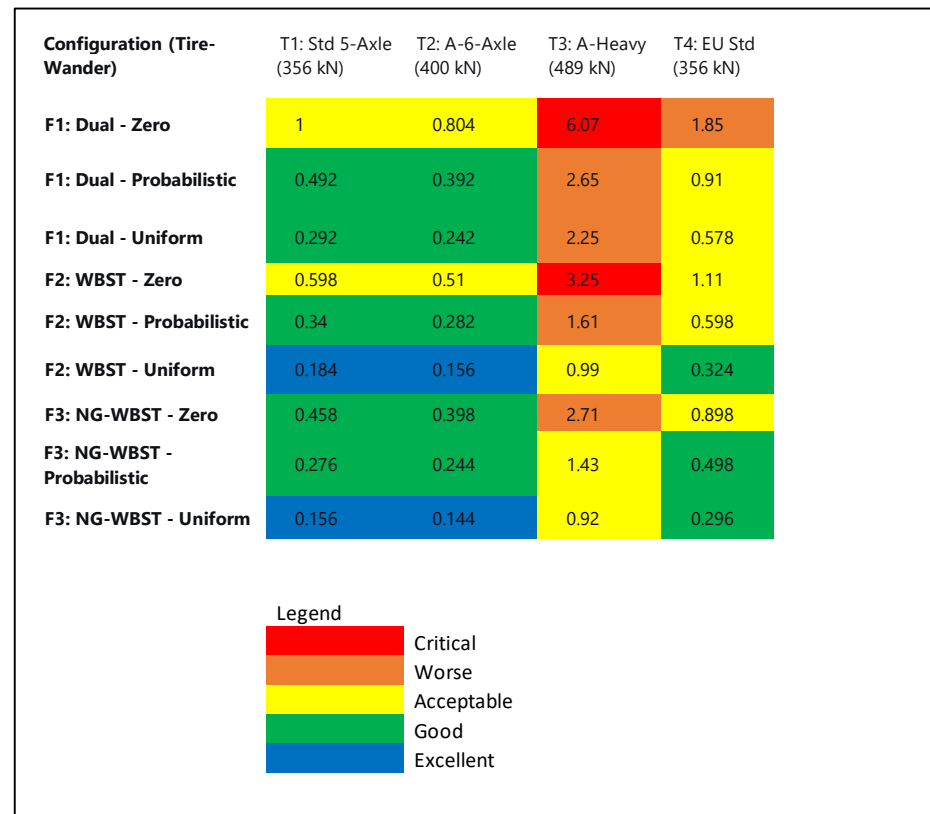


Figure 19. Heat map for optimum scenarios.

5. Conclusions and Findings

In this research, four different types of trucks with varying maximum gross weight and axle combinations have been selected to assess their impacts on pavement response based on three different lateral wander modes, consisting of uniform wander mode, zero wander mode, and the probabilistic human-driven mode. Furthermore, three different truck tire footprints have been evaluated: the dual tire assembly, the conventional wide base tire, and the new generation wide base tire. The 3D finite element modeling practice has been developed to perform the microstrain analysis and predict performance in terms of rutting and fatigue damage. The material model has been prepared using the generalized Maxwell model with Prony series parameters for a conventional four-layered pavement section.

Based on the analysis, the T2 autonomous truck is the least damaging to the pavement structure when used with the NG-WBST under uniform wander mode. The use of dual tires in all trucks significantly impacts the damage potential, both in terms of rutting and fatigue damage. Furthermore, the use of zero wander is the most damaging among all lateral wander scenarios due to the occurrence of channelized loading and very little recovery time, followed by the human-driven probabilistic wander. The uniform wander mode performs with reduced damage on the pavement structure, where the loading for each pass is distributed evenly by each truck. Among the truck types used, the T3 truck, although the

best candidate to haul higher magnitudes of loads, has significant damage to pavement due to increased axle loads. Therefore, among the trucks analyzed, the T2 truck with an axle load of 356 kN exerts the least magnitude of damage on pavement in terms of rutting and fatigue occurrence.

Therefore, channelized loading creates stress concentration at a single pavement location, preventing the viscoelastic recovery essential for asphalt concrete durability. The viscoelastic constitutive model shows that the pavement requires approximately 2–5 s for 95% stress recovery; however, zero wander eliminates this recovery period, leading to cumulative damage accumulation rather than distributed damage dissipation. Therefore, probabilistic wander with its natural variation reduces damage by 48–55%, and uniform wander achieves a greater reduction through systematic load distribution.

Moreover, the nonlinear damage amplification observed with exponents of 3.949 for fatigue and 4.477 for rutting is due to the fact that small strain differences yield large damage variations. This non-linearity originates from microstructural damage mechanisms where fatigue cracking initiates at binder aggregate interfaces, where stress concentrations exceed adhesion strength, and, on the other hand, rutting involves permanent rearrangement of aggregates under compression.

Furthermore, dual tires create two overlapping stress bulbs that interact at shallow depths of 20–50 mm, generating stress concentration factors of 1.42–1.45 due to their proximity at 310 mm spacing. The NG-WBST's larger diameter and elliptical contact patch create a shallower stress gradient of 0.18 MPa/mm compared to 0.28 MPa/mm for dual tires, thereby reducing near-surface shear stresses that develop top-down cracking.

The findings of this study both align with and extend previous research on autonomous truck pavement impacts. Channelized traffic from autonomous vehicles significantly accelerates pavement deterioration, though the present study's quantification of $6.07\times$ damage for heavy autonomous trucks exceeds earlier estimates because previous work examined wander or load effects in isolation rather than their combined interaction. Regarding tire technology, the demonstration that NG-WBST outperforms dual tires under optimized wander patterns, with dual tires performing, shows relevance with previous research. The exponential damage scaling observed at 4.477 power for rutting validates classical fourth power law approximations while refining them for autonomous contexts, confirming the previous observation that traditional models may underestimate channelized loading effects by 30–50%. Furthermore, the proposed uniform wander strategy provides the first quantitative validation, showing that programmable autonomous vehicles can achieve 48–72% damage reduction compared to channelized operation.

In terms of limitations, the variation in temperature patterns during hot and cold climatic conditions has not been taken into account. Furthermore, the variation in traffic mix consisting of human-driven and autonomous trucks has not been included. The un-forwarded wander mode can be further optimized for realistic implications for autonomous trucks. Future research work deals with the inclusion of environmental variables for simulations in both cold and hot climatic conditions. Furthermore, future work will include different variants of traffic mix scenarios for autonomous and human-driven trucks, comprising different axle-loading configurations with the uniform wander mode. In terms of limitations, the variation in temperature patterns during hot and cold climatic conditions has not been taken into account. Furthermore, the variation in traffic mix consisting of human-driven and autonomous trucks has not been included. The un-forwarded wander mode can be further optimized for realistic implications for autonomous trucks. Future research work deals with the inclusion of environmental variables for simulations in both cold and hot climatic conditions. Furthermore, future work includes different variants

of traffic mix scenarios for autonomous and human-driven trucks, comprising different axle-loading configurations with the uniform wander mode. The findings are as follows.

1. The highest compressive and tensile strain accumulation is exhibited by the dual tire assembly, which is 15% more than the wide base tire and 215% more than the new generation wide base tire. Uniform wandering reduces the strain accumulation by 16% in the case of the T2 electric autonomous truck.
2. The highest strain accumulation based on the type of trucks is exhibited by T3 trucks due to their maximum gross weight of 400 kN. However, when used in a uniform wander mode, it exerts the same amount of strain as the dual tire assembly in a human-driven T1 scenario.
3. The least strain accumulation is exhibited by the T2 electric autonomous trucks, where, due to the battery packs in the tractor head, the load is distributed evenly on both drive and trailer axles. Therefore, the T2 truck with a gross weight of 365 kN is the least damaging truck type when combined with the new generation wide base tire and uniform wander mode.
4. The highest pavement life is exhibited by truck T2-F3 under uniform wander mode at 62.5 million passes.
5. Truck T3 with F1 tire and moving under zero wander mode exhibits the highest rut depth at 20 mm.
6. Rutting damage factor for truck T1 decreases by an average of 36% across all tire type scenarios when moving from zero wander mode to uniform wander mode.
7. Fatigue damage decreases by 28% while moving from dual tire to the NG-WBST tire type for trucks T1 and T2.
8. Truck T3 exhibited the most serious damage on pavement, with a reduced number of allowable passes for fatigue and rutting damage by 46% when compared to truck T1 under the NG-WBST configuration and uniform wander mode.
9. Truck T4 exhibits almost similar performance to trucks T1 and T2 when rutting damage is compared; however, in terms of fatigue damage, the damage magnitude increases by 13% and 18% when compared to trucks T2 and T1, respectively.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The author declares no conflicts of interest.

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